
Copernicus ex- ante benefits assessment

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1. Introduction

1.1 Objective of the study

The objective of the study was to carry out an impact assessment in support of the future European Commission Impact Assessment (IA) on the evolution of the Copernicus programme. This IA analysed three potential options for the evolution of the Copernicus programme, comparing them to a baseline option of ensuring continuity of the Copernicus programme as is (i.e. with unchanged scope). The options under scrutiny are the following:

- Option 1 – Baseline option: the Copernicus programme continues after 2030 (renew Sentinels after 2030)
- Option 2 – Shutdown option: the Copernicus programme is stopped after 2030, transferring ownership of remaining satellites and disassembling services
- Option 3 – Enhanced environmental services: the Copernicus programme continues after 2030 (renew Sentinels after 2030) and expands the scope of environmental services. This option is compounded of four different non-exclusive modules:
 - Option 3A – Anthropogenic CO₂ emissions monitoring;
 - Option 3B – Arctic (polar) & snow monitoring;
 - Option 3C – Additional thermal infrared capability;
 - Option 3D – Additional hyperspectral capability.
- Option 4 – Enhanced security services: the Copernicus programme continues after 2030 (renew Sentinels after 2030) and expands the scope of security services.

The baseline option (option 1) was characterised with an ex-ante assessment of its expected evolution up to 2035, in order to assess how the current scope of Copernicus would evolve in case of no additional or extended services.

The present study focuses on the **assessment of Copernicus Data and information (D&I) spillovers**, meaning the impacts on the wider European society of the **utilisation and exploitation of Copernicus D&I**. These benefits are split between intermediate users and end-users benefits, but it does not take into account the cost of the options under scrutiny. Moreover, this report **does not take into account the GDP impact of the Copernicus programme**, including **upstream revenues** attributed to the **development of the infrastructure** (space manufacturing, ground segment manufacturing) and **downstream revenues attributed to services development and services operation**. Such benefits, together with the employment impact of the Copernicus programme, were assessed in a separate document. **Nevertheless, costs, GDP impact and employment impact were all assessed for the Copernicus programme and are provided in a separated document.**

The assessment of spillovers derived from open data policy is by nature complex and intangible. This complexity is even higher in the case of an ex-ante assessment projecting benefits up to 2035. Nevertheless, the approach proposed for this study provides a robust

and defensible methodology **presenting an order of magnitude of impacts of these options, more than a highly accurate assessment.** Several assumptions were required, adding a certain level of uncertainty on the outcomes. Indeed, there are at the moment very few and scarce information related to Copernicus' economic evidence (i.e. case studies; demonstration of benefits; etc.) in many applications. In some other domains, even when data exists on the expected experience by end users, it was difficult to assess the extent of the impact of Copernicus, taking into account counterfactuals and alternatives solutions that could have potentially be found by intermediate and end-users (cost of opportunity). These challenges led to hindrances in the development of quantitative valuations of the potential impacts, which can be summarised as four possible levels of issues:

1. The use/functionality of Copernicus D&I is not clearly understood by end users (i.e. most of the end-users are indirect users in most of the cases not even aware they benefit from Copernicus D&I), which adds complexity in the assessment;
2. The appropriate baseline against which to assess benefits is unclear (i.e. comparison with what will have happen without the Copernicus programme);
3. The impact of Copernicus in terms of behavioural change¹ is to estimate; and
4. Implementation may require additional costs on governments or businesses that are not covered by this study.

More details on the issues and the mitigation actions undertaken to address them in the development of the economic model for impacts are presented in section 3.1.2. All assumptions behind benefits quantification and assessment are duly listed and detailed, together with the approach used by the team to assess (in monetary terms) each impact.

1.2 Taxonomy and definitions

A common terminology is required to facilitate reader comprehension, in a context where more and more studies are published on the Copernicus programme and Earth Observation (EO) in general. Such taxonomy also ensures comparability between studies, using the same definition, commonly accepted among the community.

The current study relies on a taxonomy developed by the European Association of Remote Sensing Companies (EARSC) issued for the second time in 2015 in Taxonomy for the EO Services Market² for all the specific subject matter definitions related to EO.

The following table presents functional definitions (mostly related to economics and impact assessment), plus selected subject matter definitions (non-exhaustive, and in line with EARSC taxonomy).

Item	Description
Earth Observation (EO)	Earth Observation (EO) can be carried out by satellites or airborne (aircraft, drones etc.). EO refers in this study to the activity using satellites to monitor Earth from Space. Remote sensing is used in this study as a synonym for EO.
Application	The term <i>application</i> in the present study refers to the term “EO services” within EARSC’s taxonomy. Note that the term application was preferred to “EO services” to avoid confusion with Copernicus core services

¹ Please refer to section 1.2 for a definition of behavioural change (economic definition).

² EARSC, 2015. Taxonomy for the EO Services Market.

Behavioural change	Behavioural change refers in economy to the impact a given investment (in the context of this study the investment that enabled the availability of free and open Copernicus data & information) will have on individuals. This behavioural change (i.e. reducing air pollution by reducing the traffic) will have monetary implications (i.e. avoided fatalities, reduction of hospitalization costs, etc.).
Direct end-users	<i>Direct end-users</i> refers to end-users using EO-based data and information, without requiring intermediate users' services. Such type of actors have in-house EO capabilities (processing, storage, etc.).
Economic benefits	Measures the direct, indirect and induced economic impacts of Copernicus, e.g. number of jobs supported or tax revenues. Also includes spillovers, such as new business creation due to open data.
Economic Net Present Value (ENPV)	All future costs and benefits summed and discounted to current real value of money (i.e. EUR 3.6 M). N.B. This includes environmental, social and economic benefits and costs, so it is NOT a financial NPV sometimes reported in other investment appraisals.
Economic payback period	The time needed to recover the initial/total investment or the break-even point. I.e. 5.7 years. N.B. This includes environmental, social and economic benefits and costs, so it is NOT a measure of financial payback.
Economic investment appraisal indicators	A series of indicators which consider the environmental, social and economic costs and benefits and can help facilitate investment decisions. N.B. These indicators are NOT financial investment indicators.
Economic Rate of Return (ERR)	The equivalent of the headline savings rate you would need to enjoy at a bank to make you indifferent between this investment and putting the money in the bank. Or the discount rate which would yield an ENPV of zero. I.e. 6.8%. N.B. This includes environmental, social and economic benefits and costs, so it is NOT a measure of financial return.
Employment Impact	Impact on employment associated with increased economic activity
End-users	<i>End-users</i> refers to final users, either public or private, of applications derived from the utilisation of EO data. <i>End-users</i> can be using directly EO data but in most of the cases they are indirect users. <i>End users</i> are often not even aware of being an EO's user.
Environmental benefits	Measures the environmental impacts of Copernicus, i.e. reducing negative environmental externalities (e.g. air pollution, GHG emissions) and contributing to environmental policies.
EO downstream sector	The EO downstream sector includes all actors involved in exploiting the EO space data and providing EO-related products and services to end users. This includes in particular Value Added Services (VAS) and geo-information companies, whose core business is to process satellite EO data and turn it into geo-information products, usable by the final users. The data is aligned against reference frames (in time and space), and becomes comparable with other data generated by other EO instruments. It is important to note that the EO downstream sector does not include specific consumer equipment manufacturing (e.g. GNSS receivers for Navigation or satellite dishes for Telecommunications).
Geographic Information System	An information system which allows the user to analyse, display, and manipulate spatial data, such as from surveying and remote sensing, typically in the production of maps.
Impact driver	An impact driver correspond to a sector, a field or an application from which the benefits will be generated.
Impact pathways	An impact pathway maps out the total impact of an action/event (impact driver) through to the particular impacts and societal value.

Indirect end-users	<i>Indirect end-users</i> refers to end-users that benefits from EO-based data and information, without being aware of it. This end-users' category includes a wide range of actors, from a citizen benefiting from a better air quality to industries benefiting from a more efficient maritime transportation enabled by the utilisation of EO data and information.
Inflation	Inflation will be used to convert nominal values to real values
Intermediate users	<i>Intermediate users</i> refer to entities acquiring EO data and/or products and add value on the top of the existing form of the EO-based products or data to make a profit. Intermediate users can acquire commercial data (i.e. buying satellite-based imagery) or open data (i.e. data free of charge such as Copernicus or Landsat D&I).
In situ data	In situ data means observation data from ground-, sea- or air-borne sensors as well as reference and ancillary data licensed or provided for use in Copernicus
In situ sensor	In-situ sensors provide various data about their local environment, by measuring physical and chemical parameters at a given spatial position. It can designate for instance sonars, thermometers, wind gauges or ocean buoys
Monetary benefits	All categories of benefits (economic, social and environmental) that can be measured in monetary terms (in EUR).
Non-monetary benefits	All categories of benefits (economic, social and environmental) that cannot be measured in monetary terms, and then treated qualitatively.
Qualitative impacts	Non quantifiable socio-economic impacts of the Copernicus programme that will be described narratively in the socio-economic study.
Quantitative impacts	Economic, environmental and social impacts to which monetary values will be applied, and included in the benefits assessment
Social benefits	Measures social impacts of Copernicus, e.g. human life saved.
Spatial resolution	The spatial resolution is based on the size of a pixel on an EO image (meter per pixel). Low, medium, high and very-high imagery resolution can usually be available to VAS. Depending on the exact need of the end user, a broad picture of low resolution can be sufficient, but in some cases the user requires a specific area to be monitored with very-high resolution;
Spectral resolution	The spectral resolution represents the wavelength used to produce the EO imagery. Different types of wavelength band of a given sensor (radar for example) can usually be offered by the same satellite. The wavelength band choice is tied to what needs to be detected: each band is more suitable than another to monitor a specific element. For example, some wavelength are appropriate to monitor the upper part of trees, with others it is possible to see through trees to map soils or underground materials
Spillover	Spillover is an economic term referring to the indirect impact a given investment or infrastructure may have on the economy and society, stimulating innovation and knowledge creation. This report focuses on the assessment of the spillovers derived from Copernicus D&I.
Temporal resolution	The temporal resolution refers to the revisit time or period which represents the period of time necessary for a satellite to complete an entire orbit cycle. One entire orbit circle refers to the time necessary for a satellite to take a second picture of the exact same area at the same viewing angle. Satellite orbit and altitude play also a significant role since some areas on Earth are re-imaged more frequently depending on orbit/altitude. Collecting and comparing multi-temporal imagery of the same area enable to detect changes and extract interesting information for the end users.
Thematic sector	The term <i>thematic sector</i> refers to commercial and non-commercial sectors or fields that are impacted by EO services (also called application). This term is part of the EARSC's taxonomy.
Upstream sector	The upstream sector includes all actors involved in the value chain leading to an operational EO space system: <ul style="list-style-type: none"> • EO satellites and ground segments manufacturers • Launch services providers (activity related to EO only)

- EO payloads manufacturers (optical and radar instruments)
- Space agencies EO programmes

Valuation coefficient	The valuation coefficients are tools developed by PwC aiming at giving a monetary value to an environmental cost ³ .
Value Added	The enhancement a company gives to a product or service before offering the product to customers. In case of space manufacturing, it is given by the transformation performed on base materials, components or subsystem into the final product. It is, for a given company, equal to profit + labour, i.e. sales excluding all supplies and external costs.

Table 1 - Taxonomy and definitions

1.3 List of acronyms

The following table provides a list of acronyms used in the present report.

Acronym	Elaboration
AWS	Amazon Web Services
CBA	Cost Benefit Analysis
CAMS	Copernicus Atmosphere Monitoring Service
CLMS	Copernicus Land Monitoring Service
CSS	Copernicus Security Service
C3S	Copernicus Climate Change Services
CMEMS	Copernicus Marine Environment Monitoring Service
Copernicus D&I	Copernicus Data and Information
EARSC	European Association of Remote Sensing Companies
EC	European Commission
EEA	European Environmental Agency
EMS	Copernicus Emergency Management Service
EO	Earth Observation
ESA	European Space Agency
EU	European Union
EU MSs	European Union Member States
GDP	Gross Domestic Product
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
IA	Impact Assessment
N/A	Not applicable
NSR	Northern Sky Research (company)
SDR	Social Discount Rate
TBC	To Be Confirmed
TBD	To Be Defined

³ For more details on the methodologies behind the valuation coefficients, please refer to: PwC, 2015, Valuing corporate environmental impacts, PwC Methodology document.

USGS	The US Geological Survey
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VHR	Very High Resolution
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Table 2 - Acronyms

2 The Copernicus programme

2.1 Introduction to the Copernicus programme

The Copernicus programme is one of the European flagship programme providing free and open data and information relying on satellite-based imagery, models and in-situ data. More than only data and information, the Copernicus programme provides state-of-the-art models to be used for societal and environmental purposes. The Copernicus programme is a public service designed to respond to policy and public administrations and fostering economic growth in Europe by:

- Supporting public users at local, national and European level;
- Helping Europe to maintain a prominent role in the international context;
- Strengthening intermediate users, downstream companies and value-added service providers.

Initially developed to focus on environment and security – the former name of the Copernicus programme was Global Monitoring for Environment and Security (GMES) – the Copernicus programme has developed several specific services providing free data and information enabling applications in a vast variety of fields (i.e. agriculture, biodiversity protection, air quality, search and rescue, etc.). Even if the programme is considered an Earth Observation programme, it is offering way more than satellite-based imagery by offering a free and open access to many information products develop by its six core services but also to many sources of in-situ data provided by European Union Member' States (EU MS).

The European Commission (EC) is managing the Copernicus programme and its 3 main components: Space, Services and In-situ components. The high level structure of the Copernicus programme is presented in the figure below.

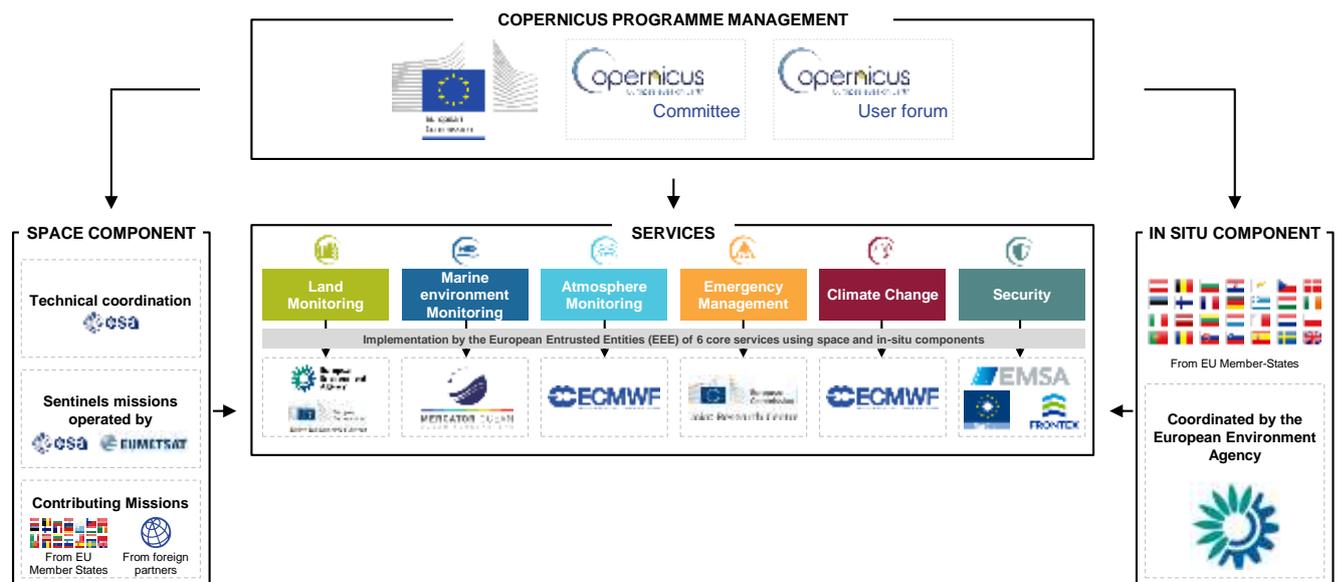


Figure 1 - High level structure of the Copernicus programme

The Copernicus Space Component includes the procurement, the launch, the operation and the distribution of Sentinels data and of contributing missions' data. The technical coordination and procurement for the Sentinels fleet are led by ESA and operated by collaboration between ESA and EUMETSAT. This element also includes the procurement of the overall space infrastructure, including satellites design, satellites manufacturing (procurement to the industry), satellites launches and ground infrastructure manufacturing (procurement to the industry). Finally, ESA is also in charge of acquisition, storage and distribution of the Sentinels data via the ESA Scientific Hub platform. As a transnational space agency collaborating with all the European national space agencies, ESA has access to several national EO programme's data, including archives of such programmes. This additional data source is called contributing missions and provide, for registered users, access to a wide range of commercial (i.e. Worldview, SPOT, TerraSAR, Radarsat 2, etc.) and civilian (i.e. Landsat, COSMO-SkyMed, RISAT, etc.) EO data sources. This data source offer in some cases higher spatial resolution than the Sentinels spacecraft to support the development of specific information products provided by Copernicus core services. However, the access to contributing mission is based on restrictions and so not fully open to everyone.⁴ For obvious reasons, high and very high resolution imagery are only open to a restricted list of authorized users in the field of security and emergency.

The Copernicus In-situ component offers an access to observation from the ground, sea and airborne sensors but also reference and ancillary data licensed. The in-situ component supports the space component to offer access to sustainable and reliable data to produce, validate and calibrate Copernicus products for the services component. The In-situ component is implemented in two tiers:

- At the level of the service: each core service is in charge of daily operation and ingestion of specific in-situ data of interest per problematic (marine service, land monitoring ... etc.) to offer valuable products for their end-users. This means that specific sources of in-situ data are tailored for each core service;⁵
- At the programme level: the European Environment Agency manages the cross-cutting service offering general in-situ data accessible through specific agreement with data providers/networks at programme level.⁵

The Copernicus Services component aims to deliver data and products freely available for a wide variety of users. These services integrate together data from the Space and In-situ components, together with state-of-the-art models, in order to offer Copernicus products tailored to the needs of specific end-users. To better reach end-users, six different core services were developed or are currently being developed in different areas:

- Copernicus Land Monitoring Service (CLMS);
- Copernicus Marine Environment Monitoring Service (CMEMS);
- Copernicus Atmosphere Monitoring Service (CAMS);
- Copernicus Climate Change Services (C3S);
- Copernicus Emergency Management Service (EMS);

⁴ PwC, 2016. Study to examine the socio-economic impact of Copernicus in the EU.

Report on the Copernicus downstream sector and user benefits. Report prepared for the European Commission. Brussels, Belgium.

⁵ Group on Earth Observation (GEO), 2016. Cross-cutting Coordination of the Copernicus In Situ Component.

- Copernicus Security Service (CSS).

Each of the six core services responds to a very specific problematic identified as key for the European society. The services were designed to respond to very specific needs of the European society, targeting specifically public authorities but also research and scientific communities. Nevertheless, the quantity and quality of the data and products offered by services also respond to commercial end-users needs. In this context, most of the products provided for free and openly accessible for everyone were designed for not directly harming the European downstream industry.

2.2 Introduction to Earth Observation, GIS and information products – Basic introduction

The boundary between Earth Observation and Geographic Information System (GIS) is nowadays blurring into a wide geospatial information market supported by modelling and dynamic monitoring information. The geospatial market relies more and more on information products merging together many different sources of data where satellite imagery is only a contributor – a key contributor per se – among many. GIS enables the users to create dynamic relations between spatial geo-referenced data and situational/relational data based on the specific need of the users such as internal statistic or in-situ data. The combination of these types of data brings a large value-added for both public and private end-users, linking imagery to a multitude of complementary other sources of data.⁶ The chart below illustrates how value is created in imagery and GIS market, through the development of an information product.

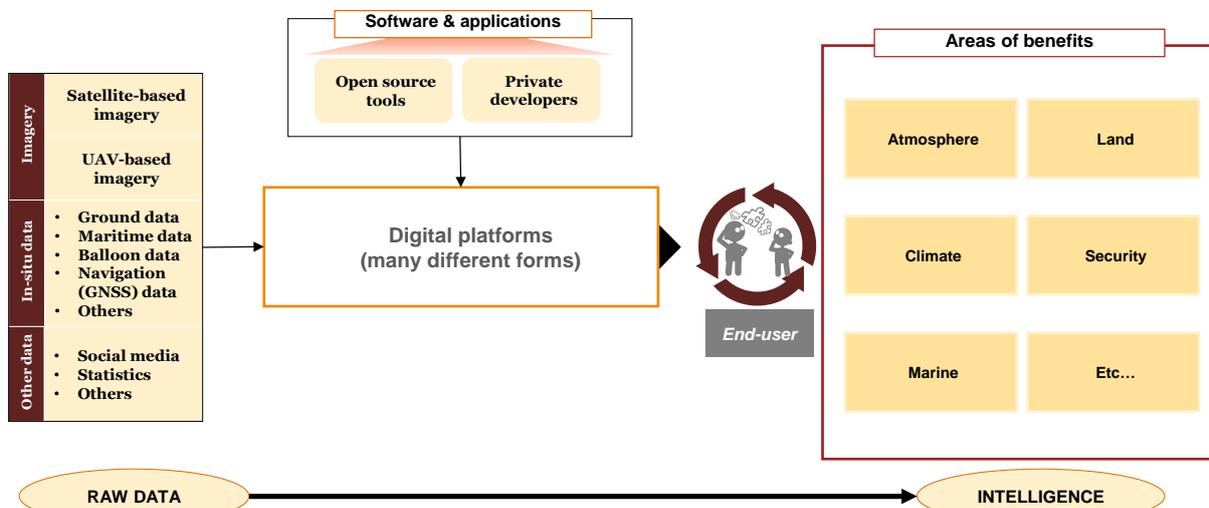


Figure 2 - Illustration of the information product value-chain (Sources: PwC analysis)

On the top of the imagery data, several types of data (in-situ, social media, statistics, etc.) are aggregated thanks to powerful computing and analytics power in order to create dynamic links between imagery and very specific information. Such links aim at responding to very specific end-user requirement and create added value for commercial and/or non-commercial actors. Nowadays, more and more analytics are performed on cloud-based platforms where end-user can procure open source or fee-based – commercial developers developing software or applications to make profit – software/applications, impacting the

⁶ PwC, 2016. Study to examine the socio-economic impact of Copernicus in the EU. Report on the Copernicus downstream sector and user benefits. Report prepared for the European Commission. Brussels, Belgium.

information product supply-chain. *For more details on this platform paradigm, please refer to PwC (2016).*

These platforms support end-users to develop EO products (imagery-based information products) but also to integrate EO products with in-situ data – and potentially with other sources of data such as social media or statistics – to create advanced geospatial products. Both products are information products which are then used in specific areas (land, security, marine, etc.), leading to benefits for the society. Contribution of Copernicus data (Sentinels) to the global information product value-chain is only marginal compared to the overall geospatial data sources. Nevertheless, the Copernicus programme also provides directly information products through its core services, directly targeting specific areas of benefits to enhance society welfare.

In the above backdrop, the present study assessed the impacts of the intelligence created by the Copernicus programme in its current scope and in potential evolution options on the European society. The study looked specifically at the value created to end-users, with particular focus on environmental and societal benefits, thanks to the Copernicus information products value-chain, and, as mentioned earlier on, only focused on the impacts of the utilisation and exploitation of Copernicus D&I, leaving aside impacts into and from the upstream side of the value chain (impacts on and from satellite and ground segment development and manufacturing industry). Those impact have been assessed in a separated document thanks to specific past studies (Strategy& PwC, 2015; PwC, 2016).⁷

The next chapter introduces the methodology used to assess and monetize Copernicus D&I spillovers, and the approach used to perform the impact assessment.

2.3 Discussion on the value of open data

The assessment of the value of open data is a raising concern among policy makers, public authorities and private entities. In fact, providing a free and open data policy has fix costs, related to setting up the infrastructure and make the data available, and variable costs, related to storage, maintenance and operation of the programme, that are generally incurred by the public, with apparently no direct return on investments. Nevertheless, the goals of such policies are linked to the willingness of more transparency in public administration and the willingness to foster the use of data. This last point is particularly important as illustrated by the example of the Landsat programme. Following the OPEN Government Act of 2007 within the Freedom of Information Act in the US, the White House has performed a big push on open data within US public administration. The US Geological Survey (USGS), in charge of the Landsat programme, has implemented this new governmental implication by developing a web-based open data access for Landsat 8 and all Landsat archives available on USGS EROS Centre. Before 2008, USGS was distributing around 20 000 scenes per year, selling these scenes at cost. From 2008 to 2016, downloads on the platforms have tremendously grown, with more than 35 million scenes downloaded over the period, reaching more than 10 million scenes downloaded in 2016. These numbers do not even include third parties initiatives such as Amazon Web Services (AWS) making these data available for free on their own S3 platform. This experience demonstrates that open data seems to have very strong positive impact on user uptake and data utilisation. Nevertheless, this does not demonstrate the value of open data directly.

The value of open data gathers a raising interest in academics discussions (Murray-Rust, 2008; Huijboom and Van den Broek, 2011; Janssen, Charalabidis and Zuiderwijk, 2012;

⁷ Strategy&, 2015. Study GDP Impact. The case study of the Copernicus programme. Final Report Prepared by Strategy& for the European Commission. Brussels, Belgium.

PwC, 2016. Study to examine the socio-economic impact of Copernicus in the EU. Report on the Copernicus downstream sector and user benefits. Report prepared for the European Commission. Brussels, Belgium.

Jetzek, Avital and Bjorn-Andersen, 2013)⁸. Indeed, open data does not have any value per se since data becomes valuable when it is used, meaning that the value of the data then change from one user to another. In such a context, the traditional price to market approach does not apply since the value of the data is not linked to its production cost. As already stated, even if there are fix and variable costs to produce and make data available, data are by nature non rivalrous goods since the download and usage of a data by a user A does not prevent user B to access and use this data. Then, the marginal cost of any additional user is zero. In this context, the valuation of open data needs to be carried out at users' communities' level to understand how they value access to these data for free. Moreover, open data leads in general, on the top of certain economic impacts, large societal and environmental benefits for the society that are not taken in the equation by financial assessment of "return on investment" approach applied to open data policies. Having a programme such as the Copernicus programme providing satellite based imagery, in-situ data, basic information products and advanced modelling for free is expected to lead to non-negligible benefits for the society in a context where public authorities and research centres & universities have generally very low willingness-to-pay due to budget pressure. If all these information would not have been provided for free, there is very high probability that it would have prevented most of these actors to access it, as no evidence demonstrates that the private would have been capable (and willing) to provide all these elements at European and global scale at an affordable price.

When putting together the increase of data usage and the potential impacts enabled by the availability for free of data, it seems that open data policy, and so the Copernicus programme, seems to have a positive impact on the society. **The report of "Copernicus ex-ante benefits assessment" was developed for this purpose. It aims to understanding the value created to the wider society by the availability for free of Copernicus data and information, with a particular focus on the societal and environmental value created thanks to the Copernicus programme. This report focuses only on the benefits enabled by the availability of open and free Copernicus data and information, and it does not analysed the impacts of manufacturing & setting-up the infrastructure and setting up the programme & its core services.**

⁸ Sources: Murray-Rust, 2008. Open Data in Science. *Serials Review*. Vol. 31, No. 1. P. 52-64.

Huijboom and Van den Broek, 2011. Open data: an international comparison of strategies. *European Journal of ePractice*. No. 12.

Janssen, Charalabidis and Zuiderwijk, 2012. Benefits, Adoption Barriers and Myths of Open Data and Open Government. *Information Systems Management*. Vol. 28.

Jetzek, Avital and Bjorn-Andersen, 2013. Generating Value from Open Government Data. *ICIS 2013 Proceedings*.

3 Methodology

This chapter presents the overall methodological approach used in this study. The first section gives more details on the methodology behind the impact assessment of the different options under scrutiny for the evolution of the Copernicus programme. The second section introduces the high level quantification process used to assess and monetize Copernicus D&I spillovers, meaning all benefits derived from Copernicus D&I for intermediate and end-users. It is worth to point out that the methodologies are tied to specific impact categories (with different impacts requiring different assessment methodologies): therefore, in the interest of clarity, the detailed methodological approach is presented directly in the description in each impact.

3.1 Impact assessment approach

3.1.1 General framework

The impact assessment was carried out on different evolution options under scrutiny by the European Commission and conducted through the execution of four main steps:

- **Phase 1 – Options characterisation.** Each individual option was characterised, with a particular focus on the baseline option (option 1) representing the current scope of the Copernicus programme renewed after 2030. The scope of each evolution options (options 2, 3 and 4) under scrutiny were elaborated by the European Commission; they represent potential evolution scenarios of the Copernicus programme. The description, characterisation and scope (potential number of satellites, launch date anticipated, etc.) of each option were provided by the European Commission;
- **Phase 2 – Identification of impacts.** We identified all the possible consequences (impacts) **stemming from the utilisation and exploitation of Copernicus D&I** on the basis of past assessment work and of desk research. The initial list of impacts was complemented and calibrated through consultation with experts from the Copernicus Services. The identification of impacts provides an understanding of how the specificities of each option affect and change stakeholder behaviour, through the provision of goods and services to the European society. Both direct and indirect changes are identified and characterised with the help of the rationale why / who / what.
 - **Why** would the availability of Copernicus D&I imply behavioural changes? (per option)
 - **Who** is affected by this availability of Copernicus D&I bought by an option?
 - **What** impacts are implied by the availability of Copernicus D&I brought by an option?
- **Phase 3 – Forecast of how impacts are expected to evolve over time for each option.** During this phase, impacts related to each option were assessed with particular attention on how they affect end-users, with a particular focus on social and environmental outcomes. Thanks to desk research and expert consultation, we have estimated the evolution of each impact over time, up to 2035.
- **Phase 4 – Quantification of impacts over time.** The analysis in this phase was relying on the assessment and the monetisation of all benefits enabled by Copernicus

D&I for the baseline and evolution options. Details on the methodology used to assess and monetise benefits are presented in the next section.

3.1.1.1 Phase 1 – Options characterisation

The different options to be analysed for this impact assessment have been provided by the European Commission. They represent four potential evolution scenarios of the Copernicus programme that need to be compared with the baseline option (operate as it is). The different options to be analysed are presented in the chart below.

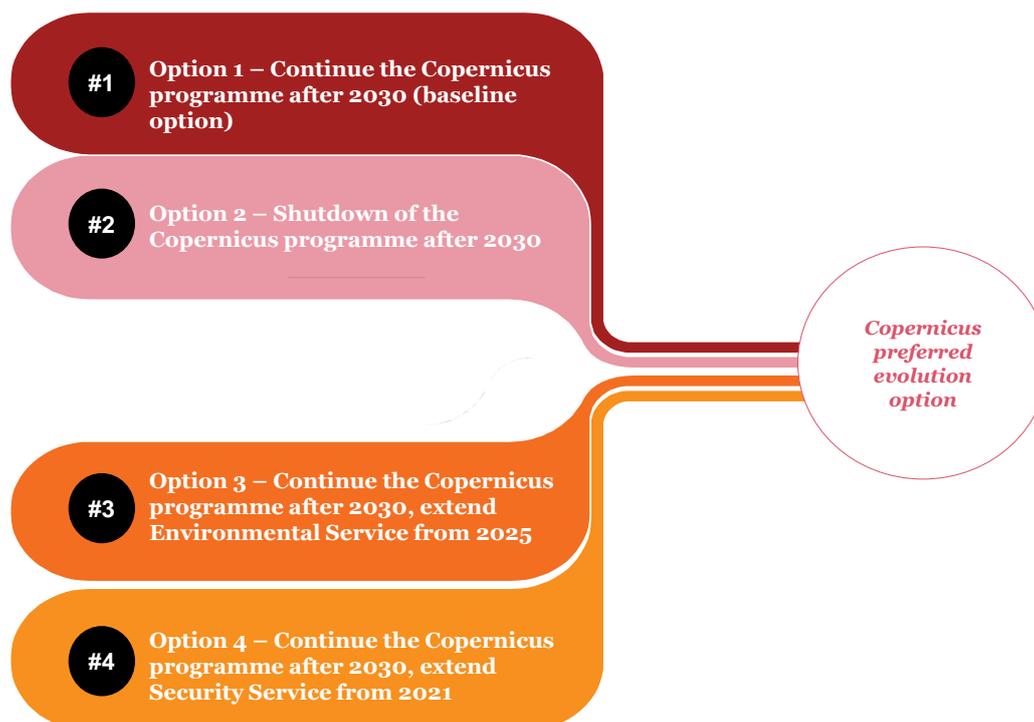


Figure 3 - Copernicus evolution options (Sources: EC)

Each option has a specific scope (i.e. enhanced Security Service; enhanced Environmental; etc. Services), leading to different types of benefits. The reference point of comparison of the analysis – the baseline option – is option 1 “Continue the Copernicus programme after 2030”. If option 2 is mutually exclusive from the other evolution options, options 3 and 4 are not mutually exclusive. As stated in the table above, option 3 is modular and each of the four modules can be developed separately together, or not, with option 4.

The following table gives additional details on each option.

	Description
Option 1 <i>(baseline option)</i>	Option 1 continues Copernicus after 2030 and represents the baseline option: <ul style="list-style-type: none"> • Continue Copernicus services after 2030 • Renew Sentinels after 2030
Option 2	Option 2 stops Copernicus services after 2030 and does not renew Sentinels <ul style="list-style-type: none"> • Transfer of ownership of satellites • Stop and disassemble services
Option 3	Option 3 continues Copernicus after 2030 and expands

	<p>environmental capabilities from 2025 with the following services:</p> <ul style="list-style-type: none"> • Option 3A – Anthropogenic CO2 emissions monitoring; • Option 3B – Arctic (polar) environment monitoring; • Option 3C – Additional thermal infrared capability; • Option 3D – Additional hyperspectral capability
Option 4	<p>Option 4 continues Copernicus after 2030 and expands security capabilities from 2021 with the following services:</p> <ul style="list-style-type: none"> • Access to VHR imagery (satellites and/or UAVs) for security applications • Access to near-real time monitoring capability for security applications • Guaranteed access for security applications

Table 3 - Options under scrutiny (Source: EC)

The four options are further detailed in chapter 4 (baseline option) and chapter 5 (evolution options).

3.1.1.2 Phase 2 – Identification and characterisation of impacts

The characterisation of the expected impacts and scoping followed the process outlined below.

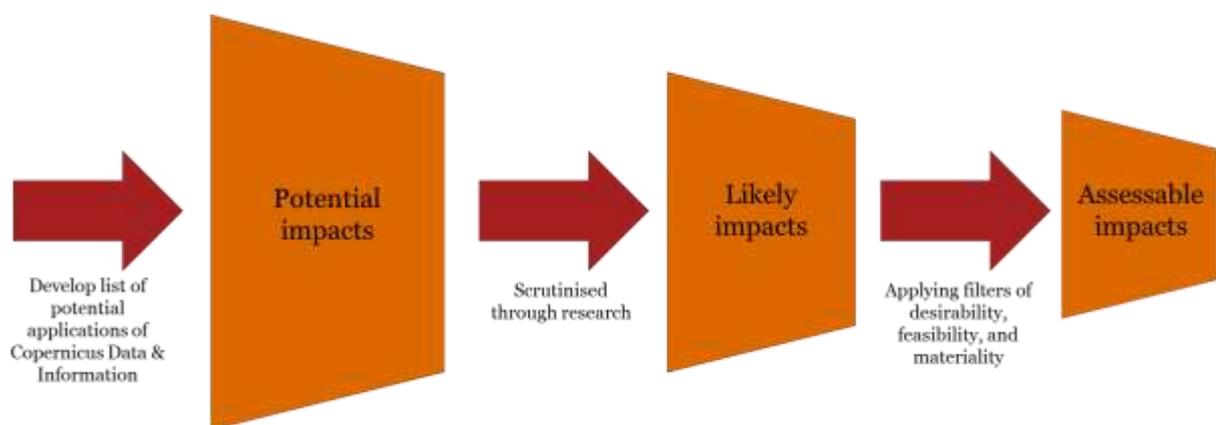


Figure 4 - Characterisation of expected impacts and scoping

3.1.1.2.1 Potential impacts

Firstly a list of extensive potential impacts was developed through a combination of understanding of the field (internal expertise and experience with the Copernicus programme) and desk research on the potential applications of Copernicus D&I. This list was calibrated and enhanced through stakeholder consultation with experts from the EC and Copernicus core services.

3.1.1.2.2 Likely impacts

As a following step, this list was scrutinised through further research to assess which of the impacts were in fact more likely to occur. This was assessed through the actual possibility to conclude that there was some potential causal relationship between the Copernicus Data & Information being available and an outcome. So either evidence of an alternative outcome was found or looked possible with further research.

3.1.1.2.3 Assessable impacts

The final stage in deciding which impacts would be in-scope was through applying the filters of desirability, feasibility, and materiality, as illustrated in the chart below.

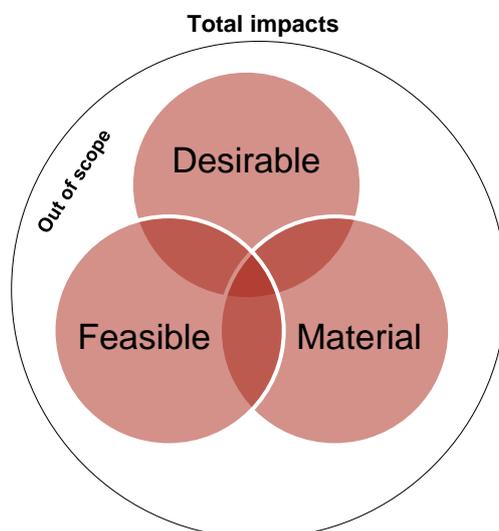


Figure 5 - Scoping of the impacts to be assessed (Sources: PwC analysis)

Desirability was determined on the basis of importance of illustrating certain impacts for the European Commission and the Copernicus core services. Feasibility was determined through research on the basis of data availability and quality of that data to assess the impacts. Materiality was determined through research on the basis of the likely magnitude of the impacts when valued. After the application of the filters the likely impacts were categorised in to three groups: quantitatively assessable impacts (in monetary terms), qualitatively assessable impacts, and impacts to be considered out-of-scope. Decision was then made to focus only on quantitatively assessable impacts, plus some key qualitatively assessable impacts.

3.1.1.3 Phase 3 & 4 – Impact Assessment

By using a combination of data gathered from previous studies, desk-based research, literature review, stakeholder consultation and PwC valuation coefficient, the different impacts were assessed for each option up to 2035. The exercise was split into two main assessments, performed on intermediate users' benefits on one hand and on end-users benefits on another hand. The next sections introduce the way those benefits were assessed.

Several PwC valuation coefficients are used in this report. The valuation coefficients aim at giving a monetary value to an environmental cost. These are therefore used to help calculating the environmental benefits induced by Copernicus (for instance, Land use and wetlands valuation coefficient, CO₂ valuation coefficient, etc.)⁹.

For each benefits, three scenarios are presented:

- The low scenario, which corresponds to the case where a conservative contribution of Copernicus is attributed: this is the very minimum benefits that can be expected from Copernicus D&I;

⁹ For more details on the methodologies behind the valuation coefficients, please refer to: PwC, 2015, Valuing corporate environmental impacts, PwC Methodology document

-
- The medium scenario, which corresponds the most likely scenario: this is either the exact average of the high and low scenarios or a scenario neither too pessimistic nor too optimistic;
 - The high scenario, which corresponds to the case where an optimistic contribution of Copernicus is attributed: this is the theoretical best case scenario, when Copernicus D&I are used as soon as it is relevant though other technologies or competitors might exist for a specific application, for instance.

Note that each impact driver may have additional elements (i.e. Paris agreement's targets for air quality monitoring) that may have been included in the definition of low, medium and high estimate. When this is the case, assumptions behind the different scenario are duly explained in the impact driver description.

3.1.1.3.1 Intermediate users benefits

Intermediate users refer to the organisations using Copernicus D&I as input to develop value-added products that are then sold to end-users. These companies add some processing layers or additional data sources (high spatial resolution imagery, private data bases, etc....) on the top of Copernicus D&I distributed to user communities. **The choice to separate intermediate users from end-users benefits was made to reduce risks of double-counting benefits.** Note that intermediate users' benefits are only economic¹⁰, as environmental and societal benefits are included and monetised in the end-users' benefits (next sub-section). The benefits for intermediate users include revenues for the European EO downstream industry and the revenues for the European EO Big Data industry. *More details on these two type of intermediate users are provided in the analysis.*

The way intermediate users' benefits was assessed is straightforward thanks to a large availability of data. Revenues for intermediate users have been assessed, taking into account user uptake for intermediate users, thanks to desk research and market studies from various sources as illustrated in the chart below.

¹⁰ Please refers to taxonomy section for definitions of the terms "intermediate user" and "end-user".

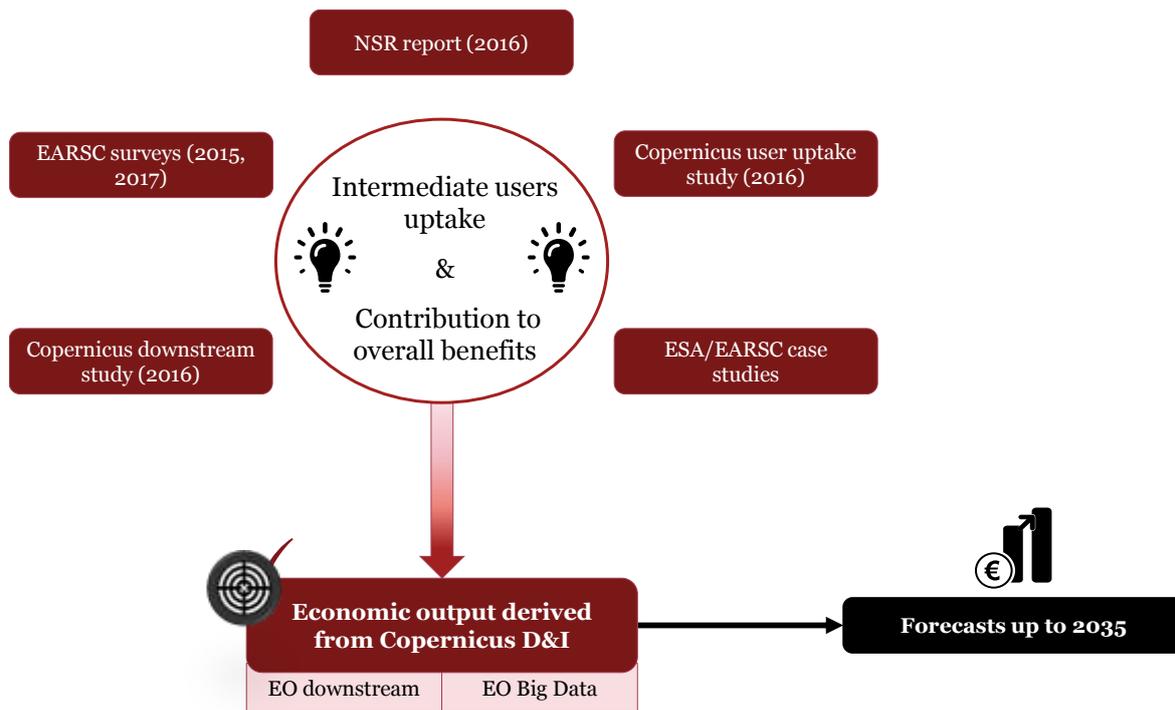


Figure 6 - Intermediate users' revenues assessment approach (Sources: PwC analysis)

Enabled revenues thanks to Copernicus D&I was directly assessed by the European Association of Remote Sensing Companies (EARSC) in their surveys (EARSC, 2015; 2017)¹¹ for the EO downstream revenues. EO Big Data revenues were extracted from the Northern Sky Research (NSR) report (NSR, 2016)¹² and discussed with experts from the field of Big Data to isolate the contribution of Copernicus D&I.

Revenues for both EO downstream and EO Big Data were then projected up to 2035 using market trends from many different sources (EARSC, 2015; 2017; NSR, 2016; EARSC & ESA, 2015; 2016; PWC, 2016; SpaceTec, 2016).

3.1.1.3.2 End-user benefits

Assessment of end-users benefits is less straightforward when compared to intermediate users' assessment. Indeed, end-users benefits can be economic (i.e. cost reduction in forest mapping), social (i.e. enhanced Search & Rescue services) or environmental (i.e. reduced water pollution), making their assessment more complex. Such type of assessment is the core of this impact assessment, with a particular focus at the monetisation of social and environmental end-users benefits.

The high level assessment relies on a five-step approach as illustrated in the chart below.

¹¹ EARSC, 2015. A Survey into the State & Health of the European EO services industry.

EARSC, 2017. A Survey into the State & Health of the European EO services industry.

¹² NSR, 2016. Satellite-Based Earth Observation (EO), 8th Edition. September, 2016.

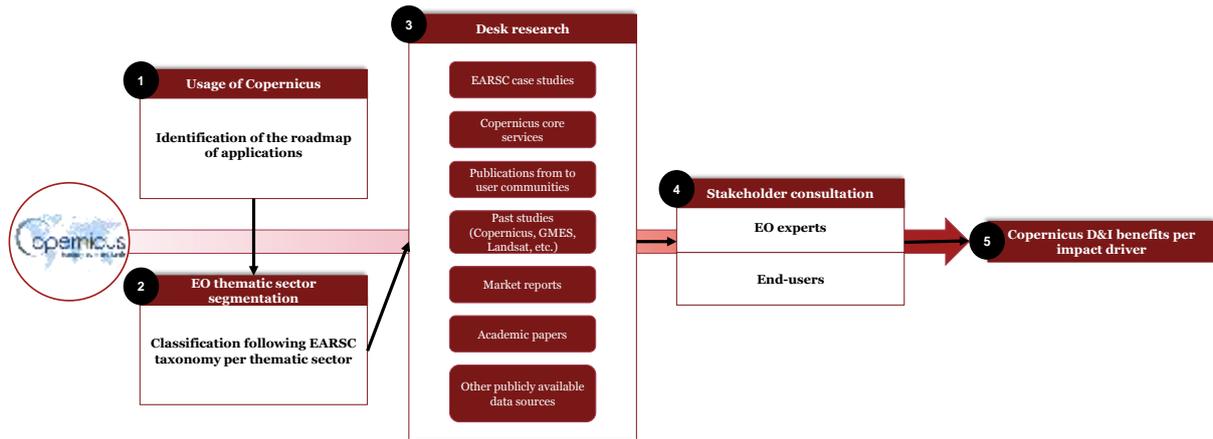


Figure 7 - High level end-users benefits assessment's approach (Source: PwC analysis)

3.1.1.3.2.1 Step 1 – Understanding the benefits derived from Copernicus D&I through a roadmap of applications

The roadmap of applications can be presented as a tree structure illustrating the main applications derived from Copernicus D&I. The rationale behind the development of this application tree is to map and track all the potential utilisation of Copernicus D&I into different commercial and non-commercial fields, as illustrated in the chart below.

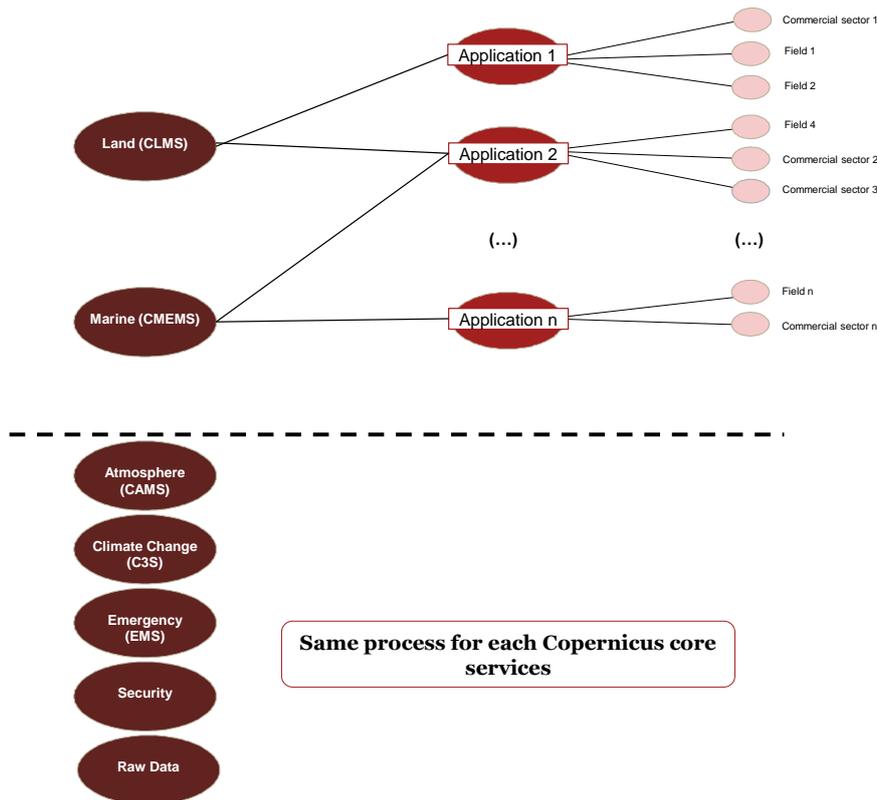


Figure 8 - Simplified representation of the applications roadmap derived from Copernicus data and information

Starting points of this characterisation tree were the six Copernicus core services, and the data and information they are providing. Each core service was then analysed to identify different sub-services offered, isolating the range of Copernicus products portfolio produced by each of them. Identification of applications is directly linked to the products provided by the six core services and raw data.

Targeted expert consultation has taken place with experts from the different Copernicus core services and entrusted entities. Such interaction has enabled the team to confirm and extend the roadmap of applications enabled by Copernicus data and information.

Current and prospective usage of Copernicus D&I have been identified per application, based on desk research and complemented & calibrated through targeted expert consultation. This step is key to understand how Copernicus D&I is used in each application, but also this will evolve in the future in order to understand potential behavioural changes enabled by Copernicus D&I.

The roadmap of applications provide a comprehensive and exhaustive list of applications derived from the utilisation of Copernicus D&I. Nevertheless, **for the purpose of this study, the long-list of applications have been reduced to the applications bringing the largest benefits to be monetised** to enhance the robustness of the assessment, as explained previously.

3.1.1.3.2.2 Step 2 – Classification of applications into EARSC taxonomy

The second step relies on the adaptation of the different Copernicus-based applications extracted from many sources (European Commission, European Space Agency (ESA), stakeholders, academics papers, past studies and publications, etc.) into EARSC taxonomy which is commonly accepted in the field of EO in Europe (EARSC, 2015; 2017). This thematic taxonomy is illustrated in the chart below.

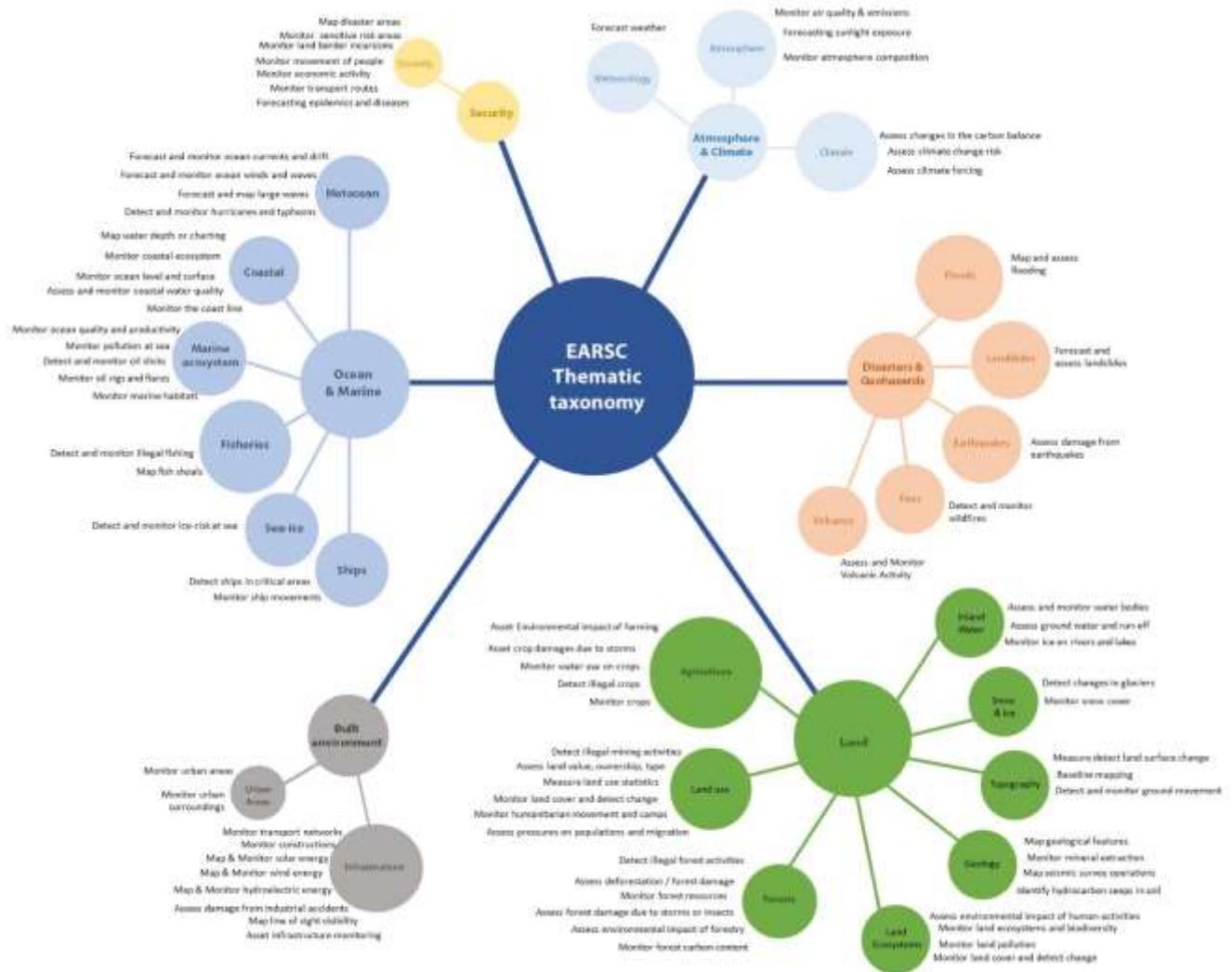


Figure 9 - EARSC thematic taxonomy (Source: EARSC, 2015)

Taxonomy used by EARSC will facilitate comparability and consistency with all the work and studies carried out in the field of EO in Europe. Being able to classify all these applications following EARSC taxonomy also facilitates the assessment and quantification of Copernicus D&I benefits for end-users.

3.1.1.3.2.3 Step 3 – Benefits assessment for end-users

Step 3 aims at assessing the benefits of end-users of Copernicus D&I. These can be direct users– such as for the O&G industry (commercial field) or for Search & Rescue at sea (non-commercial field) for example – or indirect users – such as citizens benefiting from better air quality as a result of Copernicus D&I.

A dedicated framework was developed to assess the impact of Copernicus D&I on end-users in each thematic sector, using an impact-pathway approach.

To illustrate how applications materialise into impacts that we can then quantify, we have developed impact pathways for each application under scrutiny. The aim of this approach is to show how each of the applications are expected to result in changed outcomes for industry, society, the economy and the environment. These outcomes were then assessed to estimate what value to society is enabled by Copernicus D&I. The impacts' analyses consider both tangible impact valuation and intangible impact valuation. In particular they map the

effect of specific events or actions, ‘impact drivers’, through to ‘outputs’ and ‘outcomes’ to specific ‘impacts’. Further to this the impact pathway then maps these ‘impacts’ through ‘societal outcomes’ to the impact on society called ‘societal value’. Note that these granular impacts are not illustrated in the impact pathway chart of all impacts. An impact pathway is thereby mapping the causal chain for every application with quantitatively assessable impacts considered in this study. The approach also aids thinking about which impacts can be assessed quantitatively and qualitatively. The chart below gives an example of an illustrative impact pathway approach.

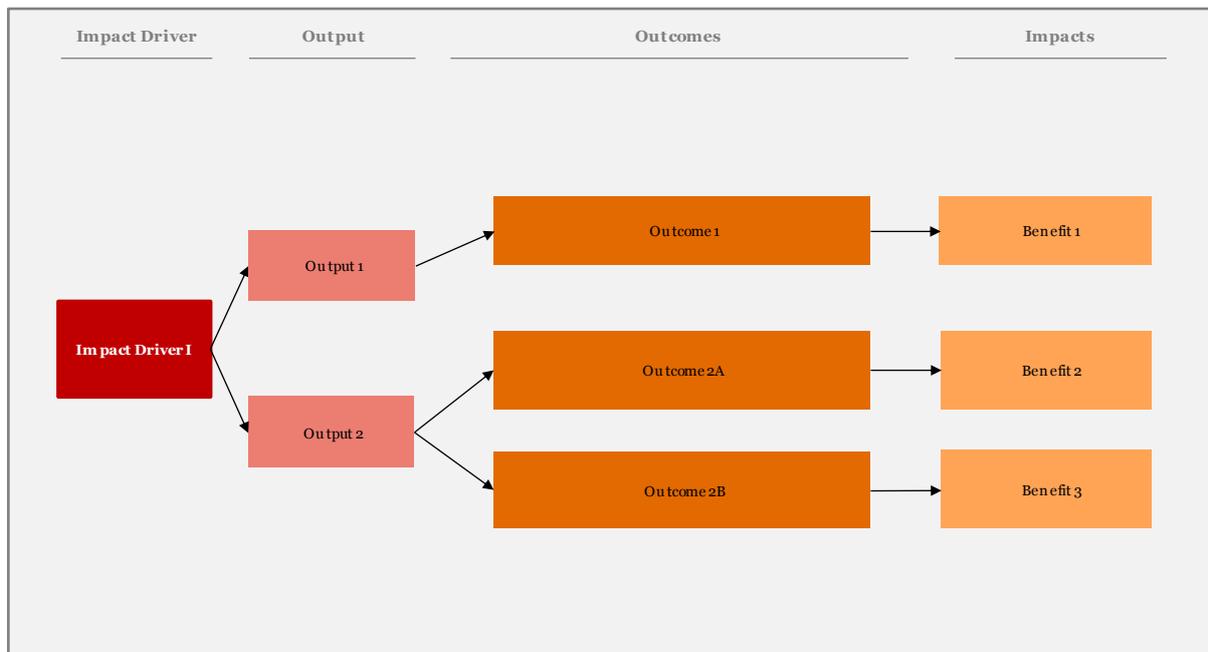


Figure 10 - Example of impact pathway (Source: PwC analysis)

Many different approaches had to be used to take into account the specificity of each end-users specific benefits. The way each end-users benefits has been assessed is directly illustrated in each impact driver in chapter 4 and 5.

3.1.2 Challenges in assessing the benefits from the Copernicus programme

Copernicus is creating new capabilities in earth observation and monitoring which will be used by a wide range of intermediate and end users. Many of the applications will be new services or enhanced applications that are likely to work quite differently to existing capabilities across a range of different domains. Given this, applying ex ante impact assessment to Copernicus is challenging. In many domains, there is no baseline data to consult as there is no precedent for the service being performed. In other domains, even where data exists on the expected experience by end users, it may not be possible to understand the extent of the impact at the EU or global level.

This challenge creates a number of issues for the development of quantitative valuations of the potential impacts. They can be grouped into four main areas and each is discussed in turn below.

1. The use/functionality of Copernicus capability by end users is not clearly understood;
2. The appropriate baseline against which to assess benefits is unclear (i.e. comparison what will have happen without the Copernicus programme);

-
3. Attribution of change to Copernicus is difficult to estimate; and
 4. Implementation will require additional costs on governments or businesses that are not covered by this study.

Each of these are explained in more detail below.

3.1.2.1 Understanding the use of Copernicus capability

Copernicus has the potential to create a range of entirely new services areas across multiple domains. For example, the air pollution services will allow for the prediction of high levels of pollution in particular areas in Europe. This should allow governments to make more timely interventions lower sources of local pollutants such as temporary reductions in speed limits on roads or incentives for industrial thermal generation plants to lower output. It is however, difficult to predict how many governments will adopt these measures and their size and scope; hence, it is difficult to estimate the potential reduction in harmful levels of exposure to specific pollutants that may result.

At an aggregate level, however, it is possible to make an estimate of the total reductions that could be achieved through these types of air pollution control measures given the overall EU targets for reduction in air pollution, and to make an assumption on the attribution of this measure to the Copernicus programme.

This is the approach we have taken on a number of the benefit areas we have analysed for this project. We have clearly stated the assumptions employed (with caveats where appropriate) and have carried out sensitivity analysis to present the results as a range rather than single values.

3.1.2.2 Baseline against which to assess Copernicus benefits is unclear

Most of the applications for Copernicus either add to existing space or ground source data. Typically, users of the services underpinned by these data will often be using a combination of sources. It is important to understand the additional capability that is created by the ongoing programme. However, the Copernicus net margin cannot easily be identified and thus quantified.

For example, climate modelling is already carried out by a range of organisations. Such organisations create models of the future climate which can be incorporated in different ways by different users. Copernicus will improve climate models in a number of specific ways, such as the provision of detailed ocean temperature data. In the future, users will therefore be using better climate models which will have enhanced benefits. However, the extent to which these have been improved by the Copernicus programme compared to both existing and future research and development projects is difficult to understand.

We have made reasonable assumptions to isolate the impact of Copernicus to understand the improvements in the applications, and therefore their estimated value. However, these assumptions are often challenging and may be subject to debate since, for many applications, they remain uncertain.

3.1.2.3 Impact of Copernicus on behavioural change

Where Copernicus is combined with other data to provide a service to end users there is also the difficulty in understanding the impact of Copernicus vis-à-vis other data. This is similar to the issue with identifying the baseline – the improvement (and net benefits) may need to be allocated between different sources of other data or services.

The case of climate modelling noted above is also an example where broader improvements are already being made in the modelling approaches and the land based acquisition of data. Here, we need to attribute the benefit to Copernicus and these other sources of information.

In some cases there is either no other contributor of data, (such as fisheries) or assumptions can be sourced through consultation with teams working in the area. Where possible, we have identified and contacted relevant experts in each area. Some are willing to contribute, others have been reluctant to commit to estimates of the attribution to Copernicus due to the uncertainty in the relevant contributions from different sources.

Further work may be required to fully understand the contribution that Copernicus makes to each impact area. Where we have had to make assumptions we have aimed for full transparency and typically used a range to show the sensitivity of the result to the assumption.

3.1.2.4 Additional cost requirements

The Copernicus programme is an enabler leading to many benefits but that may also call for specific additional cost to use Copernicus D&I. Taking the example of air pollution described above, it is clear that whilst Copernicus allows the prediction of low air quality incidents, other actions are required to implement the policies to reduce the impact.

In this situation we have attempted to estimate the potential benefits resulting from the Copernicus D&I and to attribute them to Copernicus. The only issue is that whilst we have attributed the benefits to Copernicus, on order to produce a consistent *ex ante* assessment, we should also include an attribution of the other costs.

In practice, this is considerably more difficult than examining the benefits themselves. Using the air pollution example, there are published sources for valuation of air pollution impacts that could be applied at the national or EU level. Cost data for these proposed policies does not already exist in the same format and would require a detailed approach to produce suitable values at the national or EU level.

3.1.2.5 Relative uncertainty of the different impact drivers under scrutiny in this study

As a conclusion of all the elements mentioned above, the table below gives an overview of relative level of uncertainty for all impact drivers under scrutiny in the four options. A low level of uncertainty represents a high level of confidence in the outputs of the assessment whereas a high level of uncertainty illustrates a low level of confidence.

Impact driver	Relative uncertainty
EO downstream	Low
EO Big Data	Low
Air quality and pollution monitoring and forecasting	Moderate
Air quality policy	Moderate
Solar energy monitoring and forecasting	Moderate
Climate modelling	High
Crops monitoring	Moderate

Forestry management and protection	Moderate
Wetlands monitoring	High
Ground elevation and ground motion monitoring	Moderate
Urban monitoring	High
Offshore infrastructure management (offshore wind)	High
Oil & gas activities	Low
Mining and quarrying: minerals and raw materials extraction	Medium
Coastal area monitoring	High
Marine resources management	Low
Water quality monitoring	Low
Ice monitoring to support navigation	Low
Maritime navigation	Moderate
Fire detection and monitoring	Low
Floods monitoring and forecasting	Low
Pandemic monitoring	High
Control of Illegal, Unreported and Unregulated (IUU) fishing activities in the EU	Low
Maritime safety - Search & Rescue	Moderate
Oil pollution monitoring	Moderate
Law enforcement and international crime	Low
EU border surveillance	High
Option 3A : Air quality policy	High
Option 3A : Monitoring carbon emissions	High
Option 3B: Arctic search & rescue for reported vessels	High
Option 3B : Arctic oil pollution	High
Option 3B: Arctic ice monitoring to support navigation	High
Option 3B: Water resources management	High
Option 3C: Crop monitoring	High
Option 3C: Water resources management	High

Option 3C: Wetlands monitoring	High
Option 3C: Urban area monitoring	High
Option 3C: Fire detection and monitoring	High
Option 3C: Pandemic monitoring	High
Option 3D: Wetlands monitoring	High
Option 3D: Forestry management and protection	High
Option 3D: Mining and quarrying: minerals and raw materials extraction	High
Option 4: Control of IUU fishing	High
Option 4: Maritime Safety – Search and Rescue	High
Option 4: Oil pollution monitoring	High
Option 4: Law enforcement and international crime	High
Option 4: EU borders surveillance	High

Table 4 - Level of uncertainty of the impact drivers

It is important to note the fact a high uncertainty does not mean the model developed to assess the impact driver was weak and the results should be discarded. It only illustrates the amount of robust data available (desk research and/or stakeholder) related to this area when the study was carried out. All evolutions options impacts were automatically considered highly uncertain due to data and information scarcity.

4 Baseline option – Copernicus programme overall impacts assessment

The baseline option represents the scenario under which the Copernicus programme retains the same scope as it has currently. In this context, physical assets will need to be renewed after 2030 to ensure continuity of data, including potential evolution services responding to user needs.

The baseline option would be the point of reference for the analysis of the different evolution options in section 5.

4.1 Roadmap of applications enabled by the availability of Copernicus D&I

Copernicus D&I impact many different fields and sectors, leading to economic, societal and environmental impacts. Those impacts were mapped and analysed with the support of external experts from Copernicus entrusted entities and from the industry. For the purpose of the analysis, the study had to focus only on impact drivers that can be valued in monetary terms on the most significant ones (impacts leading to the largest benefits). Each impact driver leads to a multitude of impacts that can be translated in monetary terms across the three pillars of sustainability, namely:

- Economic impacts (i.e. cost reduction for end users);
- Social impacts (i.e. human life saved);
- Environmental (i.e. protection of the ecosystem).

The table below illustrates the roadmap of applications enabled by the availability of Copernicus D&I that have been/are currently assessed and monetized.

Theme	Impact drivers
Intermediate users	EO Downstream Industry
	EO Big Data Analytics
Atmosphere and Climate	Air quality and pollution monitoring and forecasting
	Solar energy monitoring and forecasting
	Climate modelling
	Additional impacts for atmosphere and climate change (<i>qualitative impact</i>)
Land	Crops monitoring – support to agriculture
	Forestry management and protection
	Water resources management
	Wetlands monitoring
	CAP monitoring (<i>qualitative impact</i>)

	Ground elevation and ground motion monitoring
	Support to land mapping and cadastral surveying
Built Environment	Urban area monitoring
	Offshore infrastructure management (offshore wind)
	Oil and Gas infrastructure and exploration activities (onshore and offshore)
	Mining and quarrying: minerals and raw materials extraction
Marine and Ocean	Coastal monitoring
	Marine resources management
	Water quality monitoring
	Ice monitoring to support navigation/ship routing
	Maritime navigation
Disasters and Geo-Hazards	Fire detection and monitoring
	Flood monitoring and forecasting
	Pandemic monitoring
Security	Control of illegal, unreported and unregulated fishing activities
	Maritime safety – Search and Rescue
	Oil pollution monitoring
	Law enforcement and international crime
	EU border surveillance
	Support to EU external actions (<i>qualitative impact</i>)

Table 5 - Roadmap of applications enabled by Copernicus D&I (Source: PwC analysis)

4.2 Monetization of Copernicus D&I benefits for intermediate and end-users

4.2.1 Copernicus user uptake discussion

4.2.1.1 An economic discussion on innovation adoption and user uptake

The notion of time is inherent in the field of innovation since it impacts heavily adoption of an innovation within different communities of users. Time is involved in the diffusion of innovation and in the innovation decision process, where an individual goes from a preliminary knowledge to a point where he/she makes a decision to adopt (and then implement) or reject an innovation and/or new knowledge¹³. The concept of “innovation diffusion” is central to innovation and value creation; it is defined by Rogers (2007) as “*the process by which an innovation is communicated through certain channels over time among the members of a social system*”¹⁴.

This concept is clearly linked to the context of the Copernicus programme where the availability of new data and information previously not available for free stimulate innovation and knowledge creation in the field of EO, GIS and EO Big Data. Note that in the particular case of the Copernicus programme, we will talk about “user uptake” rather than “innovation diffusion” but it refers to the exact same economic concept.

¹³ Rogers, E.M., 2003. Diffusion of Innovations. Fifth edition.

¹⁴ Rogers, E.M., 2003. Diffusion of Innovations. P. 2.

In the field of innovation and technology management, adoption rate is rarely linear. Innovation adoption or user uptake may be very different from one actor to another, with some individuals being early-adopters and other requiring more time to absorb an innovation or new technology. Innovation diffusion – user uptake in the case of the Copernicus programme – is expected to follow an S-shaped curve, bringing together the notion of innovation adoption and time. This notion of user uptake has been used in the monetization of the Copernicus data and information, using an S-shaped curve as illustrated in the chart below.

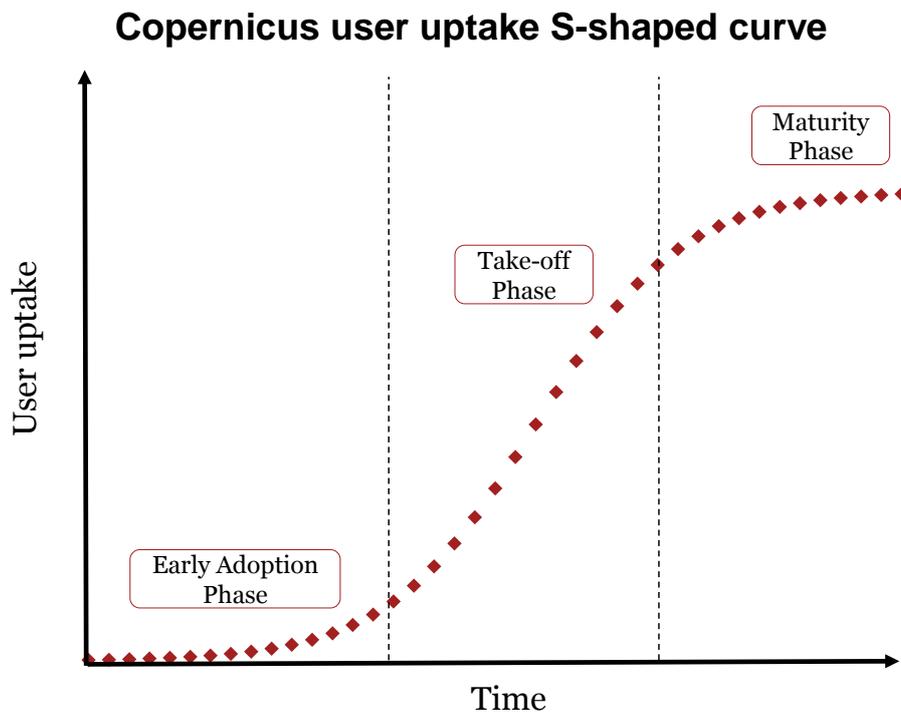


Figure 11 - High level illustration of the notion of user uptake using an S-shaped curve (Sources: adapted from Rogers, 2003; PwC analysis)

User uptake may have the same S-shaped for all Copernicus D&I, it does not mean that all impacts drivers (i.e. air quality monitoring, search and rescue, etc.) have the same level of benefits' contribution derived from Copernicus D&I.

Figure 11 split Copernicus D&I user uptake into three main phases, as detailed above:

- **Early adoption phase:** this first phase concerns very few individuals or companies that are innovators and have already strong knowledge about Earth observation, imagery and software (i.e. coders). These individuals/organisations are able to make use of Copernicus D&I almost immediately. Literature on the diffusion of innovation considers that early adoption phase concerns usually about 15% of the overall population of potential users.¹³
- **Take-off phase:** this second phase represents the vast majority of individuals and organisations trying to make use of Copernicus D&I. This phase relies on the stock of knowledge, information and software already developed by early adopters, enabling the vast majority of users to make use of Copernicus D&I and create value for the society out of it. Literature on the diffusion of innovation considers that take-off phase concerns usually almost 70% of the overall population of potential users.¹³

- **Maturity phase:** the third and last phase represents innovation laggards, representing individuals and organisations more conservative or technology-averse that require more time to absorb new knowledge and innovation. Literature on the diffusion of innovation considers that maturity phase concerns usually about 15% of the overall population of potential users.¹³

Copernicus user uptake (early adoption and take-off phases) is expected to be around **5 years**¹⁵. In this context, **most of the benefits derived from Copernicus D&I should start to be significant after 2020**, depending on the specificity of the impacts under scrutiny (i.e. some impacts can start materializing later than 2020).

4.2.2 Benefits for intermediate users

4.2.2.1 European EO downstream industry

The Copernicus programme was primarily designed to provide geospatial information in support of policy making. Such an open data programme in the field of geospatial information, providing free-of-use satellite-based imagery but also many sources of in-situ data, could have been seen as a threat for the private EO services industry.

Nevertheless, the European downstream industry considers Copernicus data and information contribute to strengthen their competitive advantage by offering new business opportunities and raising awareness about the benefits derived from geospatial information both in Europe and outside. Additionally, acting as participants of the Copernicus programme and recipients of research and innovation funding (i.e. H2020), European intermediate users directly benefits from the Copernicus programme, stimulating their competitiveness on global markets.

EARSC carries every two years an industry survey assessing the European market for European downstream companies. Global European downstream industry is estimated at EUR 1.2 B in 2017 by the European Association of Remote Sensing Companies (EARSC)¹⁶, with a growth rate of around 10% annually. This industry supports more than 7,000 highly skilled jobs in Europe and has an average annual growth rate of 10%¹⁷. In these surveys, a particular focus has been given to the Copernicus programme and the contribution of Copernicus D&I to European intermediate users. This assessment is illustrated in the table below.

<i>EUR M; EUR 2017; not discounted values</i>	2015	2017
Overall European intermediate users revenues	910	1 226
Revenues enabled by free Copernicus data & information	60	92
Share of overall European intermediate users' revenues enabled by Copernicus data & information	6.6%	7.5%

Table 6 - Summary of revenues driven by free Copernicus D&I (Sources: EARSC, 2015; EARSC; 2017)

NSR (2016) estimations of European Compound Annual Growth Rate (CAGR) was used to project overall European intermediate users revenues over the period 2017 – 2025. Since CAGR is expected to slow down after 2025 due to the fact that the intermediate user market

¹⁵ Expert consultation

¹⁶ EARSC, 2017. EO services industry. A Survey into the State and Health of the European EO Services Industry.

¹⁷ EARSC, 2017. Copernicus Evolution: Fostering Growth in the EO Downstream Services Sector.

will reach a certain level of maturity, a conservative assumption was taken that CAGR would be equal to around 5% over the period 2025 – 2035.

As discussed in the section 4.2.1, user uptake is estimated to be around 5 years. The full constellation is expected to be operational by 2019-2020, meaning the period 2020 – 2025 is expected to have the highest growth in the contribution of Copernicus D&I, before stabilizing after 2025. Starting from 2015, where Copernicus D&I represents 6,6% of the overall European EO downstream market¹⁸, two scenarios for the contribution of Copernicus D&I were developed using the so-called S-shaped curve for the user uptake:

- **High estimate:** contribution of Copernicus data and information is expected to reach 15% by 2020 and 20% by 2025¹⁹. This contribution is then expected to remain constant after 2025;
- **Low estimate:** contribution of Copernicus data and information is expected to reach 10% by 2020 and 15% by 2025¹⁹. This contribution is then expected to remain constant after 2025.

Medium estimate is obtained by making an average between low and high estimate. The strong growth up to 2025 for traditional EO downstream is expected to be supported by

Cumulative revenues of European intermediate users' revenues over the period 2017 – 2035 is expected to range between EUR 5 705 M (low estimate) and EUR 7 648 M (high estimate), reaching around EUR 474 M (low estimate) and EUR 633 M (high estimate) by 2035. Expected evolution of these revenues is displayed in the chart below.

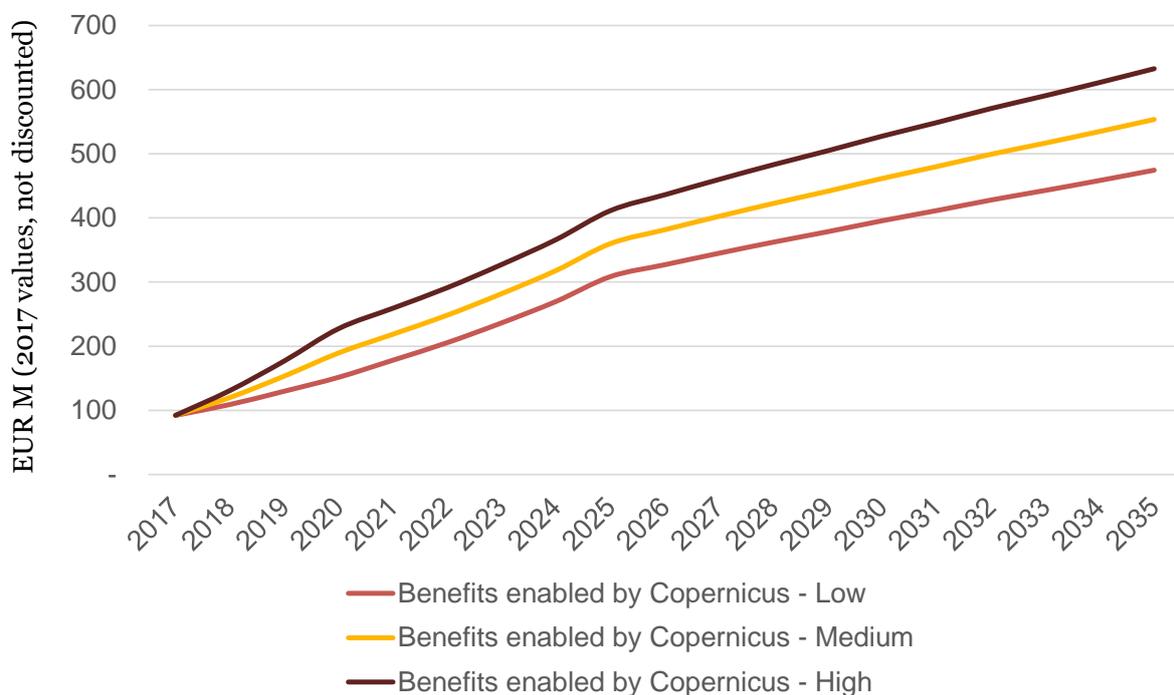


Figure 12 - European intermediate users enabled by Copernicus data and information (Sources: EARSC, 2015; NSR, 2016; PwC, 2016; EARSC, 2017; PwC analysis)

¹⁸ EARSC, 2015. EO services industry. A Survey into the State and Health of the European EO Services Industry.

¹⁹ PwC, 2016. Study to examine the socio-economic impact of Copernicus in the EU. Report on the Copernicus downstream sector and user benefits. Report prepared for the European Commission. Brussels, Belgium.

Calibrated with EO experts

4.2.2.2 Contribution to Big Data in Europe

Today's context of the digital economy and Big Data paradigm are disrupting intermediate users market by shifting traditional EO services' business models towards digital services relying on strong computing power, cloud-based platforms and the merger of more and more data sources. Big Data analytics based on satellite imagery is considered as a derivative of EO downstream information products' market²⁰ but re are then not included in the previous section on European EO downstream industry revenues. In fact, this new market is enabled by the availability of very large sources of satellite-based imagery and in-situ data. These new sources of data are available at no cost through open data programmes (i.e. Landsat and Copernicus) or at very low cost through large EO commercial constellations (i.e. Planet, Spire, etc.). Market of Big Data analytics based on satellite imagery relies on the processing, analysis and fusion of multiple images and other data sources in order to create intelligence not previously available; many of EO Big Data applications rely on statistics and econometric models linking information extracted from all the different datasets to create high value-added products.

The availability of a large volume of free of charge data is considered as one of the key enablers of the EO Big Data market worldwide. In this sense, the open EO data programmes (i.e. Landsat, Copernicus, MODIS, etc.) play a key role to lower barriers to entry by enabling these new entrants to have access to a fertile playground of innovation in the field of Big Data analytics. Indeed, these expert can then develop and test their algorithms on large volumes of standardised data free of charge before being commercially viable.

The Copernicus programme is considered to be at the origin of the market of Big Data analytics based on satellite imagery in Europe, more than any other open EO data programme. Even if current market has not yet take off in Europe, the Copernicus programme is expected to play a major role in stimulating this market over the next years, on account of:

- **The volume of data provided by Copernicus:** The Copernicus programme is expected to provide a tremendous volume of data once all the services and satellites would be operational. Such volume will constitute a huge repository of data in the next years, including satellite-based imagery but also many sources of in-situ data. This amount of data available for free is expected to highly stimulate Big Data analytics capabilities in Europe in the next decades;
- **The variety of data provided by Copernicus:** Continuity of the Copernicus programme will enable the creation of long archives of imagery from different type of sensors, different wavelengths, and different spatial and temporal resolutions, but also archives of many different sources of in-situ data from all over Europe. The richness of this large repository of data should also contribute to develop a strong European Big Data analytics market.

EO Big Data revenues are expected to grow globally at an average CAGR of 27% over the period 2015 – 2025, reflecting a strong commercial interest in the super-fast growing market of Big Data analytics using imagery over the next decade. NSR (2016) highlights the fact that the Big Data analytics market based on imagery is and would remain very strong in North America. This can be explained by the presence of the so-called GAFA (Google Apple Facebook Amazon) and their ecosystems. Compared to traditional EO downstream industry mostly relying on public authorities' customers, the services industry (i.e. financial industry) is expected to be the largest customer for Big Data analytics based on imagery in the next years. Indeed, the financial community is currently heavily adopting Big Data analytics relying on imagery, providing better risk mapping and assessment for financial activities.²⁰

²⁰ NSR, 2016. Satellite-Based Earth Observation (EO), 8th Edition. September, 2016.

The Copernicus programme is considered to have been at the origin of the development of a market in Europe for imagery and in-situ data into the Big Data analytics economy. As previously mentioned, the amount of information and data (both space-based and in-situ) available for free has given a spark to this new, highly promising market in Europe. The Copernicus programme is currently stimulating strong interest from private actors and individuals that is expected to lead to a tremendous growth on this market, leading to a reduction of the contribution of Copernicus data and information into the overall Big Data analytics using imagery. Large private constellations of satellites planned to be launched over the next year are indeed also expected to play a key role into the take-off of the Big Data analytics market in Europe. The expected contribution of Copernicus data and information to the overall European market for Big Data analytics relying on imagery is illustrated in the chart below. The assessment relies on two scenarios (low and high estimates) where Copernicus' contribution evolves from 100% in 2015 to an approximation of 40%-60% (low estimate – high estimate) of the overall European Big Data analytics relying on imagery around 2020-2021 (once all the Sentinels fleet will be flying)²¹. This contribution is then expected to stay almost the same over the period 2020 – 2035, as illustrated in the figure below.

Even if this contribution seems to be quite high, the amount of imagery from many different sensors and wavelength, in-situ data and modelling made available for free is unprecedented in Europe and worldwide. The spillovers of these new materials available for free on digital platform – making them really easy to be accessed and used – is considered to be the major driver of the emergence of Big Data analytics market related to geospatial in Europe

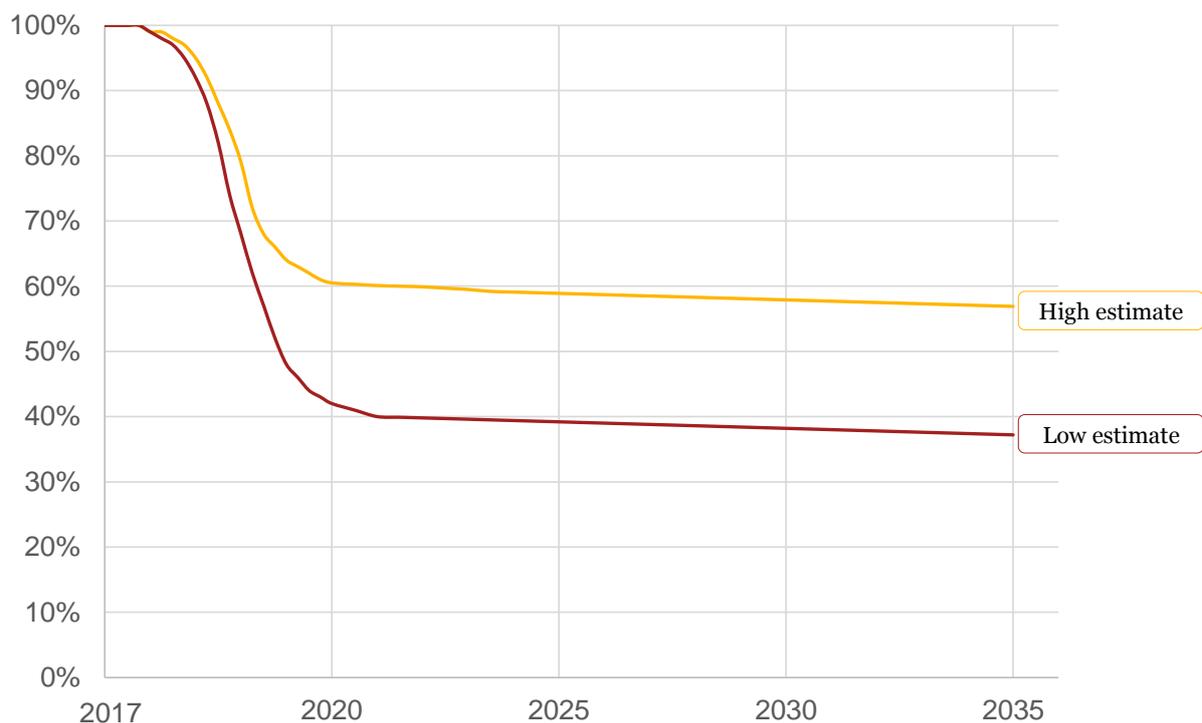


Figure 13 - Share of revenues attributed to Copernicus D&I as the contribution of imagery to Big Data analytics in Europe (Sources: NSR, 2016; expert consultation; PwC analysis)

Medium estimate is obtained by assessing the average value between high and low estimate. Current benefits attributed to Copernicus data and information in the field of Big Data analytics are estimated to be around EUR 13 M in 2015. Big data analytics using imagery

²¹ This assessment is based on consultation of experts in the field of “Big Data analytics” and “Remote sensing market”. The aim is to show here an order of magnitude rather than an exact benefits assessment since no previous study has ever tried to look at this type of benefits.

represents an estimated market of EUR 100 M worldwide in 2015. Having such low benefits is coherent with the current early operational stage of the Copernicus programme, where the volume of data (satellite-based imagery and in-situ data) available does not enable the market to take-off in Europe. Nevertheless, this market in Europe is expected to grow tremendously over the next decade (2015 – 2025) with an average CAGR 34%²². No data being available on average CAGR after 2025, the decision was made to use a CAGR reduced by 1% each year over the period 2025 – 2035 to illustrate the fact the market will reach a certain level of maturity. Overall revenues derived from Copernicus D&I over the period 2015 – 2035 is illustrated in the chart below.

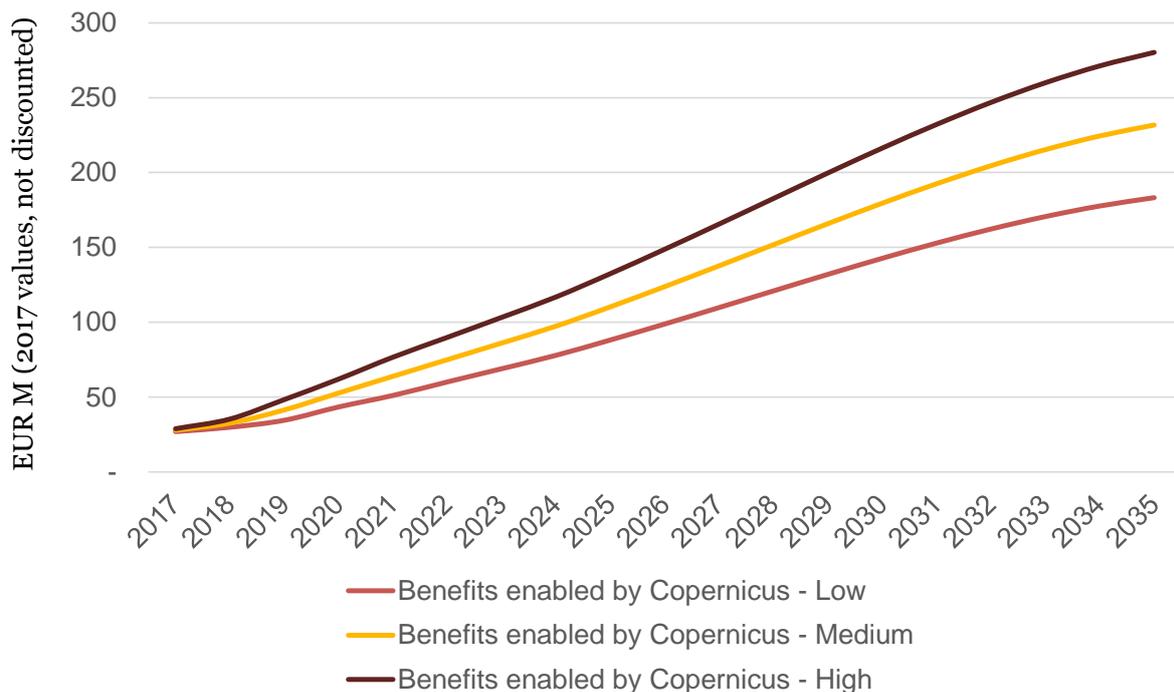


Figure 14 - Big Data analytics revenues enabled by the availability of Copernicus data and information (Sources: NSR, 2016; PwC analysis)

Over the period 2017 – 2035, Big Data analytics revenues enabled by the availability of Copernicus data and information are estimated to range between EUR 1 932 M (pessimistic scenario) and EUR 2 898 M (optimistic scenario) in cumulative terms.

4.2.2.3 Overall European intermediate users’ benefits derived from Copernicus data and information

The Copernicus programme is expected to lead to significant benefits for European intermediate users (EO traditional downstream and Big Data analytics based on imagery), contributing to reinforce their competitive advantage. In the coming years, EO traditional downstream and Big Data analytics actors are expected to converge into the large data and digital economy, even if the type of products provided, and so the revenues, will remain two distinct categories.

Copernicus data and information should also stimulate exports of EO services outside Europe but the share of exportations versus European-only revenues was not possible to be assessed accurately. Recent EU initiatives in Africa and Latin America, such as the EU Africa

²² NSR, 2016. Satellite-Based Earth Observation (EO), 8th Edition. September, 2016.

Partnership²³ or the Cooperation Programme on Drugs Policies (COPOLAD) between the EU and Latin America²⁴, should indeed contribute to stimulate exportations of information products and services of European intermediate users to these regions.

Over the period 2017 – 2035, the availability of Copernicus D&I is expected to lead between EUR 7 637 M (pessimistic scenario) and EUR 10 545 M (optimistic scenario) revenues for European intermediate users, with a medium scenario of EUR 9 091 M. This trend is illustrated in the chart below. Note that European intermediate users’ benefits sum together European EO downstream industry revenues and Big Data analytics based on imagery revenues enabled by Copernicus D&I.

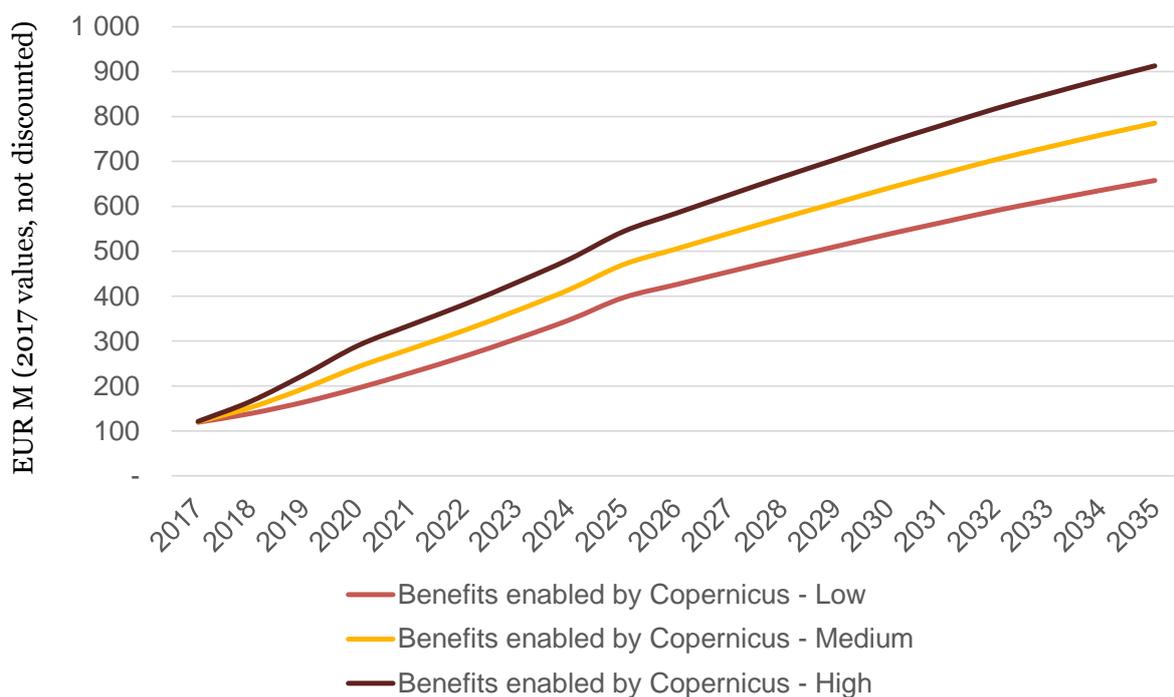


Figure 15 - Overall European intermediate users revenues enabled by Copernicus data and information (Sources: EARSC, 2015; NSR, 2016; EARSC, 2017; PwC analysis)

4.2.3 Benefits for end-users

If the previous section has highlighted all the revenues enabled by Copernicus D&I, these information have wider impacts on the European society through its diffusion to end-users. End-users may be direct users (such as end-users in the O&G industry) or indirect users not even aware of using or benefiting from Copernicus D&I (i.e. citizens benefiting from a better air quality or a reduced pollution of groundwater). This section gives a specific focus to social and environmental benefits.

²³ More details available on the EU Africa Partnership website

Link: <http://www.africa-eu-partnership.org/en>

²⁴ More details available on the EU International Cooperation and Development website

Link: https://ec.europa.eu/europeaid/regions/latin-america/copolad-cooperation-programme-between-latin-america-and-european-union-drugs_en

The following sub-sections introduce all the impacts enabled by Copernicus D&I that accrue to end users that can be assessed and transformed into monetary values. Benefits are split among six families of impacts, following EARSC taxonomy on EO services²⁵.

4.2.3.1 Atmosphere and climate

4.2.3.1.1 Air quality and pollution monitoring and forecasting

Air pollution is the largest environmental risk to health; indeed, the WHO estimates that in 2012, one in nine deaths globally was the result of air-pollution related health conditions²⁶. Although in Europe air quality has improved significantly in past decades, air pollution concentrations remain high and a large proportion of Europe's population lives in areas with air pollution above EU limits²⁷. Monitoring air quality is key to determine whether areas are meeting pollution targets and to assess the impact of air pollution policies.

Satellite data on atmospheric composition has only recently been incorporated into air quality models, and is useful to monitor, assess and forecast air quality conditions by providing views of air pollution over large areas. One of the many uses of satellite data is that it can be used for users and policymakers to verify data from air quality monitoring stations when combined with on-ground measurements²⁸.

Through CAMS (Copernicus Atmosphere Monitoring Service), the state of the atmosphere is estimated daily and forecasts are provided based on models and observations. CAMS uses a wide range of satellite data, on the ground measurements and models. One of the CAMS products provides air quality forecasts for Europe (resolution of 10km) 4 days in advance and globally (resolution of 40km) 5 days in advance. CAMS provides information at national and regional level which is included in local air quality analysis and forecast models. Whilst local on-ground measurements provide highly localised information of pollution, CAMS data provides regional effects and forecasts which are used to improve the accuracy of air pollution forecasts²⁹.

The availability of air quality and pollution data can enable policymakers to devise measures to prevent acute air pollution episodes and meeting EU air quality targets, and be used as a data input to air quality alert services (e.g. airTEXT, which provides air pollution warnings via text message or smartphone application in advance of medium or high air pollution episodes). This leads to the following impact pathway, which maps out the total impact of the air quality monitoring application (impact driver) through to the particular environmental, societal or economic benefits (impacts):

²⁵ EARSC, 2015. Taxonomy for the EO Services Market.

²⁶ WHO 2016. Ambient air pollution: a global assessment of exposure and burden of disease.

²⁷ European Environmental Agency, 2017.

²⁸ Diofantos G. Hadjimitsis, Kyriacos Themistocleous and Argyro Nisantzi, 2012. Air Pollution Monitoring Using Earth Observation & GIS.

²⁹ Interview with Amy Stidworthy (AirTEXT) on 3rd July 2017.

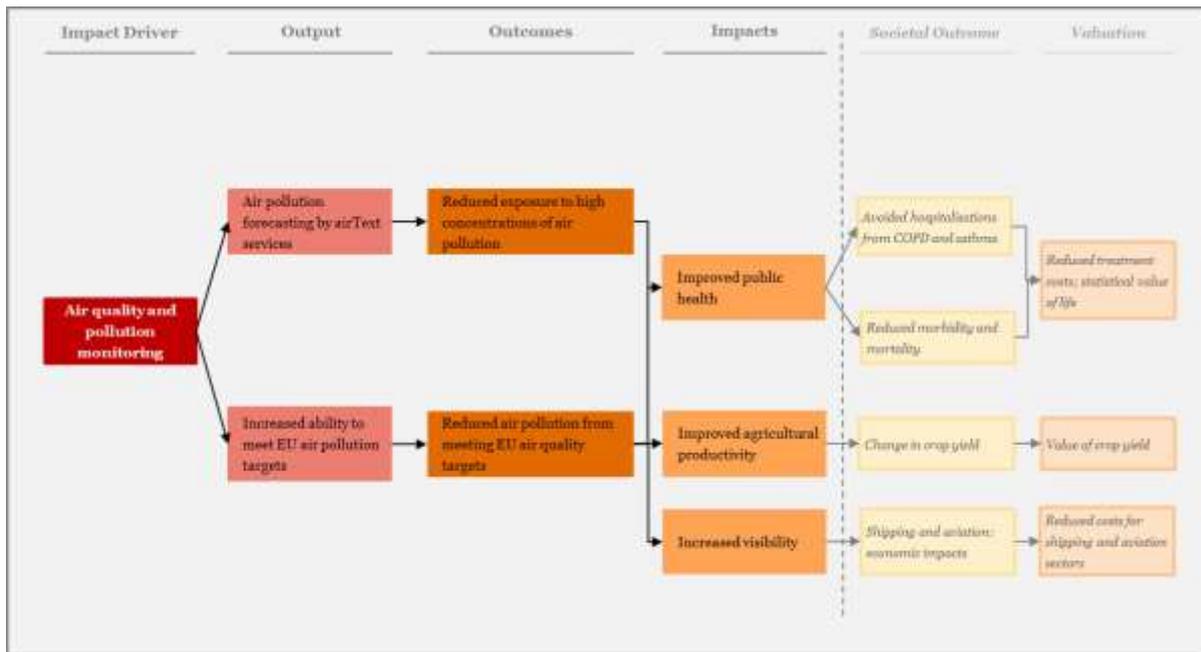


Figure 16 - Impact pathway for air quality and pollution monitoring (Source: PwC analysis)

The quantification of the benefit mentioned above is based on the following outcomes which can be assumed:

- Decreased exposure to air pollution as a result of air pollution alert services;
- Enabling policymakers to meet EU air pollution targets under the Clean Air Programme (Directive 2016), through improved mitigation and response to acute air pollution episodes.

4.2.3.1.1.1 Decreased exposure to air pollution as a result of air pollution alert services

The impacts from air quality and pollution warning systems, such as airTEXT, are valued by calculating the reduced exposure to air pollution in populations living in high pollution areas. CAMS regional air pollution forecast data is used as a key input in the models that provide the airTEXT warnings. It is assumed that CAMS downstream data users can expand airTEXT-like services to more cities in Europe from 2018 onwards (currently London, Barcelona, Vienna and Riga have a service in place³⁰) and then globally from 2020. Several other air quality smartphone and/or website apps using CAMS forecast data are already available for Europe and the rest of the world from commercial providers (e.g., PlumeLabs, Breezometer) and national environmental agencies (e.g., RIVM, DEFRA, PREV’AIR). Reduced exposure to air pollution as a result of this service results in improved health, which is measured by the health valuations of asthma and chronic obstructive pulmonary disease (COPD) cases, which includes saved treatment costs and valuations of quality of life. As the quality of forecasts has been estimated to be improved by 10-20%, it is assumed that Copernicus contributes 15% to the improved health impacts of the airTEXT service³¹.



Methodological approach to decreased air pollution exposure

Our approach is based on studies of air alert services and saved costs from avoided hospitalisation from people taking action to reduce their exposure to air pollution. The steps are:

1. Determine the number of people using airTEXT and taking action based on these

³⁰ Interview with Amy Stidworthy (AirTEXT) on 3rd July 2017.

³¹ PwC, 2016. Study to examine the socio-economic impact of Copernicus in the EU.

- alerts
2. Calculate the prevalence of COPD and asthma to find the avoided hospitalisations from reduced exposure to air pollution
 3. Multiply by the contribution of Copernicus in improving air pollution forecasts of airTEXT
 4. Apply the contribution of Copernicus to this reduction

Decreased exposure to air pollution from air pollution alert services

Valuation approach



Currently, 0.23% of the population in cities where airTEXT is available use this service. However, it is expected that take-up will increase exponentially as more people become aware of the service and concerns about air pollution. Furthermore, mobile phone and smartphone penetration will continue to increase (global penetration of mobile phones stood at 93% in 2013 and smartphone penetration is expected at 60% in 2020³²). In the mid-range scenario, it is assumed that 10% of the EU population³³ and 10% of the global population living in polluted areas are using an airText-like service enabled by CAMS data by 2035. In the low scenario, 5% of the EU and global population in polluted areas use the service; and in the high scenario, 15% of the EU and global population in polluted areas use air alerts.

Based on several studies, it has been assumed that 30% of people receiving air pollution alerts take action and that the action is 100% effective in averting all pollutants, e.g. by reducing time spent outdoors³⁴. A study conducted for London and the region of Sussex has estimated the numbers of airTEXT users with asthma and COPD required to avoid one hospital admission³⁵. This analysis has been used as a proxy for EU and globally, scaled by relative healthcare costs³⁶.

Based on this study, it has been assumed that the prevalence of these conditions is 10% higher in polluted areas than in the general population due to two factors. Firstly, these conditions occur with higher frequency in highly polluted areas; and secondly, people with these conditions are more likely to subscribe to airTEXT. As air alert services use CAMS data as one of several data inputs in their air pollution forecasting, 15% of the benefit is attributed to Copernicus. This is based on the 2016 PwC study which estimated quality improvements in forecasting of between 10-20%³⁷. The average global health value of a respiratory hospital admission is EUR 1,730 and the average global health value of a COPD case is EUR 26,801³⁸.

³² GSMA, 2016. Global mobile phone trends. Available at: <https://www.gsmainelligence.com/research/?file=357f1541c77358e61787fac35259dc92&download>

³³ Discussions with AirTEXT.

³⁴ Semenza et al 2008; Wen et al 2009; Clift & Smallbone.

³⁵ King's College London 2014. Air pollution alert services evidence development strategy.

³⁶ WHO-CHOICE 2011 unit costs by country and GBD region.

³⁷ PwC, 2016. Study to examine the socio-economic impact of Copernicus in the EU.

³⁸ King's College (2015) Understanding the Health Impacts of Air Pollution in London. The health value for a respiratory hospital admission in UK is EUR 8,505 and EUR 131,690 for COPD. These have been scaled to find the global average using WHO (2011) data on the global health care cost ratio.

As a result, total benefits for the EU in avoided asthma and COPD hospitalisations from air alert services are expected to start at EUR 0.01 M in 2017 and rise between EUR 2 M to EUR 6.1 M in 2035, for a total cumulative value ranging from EUR 8.3 M to EUR 21.0 M (in 2017 not discounted prices).

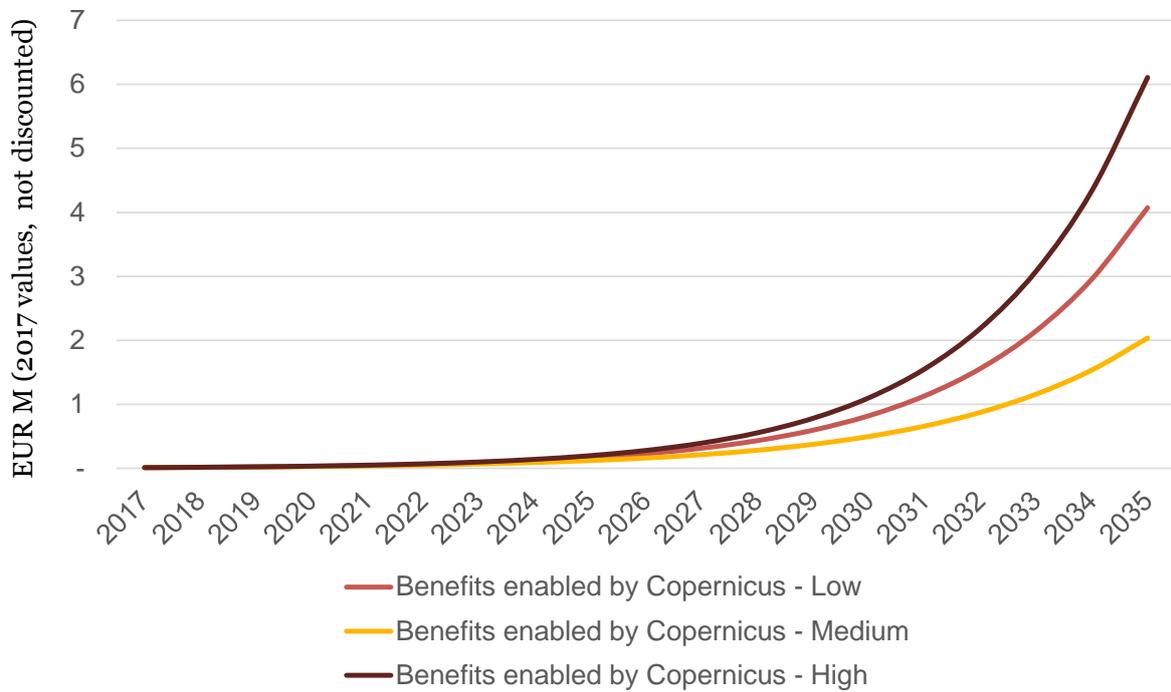


Figure 17 - EU benefits enabled by Copernicus D&I related to air quality and pollution monitoring –airTEXT (2017 EUR in undiscounted values) (Source: PwC analysis)

Total benefits globally (including EU) start at EUR 0.01 M in 2017 and rise until a range between EUR 111.3 M and EUR 333.8 M in 2035, for a total cumulative value ranging from EUR 341 M to EUR 894 M (in 2017 not discounted prices).

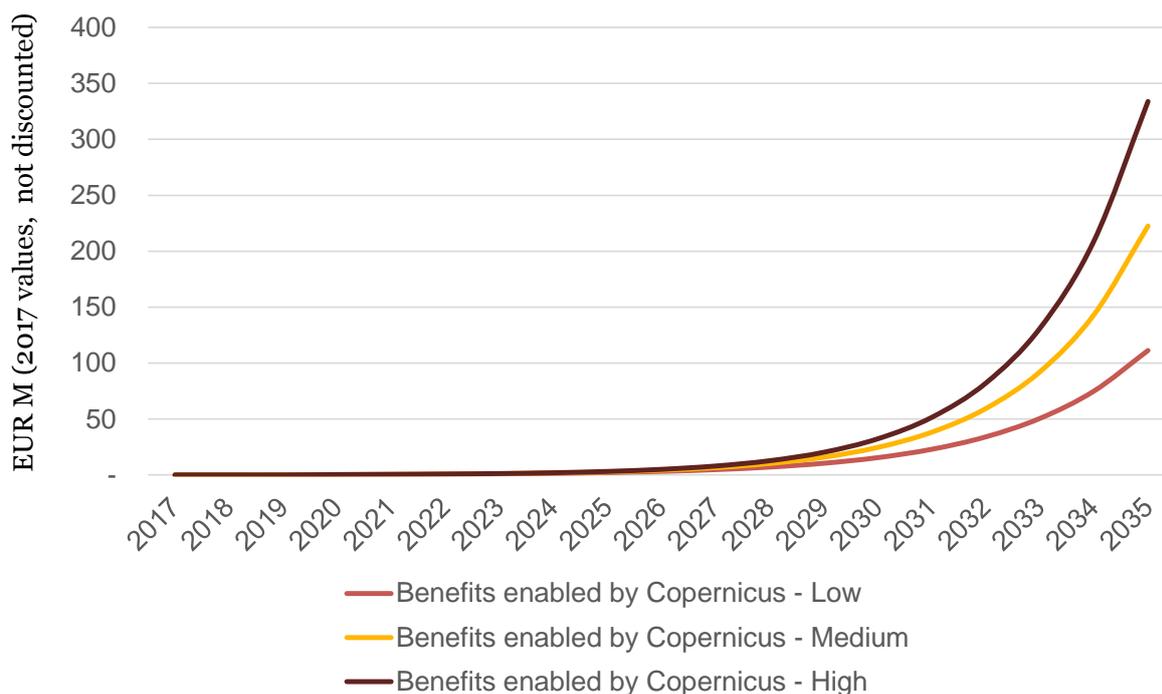


Figure 18 - Global benefits enabled by Copernicus D&I related to air quality and pollution monitoring – airTEXT (2017 EUR in undiscounted values) (Source: PwC analysis)

4.2.3.1.1.2 Enabling policymakers to meet EU air pollution targets under the 2013 National Emission Ceilings Directive

CAMS provides air quality forecasts for Europe (resolution of 10km) 4 days in advance. This provides policymakers with information to pre-emptively mitigate or reduce the impacts of severe air pollution episodes a few days in advance, rather than solely relying on real time observations. CAMS allows decision makers to select emission reduction strategies most adapted to each situation, enabling more effective public decision making on reducing air pollution. This can enable policies such as restricting traffic through cities, temporary speed reductions on motorways, changes in airplane schedules or compensating industrial energy users to reduce capacity during periods of high air pollution. If these reduction measures are taken, pollutant levels will go down, CAMS provides policy support for the management of air pollution episodes through its green scenario tool, by forecasting the impact of air pollutant emissions reduction scenarios on air pollutant concentrations.³⁹ This allows an evaluation of the effectiveness of pollution reduction strategies. Potential reductions in air pollution predominantly benefit health, but also agricultural productivity (as certain pollutants negatively impact the growth of crops) and visibility (air emissions can form smog which affects navigation and enjoyment of recreational sites).

³⁹ CAMS Green Scenarios Documentation 2017.

http://policy.atmosphere.copernicus.eu/reports/CAMS71_2016SC1_D71.2.1b_201701_GreenScenariosDocumentation_v3.pdf



Methodological approach to meeting EU air pollution targets

Our approach is based on the increased ability to meet EU National Emission Ceilings as a result of better air pollution forecasts improving the effectiveness of policy actions.

1. Determine the number of people using airTEXT and taking action based on these alerts
2. Calculate the prevalence of COPD and asthma to find the avoided hospitalisations from reduced exposure to air pollution
3. Multiply by the contribution of Copernicus in improving air pollution forecasts of airTEXT

Increased ability to meet EU air pollution targets

Valuation approach



Based on consultations with experts⁴⁰, we have taken the approach of valuing the benefits of CAMS in managing and reducing the effects of acute air pollution episodes. As the effects on particular air pollution concentrations vary significantly by time and geography, the valuation methodology taken here is that the information from CAMS air quality forecasting is different from existing ground measurement sources. The value of this information is that by forecasting acute air pollution episodes, CAMS enables policymakers and individuals to take action to reduce air pollution or avoid its impacts. This in turn contributes to enabling policymakers in the EU to meet the air quality limits under Directive 2016/2284/EU on the reduction of national emissions of air pollutants (entered into force December 2016), which is what has been modelled here. Under this directive, national emission ceilings (NEC) per pollutant have been set between 2020 and 2030 and stricter targets from 2030 onwards. Whilst CAMS itself does not lead to specific policy actions, it can provide actionable information to support these. In this study, following consultation with stakeholders, the assumption has been taken that CAMS will contribute between 2.5-5% of the ability to meet the National Emission Ceilings under this legislation in 2017 and 5-10% contribution in 2035. This is due to improved information and data which can assist countries in evaluating and improving their policies to reduce air pollution. However, as this is an assumption, there is uncertainty around the results.

To assess the benefits of Copernicus, the air pollution emissions level under Directive 2016/2284/EU is compared to a baseline. This baseline has been constructed by taking the current level of pollutants NH₃, NO_x, SO_x, PM₁₀, PM_{2.5} and VOC and projecting forward this level based on the decrease in these pollutants since 2000 across the EU-27. The difference between the baseline levels of pollution and those involving policy intervention has been quantified using the PwC valuation methodology on air pollution⁴¹. This methodology values the costs from air pollution in monetary terms, from impacts on human health, agriculture and visibility. It is important to note that the benefits monetised here are

⁴⁰ Vincent-Henri Peuch (ECWMF), Richard Engelen (ECMWF), Juan Garces De Marcilla (ECMWF), Carlo Buontemp (ECMWF).

⁴¹ PwC, 2015. Available at: <http://pdf.pwc.co.uk/pwc-environmental-valuation-methodologies.pdf>

contingent on policymakers acting on the Copernicus data to enable more rapid or effective policy change.

The benefits of reduced air pollution from CAMS is valued between EUR 272.8 M and 545.5 M in 2017, rising to between EUR 768 M and EUR 1,525 M per year in 2035 (in 2017 undiscounted prices). 76% of this benefit (EUR 11,740 M in the medium scenario over the total period) is from avoided negative effects on health. The total cumulative value ranges from EUR 10,379 M to 20,746 M (not discounted value). Whilst these benefits appear high, a WHO report in 2015 estimated that the economic cost of health impacts and mortality was US\$1.575 trillion per year⁴² and the European Commission has estimated health related costs of air pollution between EUR 390 to 940 billion per year.⁴³

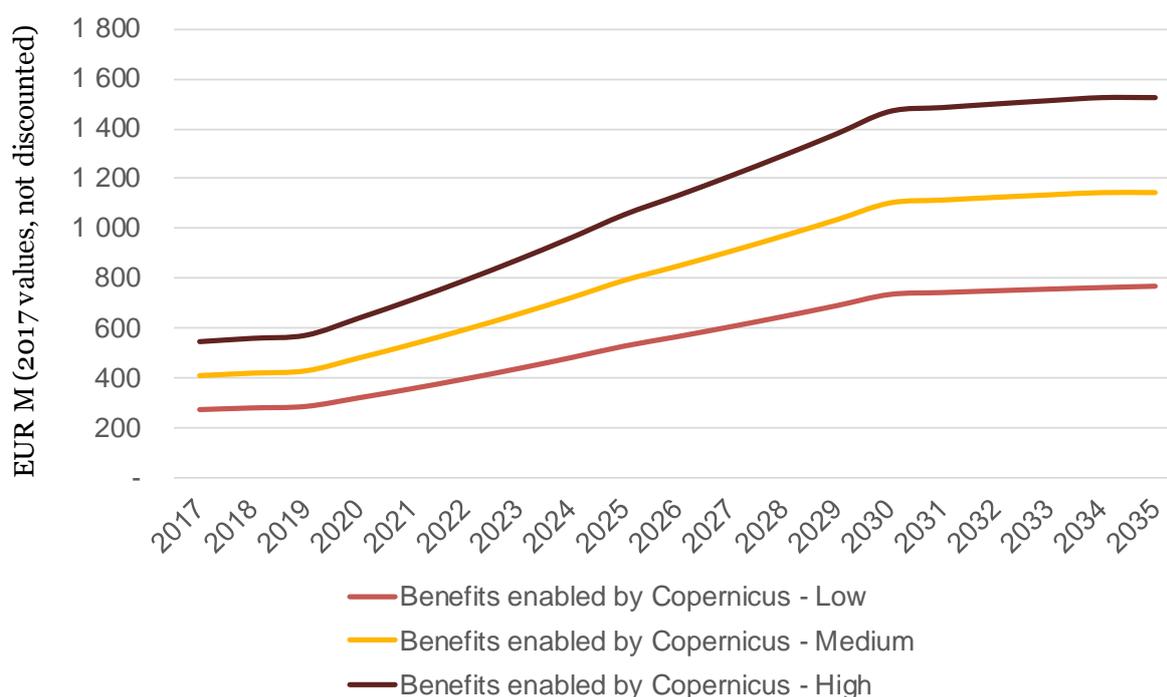


Figure 19 - Total EU benefits enabled by Copernicus data and information related to meeting EU air quality regulations (2017 EUR in undiscounted values) (Source: PwC analysis)

4.2.3.1.1.3 Summary of Copernicus contribution to “Air quality and pollution”

The total not discounted benefits linked to Copernicus in the EU, are expected to amount to:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	272.8	527.7	768.1	10,378.7
Medium estimate	409.1	791.5	1,143.8	15,559.7
High estimate	545.5	1,055.4	1,525.1	20,746.2

Table 7 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

42 WHO Regional Office for Europe, OECD (2015). Economic cost of the health impact of air pollution in Europe: Clean air, health and wealth.

43 European Parliament, January 2017. Briefing – Reducing air pollution. Available at:

[http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/595893/EPRS_BRI\(2017\)595893_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/BRIE/2017/595893/EPRS_BRI(2017)595893_EN.pdf)

Differentiation factor of EO and Copernicus D&I

The air quality forecasts from Copernicus are important to monitor air pollution in Europe, as they are reliable and accurate. There are few alternatives to this CAMS product and as existing alternatives are less reliable and have a lower spatial resolution, they would be less suitable to feed the air pollution forecast models. Therefore, if Copernicus assets are shut down by 2030, other air quality forecasts could be used but these would be less reliable, not freely available and of inferior spatial resolution, therefore not enabling the same outcomes.

4.2.3.1.2 Solar energy monitoring and forecasting

With the recent NDC targets under the COP21 Paris Agreement as well as the revised European Renewable Energy Directive targeting a 27% share of renewables in the final energy consumption by 2030, renewable energy and, as part of it, solar energy has a significant role to play.

The Copernicus Atmosphere Monitoring service (CAMS) provides a service theme dedicated to solar radiation⁴⁴. Solar radiation may vary depending on several parameters (clouds, aerosols, water vapour or ozone) which are all monitored by CAMS⁴⁵. Being able to track these parameters upstream enables the provision of accurate solar radiation products. These products are especially relevant for the solar energy industry and the electricity sector. CAMS deals with the visible solar spectrum on a wide geographical coverage (Europe but also Africa, the Middle East and Asia) and provides 4-day forecasts, therefore enabling a better monitoring and forecasting of solar energy⁴⁶. Copernicus can therefore be an asset for solar energy dedicated to electricity generation.

The availability of precise information on solar radiation through CAMS products is key to enhance the management of solar energy as shown in the following impact pathway, which maps out the total impact of the solar energy monitoring and forecasting application (impact driver) through to the particular environmental, societal or economic benefits (impacts):

⁴⁴ CAMS portal. (Online) Available at: <http://atmosphere.copernicus.eu/services/solar-radiation> (Accessed: July 20th 2017)

⁴⁵ CAMS catalogue. (Online) Available at: <http://atmosphere.copernicus.eu/catalogue/#/> (Accessed: July 20th 2017)

⁴⁶ Copernicus factsheets. (Online) Available at:

http://www.copernicus.eu/sites/default/files/documents/Copernicus_Factsheets/Copernicus_AtmosphereMonitoring_Feb2017.pdf (Accessed: July 20th 2017)

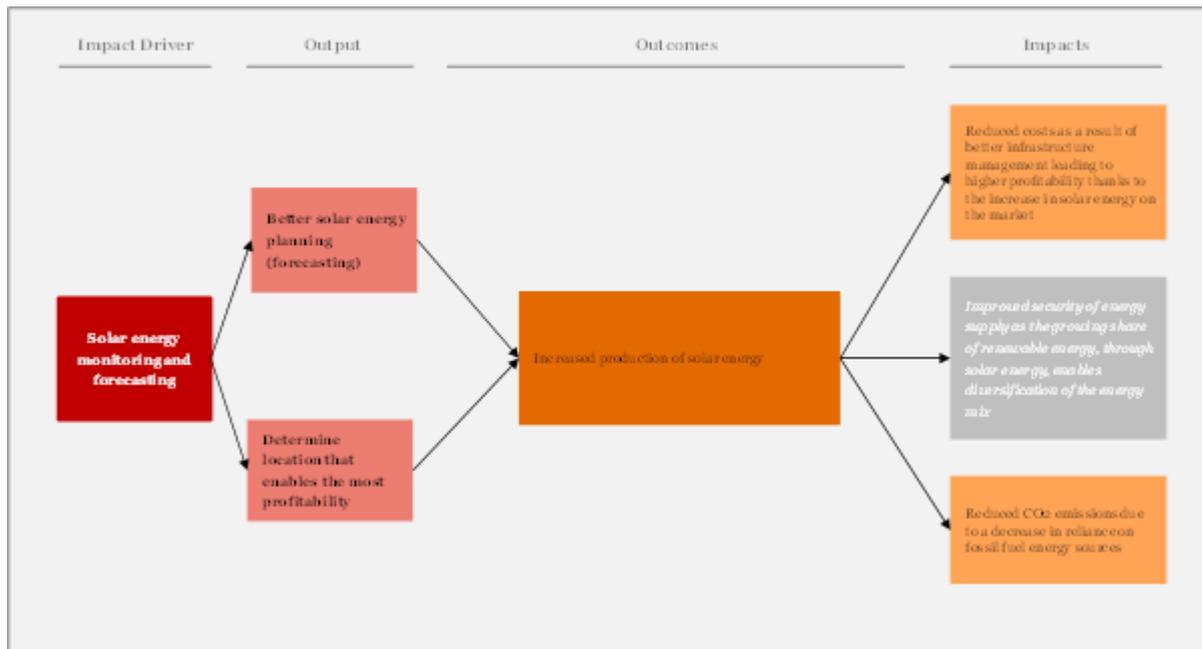


Figure 20 - Impact pathway for solar energy monitoring and forecasting (Source: PwC analysis)

Copernicus can play two key roles in the increase of solar energy generation for electricity in the next years. Firstly, by enabling the determination of the site location that will generate the most profitability in the long run. For instance, solar panels are less efficient when they are subject to desert dust⁴⁷. However, deserts are great locations for solar panels as solar irradiance is very high. Desert dust makes the solar mirrors dirty, hindering them from working at full capacity and therefore leading to energy losses. More globally, any kind of dust and air pollution impact the productivity of solar power plants⁴⁸, hence the necessity to find the right site location, one that has a high solar irradiance and that is not subject to dust or air pollution. Secondly, as a potential CAMS service evolution, by giving the ability to better forecast energy production. Indeed, with the use of CAMS products, the potential yield of solar plants can be assessed⁴⁹. For instance, under most regulatory regimes, Photovoltaic (PV) electricity producers have to provide electricity grid manager with energy production forecasts a day in advance. When their forecasts are too far from the electricity that was actually generated, they need to pay penalties. Though, no prediction is ever 100% accurate, Copernicus products help reduce the error rate of the forecasts and as such the penalties incurred⁵⁰. Similarly, forecasting enables solar panels to be used more efficiently: knowing in advance that solar radiations will be low at a specific date and time in a designated area enables the PV electricity producer to not rely on the panels in this area. These two elements enable the increased production of solar energy. This increase in solar energy generation enables the following benefits:

- Reduced costs as a result of better infrastructure management leading to higher profitability thanks to the increase in solar energy on the market;
- Improved security of energy supply as the growing share of renewable energy, through solar energy, enables diversification of the energy mix;
- Reduced CO₂ emissions due to a decrease in reliance on fossil fuel energy sources.

47 CAMS portal. (Online) Available at: <http://atmosphere.copernicus.eu/services/solar-radiation> (Accessed: July 20th 2017)

48 Pollution could block 25 percent of the light that would become solar power. (Online) Available at: <http://www.popularmechanics.com/science/energy/news/a27112/pollution-can-block-25-percent-of-solar-power/> (Accessed: July 20th 2017)

49 CAMS presentation: products, services and opportunities. (Online) Available at: http://www.snsb.se/Global/Fj%C3%A4rranalysanv%C3%A4ndare/Fj%C3%A4rranalysdagarna%202015/Plenarsalen_Plenum/3%20CAMS_Peuch_Fj%C3%A4rranalysdagarna2015_21October2015.pdf (Accessed: July 20th 2017)

50 PwC, 2016, Study to examine the socio-economic impact of Copernicus in the EU: Report on the Copernicus downstream sector and user benefits

The quantification of the benefits mentioned above is as follows:

4.2.3.1.2.1 Reduced costs of energy:

Profitability of the solar energy market is going to increase in the next few years. There are several reasons for this: solar infrastructure prices are slowly decreasing⁵¹; European and often national directives push forward for a larger share of renewable energy in the energy mix, of which solar, along with wind, is crucial⁵²; and environmental awareness of citizens has brought attention upon renewable energy sources as opposed to fossil fuel energy sources⁵³.

As such, Copernicus can play a part in the increase in profitability through its ability to help improve site selection and farm design. Indeed, the development of new technologies has improved the capacity of solar panels making them able to generate more than before: technological innovations therefore impact the cost to produce energy from solar PV infrastructure. Site location has a particular role to play: depending on the solar irradiance and potential pollution in a specific area, different types of solar panels should be installed. Copernicus has the ability to track these two factors and enables the solar PV producer to choose to install the solar PV type with the right characteristics depending on its location.



Methodological approach to value reduced costs of energy

Our model is based on the evolution of the Levelized Cost of Energy (LCOE) for solar power electricity and the yearly increase in energy generation. The steps are:

1. Determine the volume of new electricity generated every year
2. Calculate the LCOE evolution over the years
3. Assess the cost reduction to produce new solar electricity
4. Apply the contribution of Copernicus to this cost reduction

Reduced costs as a result of better infrastructure management leading to higher profitability thanks to the increase in solar energy on the market

Valuation approach



The analysis considers the evolution of solar electricity generation over the period based on the European Union new policies scenarios extracted from the IEA's 2016 World Energy Outlook⁵⁴. This is assumed to be broadly equivalent to the EU's NDC and 2030 Climate & Energy package. These information are then used to calculate the yearly increase in solar

51 J. Doyne Farmer & François Lafond, 2016, "How predictable is technological progress?", Research Policy, Issue 45, pp. 647-665

52 European Parliament website. (Online) Available at: http://www.europarl.europa.eu/atyourservice/en/displayFtu.html?ftuId=FTU_5.7.4.html (Accessed: July 20th 2017)

53 Horizon 2020 programme, Intelligent Energy Europe. (Online) Available at : <https://ec.europa.eu/easme/en/intelligent-energy-europe> (Accessed: July 20th 2017)

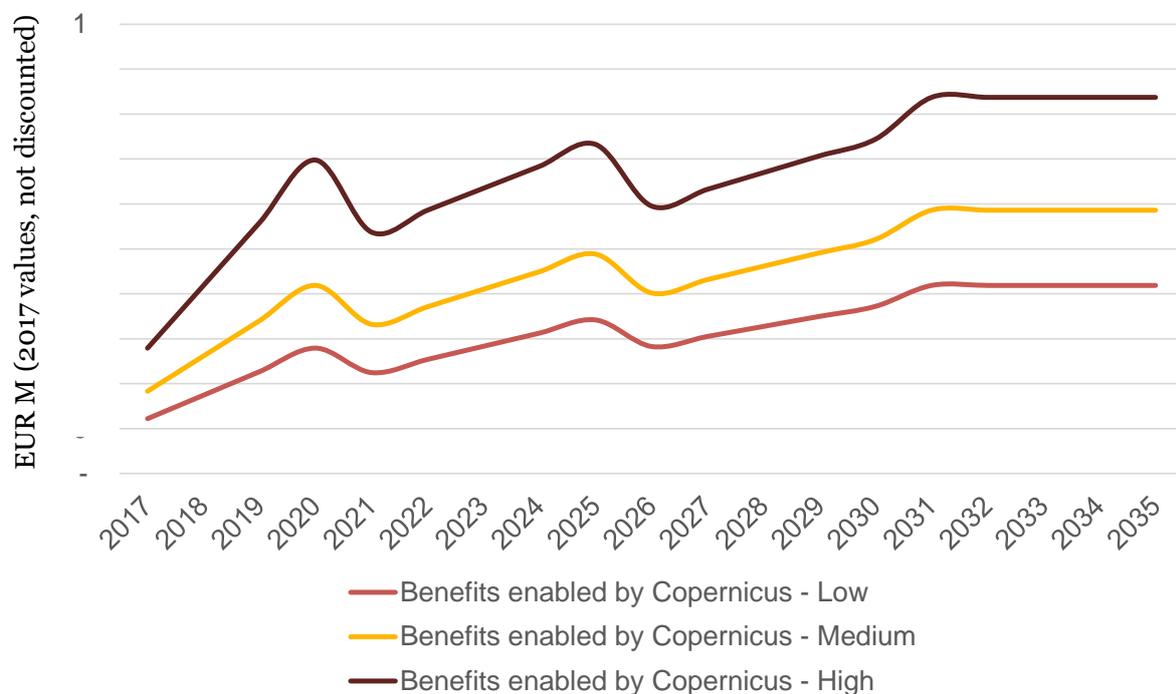
54 IEA, 2016, World Energy Outlook 2016

electricity generated, considering that new facilities are needed to support this increase in electricity production. This increase in solar electricity production is then multiplied by the decrease in cost of the Levelized Cost Of Energy (LCOE). The LCOE is the cost to produce electricity taking into account, among others, the initial capital invested in the facility as well as the cost of operations and of maintenance of the infrastructure in the long run. This cost will decrease over the years⁵⁵ and part of this reduction is attributed to Copernicus: the cost of supplying a given amount of solar capacity decreases, and, in parallel, the quantity of solar capacity that can be supplied at a given price increases. Demand for new solar farms being neither perfectly elastic nor perfectly inelastic, both price and quantity of solar capacity are therefore evolving.

Price reduction in LCOE is not only attributable to Copernicus, however, site location is one of the main elements that leads to this decrease in price. As Copernicus can provide data on solar irradiance and pollution in specific locations, it contributes to the improvement of choice of farm design in specific location. The Copernicus contribution is assumed to range between 0.5% and 1% in 2017, rising to between 2% and 5% in 2020, up to between 5% and 10% by 2030⁵⁶.

As a result, benefits linked to Copernicus are expected to amount between EUR 0.1 M and EUR 0.3 M in 2017, rising to between EUR 0.4 M and EUR 0.8 M in 2035 for a total cumulative value ranging from EUR 5.9 M to EUR 12.7 M (not discounted values).

The global trend over the period is illustrated in the chart below. The trend is composed of several bumps. Indeed, the LCOE will constantly decrease over the period, and the Copernicus contribution will constantly increase, though at a different pace depending on the years, but the new solar electricity generation will strongly vary across the years, being strong in the first 10 years of the reporting period, and being less important after.



55 KIC InnoEnergy, 2016, Future renewable energy costs: solar photovoltaics. (Online) Available at: <http://www.innoenergy.com/wp-content/uploads/2016/01/KIC-InnoEnergy-Solar-PV-anticipated-innovations-impact.pdf> (Accessed: July 20th 2017)

56 PwC analysis ; expert consultation

Figure 21 - Evolution of the Copernicus benefits for the impact “Reduced cost of energy” from 2017 to 2035
(Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The use of satellite data is essential to provide accurate climatology and forecasts of solar irradiance and thus of solar electricity production. Solar PV forecasts can come from different origins: weather forecasts, PV system data (i.e. historical data of the facility) or satellite imagery⁵⁷. These data are then feeding predictive models. As such, both data and the models are intertwined and the lack of the former directly impacts the model. Satellite imagery is considered to provide very detailed information, especially on cloud patterns that directly affect solar irradiance, hence their importance and Copernicus can provide this type of data. If all Copernicus assets were shut down in 2030, other sources of satellite data could be used but would be either too expensive, not good enough in terms of spatial resolution, not adequate in terms of delivery delay or not optimal in terms of revisit frequency⁵⁸. As such, no free solution would perfectly replace Copernicus.

4.2.3.1.2.2 Improved security of energy supply

The analysis of the contribution to the improvement of the security of energy supply consists in looking at how Copernicus enables European countries to develop renewable energy sources like solar in a profitable manner so as to avoid reliance on a single and dominant source of energy in the final consumption, especially if the energy has to be imported or if its price is highly volatile. Indeed, Copernicus can help secure a share of solar energy in the final consumption thanks to the provision of reliable and accurate forecasts, as well as by helping choose the better solar plant location in the first place. However, and though all European countries are under the obligation of the European Renewable Energy directive, it is difficult to model the benefits for the European Union of securing energy supply as this problematic is mostly national and strongly varies from a country to another, depending on their current energy mix. For instance, when looking at electricity production sources, France is mostly dependent on nuclear⁵⁹, whereas Germany still relies heavily on coal⁶⁰ and gas is important in the UK⁶¹. The share of renewable energy, and especially solar, also varies between European Union member states.

As improving security of energy supply has a different meaning for all countries and as it is hard to assess the contribution of Copernicus in such different cases, **this benefit cannot be modelled** for Europe as a whole.

4.2.3.1.2.3 Reduced CO2 emissions

The role of satellite imagery and of Copernicus in enabling the reduction in CO2 emissions is directly linked to the first benefit on the reduction of the cost of energy. As demand for electricity as a whole is inelastic, any increase in supply of solar energy displaces other (on average higher carbon) energy sources, leading to a reduction in CO2 emissions. Indeed, better site location and adapted farm design facilitate the increase in solar energy generation and CO2 emissions that would have come from other polluting energy sources are therefore avoided. As such, reduction of CO2 emissions is an indirect benefit of Copernicus.

⁵⁷ IEA, 2013, Photovoltaic and Solar Forecasting: State of the Art (Online). Available at: http://www.meteonorm.com/images/uploads/downloads/Photovoltaic_and_Solar_Forecasting_State_of_the_Art_REPORT_PVPS_T14_01_2013.pdf (Accessed: September 26th 2017)

⁵⁸ Expert consultation

⁵⁹ RTE France website. (Online) Available at : <http://www.rte-france.com/en/eco2mix/eco2mix-mix-energetique-en> (Accessed: July 20th 2017)

⁶⁰ US Energy Information Administration website. (Online) Available at : <https://www.eia.gov/todayinenergy/detail.php?id=26372> (Accessed: July 20th 2017)

⁶¹ Energy UK website. (Online) Available at: <http://www.energy-uk.org.uk/energy-industry/electricity-generation.html> (Accessed: July 20th 2017)



Methodological approach to value reduced CO2 emissions

Our model is based on the evolution of GHG emissions from electricity generation in the Europe Union compared to the growth of the share of solar electricity in the energy mix. The steps are:

1. Determine the yearly GHG emissions reduction related to the increase in renewable electricity in the European Union
2. Calculate the share of renewable electricity represented by solar PV
3. Multiply this share by the volume of CO2 emissions reduction in order to obtain the CO2 emissions avoided thanks to solar PV
4. Apply the contribution of Copernicus to this reduction

Reduced CO2 emissions due to a decrease in reliance on fossil fuel energy sources

Valuation approach



The analysis is dedicated to the reduction of CO2 emissions enabled by the increase in solar energy generation. Through information on the evolution of GHG emissions in the European Union, the yearly reduction of CO2 emissions has been derived. Assuming that the European electricity production will remain constant in the next few years, and considering that the solar power electricity generation will increase, the share of the European electricity production coming from solar PV will increase (2.9% in 2017). Moreover, knowing the share of renewable electricity in Europe thanks to the different European targets fixed notably for 2020 and 2030⁶² (30% in 2017 based on the assumption of a linear growth between the value of 2014 and the target of 2020), it is possible to derive the share of solar PV from renewable electricity in Europe (9.65% in 2017). Taking into account the fact that CO2 emissions reduction is due to the increase in renewable energy electricity, the reduction of CO2 emissions for electricity due to solar PV can be calculated (3.2 Mt CO2 in 2017). This value is then associated with a valuation coefficient of CO2 emissions⁶³, which represents the environmental cost of emitting a kilogram of CO2. To this final result can then be applied the Copernicus contribution.

The attribution of Copernicus to CO2 emissions reduction is directly linked to the factor mentioned above on the reduction of energy costs. The increase in renewable energy sources generation, and as such of solar energy generation, has for indirect consequence to decrease the reliance on fossil fuel energy sources, thus on CO2 emitting energy sources. Part of this decrease in CO2 emissions is thus enabled by Copernicus. Based on the results previously mentioned, Copernicus contribution is assumed to range between 0.5% and 1% in 2017, rising to between 2% and 5% in 2020, up to between 5% and 10% by 2030⁶⁴.

As a result, benefits linked to Copernicus are expected to amount to between EUR 2.2 M and EUR 5 M in 2017, rising to between EUR 4.7 M and EUR 9.4 M in 2035 for a total cumulative value ranging from EUR 81.9 M to EUR 175.7 M (not discounted values).

⁶² European Commission, The European union Leading in Renewables (Online) Available at:

<http://ec.europa.eu/energy/sites/ener/files/documents/cop21-brochure-web.pdf> (Accessed: September 20th 2017)

⁶³ PwC analysis

⁶⁴ PwC analysis

The global trend over the period is illustrated in the chart below. The curve is composed of three parts, from 2017 to 2020, from 2020 to 2030 and from 2030 to 2035. The difference between these three parts is marked by a bump in 2020 and in 2030. This is not the result of the Copernicus contribution but of the trend in CO2 emissions reduction. Targets set by the EU in terms of CO2 emissions reduction up to 2020 are much higher than for 2030, themselves higher than the targets for 2035. The constantly growing Copernicus contribution enables to smooth the curve but not to an extent that could make the bumps disappear.

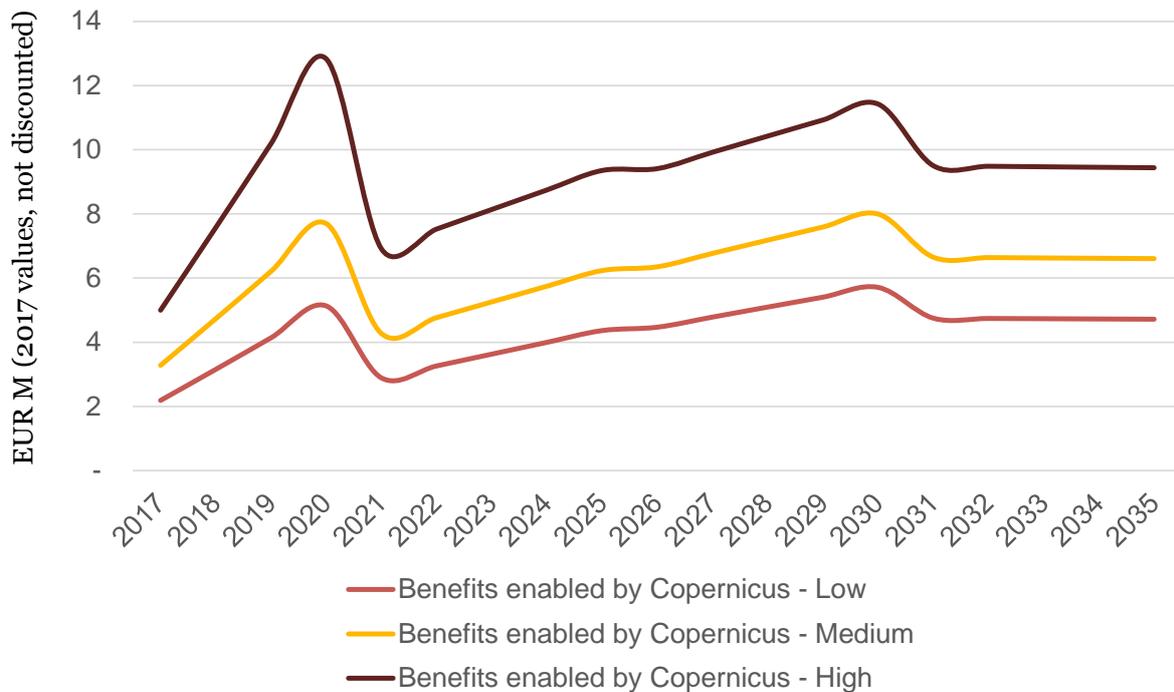


Figure 22 - Evolution of the Copernicus benefits for the impact “Reduced CO2 emissions” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The differentiation factor of EO and Copernicus is here similar to the benefit for reduced cost of energy thanks to better infrastructure management. As previously mentioned, without Copernicus, other types of satellite data could still be used but would prove less accurate, would have a less good quality or would be fee-based. All these three elements would necessarily impact the cost to produce electricity.

4.2.3.1.2.4 Summary of Copernicus contribution to “Solar energy monitoring and forecasting”

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	2.3	4.8	5.1	87.9
Medium estimate	3.5	6.8	7.2	125.7
High estimate	5.3	10	10.3	188.4

Table 8 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below. It matches the curve of the CO2 emissions reduction benefit as the contribution of the first quantified benefit is much smaller and has therefore less impact on the total benefits.

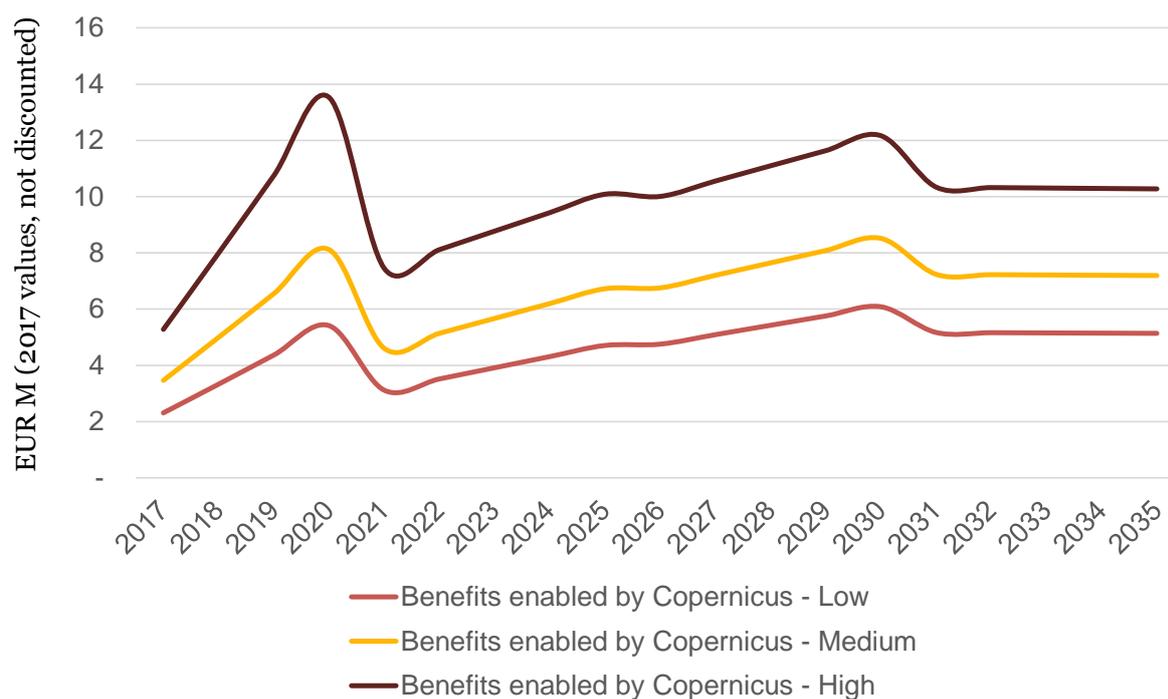


Figure 23 - Overall Copernicus D&I benefits from 2017 to 2035 (Source: PwC analysis)

4.2.3.1.3 Climate modelling

The Copernicus Climate Change Service (C3S) provides comprehensive climate information on key climate variables, such as surface air temperature, sea-ice changes as well as on a variety of other hydro-climatic variables. C3S also conducts global and regional analysis to provide detailed information on historical changes in the climate. Such approach is particularly important in regions direct observations are sparse. C3S products are used for modelling and projecting conditions in the European and global climate from now until the end of the century. C3S climate modelling rely on the climate simulations developed the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). The information is made available for free which national and local decision makers as well as users in different sectors, such as water management, agriculture, energy and infrastructure, can use it to support the European adaptation and mitigation response to climate change.

The availability and ease of access to quality controlled climate data through C3S is key to improving the accuracy of climate projections and forecasts. The benefits from improved climate modelling are difficult to assess as it depends on the response taken to projections. In this study, the approach has been taken (based on stakeholder consultations) that more reliable climate projections will improve the effectiveness and efficiency of the adaptation response to climate change, particularly by informing the planning of climate resilient infrastructure. This can be depicted in the following impact pathway, which maps out the impact of the climate modelling application (impact driver) through to the particular economic benefits (impacts):

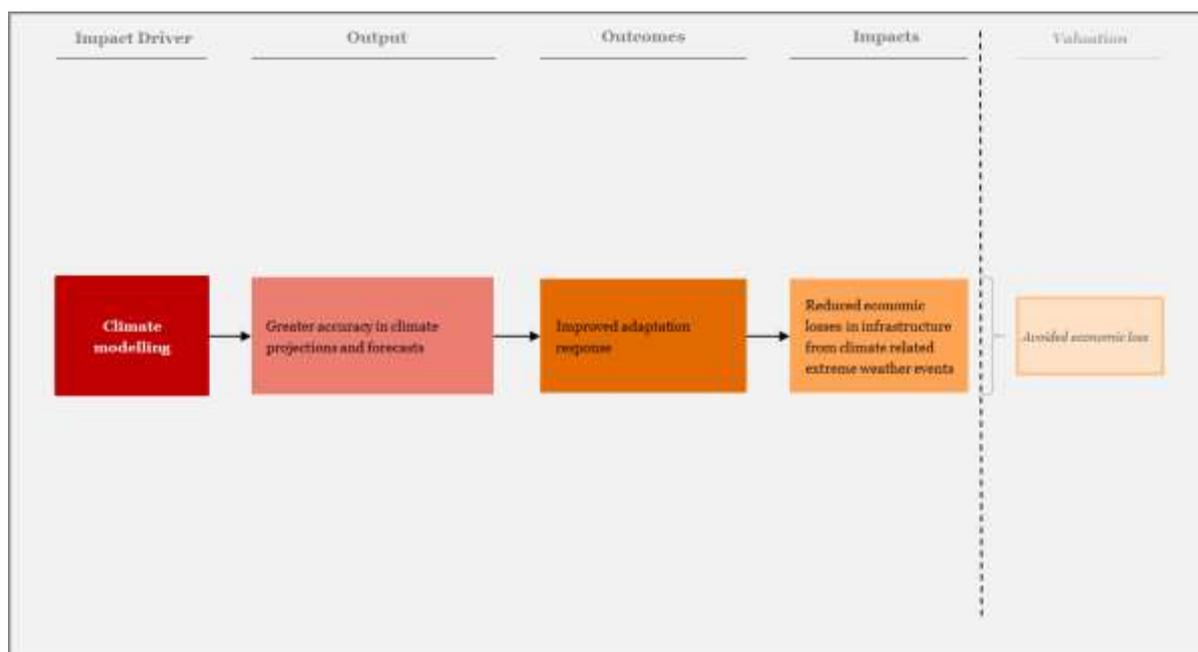


Figure 24 - Impact pathway for climate modelling (Source: PwC analysis)

There are likely to be other benefits from climate modelling, including an improved response to new diseases or diseases spreading to new areas as a result of climatic conditions, and reduced agricultural loss from drought if drought resilient crops can be cultivated. However, due to lack of data in these areas, pathways and valuation endpoints have not been defined in this study. Consequently, the benefit of Copernicus has only been valued as the reduced economic loss from climate related extreme events through improved infrastructure planning.

4.2.3.1.3.1 Reduced economic loss from climate related extreme weather events

As a result of C3S climate modelling, greater accuracy in climate projections and forecasts is assumed, which policymakers can use to enhance climate change adaptation efforts. In particular, infrastructure can be located more effectively and efficiently in order to be resilient to future climate change. To construct the impact pathway, we begin by considering the proportion of infrastructure, such as roads, railways, power supplies and ICT, that is renewed and replaced annually. This annual rate of infrastructure renewal has been calculated as 4.8% globally⁶⁵ and 2.3% for the EU⁶⁶.

We then consider economic losses drawing on data for the EU from MunichRe and the EEA⁶⁷, and globally from Aon Benfield (2017)⁶⁸ and SwissRe (2017)⁶⁹, to find the economic losses from climate related extreme weather events and the trend over the past two decades. This is the basis for a projection of expected economic losses to 2035. It is assumed that 2.3% in the EU and 4.8% globally of this annual economic loss represents infrastructure that would be renewed or replaced in that year. It is assumed that 5-10% of this new infrastructure⁷⁰ being built is located optimally to be resilient to climate related extreme weather events, as a result of climate modelling. Assuming 10% of this benefit can be attributed to C3S data, the benefit of Copernicus in terms of avoided economic loss in the EU ranges between EUR 22.7 M and EUR 34.0 M per year in 2035, in 2017 undiscounted prices.

65 Arcadis, 2016. https://www.arcadis.com/media/3/7/E/%7B37E96DF6-82D5-45A6-87D8-5427637E736D%7DAG1015_GIII%202016_ONLINE%20FINAL_SINGLE%20PAGES.pdf

66 McKinsey 2016 Bridging Global Infrastructure Gaps.

67 EEA, 2017. <https://www.eea.europa.eu/data-and-maps/indicators/direct-losses-from-weather-disasters-3/assessment>

68 Aon Benfield, 2017. Annual Global Climate and Catastrophe Report 2016.

69 SwissRe Sigma data explorer – total losses from natural catastrophes 1996-2016.

70 Assumption – to be validated



Methodological approach to avoided economic losses from climate modelling

Our approach is based on avoided damages from extreme weather events to infrastructure that can be relocated in a climate resilient location due to better climate projections and forecasts.

1. Determine the economic losses to infrastructure from climate change related floods, storms and droughts
2. Find the proportion of this economic loss that is infrastructure that is renewed or replaced each year
3. Multiply by the percentage of infrastructure that can be located to be resilient to climate change as a result of climate modelling
4. Apply the contribution of Copernicus to climate modelling and projections

Avoided economic losses from climate related extreme weather events

Valuation approach



Assuming 5-10% of this benefit globally can be attributed to C3S data, due to a larger availability of other climate information and data, due to the larger number of other climate models available, the benefit of Copernicus in terms of avoided economic losses ranges is between EUR 290.5 M and EUR 580.9M per year in 2035, in 2017 undiscounted prices. The faster increase in benefits between 2025 and 2035 is due to climate related losses being predicted to rise significantly during this time period as the global temperature rise increases and is not related to the maturity of the market. This increase in climate related losses is modelled based on the historic trends over the past two decades.

The total not discounted benefits linked to Copernicus in the EU are expected to amount to:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	1.8	5.6	22.7	161.7
Medium estimate	2.2	6.7	27.2	194.0
High estimate	2.8	8.4	34.0	242.5

Table 9 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

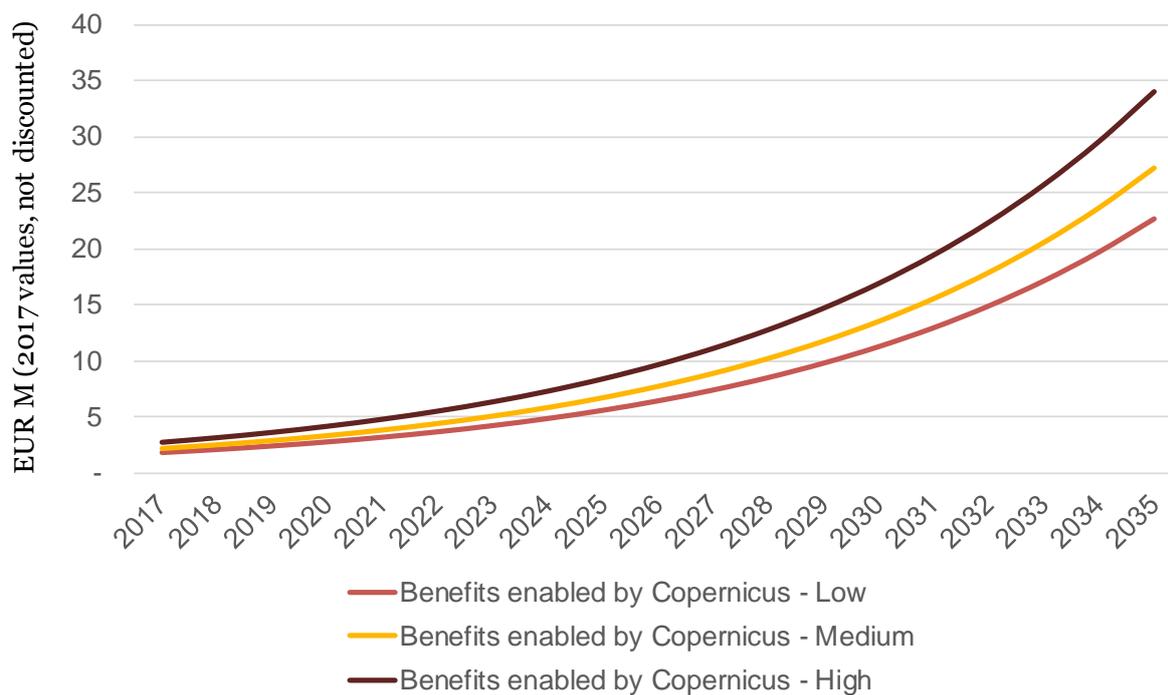


Figure 25 - Total benefits in the EU enabled by Copernicus data and information related to climate modelling (2017 EUR in undiscounted values) (Source: PwC analysis)

The total not discounted benefits linked to Copernicus globally are expected to amount to:

Copernicus Global benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	23.5	71.8	290.5	2,070
Medium estimate	35.2	107.7	435.7	3,070
High estimate	46.9	143.6	581.0	4,141

Table 10 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

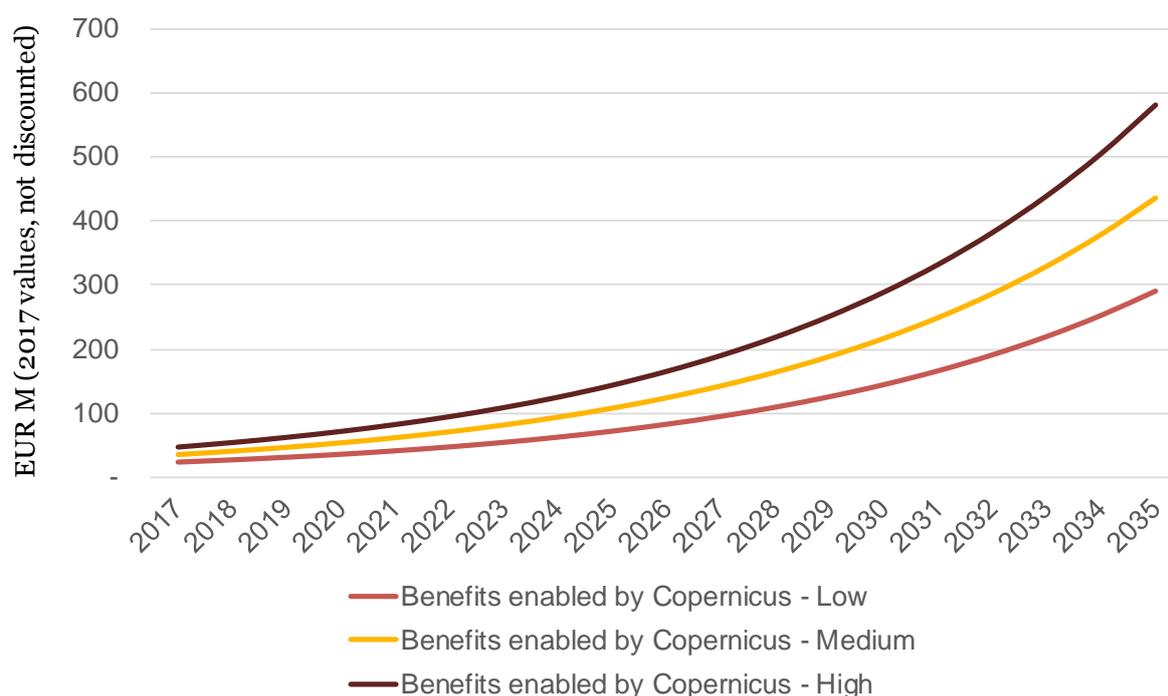


Figure 26 - Total global benefits enabled by Copernicus data and information related to climate modelling (2017 EUR in undiscounted values) (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Satellite data can play a key role in tracking climate change globally, particularly in the Arctic region, in order to provide better climate projections. Whilst Copernicus data is only one of multiple sources of data that feeds into these climate projections, it standardises the information and provides data that was previously unavailable or subject to user charges. If the C3S service is shut down in 2030, it is possible to use other data sources to provide climate projections, however these would not be in the same standardised format and not freely available.

4.2.3.1.4 Additional impacts not monetized for Atmosphere and climate

Some additional important impacts seems to be enabled by Copernicus D&I but cannot be monetized. The study had to look at them only qualitatively.

4.2.3.1.4.1 Improved sectoral adaptation to climate change

C3S is also currently developing proof of concept for additional climate adaptation projects with organisations in different sectors (Sectoral Information Systems or SIS) across Europe, such as agriculture, urban areas, water management and energy. These projects are currently being implemented in specific regions and sectors in Europe in a two-year proof of concept phase to develop the service to suit the needs of users, with the aim of these being scaled to the wider European region.

Service providers within SIS have been consulted⁷¹ to understand the potential benefit of these services if scaled to Europe. It has not been possible at this stage to quantify the benefits of these projects. This is because these proof of concept projects are in the process of

⁷¹ Projects consulted include, ECEM, SWICCA, offshore oil & gas; ECEM: Albert Troccoli; Snow: Maria Polo; Floods: Ladislav Gaal; Irrigation: Stefano Bagli; oil & gas: Robert Vautard.

gathering evidence and data there is currently no data on the economic and environmental benefits that can be scaled and assessed. As this data is not yet finalised or available, it is not possible to quantify the benefits at this stage. However, it is expected that these can have significant benefits for improving the European mitigation and adaptation response to climate change once these services becoming fully operational after 2020.

4.2.3.2 Land

The Land is one of the 6 thematic areas in the EARSC Taxonomy. It includes the following thematic segments related to EO services: agriculture, forest, inland water, snow & ice, land ecosystems, land use, topography and geology. Copernicus applications in this section are mainly derived from the Copernicus Land monitoring services (Climate Change core Service data may also be used).

The Copernicus Land Monitoring Service provides geographical information on land cover, land use, land cover-use changes over the years, and several biophysical variables related to vegetation state or water cycle, for instance.

The mapping of Land use/Land cover changes is among the primary goals of Copernicus Land services, mainly to support the environment's protection. It is provided by the Pan-European and Local Component of Copernicus Land Services. Thanks to products like Corinne Land Cover (CLC), High Resolution Layers or the Urban Atlas, authorities are able to monitor the evolution of the Land use and identify abnormal situations (EU Directive compliance monitoring) or endangered areas (degradation of natural habitats due to human activities, cities expansion...).

The Global Component produces biophysical parameters that give a picture of the state of vegetation (e.g. leaf area index, vegetation condition index), the energy budget (e.g. land surface temperature) and the water cycle (e.g. soil water index, water bodies) every ten days and on a worldwide scale. The biophysical parameters production is complemented with detailed and high resolution land cover/land use information on specific hot spot areas around the world.

Copernicus Land Services products have been designed and tailored to best meet the end users' requirements. Moreover Copernicus coverage is global, its products and data are free, open and, more importantly, harmonised among the whole Europe. All these advantages, makes Copernicus Land Service a crucial monitoring tool for national authorities (European or not) and a strong business enabler for private sector.

Through extensive desk research and stakeholders' consultations, we develop a list of Copernicus applications in the Land Service thematic area (EARSC taxonomy). The main impact drivers (e.g. Copernicus application leading to a societal, environmental or economic impacts) identified and supported by concrete examples were the following:

- Crops monitoring – support to agriculture : mostly related to Copernicus contribution to food security (early warning), and to precision farming and its impact on agriculture profitability and sustainability;
- Forest management and protection : Copernicus contributes to monitor implementation and compliance to EU Forest directives
- Water resources management : mainly related to Copernicus contribution to better irrigation and water reservoir management;
- Wetlands monitoring : mostly related to Copernicus contribution to Natura 2000;

- Ground elevation and ground motion monitoring: Through SAR sensors, Copernicus data enables the detection of surface deformation and ground instability, essential information for infrastructure building and subsidence and slope stability associated with mining and quarrying activities;
- Support to CAP (Common Agriculture Policy) implementation: Copernicus can contribute to controls and on-the-spot check of certain parameters influencing the level of subsidies (greening measures);
- Support to land mapping and cadastral surveying: Copernicus helps the implementation of a homogenous geospatial information dataset at European level.

For some impacts of the Land thematic areas, the land use valuation coefficient was used. It represents the calculation of the value of ecosystem services from a hectare of land (whether it is forest, wetlands, etc.) per year. It was based on and built on the approach and dataset of The Economics of Ecosystem and Biodiversity (TEEB, 2010, Van der Ploeg, 2010). At the time of publishing in 2010, the TEEB dataset was the most comprehensive dataset of ecosystem service valuations. Over the last few years, it had been updated with new literature, such that it now contains over 1,500 estimates of individual ecosystem service values. We then filtered and adjusted the extended TEEB dataset to reflect the relevant European countries and ecosystem types, extracting and applying values based on the methodology described in detail in PwC (2015) 'Valuing corporate environmental impacts: Land use and biodiversity', available at www.pwc.co.uk/naturalcapital.

4.2.3.2.1 Crop monitoring – support to agriculture

The agriculture sector today faces unprecedented challenges and its capability to overcome them will be crucial for our future. Indeed, in Europe farmers are confronted with a double issue: keep producing to ensure food security whilst reducing their impact on the environment and the climate and protecting biodiversity. At a global level, the Food and Agricultural Organization projects that food production will have to increase by 70% by 2050 to feed more than 9 billion people⁷² globally (mainly in developing countries). To increase global food production while ensuring a preserved environment, agriculture will need to increase its productivity by using new technologies such as remote data sensors.

Historically, agriculture has been one of the key sectors to which Earth Observation applications bring added-value. Indeed, precision farming techniques using EO data started to emerge in the 1990s. Satellite data have a wide range of applications for agriculture users: mapping the underlying soil and crops, yield estimation mapping, input variable rate management, irrigation management (see water resources impact driver) or long term land use change.

Copernicus serves two purposes for agriculture:

- Helping monitor agricultural land use and their compliance to EU-Agriculture directives leading to the advent of a more sustainable farming sector (mainly related to CAP, see “Support to CAP implementation” impact driver)
- Helping assess crop conditions and yield forecast, for precision farming and food security applications. We will focus on this aspect in this section (see below).

Through its dedicated Land monitoring service, Copernicus provides data on various biochemical variables related to the status of vegetation: NDVI (Normalised Difference Vegetation Index), DMP (Dry Matter Productivity), soil moisture as well as rain fall estimate,

⁷² FAO report, “How to feed the world in 2050”- 2009.

etc., and on the Land use/cover : maps of agricultural area, LPIS, etc.. These products and raw data feed the development of applications for precision farming (Farmstar or Geosys for example⁷³) that support farmers' productivity and profitability, as well as the development of early warning applications for food security matter (SIG Sahel for example).

Copernicus monitoring capacity can support the transition to a more productive and sustainable agriculture model by enhancing adoption of precision farming techniques. The following impact pathway maps out the impacts of crop monitoring (impact driver) through the particular environmental, societal or economic benefits (impacts):

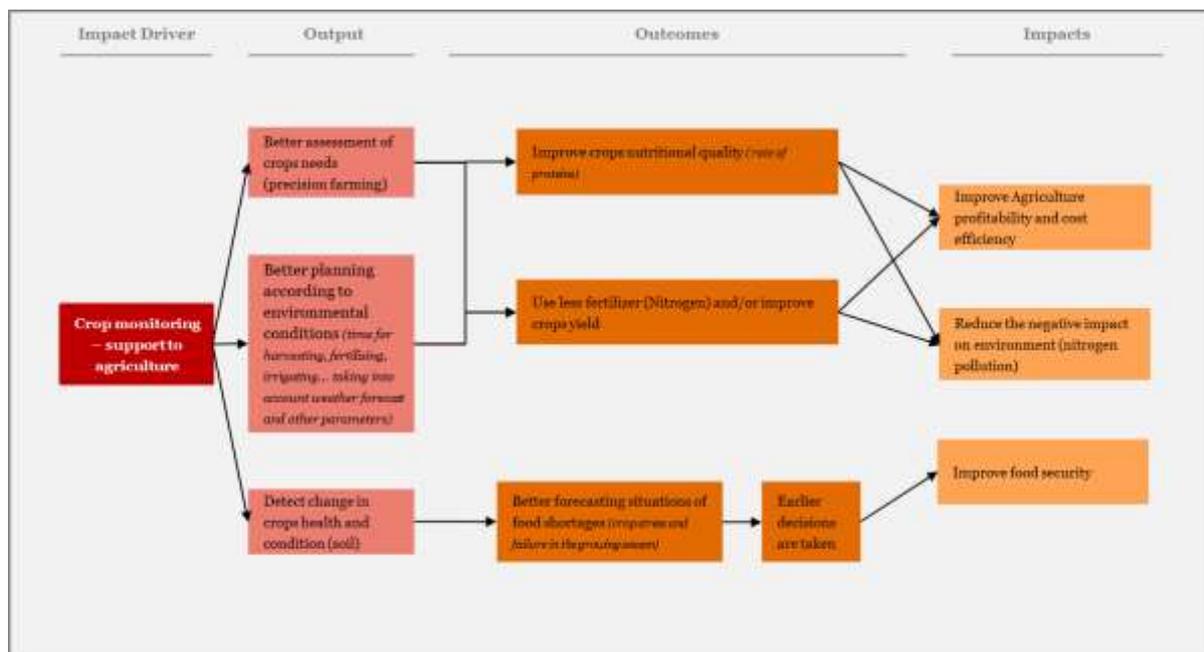


Figure 27 - Impact pathway for Crop monitoring (Source PwC: analysis)

Precision farming relies mainly on a better assessment of crop needs and a better planning of the environmental conditions. It means giving the crops exactly what they need (quantity) at the right moment (timing). Therefore farmers use less fertilizer (nitrogen) while improving the nutritional quality (e.g. the price) of the crops and potentially, their yields.

Detecting change in crop health in a timely manner is crucial to support early warning and strategic decision on food security. This helps to keep costs down and increase the effectiveness to stave off hunger.

As a result of all these outputs, several benefits can be pointed out:

- Improve agriculture profitability and cost efficiency
- Ensure food security
- Reduce the negative impacts on the environment

4.2.3.2.1.1 Improved agriculture profitability and cost efficiency

The main benefit of Copernicus for farmers is linked to the savings enabled by precision farming.

⁷³ Farmstar website. (Online) : <http://www.farmstar-conseil.fr/fr/la-technologie/>

Thanks to EO data and information such as NDVI, soil moisture or biomass, it is possible to measure accurately intra-field variability in crops and site specificities. Indeed crops needs for inputs vary across the time and inside a same field. Based on these accurate measures and on agronomist expertise, applications have been developed to supply intra-field level recommendation maps to farmers, in order to optimize input placement. Therefore farmers can adapt the rate of inputs (Nitrogen fertilizer) to the exact site-specific crops needs. This technique is called Variable Rate Technologies and it requires access to recommendation maps and a variable rate control system with application equipment, in order to put the right input, in the right place, in the right amount by analysing past and in-season field behaviour.

Copernicus data are used to develop these recommendation maps (Farmstar⁷⁴ for example), among other sources of EO data (Spot, Modis, Pléiades, etc.). Varying the application of inputs and especially Nitrogen fertilizer (main inputs) can reduce the costs, improve the nutritional quality of the crops (Nitrogen impacts the rate of proteins in crops), and maximize productivity. It also reduces the impact over-application of nitrogen may have on yields (stem lodging) and on the environment (Nitrogen leaching, GHG... see second impact below)

Therefore we can say that Copernicus applications for crops monitoring lead to more profitability and cost efficiency in the agriculture sector. Details of the model developed to quantitatively assess this benefit can be found in the box below:



Methodological approach to value the profitability increase in Agriculture

Our model is based on the amount of savings per hectare a farmer can achieve using Earth Observation data for precision farming application (variable rate technologies for fertilizer spreading, in this case). The steps are:

1. Assess the surface of crops monitored/exploited with precision farming techniques like VRT (Cereals and Canola represent the vast majority of crops monitored with PF techniques)
2. Assess the gain per hectare enabled by this technology
3. Assess Copernicus contribution to precision farming, i.e. to what extent intermediate users develop PF applications based on Copernicus data. And multiply the three.

Improved agriculture profitability and cost efficiency

Valuation approach



The amount of savings per hectare a farmer can achieve using Earth Observation data for precision farming application (VRT), is approximately EUR 25 per ha (between EUR 11 per ha and EUR 37 per ha according to desk research^{75 76}). It represents 1.6% of the average cost for growing 1 ha of cereals⁷⁷. These savings amount will tend to increase as the capacity and

⁷⁴ Airbus website. "airbus boosts its capacity in the agricultural sector with European sentinel satellites"

⁷⁵ SpaceTec Partners, 2012. Assessing the economic value of Copernicus. The potential of Earth Observation and Copernicus Downstream Services for the Agriculture Sector.

⁷⁶ EU Parliament study : "Precision agriculture: an opportunity for EU farmers - potential support with the CAP" - 2014

⁷⁷ Interview inputs – EEA : it has been assessed as being 1% to 7%

the quality of the data will improve, leading to a more reliable service for farmers^{78 79}. Assuming the crops surface monitored with satellite based-tool used for VRT (approximately 25%^{80 81} of Cereals and Rapeseeds crops), we obtain the total savings enabled by PF. The share of savings attributable to Copernicus is obtained by applying the percentage of Copernicus contribution to precision farming.

Major evolutions occurring between 2016 and 2035 are (for medium scenario): the share of crops monitored with satellite data (adoption rate from 25% in 2016 to 63% in 2035⁸²), savings achieved thanks to satellite-based tool used for VRT (from EUR 25 to EUR 80 in 2030) and the Copernicus contribution to precision farming which goes from 2.49% in 2015 to 17% in 2020⁸³. As the agriculture sector is a key target for Copernicus, we can assume that its contribution will evolve. We estimate it will reach no more than 20% by the end of the period as many commercial satellites are available on this market and VHR is also needed.

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 14.9 M and EUR 65 M in 2017, rising to between EUR 366.7 M and EUR 981 M in 2035 for a total cumulative value ranging from EUR 3.5 B to EUR 10 B.

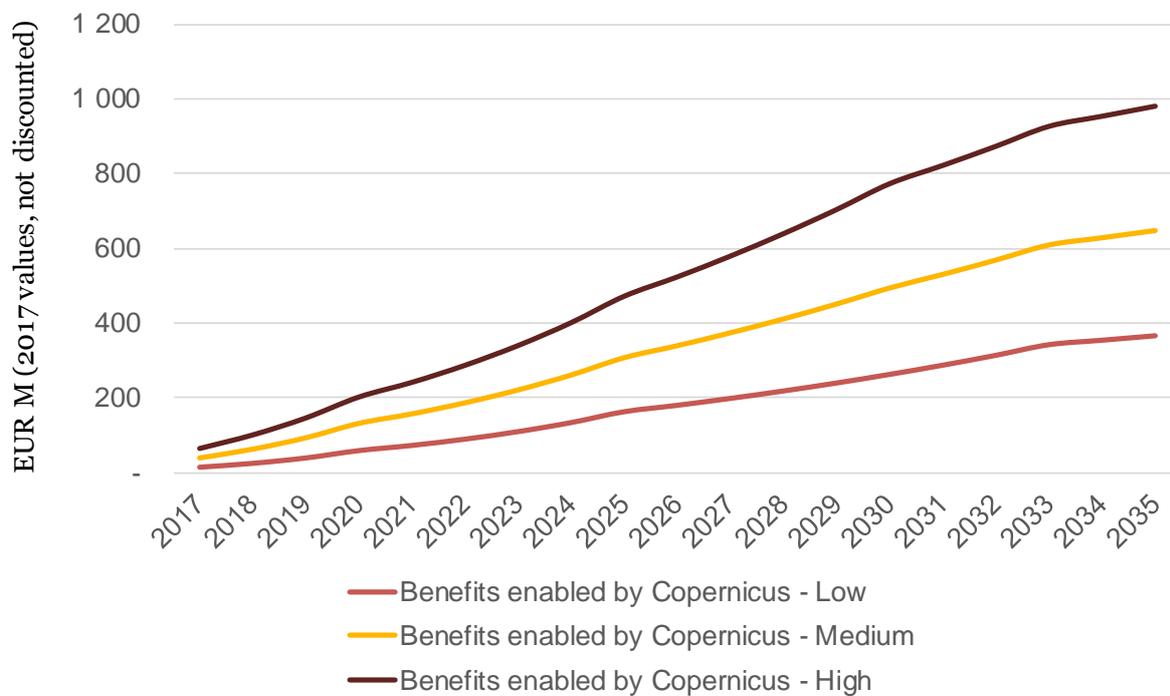


Figure 28 - Evolution of the Copernicus benefits for the impact “Improve agriculture profitability– Crop monitoring” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Copernicus data (Sentinel 2 and 3 particularly, and contributing mission like SPOT and DMC) improves the level of availability and enhances the quality of the precision farming applications developed by the downstream sector. Agriculture is a demanding field which requires monitoring at a pace dictated by the crop cycle. A reliable access to imagery is

78 Farmstar website

79 Books on Google: Agriculture connectée. Arnaque ou remède ?

80 PwC, “Study on the potential impact of space assets loss” – 2017

81 EU Parliament study : “Precision agriculture: an opportunity for EU farmers - potential support with the CAP” - 2014

82 Assuming +2% per year : PwC Assumption for market uptake.

83 PwC, Copernicus report on Downstream sector - 2016

needed, and frequent revisit time is a must in order to maximize the chances of obtaining the right image at the right time, despite any cloud cover which could compromise imaging at the ideal moment in the crop development cycle. Sentinel-2 missions provide wide area optical imagery with 10m (visual and near-infrared) resolution and a 10-days revisit frequency. Sentinel 3 includes an “Ocean and Land Color instrument”, with 21 spectral bands at 300 m resolution and a 3-days revisit frequency. Sentinel sensors capacity are particularly relevant for their use in agricultural mapping and monitoring. They are technically superior to current other “free and open” sensors like Landsat 8 and MODIS because they offer richer spectral information and they guarantee regular acquisitions, while enhancing the quality of the vegetation maps produced to quantify variations in the annual biomass. However Very High resolution is also needed to do precision farming, therefore Copernicus is a complement to already existing private-owned sensors used in agricultural services. UAV (Drones) are also a possible alternative (serious competitor) for real time, remote sensing data for agriculture. However, if Copernicus did not exist, business models of precision farming service providers would be different as they would have to use only private licensed satellite data or UAV to achieve the same level of quality and reliability. Alternatives in the same resolution domain and under “free and open” licenses do not exist today.

4.2.3.2.1.2 Reduce the negative impact on environment

As exposed above, thanks to precision farming, farmers are using less fertilizers for their crops, without reducing their yield. There is a broad recognition that above-optimal applications of fertilizer nutrients lead to an enhanced risk of pollution. Fertilizers contain mainly Nitrogen (N) which is responsible for:

- Nitrogen leaching leading to underground water pollution,
- Chemical reaction with air components leading to GHG emission (N₂O), and air pollution with NO_x and NH₃.

Details of the model developed to quantitatively assess the benefit of using Copernicus to reduce Nitrogen surplus (crops can only absorbed a certain dose of nutrient at certain time of their growth), are exposed in the box below:



Methodological approach to value the reduction in environmental negative impact

Our model is based on the volume of Surplus Nitrogen that can be saved thanks to Earth Observation data for precision farming application (variable rate technologies for fertilizer spreading, in this case). The steps are:

1. Assess the volume of nitrogen used on crops monitored by PF/satellite data based tools (kg per Ha)
2. Assess the percentage of surplus Nitrogen (i.e. not absorbed by the crops) that can be saved thanks to VRT
3. Multiply by the costs avoided associated with this pollution
4. Assess Copernicus contribution to precision farming, i.e. to what extent intermediate users develop PF applications based on Copernicus data. And multiply the three.²

Reduce the negative impact on environment

Valuation approach

$$\text{Impact (EUR)} = \text{Contribution of Copernicus to precision farming} \times \text{Volume of surplus Nitrogen saved thanks to precision farming} \times \text{Cost of pollution from N}_2\text{O, NO}_x, \text{NH}_3 \text{ and N-leaching in water}$$

This environmental benefit can be evaluated, knowing the extent of the decrease in pollution due to precision farming. The valuation of this impact is based on a valuation coefficient assessing the avoided cost associated with this pollution (human health cost).

On average, farmers using VRT techniques (PF) decrease their Nitrogen surplus by 12%⁸⁴ ⁸⁵. Given that, it is possible to calculate how much N-leaching, N₂O, NO_x and NH₃ would have resulted from this Nitrogen surplus. The cost avoided associated with this pollution comes from valuation coefficient developed by PwC. Copernicus contribution is the same as in the previous model 4.2.3.2.1.1, as it is related to precision farming.

Major evolutions occurring between 2016 and 2035 are (for medium scenario): the volume of surplus Nitrogen that can be saved, as precision farming technologies will improve (from 12% to 25%), and the Copernicus contribution to precision farming which goes from 2,49% in 2015 to 17% in 2020 (see explanation above).

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 26.8 M and EUR 45.1 M in 2017, rising to between EUR 339.5 M and EUR 660.1 M in 2035 for a total cumulative value ranging from EUR 3.7 B to EUR 7.0 B.

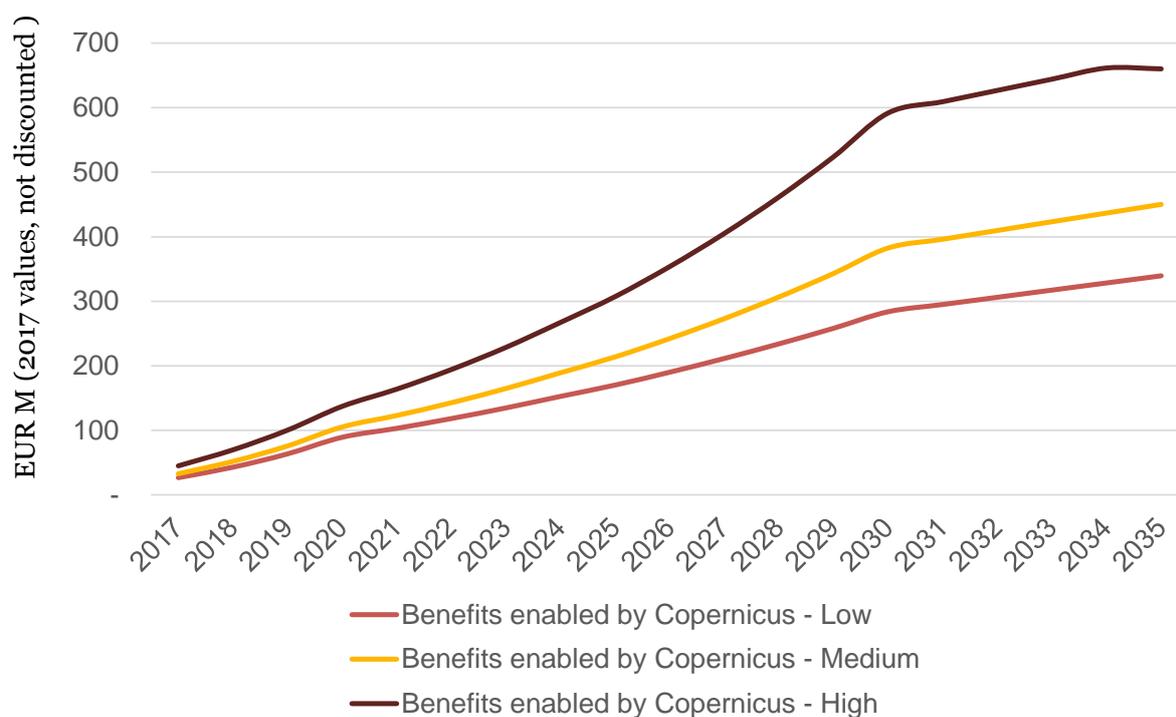


Figure 29 - Evolution of the Copernicus benefits for the impact “Reduce negative impact on the environment – Crop monitoring” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

As this benefit derived from Copernicus’ use in precision farming (VRT) application, the potential alternatives are the same as in the previous paragraph 4.2.3.2.1.1 “Improve agriculture profitability and cost efficiency”.

84 Precision agriculture and sustainability, R. Bongiovanni, J. Lowenberg-Deboer - 2004

85 Precision farming for sustainable agriculture, Yara factsheet (Online) : <http://yara.com/>

4.2.3.2.1.3 Improve food security

The main benefit of Copernicus related to food security is Early Warning for situation of crop stress or failure that can lead to humanitarian crisis (hunger). Satellite data provide information like soil moisture, DMP (Dry Matter Productivity), NDVI (Normalized Difference Vegetation Index), WRSI (Water Requirements Satisfaction Index), grassland production (for herders) and rainfall estimation that support early forecasting of drought, floods or extreme weather events leading to harvest failure.

The benefits of an early reaction after detecting a harvest failure that may potentially lead to a hunger issue, has been evaluated and is clearly illustrated by crops insurance or climate risk insurance (Weather Index based). Indeed the development of small holders insurance against climate risk in vulnerable countries, is seen as a powerful tool against hunger⁸⁶ (G7 summit⁸⁷), and it is a clear example of the benefit of early warning. The quick payout time is the main advantage comparing to current emergency aid: USD 1 investing in early assistance through insurance payout, saves USD 4.4 that should have been disbursed if the crisis was allowed to evolve (equivalent in emergency aid compared to early aid). In times of severe ongoing drought, insurance payouts cannot replace international assistance, but early cash assistance to families from insurance reduces the overall need for aid.

Reliable assessment of crops status required trend analysis and production of Index which are compared to standard values. EO data are particularly relevant for this kind of activities as they cover vast areas of land rapidly and on a regular basis. Thanks to EO data, authorities in charge of crops insurance programs or NGOs are immediately aware when the index goes under a defined threshold, which means damages have occurred (or will occur). Hence they can quickly trigger the payout to farmers or send food to endangered communities.

Copernicus Land service proposes products particularly adapted to food security matter: like the NDVI or the DMP map, which are really useful for crops insurance or NGO in Sahel for example. Index of soil moisture are useful for rice culture (RIICE project for example). Early action is crucial when it comes to food security matter. Bad harvest can be forecasted and their consequences can be tackled before becoming a national famine.

Therefore we can say the Copernicus application for crops monitoring (early warning in this case) lead to improved results and better aid spending in food security. Details of the model developed to quantitatively assess this benefit can be found in the box below:



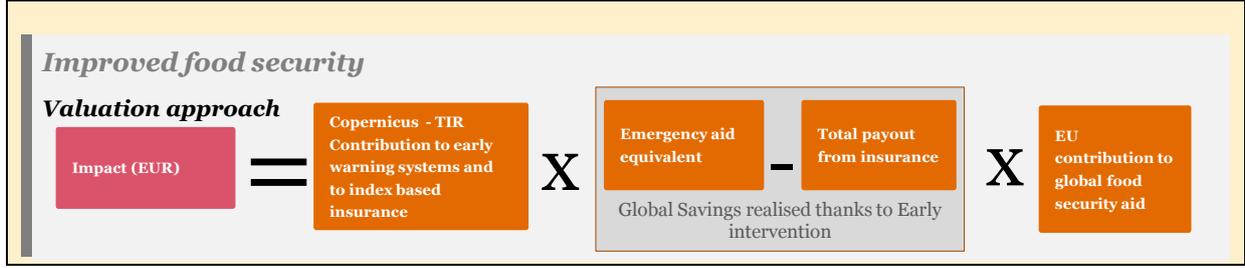
Methodological approach to value the impact on food security

We measured the impact of Copernicus on food security by assessing the decrease in the amount of money disbursed for food assistance (by the EU). This decrease is enabled by early warning system like the ones used for small holder insurance. We took crops insurance as a proxy to assess the benefit of early warning. The steps are:

1. Assess the total pay-out from small holder insurance in case of harvest failure (risk modelling).
2. Calculate the equivalent in emergency aid that should have been disbursed if the crisis has evolved (ratio of 4.4)
3. Make the difference between the two to have the saving realised thanks to Early intervention
4. Assess Copernicus contribution to early warning system and to index based insurance

⁸⁶ WFP, (online) : <http://www.wfp.org/stories/weather-index-insurance-powerful-tool-against-hunger>

⁸⁷ G7, June 2015, InsuResilience initiative (online) : <http://www.mofa.go.jp/mofaj/files/000084023.pdf>



Our model is based on this ratio of USD 1 to USD 4.4 between the money invested in early assistance (through insurance) and the money disbursed in the current pattern of emergency aid⁸⁸. Given this ratio of USD 1 to USD 4,4, we assumed the total crops insurance payout per year (based on an average payout per beneficiary), we multiplied it by 4,4 to have the equivalent in “emergency aid” that should have been disbursed, and obtained the savings thanks to early warning. Copernicus contribution to these savings is relatively low in 2017 (around 6%) because Copernicus products and programs dedicated to food security matter (GMFS, SIG Sahel or RIICE project for example), are focused only on certain areas (Sahel, South eastern Asia). Moreover weather index-based insurance need historical data to develop their risk model, and Copernicus archives are short for the moment. On the contrary Landsat and MODIS have 35 years of historical data (but less qualitative). However, we can reasonably assume that Copernicus contribution will increase quickly in the coming years, as it perfectly meet the requirements for small holder insurance and other NGOs early warning systems⁸⁹.

The major changes assumed to occur between 2016 and 2035 are the contribution of Copernicus to early warning and index-based insurance (from 6% to 40%), and the number of people covered by a crops insurance in poor countries (from 100 million in 2016 to 500 million in 2023⁹⁰)

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 56.5 M and EUR 76.7 M in 2017, rising to between EUR 773.4 M and EUR 1,289 M in 2035 for a total cumulative value ranging from EUR 8.3 B to EUR 14.6 B.

88 African Risk Capacity website (online) : <http://www.africanriskcapacity.org/2016/10/29/how-arc-works/>

89 Interview input with ACF “Action Against Hunger”, which developed SigSahel (Online) : <http://sigsahel.info/>

90 G7, June 2015, InsuResilience initiative (online) : <http://www.mofa.go.jp/mofaj/files/000084023.pdf>

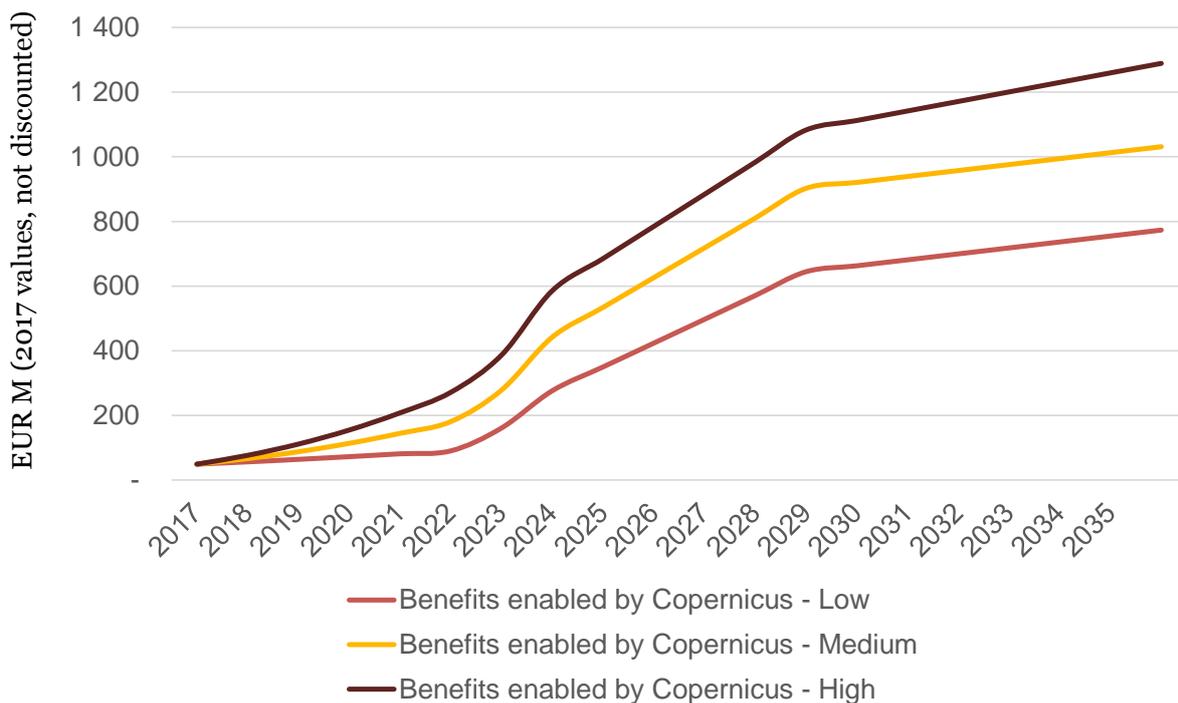


Figure 30 - Evolution of the Copernicus benefits for the impact “Improve food security – Crop monitoring” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Food security depends on complex interactions between climate, soil conditions, local agricultural practices, politics and macro-economic factors. Having both the detail and the wider picture as well as the dynamic in order to understand what is happening literally on the ground, is the first step and an essential tool to tackle food security issues. Copernicus is perfectly tailored to do that. It has the coverage, a frequent revisit time (5-10 days), it provides already processed data like soil moisture map, DMP or NDVI map, which are exactly the information needed for early warning. It has a better resolution and more spectral bands than Landsat, allowing the users to discern more information about the crops or grasslands status. More importantly, Copernicus (like Landsat) is free and open, enabling poor countries and NGOs to develop early warning system at a low price, and insurers can propose low premiums to small farmers. Copernicus is also a long term sustained program. Data are secured and will be always available. For all these reasons and from interview inputs, we can say that Copernicus is a very precious tool to stave off hunger. Its contribution is already crucial in certain region (Sahel for example) and it will increase in the future with the extending coverage and archives. If Landsat can be an alternative to Copernicus in fighting food insecurity, it is unable to achieve the same level of service as Copernicus. Without Copernicus, food security matters would be less efficiently managed.

4.2.3.2.1.4 Summary of Copernicus contribution to “Crops monitoring – support to agriculture”

The total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	98.2	757.3	1,479.6	15,462.2
Medium estimate	139.2	1,148.1	2,129.5	23,025.8
High estimate	186.8	1,564.3	2,930.0	31,711.1

Table 11 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below (not discounted).

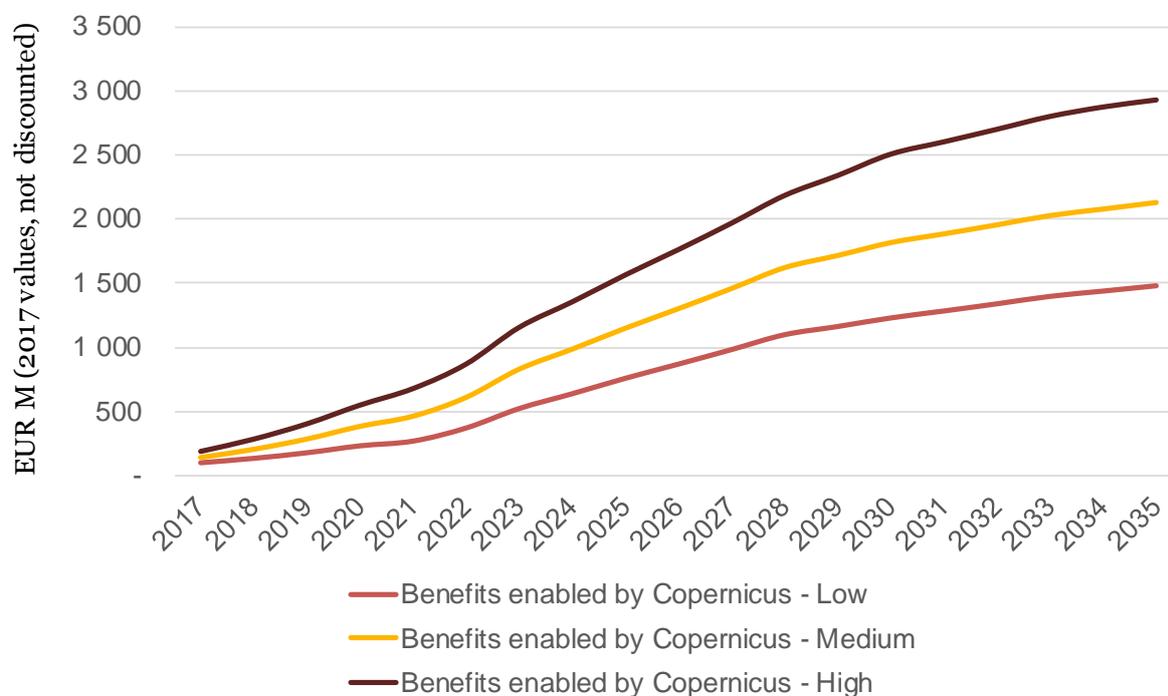


Figure 31 - Overall Copernicus D&I benefits for Crop monitoring – support to agriculture, from 2017 to 2035 (Source: PwC analysis)

4.2.3.2 Forestry Management and Protection

In 1993, during the Noordwijk Ministerial Declaration on Climate Change, environment ministers from 68 nations proposed afforestation of 12 million hectares annually worldwide, due to the recognised impact forests have on mitigating climate change. Later on, the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol provided indications for forest management – should it be through better management or through afforestation/reforestation.

The challenges linked to Forestry are not the same globally or at the European level. In Europe forest is increasing slowly (slightly more than 1M ha every 5 years according to Eurostat⁹¹), but most of the forest ecosystems are in a poor state and the legislation concerning sustainable forest management practices is flouted in too many cases.

At global scale, the main issue is fighting deforestation to reduce carbon emission resulting from forest destruction and degradation. Indeed deforestation and forest degradation account for approximately 17 % of carbon emissions⁹². The reason is that forest ecosystems (especially tropical ones) are huge carbon sink. They store 20 to 50 times more CO₂ than any other ecosystems. But when trees are felled they release the carbon they are storing into the atmosphere, where it mingles with greenhouse gases from other sources and contributes to

91 http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=for_area&lang=en (Accessed: July 24th 2017)

92 UN-REDD website (Online) : <http://www.unredd.net/about/what-is-redd-plus.html>

global warming accordingly. The UN-REDD program (Reducing emissions from deforestation and forest degradation) has been launched in 2008 to assist developing countries to meet the REDD+ requirements. The REDD+ is a mitigation mechanism which creates financial value for the carbon stored in forests by offering incentives for developing countries to reduce emissions from forested lands. Developing countries would receive results-based payments for results-based actions.

Authorities need reliable monitoring tools to tackle the forest issues. EO data and particularly Copernicus, can really be helpful to implement new directives and behaviour changes which will contribute eventually to preserve forest ecosystem's services.

Copernicus serves several purposes for Forestry:

- **In Europe:**
 - It supports National Forest agencies to enforce laws concerning sustainable management practices for forestry (replanting/reforestation activities after clear cut)
 - By enhancing the adoption of sustainable management practices through efficient monitoring of clear cut, Copernicus use leads to economical long term benefits for the forest industry
 - It supports the implementation of the European Habitat directive which aims at safeguarding biodiversity in Europe, especially in Forest areas⁹³.
- **Globally (out of the scope of the study but mentioned for information purposes):**
 - It supports the UN-REDD program: a service component for REDD+⁹⁴ is being developed using the high resolution imaging (10m spatial resolution) from Sentinels 2A and 2B. Due to data acquired every 10 to 5 days and resolution higher than Landsat (40m), Sentinel 2 can be used to monitor and map deforestation and enable REDD+. Due to the free data, it could allow global users to use the data in their forest monitoring programmes. Through stakeholder consultation, it has not been possible to attribute reduced deforestation due to improved monitoring capacity through Copernicus. Therefore, this impact has not been monetized. As REDD+ is part of the UNFCCC and climate action as a mitigation activity and most NDC targets under the Paris Agreement include land use, land-use changes and forestry (LULUCF), it has been assumed that efforts to reduce deforestation through the REDD+ initiative are covered by the valuation in the CO₂ monitoring section.

Copernicus satellite data and information contribute to monitor the forest through the Copernicus Land service. For Europe, the main sources of information come from the Sentinel data and products of the Pan-European and Local component:

- The High Resolution Layers (HRL) provide specific land cover characteristics that are complementary to land cover in a 20m resolution. In this specific case, the forest HRL consists of two products: the tree cover density map and the forest type map
- Natura 2000 is a product that is in-use to support the EU network of nature protection areas established under the 1992 Habitats directive in order to support bio-diversity
- Riparian zones maps monitor the lands that are in proximity of freshwater ecosystems

⁹³ The Habitats Directive (Online) : http://ec.europa.eu/environment/nature/pdf/20yrs_brochure.pdf

⁹⁴ This is a UNFCCC programme negotiated in 2005 with the objective of mitigating climate change.

- Coordination of Information on the Environment (CORINE) Land Cover (CLC) is an inventory of land cover in 44 classes and presents changes in land cover
- Small woody features upcoming product that is based on Very High Resolution data and will be able to monitor small areas of trees

The overall benefits derived from Copernicus data and information to monitor Forest coverage, can be summarised by the impact pathway below:

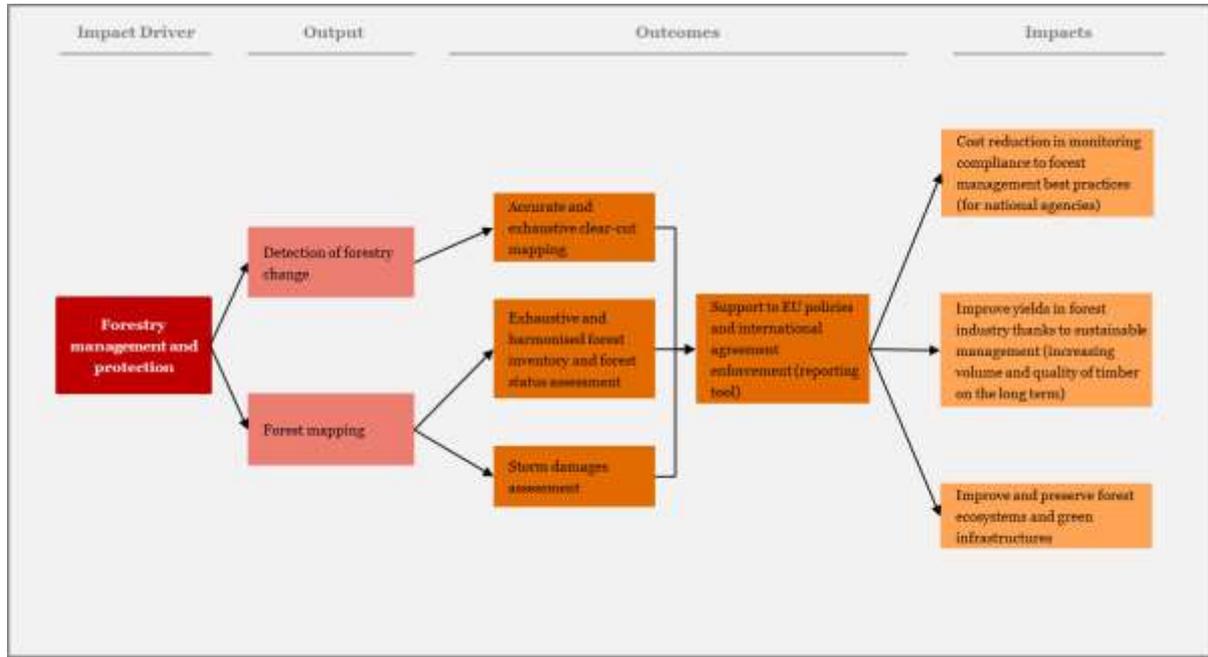


Figure 32 - Impact pathway for Forestry Management and protection (Source: PwC analysis)

EO data provide forest authorities accurate forest mapping, really useful for storm damages assessment, inventory and validation of forest strand for wood purchaser. Thanks to time series of satellite images forest authorities are also able to detect change in the Land cover/land use in forest areas like illegal clear cut for example, or urban areas expansion threatening the ecosystem. All these information support the implementation of EU policies aiming at sustainably managing and eventually safeguarding our forests.

As a result of all these outputs, several benefits can be pointed out:

- Cost reduction in monitoring compliance to forest management best practices (for national forest agencies)
- Improved yields in forest industry thanks to sustainable management (increasing volume and quality of timber on the long term)
- Improve and preserve forest ecosystems and green infrastructures

4.2.3.2.2.1 Cost reduction in monitoring compliance to forest management best practices (for national forest agencies)

Due to the fact that in Europe 60% of forests are privately owned⁹⁵, EO data is mostly used by national forest agencies to monitor the compliance of the forest owners to the law. Indeed rules have been implemented to prevent private owners of forest from depleting this national asset. For example in Sweden (similar in France), when a forest owner wishes to fell an area of forest over 0.3ha in size he is obliged to notify the Sweden Forest Agency (SFA) of his

⁹⁵ http://ec.europa.eu/eurostat/statistics-explained/index.php/Forestry_statistics

intention to do so⁹⁶. Afterwards the owner has 3 years to replant the trees, and within 10 years of re-planting, a first thinning ought to take place (“pre-commercial thinning”).

Without satellite imagery the SFA has no means to know directly whether the forest area has been cleared or not according to the notification and, when it has been, whether the area has been replanted or not. EO data is clearly the optimal tool to develop clear-cut map which will enable the authorities to enforce the rules in forestry sector. Forest agencies in other European countries face the same issues in monitoring clear cut area. Like SFA, they used to use commercial satellite imagery to prepare their clear-cut map. The cost of purchasing these satellite images has significantly fallen as commercial data are gradually replaced by Sentinel 2 data which are free of charge.

Therefore we can say that Copernicus application for forestry leads to cost reduction for authorities. Details of the model developed to quantitatively assess this benefit can be found in the box below:



Methodological approach to value the cost reduction for forest agencies

Our model is based on the cost reduction resulting from the fact that Copernicus data are free of charge, whereas authorities used to pay for commercial data. The steps are:

1. Calculate the cost to cover EU28 forest area with commercial satellite images⁹⁷
2. Assess the percentage of commercial data replaced by Copernicus data (progressive increase)
3. Multiply the two

Cost reduction for Forest agencies

Valuation approach

$$\text{Impact (EUR)} = \text{Percentage of commercial data replaced by Copernicus data} \times \text{Cost of purchasing commercial satellite imagery to cover EU28 forests}$$

The cost of commercial EO data to cover 1ha of forest was given by the EARSC case study (0,016 euros). We assumed Copernicus data will gradually replace the commercial data as they meet the requirements for clear cut maps development (resolution, re-visit time, spectral band) and they are free.

Major evolution occurring in this model is the percentage of Copernicus data used to prepare the clear-cut map: from 15% in 2016 to 75% in 2035 (VHR will still be needed in some case).

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 0.5 M and EUR 0.8 M in 2017, rising to between EUR 1.7 M and EUR 2.2 M in 2035 for a total cumulative value ranging from EUR 28.2 M to EUR 37.6 M.

⁹⁶ Based on EARSC case study on Copernicus Economic Value: Forest Management in Sweden, January 2016

⁹⁷ Based on EARSC case study on Forest Management in Sweden, extrapolated for Europe

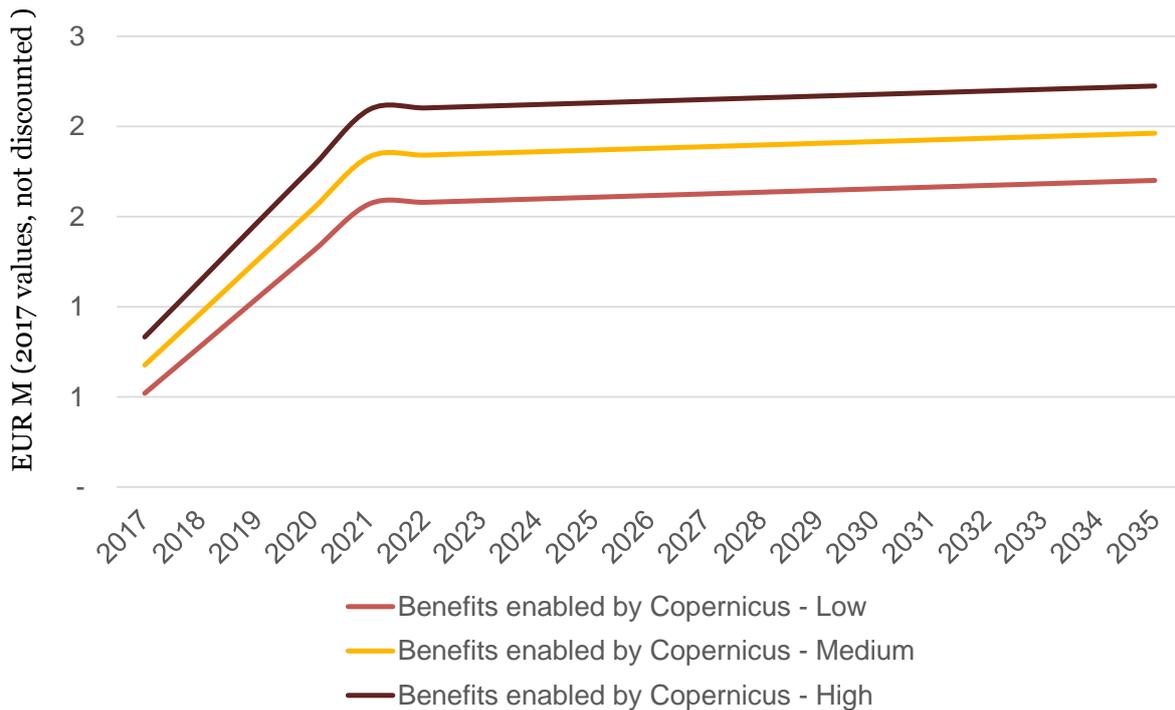


Figure 33 - Evolution of the Copernicus benefits for the impact “Reduce cost for Forest agencies” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Clear-cut map can be developed without EO technologies (aircraft imagery or on-field inspection) but it is really more expensive (between EUR 9 M and EUR 11 M⁹⁸) and less efficient (coverage is smaller). EO in this case, is really the best tool.

Before Copernicus’ entry into service data used by the forest agencies (SFA in the EARSC case study) were coming from SPOT and Landsat satellites, with moderate resolution. Spot 4 data provides data at 10m resolution and Landsat at around 20-30 m resolution. The short-wave infra-red channel is necessary for the monitoring of the clear cut area⁹⁹. Sentinel-2 can reach 10 m resolution and its spectral capacity includes Short-Wave Infra-Red. Therefore Copernicus is fully relevant for this application and the fact that it is free and open, while providing richer spatial information and a better resolution than Landsat, makes it the best option for Forest Agencies. Moreover according to the EARSC case study on Forest Management in Sweden, imagery with full coverage of Sweden has been collected each summer i.e. once a year. With Sentinel revisit time capacity (5 days), data updating is clearly improved and so is the quality of clear-cut maps.

4.2.3.2.2.2 Improved yields in forest industry thanks to sustainable management (increasing volume and quality of timber on the long term)

As exposed above Copernicus helps monitor the compliance to good practices in forestry. Sustainable management of forest requires certain activities like replanting within 3 years after the clear-cut and one or even two pre-commercial thinning within the 10 years after replanting. These are costly investments for private owners if they only looked at short term optimization of returns. However, on the long term (approximately 80 years) the profitability of the forest is improved as this sound asset management results in more wood for the final clear cut (80 years old wood is more expensive).

98 Copernicus Sentinels’ Products Economic Value: A Case Study of Forests management in Sweden – EARSC, 2016

99 Copernicus Sentinels’ Products Economic Value: A Case Study of Forests management in Sweden – EARSC, 2016

Therefore we can say that Copernicus leads to improved yields in the forest sector, by monitoring forest owners' compliance to sustainable practices. Details of the model developed to quantitatively assess this benefit can be found in the box below:



Methodological approach to value the improved yields in forest industry

Our models relies on the progress made in forest management thanks to Copernicus. Clear-cut areas not replanted or not notified, are spotted with EO and authorities can remind the owners to manage their assets better. The steps are:

1. Assess the percentage of clear-cut areas spotted as uncompliant regarding sustainable management (not replanted, no pre-commercial thinning)
2. Derive from it the clear cut areas being managed better thanks to authorities' reminder.
3. Multiply by the additional yield resulting from sustainable forest management practices
4. Multiply by the Copernicus contribution to this benefit i.e. the percentage of Copernicus data used to develop reliable clear-cut maps

Improve yields in forest industry thanks to sustainable management

Valuation approach



According to the EARSC case study on forest management in Sweden¹⁰⁰, EO imagery revealed that nearly 10% of the clear-cut areas were not cut in accordance with the notifications i.e. the boundaries of the cut area were not as they were supposed to be according to the notification or, there was no notification at all for this cut area. Access to this information has allowed for a diametrical change in forest management by the SFA (Swedish Forest Agency). Indeed breaking the rules does no longer make sense for private owners: the SFA will notice. Moreover the SFA can now monitor the owners' compliance with replanting and thinning obligations, leading eventually to improved yields for the forest sector.

We took the information of this Case study in Sweden, as a proxy for 40% of the forest in Europe. It was considered, after consultation with experts, that forests similar to the Swedish one represent 40% of the whole European forests. Therefore we can extrapolate the case study to 40% of Europe Forests.

Based on information extrapolated from the Swedish case, we assume a percentage of forest cut each year. 10% of these cut would not have been replanting and thinning according to sustainable management practices, if the authorities were unable to monitor them. But thanks to Copernicus they detect it and make owners change their behaviour. Hence it is possible to calculate the clear cut area being managed better thanks to satellite monitoring, and so the additional revenues which results from a better sustainable management (replanting and thinning). Copernicus contribution, in this case, is the percentage of Copernicus data use to develop clear cut map (replacing commercial data).

100 Copernicus Sentinels' Products Economic Value: A Case Study of Forests management in Sweden – EARC, 2016

The major changes assumed to occur between 2016 and 2035 are the percentage of clear cut area spotted as non-compliant (from 10% in 2016 to 2% in 2026 and then flattens out as the EO imagery enables efficient monitoring), and the percentage of Copernicus data used to prepare the clear-cut map (from 15% in 2016 to 75% in 2035). These figures are for the medium scenario.

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 3.5 M and EUR 5.6 M in 2017, rising to between EUR 60.7 M and EUR 79.4 M in 2035 for a total cumulative value ranging from EUR 752.2 M to EUR 996 M.

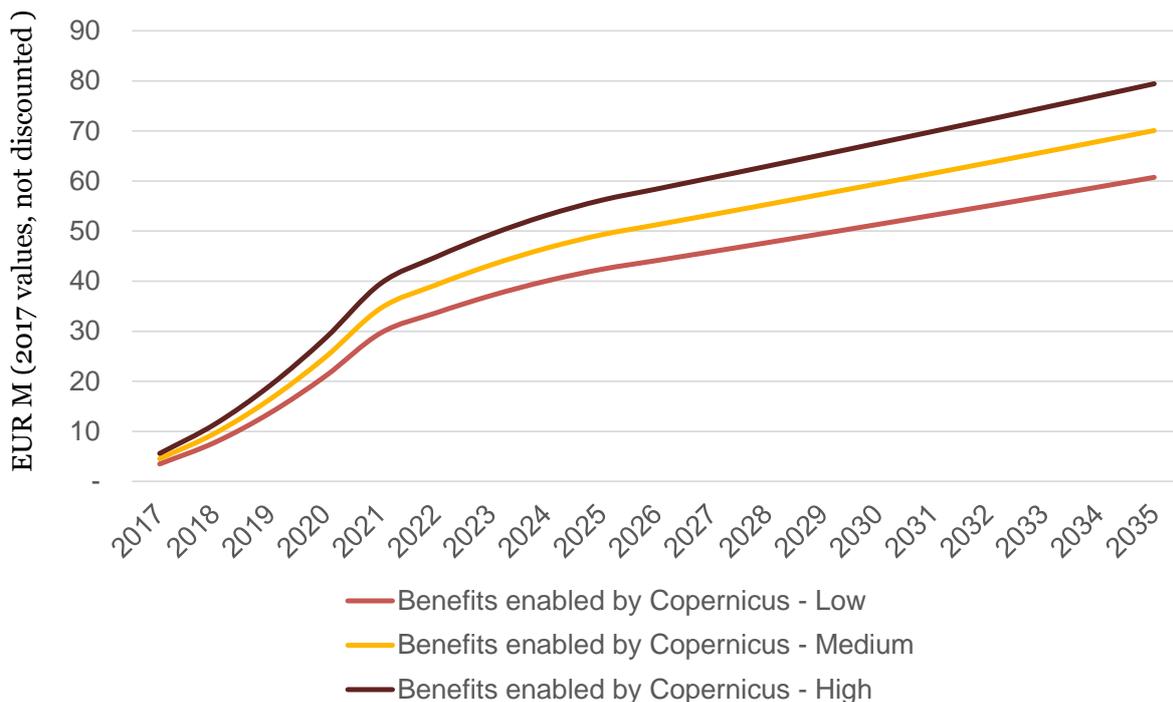


Figure 34 - Evolution of the Copernicus benefits for the impact "Improve yields in forest industry" from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

As this benefit derived from the same Copernicus application for clear-cut map preparation, the differentiation factor and alternatives for Copernicus are the same as in the previous chapter (Commercial data but it is more expensive).

4.2.3.2.2.3 Improve and preserve forest ecosystems and green infrastructures

Forests and other wooded land within the EU-28 currently cover 176 million ha which represents around 42 % of EU land area. They are hosting a significant proportion of Europe's rich biodiversity, and they provide very important benefits to society and the economy via the provision of ecosystem services (soils erosion protection, watershed regulation, climate regulation, carbon storage and water/air purification). Hence preserving forest ecosystems and green infrastructure is crucial for our well-being.

Copernicus Land Monitoring Services provide a common framework for a frequently updated monitoring system of environmental change at European scale. In 1992, in response to the alarming status of biodiversity in Europe, EU governments unanimously adopted the Habitats Directive. Its purpose was to safeguard the most threatened species and habitats across the EU and one of the main component of this directive was the development of a vast network of protected areas: the Natura 2000 project.

Copernicus products portfolio is clearly relevant and useful to monitor the Natura 2000 network and to meet the requirements of the Habitats Directive Article 17¹⁰¹. Article 17 requires a report to be sent to the European Commission every 6 years assessing the conservation status of the habitats and species targeted by the directive. The following Copernicus products can clearly contribute to this assessment: High Resolution Layers (HRL) Forest Type/Density, HRL natural and semi-natural grasslands, HRL imperviousness and other HRL (wetlands, permanent water bodies); Urban atlas; Riparian Zones; Natura 2000 specific grassland types only. By combining these products information, one could establish a high resolution land cover map to populate Natura 2000 areas and their surroundings. Hence Copernicus products are mainly suitable to refine a range of different analyses previously performed at coarser spatial resolution. They enhance assessment of the conservation status by covering more areas, and analysis of pressures in and outside Natura 2000 (urbanization, agricultural intensification) by detecting change earlier.

Therefore we can say that Copernicus leads to improve and preserve forest biodiversity, by supporting Natura 2000 network and Habitats Directive implementation. Our focus here is on Forest but Copernicus benefits for other valuable ecosystems (Wetlands, Agricultural habitats...) will be addressed in other impact drivers. Details of the model developed to quantitatively assess the benefit for forest biodiversity can be found in the box below



Methodological approach to value the improved forest ecosystems

Our model is based on Copernicus contribution to the implementation of the Habitats Directive through the monitoring of Natura 2000 areas. Thanks to these initiatives Forests in favourable conservation status are restored every year. The steps are:

1. Assess the additional forest area restored each year thanks to Nature 2000 i.e. the surface of forest which goes from “unfavourable” to “favourable” status
2. Multiply it by the valuation coefficient of 1ha of forest in good health. It corresponds to the economic value of lost ecosystem services associated with the conversion and/or degradation of forest areas (erosion control, water filtration...)
3. Assess the contribution of Copernicus to the Habitats Directive: [Natura 2000 areas covered by Copernicus products x effective use of Copernicus by authorities x quality requirements fulfilled by Copernicus].
4. Then multiply the rest by it.

Improve and restore forest ecosystems and green infrastructures

Valuation approach



Approximately 21% of the total forest resource in the EU is in the Natura 2000 network, and forests represent around 50% of the total area in Natura 2000¹⁰². It has been assessed that in 2015, only 17% of the Forest habitats are in a favourable conservation status¹⁰³. We assumed that in 2020, the EU Biodiversity Strategy will achieve (approximately) its target by reaching 30% of favourable assessment within the forests. The improvements will continue at the same path. We can then calculate how much forest area is restored each year thanks to the

101 Contribution of Copernicus in support to monitoring of habitats, species and the Natura 2000 network – Working Paper EEA, 2016

102 “Natura 2000 and Forests”, EC technical Report - 2015

103 “Natura 2000 and Forests”, EC technical Report – 2015 : :15% in 2012

Habitats Directive, and multiplied it by the value of forest ecosystem services (developed by PwC). Assessment of Copernicus contribution is exposed above (point 3).

The major changes assumed to occur between 2016 and 2035 are the percentage of forest in “favourable conservation status” (from 19% in 2016 to 70% in 2035) and the Copernicus contribution to these improvement (from 2% to around 9%) as the coverage of Copernicus products portfolio will extend and more Environment Agencies will use it. These figures are for the medium scenario.

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 12.5 M and EUR 37.6 M in 2017, rising to between EUR 427.5 M and EUR 1 282 M in 2035 for a total cumulative value ranging from EUR 4 B to EUR 12 B.

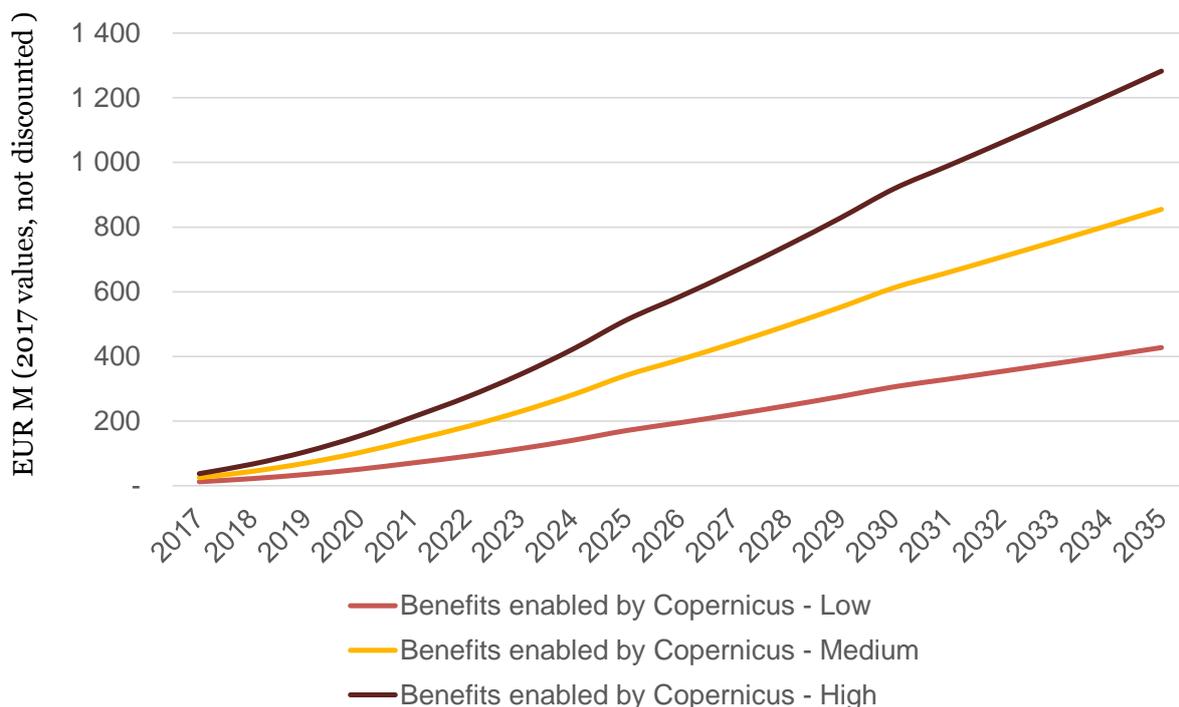


Figure 35 - Evolution of the Copernicus benefits for the impact “Improve and preserve forest ecosystems and green infrastructures” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

As exposed above Copernicus products portfolio is particularly relevant when it comes to biodiversity and habitats monitoring. Dedicated product like HRL for Forest and Imperviousness or Natura 2000 site map (local component for grassland) have been tailored to support ecosystems monitoring. Copernicus’ differentiation factor in this field relies on these specially designed products and its more frequent updating as compared to traditional methods (on-field inspection) and to Landsat (less frequent re-visit time). Even if classic ecological survey (on-field) are still needed to monitor biodiversity, Copernicus is clearly a critical tool for the implementation and enforcement of EU directive on ecosystems preservation. The alternative would be to pay the commercial sector to develop similar products/maps, which would be clearly expensive for Environment Agencies among Europe.

4.2.3.2.2.4 Summary of Copernicus contribution to “Forestry Management and protection”

The total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	16.6	215.1	489.9	4,628.6
Medium estimate	30.3	393.4	927.0	8,603.5
High estimate	44.1	571.7	1,364.1	12,578.3

Table 12 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below (Not discounted).

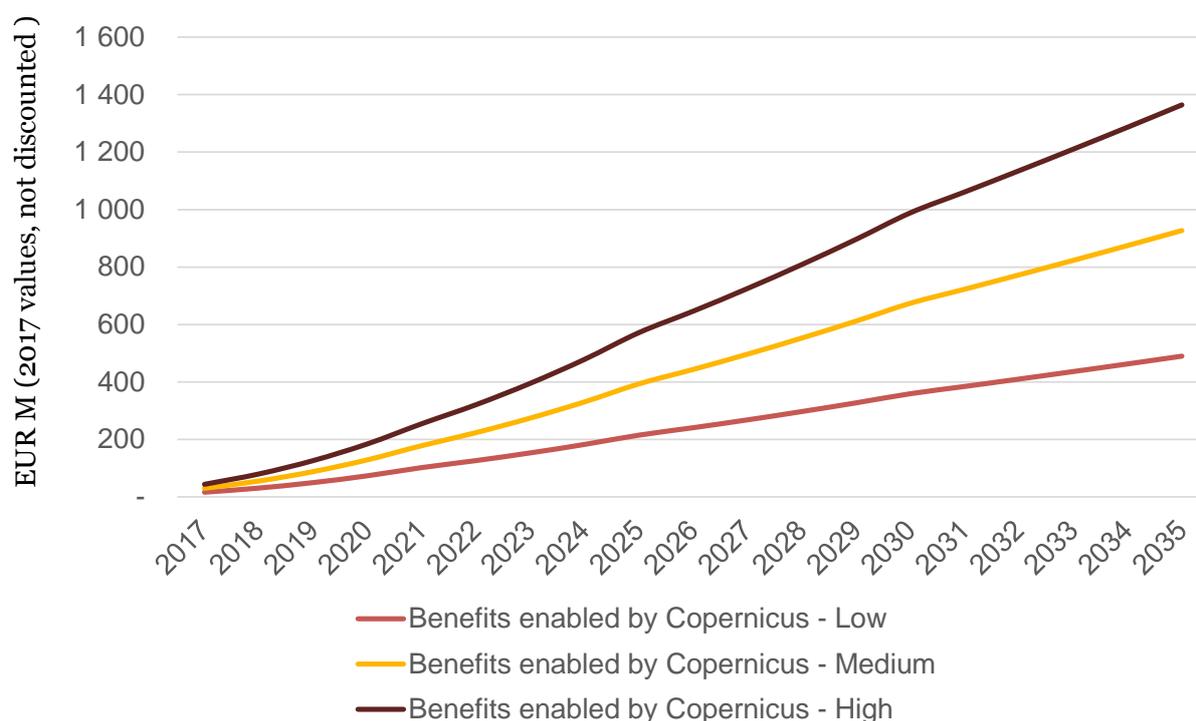


Figure 36 - Overall Copernicus D&I benefits for Forestry Management, from 2017 to 2035 (Source: PwC analysis)

4.2.3.2.3 Water resources management

Water is a limited resource that needs to be preserved. Nowadays, 20% of all surface water in the EU is already seriously threatened by pollution and the number of people and area affected by water scarcity and drought has increased by 20% in the past 30 years¹⁰⁴. The depletion of current water resources is compounded by a growing urban population expecting better living standards and by the effects of climate change. These social and environmental factors leads to an increasing competition between farmers, industry sector and citizen for access to water. Indeed in addition to the farming sector (first water consumer), several other economic sectors relies on water availability like the hydropower sector and the inland waterway transport sector. Therefore sustainable water resources management is one of the main challenges for the future and requires the development of new technological and scientific tools.

104 ESA Portal (Online) : http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Land

Thanks to satellite imagery, decision makers (public authorities, farmers, dam managers...) can better assess the level of supply and demand for water in order to ensure a sustainable, optimized and equitable management of this vital resource.

Through its dedicated Land Service, Copernicus provides regular and comprehensive data to monitor water cycle parameters (soil moisture, meteorological data). and the availability and quality of surface water bodies (e.g. fresh water reservoirs). One of the main indicators used for water resources management is the Soil Water Index provided by Sentinel-1. Soil moisture data combined with evapotranspiration and rainfall data, are crucial to assess the water requirement of crops and to forecast drought and water stress situation. Sentinel-2 and 3 provide observations on the state of water bodies and river run-off (quality, extent and depth). When combining these data with spatial planning information, it is possible to assess the balance between the supply and the demand of water (irrigation, energy production etc.) in a given area.

With Copernicus data, decision-makers have an effective tool to monitor water resources. The following impact pathway maps out the impacts of water resources management (impact driver) through the particular environmental, societal or economic benefits (impacts):

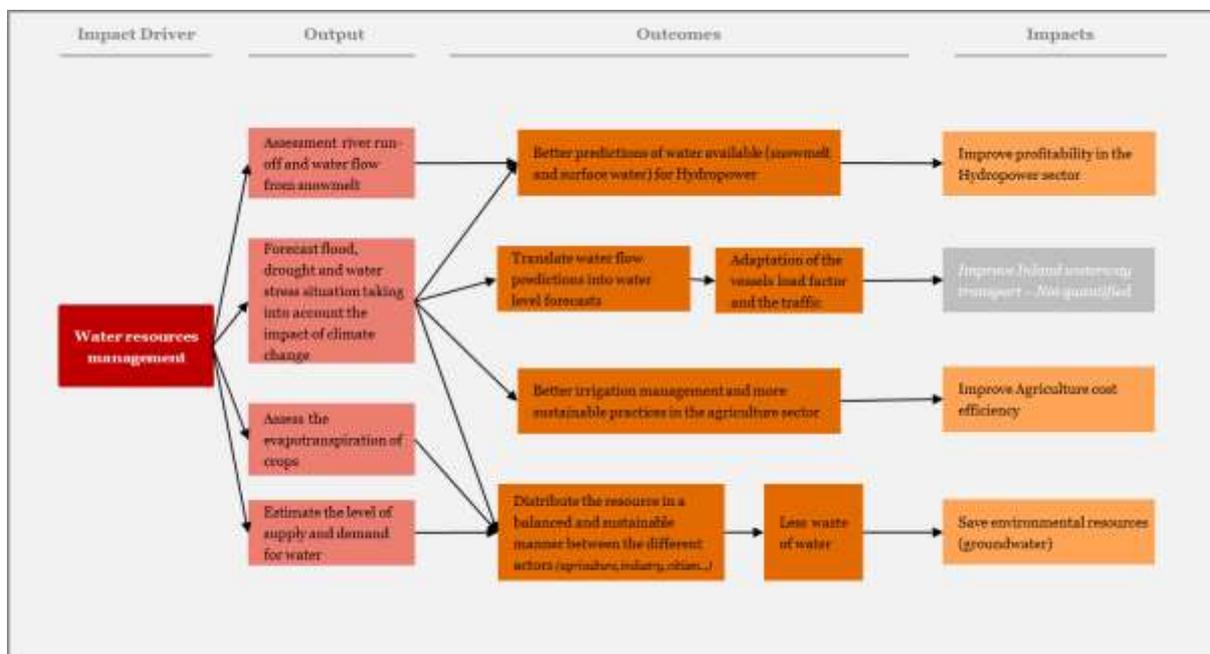


Figure 37 - Impact pathway for Water resources management (Source: PwC analysis)

Indeed, estimating and forecasting accurately the volume of water available and the level of water requirements, taking into account possible future weather conditions evolution and climate change effect, can lead to better distribution/allocation of water and a change in water consumption/water use habits. Agriculture can adopt better irrigation practices, wasting less water and so limiting ground water depletion. With the assessment of the volume of water flow from snowmelt and river run-off, Copernicus provides reliable and global information on water availability which is very useful to energy providers for the management of hydrological power plants. Hence hydropower productivity and Inland Navigation optimization (load factor, ship design) are improved thanks to better long term forecast of water flow.

As a result of all these outputs several benefits can be pointed out:

- Improve profitability in the Hydropower sector

- Improve Inland waterway transport optimization
- Improve agriculture cost efficiency by saving irrigation costs and reducing water usage
- Save environmental resources (reduction in groundwater depletion)

The quantification of the benefits mentioned above is as follows.

4.2.3.2.3.1 Improve profitability in the Hydropower sector

Copernicus data support hydroelectric plant management, by providing information on water catchment properties, precipitation and the amount of snow stored during winter. These are extremely useful to energy providers for optimizing hydroelectric power production, regulating dam levels and setting electricity prices.

Copernicus advantages in this field is different between Europe and developing countries.

In developing countries (Africa for example), rivers are poorly equipped with in-situ stations and historical data on water level are scarce. Rivers may cross several borders upstream the dam and water flow data are not always shared between the different stakeholders (different countries). In the absence of in-situ stations and reliable data, measurements by EO based tools is the only option. Satellite are able to assess the water flow and water level without ground installation and with a more global view in terms of area covered (larger).

European dams manager are more interested in satellite for long term inflow forecast as EO technologies can take many parameters into account. Indeed satellite information are composed of snow water content, soil moisture, water bodies map, water flow assessment and climate forecasts. Combining all of these data while incorporating more global elements like climate change, El Nino effect, which cannot be captured by in-situ stations, clearly improves river runoff predictions on the long term. Currently, hydropower companies often use Statistics of historical data (climatology) to forecast water level. However in a changing climate context, long term predictions based on historic trends tend to be less accurate. To address this issue, programs like SWICCA¹⁰⁵ or CLIM4ENERGY¹⁰⁶, use Copernicus real time data to forecast rivers flow in a context of global warming.

A typical goal of water management is to keep reservoirs as full as possible, while minimizing spill, to maintain maximum hydropower production. Hydropower's operational flexibility and its unique ability to change output allows water managers to respond effectively to forecast data. Therefore improved and additional predictability in hydro models, reduces uncertainty in flow volumes and eventually translates into greater hydropower benefits¹⁰⁷.

Therefore we can say that Copernicus leads to improve profitability in the Hydropower sector. Details of the model developed to quantitatively assess this benefit can be found in the box below:

¹⁰⁵ SWICCA portal (online) : <http://swicca.climate.copernicus.eu/>

¹⁰⁶ CLIM4ENERGY project (online) : <http://clim4energy.climate.copernicus.eu/>

¹⁰⁷ Nasa Scientific Visualisation studio – Earth Feature Story : The Benefits of Hydrologic Predictability



Methodological approach to value the improved profitability in the Hydropower sector

Our model is based on the fact that improved and additional predictability in long term water flow model results in higher benefits for hydropower plants through better reservoir optimization. The steps are:

1. Assess the percentage of hydroelectricity generated by dams using LT forecast based on satellite data (for large dams and small dams)
2. Assess the increase in benefits thanks to improved LT forecast
3. Assess Copernicus contribution, i.e. the percentage of Copernicus data used in the development of improved LT water flow models

Improve profitability in the Hydropower sector

Valuation approach



There are approximately 23,000 dams in Europe, of which approximately 2000 are large ones, i.e. with a reservoir of more than 3 million cubic meters¹⁰⁸. Small dams make up 91% of the total hydropower plants, but generate only 13% of all hydropower.

We understood from interview that for the moment, Hydropower plants mainly used models based on historical data for seasonal forecast. However they start to integrate satellite based data as the geographical coverage is wider, they measure snow cover and they are more accurate for long term predictions (climate change effect). Access to this kind of data has not the same impact whether it a small or large dam. Indeed large dams have such large storage capacities that variations in annual inflow have little impact on hydropower generation. But, smaller water systems are more influenced by changing environmental conditions and thus more eager to adopt improved long-lead forecasts based on EO data, as it will increase their benefit significantly. Overall we assume that around 10% (conservative) of the hydroelectricity generated in Europe comes from dams which used stream flow models based on satellite data.

Studies showed that increase in Hydropower benefits due to better inflow predictions, can reach +1.8% for large dams and +7.1% for small dams¹⁰⁹. Therefore we have been able to calculate additional revenues for the hydropower sector. Finally we have multiplied these additional revenues due to improved hydrologic model based on satellite data, by the percentage of Copernicus data used to develop it. We deducted from interview inputs¹¹⁰ that it is very minimal for the moment (0.5 % in 2017) but it should increase in the future with the development of project like SWICCA and CLIM4ENERGY.

The major changes assumed to occur between 2017 and 2035 are the contribution of Copernicus to hydrologic model for energy sector (from 0.5% to 50%, medium scenario, as special product like SWICCA are designed for that) and the adoption of stream flow model derived from satellite based data by the Hydropower sector (from 10% in 2017 to 60% in 2035, medium scenario).

108 The power of dams – 2017 (online) : <http://www.technologist.eu/the-power-of-dams/>

109 Potential Effects of Long-Lead Hydrologic Predictability on Missouri River Main-Stem Reservoirs – E.P Maurer, 2004

110 Discussion with a person from the SWICCA – Case study on Hydropower

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 0.1 M and EUR 0.3 M in 2017, rising to between EUR 71.4 M and EUR 176 M in 2035 for a total cumulative value ranging from EUR 608 M to EUR 1,563 M.

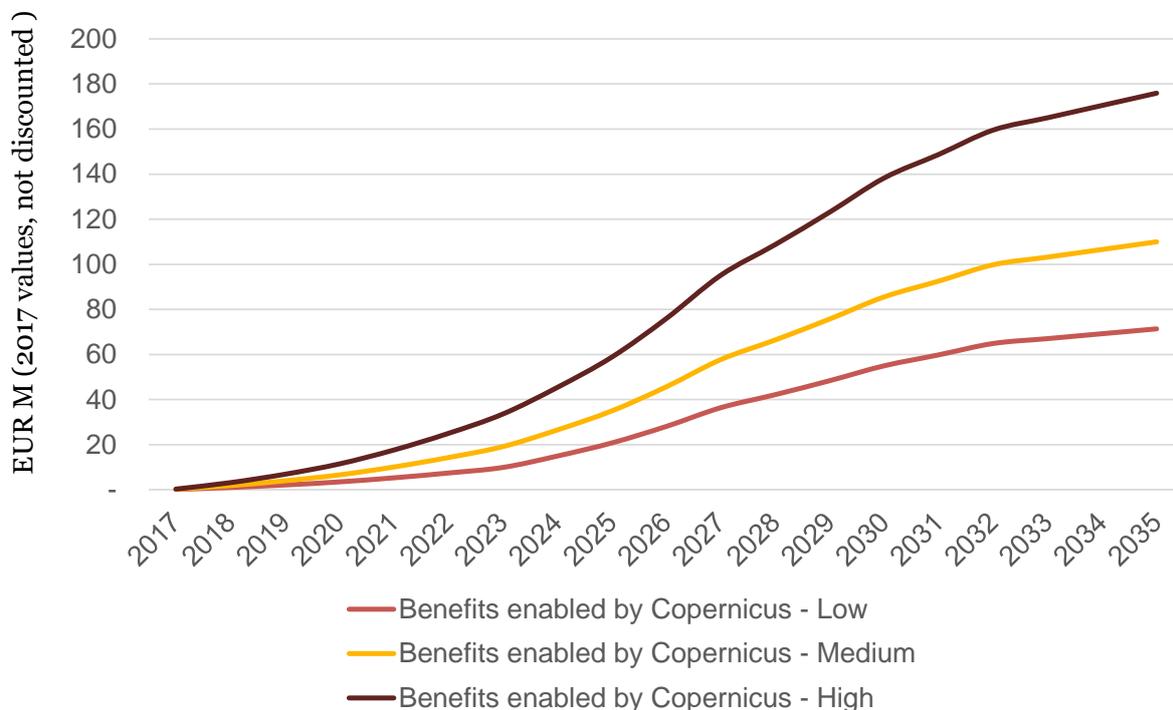


Figure 38 - Evolution of the Copernicus benefits for the impact “improve profitability in hydropower sector” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

From interview inputs we understood that Hydropower companies in North Europe (major dams) have not yet started to use Copernicus dedicated products like SWICCA. However they may use Copernicus data concerning snow cover but on very small range for the moment. For seasonal forecast majority of hydropower companies use statistics of historical data, which are sufficient for the moment in Europe (in developing countries historical statistics are less available). The value added of Copernicus for this benefit would come from its ability to provide more accurate data for long term hydrologic models. In this context Landsat data accuracy seems to be lower than Copernicus’. Private offers using satellite data is also an alternative to Copernicus, but it seems not really developed for the moment.

4.2.3.2.3.2 Improve Inland waterways transport

This benefit has not been quantitatively assessed because, as for today, there is no proof of behavioural changes due to the use of Copernicus in this field. Even if some cases study exist on the subject¹¹¹. Quantitative data are unavailable as Copernicus seems to be at its early stage in Europe. However as climate change will have an impact on water availability and so on rivers, Copernicus impact in this sector may improve in the future.

4.2.3.2.3.3 Improve Agriculture productivity (irrigation management)

The largest use of freshwater resources is for agriculture irrigation. It accounts for, on average, 70% of all water withdrawal globally¹¹². As exposed in a previous impact drivers (Crops monitoring), EO technology is used for precision farming. Similar to

¹¹¹ SWICCA case study : Inland Navigation (Rhine River)

¹¹² World Bank website (online) : <http://www.worldbank.org/en/topic/water/brief/water-in-agriculture>

recommendation map for fertilizer dosage inside a same field, optimized water inputs can be deducted from EO data. Having access to these information, farmers can reduce the overall level of irrigation, while maintaining the same yield.

Therefore we can say that Copernicus leads to improve productivity in the agriculture by enabling a better irrigation management through precision farming techniques. Details of the model developed to quantitatively assess this benefit can be found in the box below:



Methodological approach to value the improved Productivity for Agriculture (irrigation)

Our model is based on the volume of water saved thanks to better irrigation management enabled by EO information. The steps are:

1. Assess the volume of irrigation water used on crops monitored by PF/satellite data based tools.
2. Assess the percentage of water saved thanks to better irrigation management enabled by EO information and multiply it by the price of 1 m³ of irrigation water
3. Multiply by Copernicus contribution to Precision Farming



The quantitative analysis is based on a study of the benefits of satellite-based tool (Earth Observation) for irrigation management¹¹³. This study compared the irrigation volume estimated from satellite data (based on evapotranspiration data) versus the irrigation volume used by farmers without satellite data. It shows that, with correct irrigation application from satellite data, at least 10% of the irrigation water could be saved. This study was conducted in Austria, but its results have been used as a proxy for all of the irrigated crops in Europe.

We assume that crops surface monitored with satellite based-tool is approximately 25% (see impact drivers “crops monitoring”). Knowing the volume of irrigation water for 1 ha we can derive the total volume of irrigation water monitored with satellite based systems. 10% of this volume is saved thanks to EO services. Given the cost of 1 cubic meter of irrigation water, we calculate the money saved. Then we multiply the total savings by Copernicus contribution to Precision Farming.

Major evolutions occurring between 2016 and 2035 are (for medium scenario): the share of crops monitored with satellite data (adoption rate from 25% in 2016 to 63% in 2035¹¹⁴), the volume of water used for irrigation (e.g. due to climate change) and the Copernicus

¹¹³ Costs and benefits of satellite-based tools for irrigation management, Institute of Surveying, Remote Sensing and Land Information, University of Natural Resources and Life Sciences, Vienna, Austria - 2015

¹¹⁴ Assuming +2% per year : PwC Assumption for market uptake.

contribution to irrigation management (through precision farming) which goes from 2.49% in 2015 to 17% in 2020¹¹⁵.

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 16.7 M and EUR 28.1 M in 2017, rising to between EUR 144 M and EUR 311.3 M in 2035 for a total cumulative value ranging from EUR 1,703 M to EUR 3,507 M.

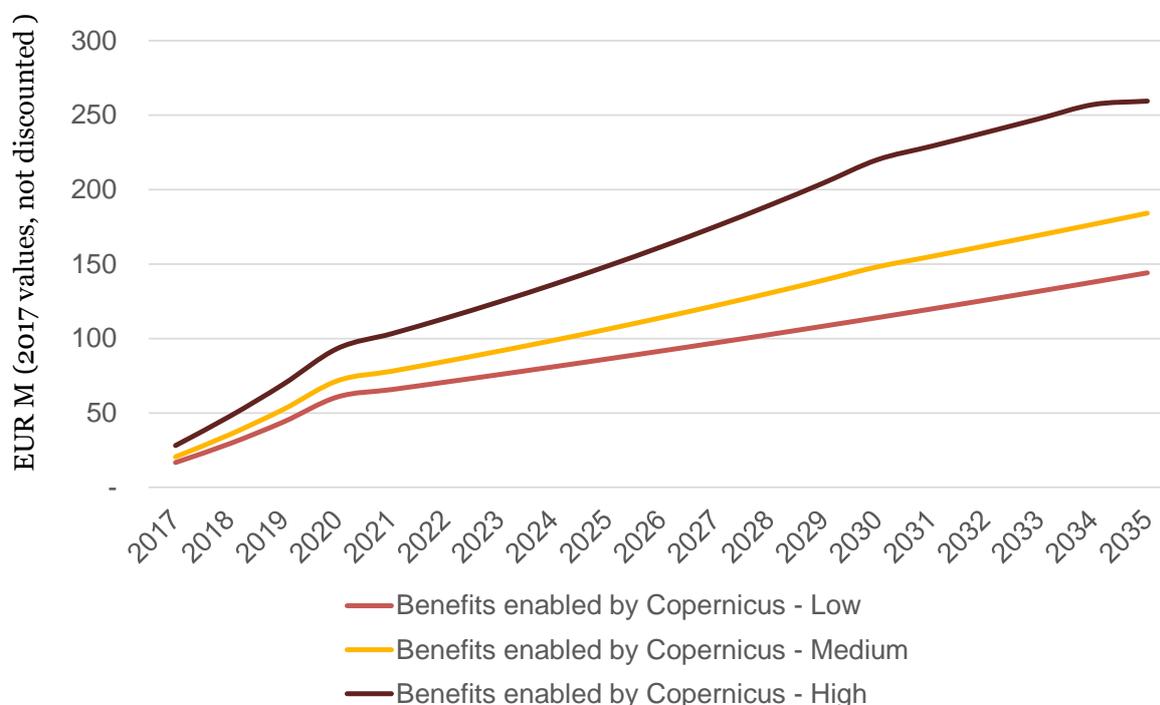


Figure 39 - Evolution of the Copernicus benefits for the impact “improve agriculture productivity (irrigation management)” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

As this benefit derived from the same Copernicus application for precision farming, but in this case, looking at irrigation issues, the differentiation factor and alternatives for Copernicus are the same as in the section “Crops monitoring – Improve agriculture profitability and cost efficiency”.

4.2.3.2.3.4 Save environmental resources (ground water)

As exposed in the previous paragraph, Copernicus enables water savings through better irrigation management. Using less water for irrigation reduce the need for pumping underground water. Hence underground water depletion is reduced and environmental resources are saved for other services (industry, citizen health...)

Therefore we can say that Copernicus leads to environmental benefit by saving water resources. Details of the model developed to quantitatively assess this benefit can be found in the box below:

115 PwC, Copernicus report on Downstream sector - 2016



Methodological approach to value the saving of environmental resources (ground water)

Our model is based on the volume of water saved thanks to better irrigation management enabled by EO techniques, resulting in a reduction in ground water depletion. The steps are:

1. Assess the percentage of water saved thanks to better irrigation management enabled by EO information
2. Multiply this volume of water saved by the “resource cost” (valuation coefficient developed by PwC)
3. Multiply by Copernicus contribution

Save Environmental resources

Valuation approach

$$\text{Impact (EUR)} = \text{Copernicus contribution to PF} \times \text{Volume of water saved thanks to better irrigation management} \times \text{Cost of coping with ground water depletion}$$

In order to quantify this environmental benefit of Copernicus derived from “Water resources management”, the same kind of assumptions as for the impact on irrigation management were used. Given the volume of water saved thanks to satellite-based data, we multiply it by a valuation coefficient (€/m³, developed by PwC) to obtain the “resource cost” i.e. the average cost of coping with groundwater depletion. These costs have been avoided (saved) thanks to satellite-based resource management.

Changes between 2016 and 2035 are assumed to be the same as for the impact on agriculture profitability (adoption rate of satellite-based tools for crops monitoring, volume of irrigation water and Copernicus contribution).

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 2.7 M and EUR 4.5 M in 2017, rising to between EUR 23.3 M and EUR 42 M in 2035 for a total cumulative value ranging from EUR 275 M to EUR 493 M.

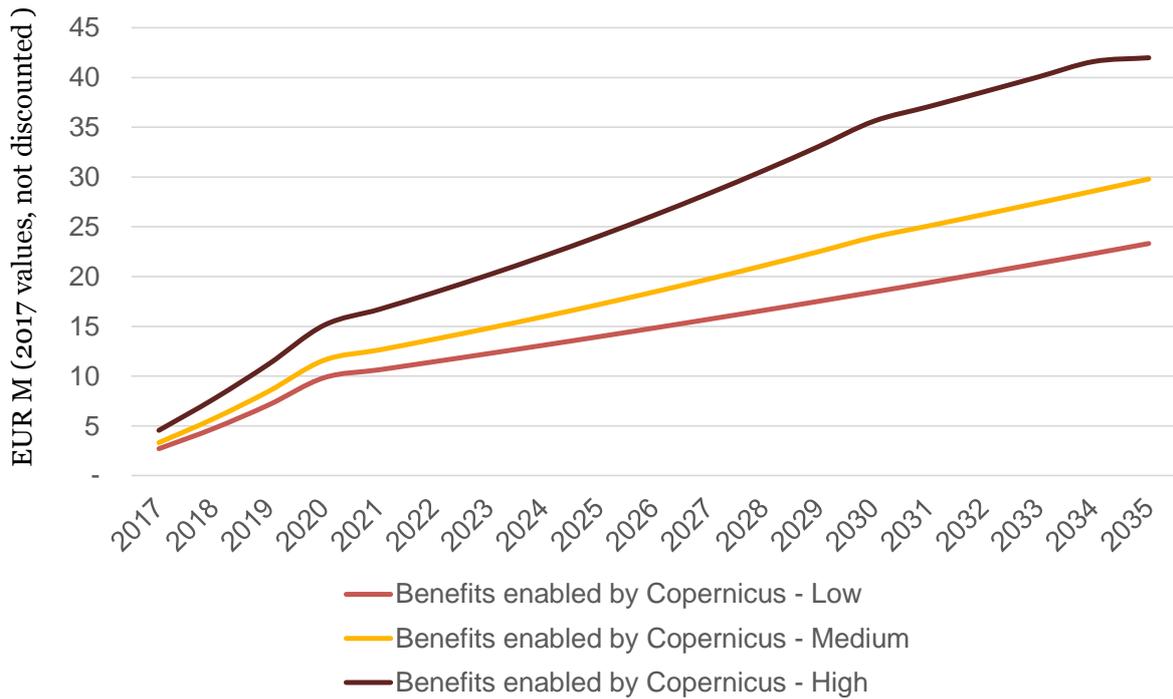


Figure 40 - Evolution of the Copernicus benefits for the impact “Save environmental resources (groundwater)” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

As this benefit derived from the previous one on irrigation management, the differentiation factor and alternatives for Copernicus are the same as in the previous section.

4.2.3.2.3.5 Summary of Copernicus contribution to “Water resources management”

The total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	19.6	121.0	238.8	2,586.5
Medium estimate	24.0	158.4	323.9	3,447.7
High estimate	33.0	234.4	485.7	5,103.3

Table 13 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below (Not discounted).

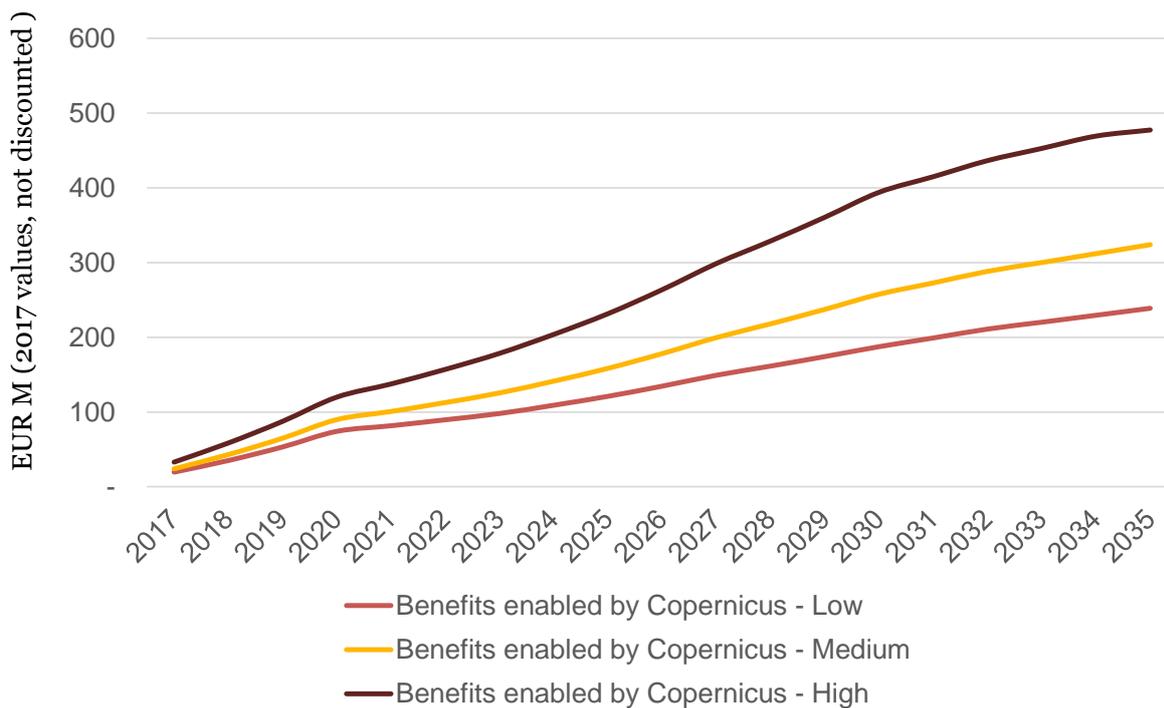


Figure 41 - Overall Copernicus D&I benefits for Water Resources Management, from 2017 to 2035 (Source: PwC analysis)

4.2.3.2.4 Wetlands monitoring

Wetlands, including mires, bogs and fens, are among the most threatened ecosystems in Europe, having been subject to major losses in recent decades. However Wetlands are some of the planet’s most productive ecosystems. They hold an important part of Europe’s biodiversity. A significant number of birds and mammals depend on freshwater wetlands for breeding or feeding. And they provide spawning grounds for fish and ideal conditions for other species groups such as dragonflies and amphibians. Moreover Wetlands are particularly important for carbon sequestration. They also provide a wide range of other services such as water provisioning, management and purification and flood defence and offer recreational and tourism opportunities.

Recognising the importance of protecting Europe’s remaining wetlands and of restoring those that have been degraded is crucial for biodiversity preservation. Wetlands protection is a global issue, some 50% of all wetlands have disappeared in the last century. Hence in 1971, a first international environmental agreement on Wetlands protection, the Ramsar convention¹¹⁶, was adopted. It is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. Since its launch in 1971, 47 European countries have ratified the Convention. When joining the Convention, each Contracting Party must designate wetland sites within their territory for inclusion in the Ramsar List. Sites registered on the Ramsar List have to be protected and monitored by governments, to ensure that their ecological character is maintained.

Ramsar Convention is an international agreement, but at the EU level the Habitats and Birds directives and the Water Framework Directive (WFD) are the key EU legislation ensuring the protection of Europe’s wetlands. The EU wide Natura 2000 network of protected sites has a

¹¹⁶ Ramsar Convention website (online) : <http://www.ramsar.org/>

major role together with the integration of wetlands into river basin management planning under the WFD in helping to guarantee their future conservation and sustainable use. Ramsar convention and Natura 2000 have the same goals. Indeed most Ramsar (vast majority) site are coincident with Natura 2000 sites.

As seen in a previous section on “Improve and preserve forest ecosystems”, Copernicus’ products portfolio is clearly relevant and useful to monitor the Natura 2000 network and to meet the requirements of the Habitats Directive Article 17¹¹⁷. Good quality knowledge on the status of and trends for habitats and species protected by the directives underpins the effective implementation of the directives. Similar as for the Forest ecosystem preservation, the following Copernicus products can clearly contribute to this assessment: High Resolution Layers (HRL) Forest Type/Density, HRL natural and semi-natural grasslands, HRL imperviousness and other HRL (wetlands, permanent water bodies); Urban atlas; Riparian Zones; Natura 2000 specific grassland types only. The soil moisture index is also really important to assess wetlands health status.

The overall benefits derived from Copernicus data and information to monitor Wetlands, can be summarised by the impact pathway below:

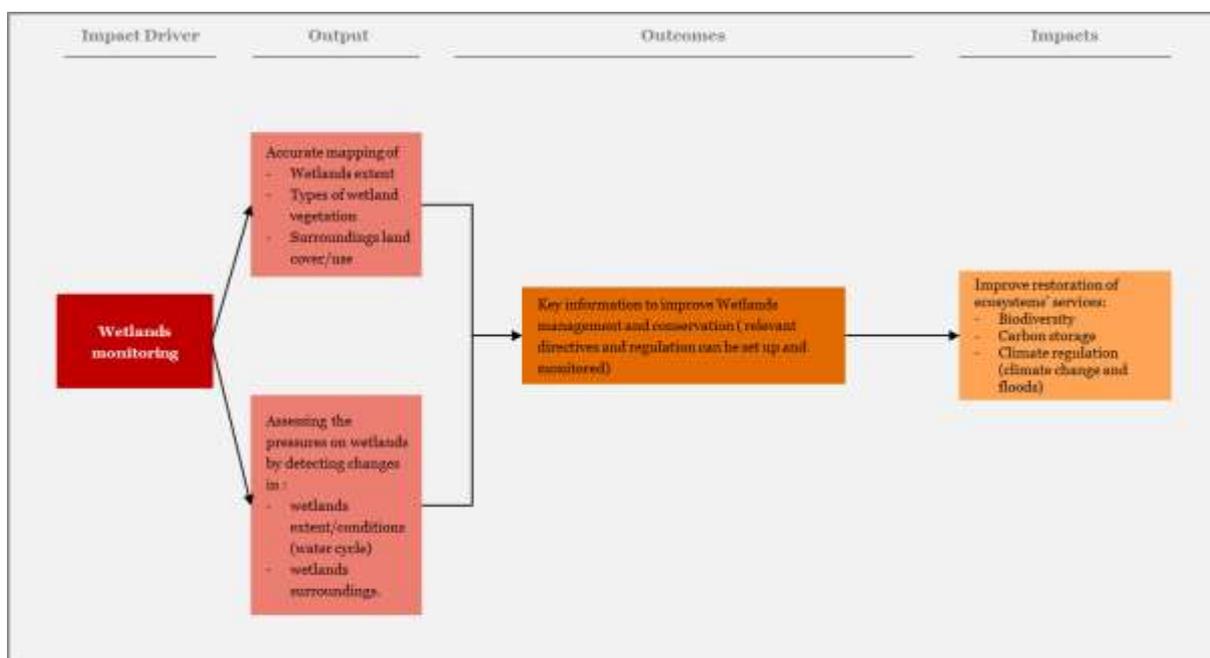


Figure 42 - Impact pathway for Water resources management (Source: PwC analysis)

EO data provide environmental authorities accurate wetlands mapping, to identify and register wetlands area and their surroundings, assess their status (soil moisture index) and measure their extent. Thanks to time series of satellite images authorities can detect change in the Land cover/land use in wetlands areas like anthropogenic pressures (agricultural activities, urban expansion...) implying changes in hydrology (such as drainage) threatening the whole ecosystems.

As a result of these outputs, one benefits can be pointed out:

- Improve restoration of wetlands ecosystems' services

The quantification of the benefits mentioned above is as follows.

117 Contribution of Copernicus in support to monitoring of habitats, species and the Natura 2000 network – Working Paper EEA, 2016

4.2.3.2.4.1 Improve restoration of wetlands ecosystems' services

Copernicus leads to improve restoration of wetlands ecosystems, by supporting Natura 2000 network and Habitats & Birds Directives implementation. Most of all Copernicus provide a valuable tool for the assessment of the ecosystems status required by the Article 17 directive. Details of the model developed to quantitatively assess the benefit for Wetlands ecosystems restoration can be found in the box below:



Methodological approach to value the restoration of wetland ecosystems

Our model is based on Copernicus contribution to the implementation of the Habitats and Birds Directive through the monitoring of Natura 2000 areas. Thanks to these initiatives Wetlands in favourable conservation status are restored every year. The steps are:

1. Assess the additional Wetlands area restored each year thanks to Natura 2000 i.e. the surface of Wetlands which goes from “unfavourable” to “favourable” status
2. Multiply it by the valuation coefficient associated with 1ha of Wetland in good health. It corresponds to the economic value of lost ecosystem services associate with the conversion and/or degradation of wetlands areas (water filtration, climate regulation...)
3. Assess the contribution of Copernicus to the Habitats Directive: [Natura 2000 areas covered by Copernicus products¹¹⁸ x effective use of Copernicus by authorities x quality requirements fulfilled by Copernicus]. Then multiply the rest by it.

Improve restoration of wetlands ecosystems

Valuation approach



Wetlands represent approximately 2% of the European territory. We can assume reasonably that, given their high ecological value and their fragile status, all of the wetlands area in Europe are protected by the Habitats directive (or Ramsar Convention as they overlap for the vast majority). It has been assessed that in 2011, only 10% of the Wetlands habitats are in a favourable conservation status¹¹⁹. We assumed that in 2020, the EU Biodiversity Strategy will achieve (approximately) its target by reaching 35% of favourable assessment within the wetlands. The improvements will continue at the same path. We can then calculate how much wetland area is restored each year thanks to the Habitats Directive, and multiplied it by the value of wetland ecosystem services (developed by PwC). Assessment of Copernicus contribution is exposed above (point 3).

The major changes assumed to occur between 2016 and 2035 are the percentage of wetlands in “favourable conservation status” (from 10% in 2011, 24% in 2016, to 75% in 2035) and the Copernicus contribution to these improvement (from 2% in 2016 to 10% in 2035) as the coverage of Copernicus products portfolio will extend and more Environment Agencies will use it. These figures are for the medium scenario.

¹¹⁸ Contribution of Copernicus in support to monitoring of habitats, species and the Natura 2000 network, EEA, 2016

¹¹⁹ EEA website : Conservation status of habitat types of European Union interest in wetland ecosystems

As a result, not discounted benefits linked to Copernicus are expected to amount between EUR 7.4 M and EUR 17.4 in 2017, rising to between EUR 434.5 M and EUR 1 B in 2035 for a total cumulative value ranging from EUR 4.6 B to EUR 10.7 B.

The total not discounted benefits linked to Copernicus in the EU are expected to amount to:

<i>Copernicus EU benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	7.4	222.1	434.5	4,594.8
Medium estimate	12.4	370.1	724.2	7,658.2
High estimate	17.4	518.2	1,013.9	10,721.4

Table 14 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

Results are illustrated in the chart below:

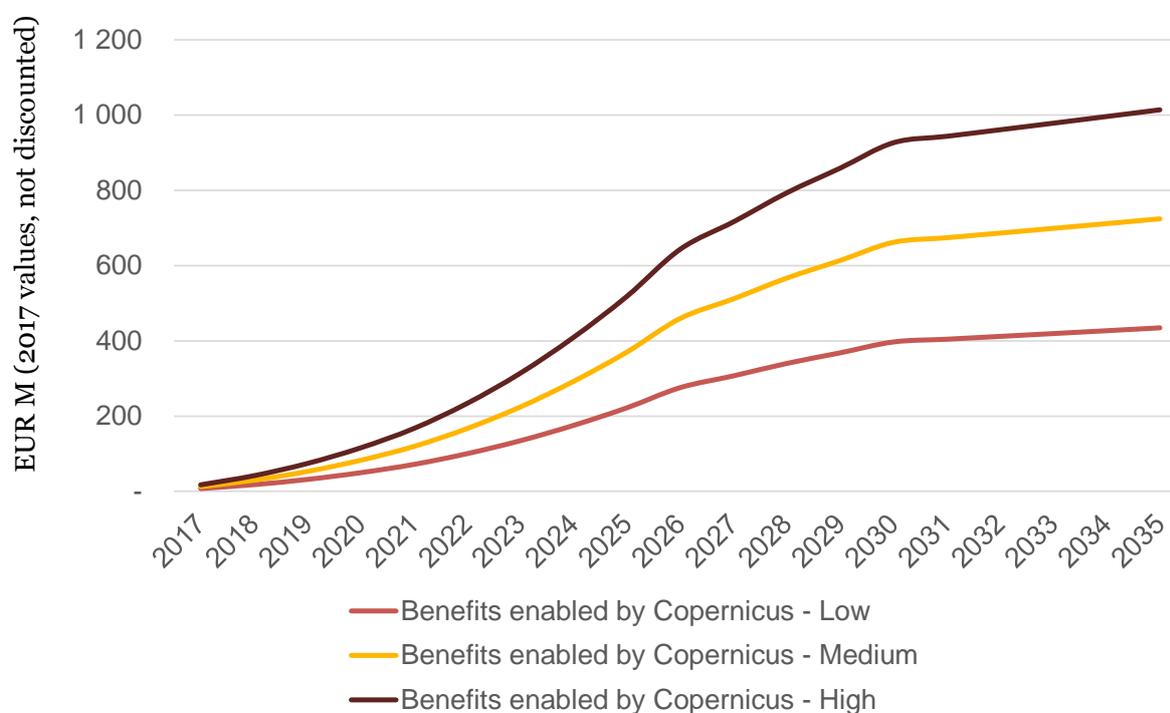


Figure 43 - Evolution of the Copernicus benefits for the impact “Improve restoration of wetlands” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The shutdown of all Copernicus assets by 2030 would have a similar effect as for the benefit of section 4.2.3.2.2.3. “Improve and preserve forest ecosystems”.

4.2.3.2.5 CAP monitoring

This section has been assessed qualitatively considering the lack of information on enabled savings for the Member States and the EC, and on the Copernicus contribution to the CAP. Moreover the regulation concerning the monitoring of the CAP is evolving quickly. During the last workshop on “Control and management of agricultural land in IACS (Integrated Agricultural Control System)” organised in May 2017 by the JRC, a reform of the regulation

concerning the controlling approach of the CAP has been announced. Therefore modelling quantitatively the benefits of Copernicus towards CAP monitoring would have relied on too many assumptions, resulting in irrelevant figures (weak level of confidence). However, through experts' interviews and extensive desk research, we managed to have a sense of what is or will be Copernicus contribution to the monitoring of the CAP, and an order of magnitude on the role of Copernicus in this field.

CAP monitoring controls relies on a complex framework named IACS (Integrated Agricultural Control System). It is the most important system for the management and control of payments to farmers made by the Member States in application of the Common Agricultural Policy. It provides a uniform basis for controls and the IT system which supports the national administration in carrying out their functions. It covers the administrative and on-the-spot controls of applications. Through operating the IACS, Member States ensure that declaration and payments are made correctly, irregularities are prevented, revealed by controls, followed up and amounts unduly paid are recovered.

The IACS cycle is represented in the graph below:

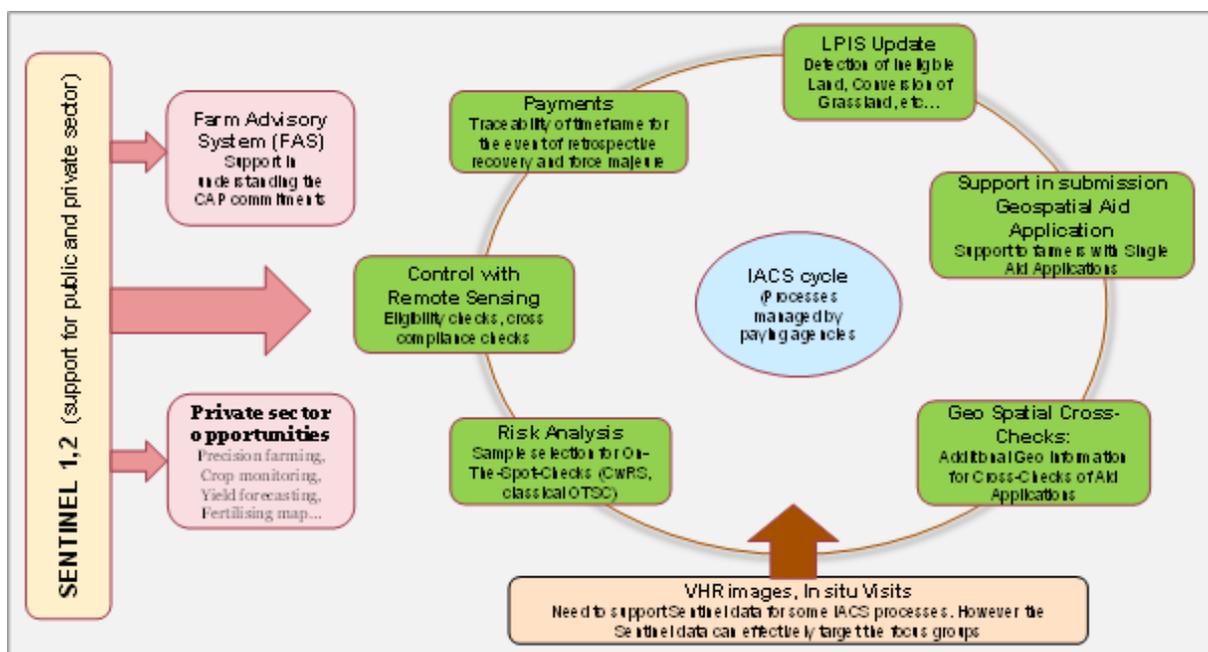


Figure 44 - IACS cycle (Source: Czech Agri Project)

As represented in the graph, the IACS relies partly on Control with Remote Sensing (CwRS). CwRS includes On-The-Spot-Checks (OTSC), which aim at checking the condition under which aid is granted on a sample of applications (crop diversification, permanent grassland, eligibility of the parcel...). OTSC consist mainly in 2 checks: area of agriculture land (Land Cover measurement), conduction of agriculture activity (Land Use). They can be done in two ways: with remote sensor (satellite images) or on field visit (classical OTSC). They are conducted on a sample of parcels (5% of the farms), through a selection that should be based on risk analysis.

EO data have been used for OTSC since the mid-1990s. They require VHR images (for accurate measurement) but also HR (10-20m) for activities identification, especially in the frame of the new CAP greening measures. The JRC, through the MARS project, is in charge of the centralization of satellite images requests and acquisition. Member States Paying

Agencies submit their Images Request on the JRC portal “G4CAP”¹²⁰ and the JRC deals with the contractor (private) to provide the requested images.

Copernicus data are clearly an asset for monitoring the CAP. Sentinel images provide improved quality data (for crop identification for example) and could replace commercial HR data. Today, already 16 out of 32 MS are using S1 or S2 data. This ratio is likely to get higher, depending on how the CAP controls framework will evolve.

Indeed in the IACS should evolve in the future in a simplified process for CAP monitoring by using more the EO technology and especially Sentinel’s data. Currently several projects are trying to demonstrate the relevance of using Copernicus data for OTSC and CwRS. A more radical change in the IACS framework should also begin in 2018 with a new regulation on monitoring controls (EU 809/2014). With this new regulation, MS Paying Agencies may opt for a full monitoring approach without OTSC.

In either cases, improving the current CwRS with Sentinel data, or suppressing completely the OTSC to shift toward a full monitoring approach, Copernicus has and will have an important role to play for the CAP monitoring activities.

The benefits generated by Copernicus have been mapped in the Impact pathway below:

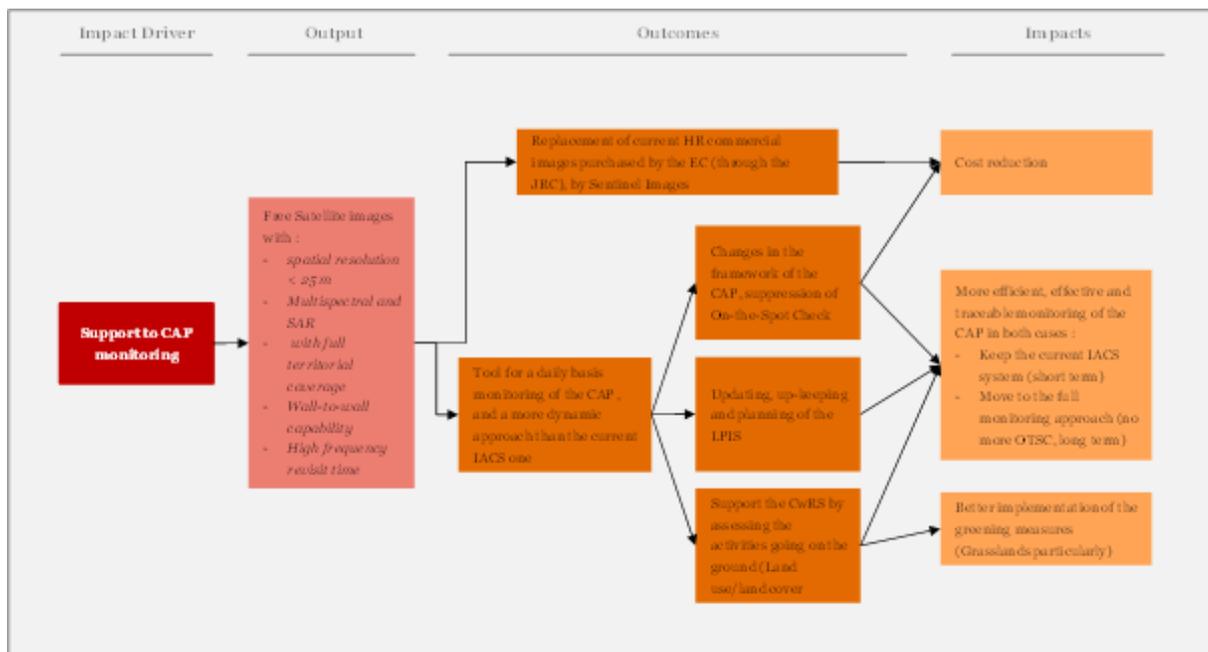


Figure 45 - Impact pathway for CAP Monitoring (Source: PwC Analysis)

Sentinels’ capabilities in terms of spatial and spectral resolution, coverage, revisit frequency and wall-to-wall capacity, provide the authorities with a powerful tool for a daily basis monitoring of the CAP. Instead of waiting for the end of the season to do OTSC based only on a parcel sample (blind selection), farmers activities can be monitored in almost “real time” during all the crop season. This shift towards a more “dynamic” approach of the IACS, results in several benefits for the Paying Agencies and the EU in general. Indeed Copernicus data can support CwRS and LPIS updating (Land Parcel Identification System) by assessing on a timely basis the activities carrying on the ground. More radically Sentinel’s capabilities open the way to a reshaping of the CAP control framework (IACS) by enabling the MS to opt for a “full monitoring” approach where OTSC are no longer relevant (new regulation starting in 2018).

120 G4CAP website (online) : <https://g4cap.jrc.ec.europa.eu/G4CAP/>

In both cases, stay in the current IACS system or shift to the suppression of OTSC, the use of Sentinel (mostly raw data in this case) will result in the following benefits:

- A more efficient, effective and traceable monitoring system of the CAP
- A better implementation of the greening measures, where Copernicus Land/land Cover capabilities are significantly useful
- A cost reduction overall, as an important part of the HR commercial images can be replaced by free Sentinel data.

4.2.3.2.5.1 Cost reduction in the monitoring of the CAP

One obvious benefit of Copernicus for CAP monitoring is the cost reduction. It results from the partial replacement of commercial HR images by Sentinel Images and the more efficient way of conducting CwRS (more effective OTSC or even suppression of them).

Each year the JRC, through the MARS project, is in charge of the images acquisition campaign. The JRC outsources the provision of satellite imagery (HR and VHR) to industry operator. Under the quality control and the framework contract managed by the JRC, the provider supply HR and VHR images according to the MS requirements and area of interest. Paying Agencies request notably the temporal window for the images acquisition (summer, winter...). For Sentinel Images the workflow is different (see box below).



Use Case: Sentinel's images for CwRS¹²¹

As explained above the JRC manages the images acquisition campaign for each year. MS Paying Agencies submit their images request on the G4CAP portal. The acquisition scenario is complex as temporal window and images' profile (HR, HHR, VHR, Ortho, Multispectral...) have to be defined in advance, but the cloud cover can jeopardise the quality of the images. For the 2017 campaign the total area to be acquired is 453,624 km² in VHR and 603,197 km² in HR (vs 862,923 km² in 2016).

Among the HR images, 30% could be replaced by Sentinel 2 data (similar profile). This percentage could be even higher with the new regulation for the full monitoring approach. The JRC has certified in 2015, that Sentinel 2 data meet the CAP CwRS technical requirements¹²².

Sentinel sensors cannot be programmed to acquire images of certain area of interest, on certain windows, like the commercial sensors. They acquire images continuously. Therefore Sentinel data acquisition is based on a system call "S2alert", managed by the JRC. It alerts the users for all valid images ie windows in area requested, with a 0% cloud cover.

Replacing all the HR images by Sentinel data would enable a saving of around EUR 400 K, which is small. The real savings come from the more efficient management of the IACS and especially for OTSC. It enables sound financial management: at EU level by safeguarding the allocation of subsidies and at national level by decreasing the costs mainly for OTSC and LPIS update agenda (no need to go on field visit, better selection of OTSC sample).

For the 2017 campaign 16 out of 32 MS Regions were using Sentinel data for their controls (S2 alerts). They were 11 out of 32 in 2016.

¹²¹ "Closing Campaign 2016, status Image provision 2017, and preparing for 2018", Johan Astrand (JRC), May 2017

¹²² "New sensors benchmark report on Sentinel-2A", JRC, 2015

4.2.3.2.5.2 More efficient, effective and traceable monitoring system for the CAP

The radiometric diversity of Sentinel Imagery enables the detection of cultivation practices, a wide range of crop types, changes in grassland and natural vegetation at regional to national scale, and observe on a wall-to-wall basis. These capabilities, plus the “free and open” access to S1 and S2 data, will lead to a more frequent and more efficient availability of high-resolution imagery in CAP management and control. The wide coverage and frequent data capture of Sentinel-1 and -2 allow the development of times series which lead to a shift from sample checks at a certain date, to ongoing monitoring at national scale. This change corresponds better to agricultural activities, heterogeneity of land characteristics and soil parameters. Moreover access to historical time series allows better traceability in the case of retrospective recovery.

Recently (May 2017) the European Commissioner for Agriculture, Phil Hogan, claimed for an increasing use of Space Technology to simplify the CAP¹²³. He said that satellite monitoring of land parcels could replace most On-The-Spot Checks, and Copernicus Sentinel data would be fully relevant in this new simplified approach to monitor the CAP. This shift toward a simplified version of controls will be applicable in 2018. As from 2018, MS may opt for the “full monitoring” approach (see box below).

In parallel, the European Space Agency has launched in 2017, a EUR 500 K tender, Sen4CAP, which will provide useful knowledge on further possibilities of using Sentinel’s satellite data in the context of the CAP. Several Member States Paying Agencies have already launched initiatives to use Copernicus for CAP monitoring. Denmark, Belgium, the Netherlands and the Czech Republic are the most advanced in testing the capability of Copernicus Sentinel for CAP monitoring. In 2017, 16 out of 32 MS regions use Sentinel 2 data through the JRC portal G4CAP (ie S2 alert), for IACS purpose. We have presented below two initiatives that will pave the way of the future of Copernicus contribution to CAP monitoring.



Use Case: CZECH AGRICULTURE PROJECT¹²⁴

The CZECH-AGRI project was jointly initiated in December 2015 by DG JRC, DG GROW, ESA and the SZIF (The Czech paying agency). It aims at demonstrating the capability of the Copernicus Sentinels for CAP monitoring. It is set up as a proof concept for national agricultural mapping and monitoring products.

Outputs are based on Sentinel 1 and 2 time series images mainly, complemented by In-Situ data, LPIS dataset and IACS data (crop declaration, OTSC). The spatial coverage is the full country and a spatial resolution of 20 meters within LPIS polygon.

The final products developed for the project are crop type maps (classification), where crops data are integrated and aggregated into LPIS parcels. The combination of Sentinel Data with IACS dataset (LPIS, crop declaration...) is crucial, to develop a robust, relevant process.

Examples of CZECH AGRICULTURE PROJECT main results are presented below:

- LPIS update: *Update cycle of LPIS can be 2 or 3 years. With Sentinel wall-to-wall data, the Czech Paying Agency has been able to detect ineligible area due to the extension of a sand mining zone*
- Support for aid applications: *Crop identification map is a tool to support farmers in submission of correct aid applications, limiting incorrect crop*

¹²³ Farmers Journal (Online) : “Space technology to simplify the CAP”, Phil Hogan, 2017

¹²⁴ “Potential Use of Sentinels for the IACS purposes (Czech Agri Project)”, SZIF , 2016

declaration.

- Risk analysis for OTSC sample selection: *Thanks to Sentinel data Czech Paying Agency has identified Maize planted on slope field that is located within an erosion sensitive area (info available in LPIS). Therefore they can target the potential risk group for a more effective OTSC sample selection and a better financial management.*
- Control with Remote Sensing: *Sentinel data can serve as additional data source for efficient CwRS. Especially in the case of checks for wide areas and for the whole year period, “Set-aside” control for example.*
- Case for decision on recovery of undue Payment: *when ineligible area is found during OTSC, it might present a case for retrospective recovery for previous years. With Sentinel Data time series, the traceability of the event is possible.*

Regulation on this topic is evolving quickly:



Use Case: Full monitoring approach (2018)¹²⁵

As from 2018, MS may opt for full monitoring approach (amendment of the Regulation EU 809/2014). “Monitoring” means a continuously tracking and tracing of activities on the land, based on AT LEAST Sentinel data. It should cover 100% of the area, and be automated as much as possible (automated classification of the activities, type of crops...). Such a monitoring approach will be built on an up-to-date LPIS mapping. It implies that :

- The current concept of On-The-Spot-Check will be substituted completely (i.e. no more samplings, no multiple visits);
- Administrative costs will be reduced;
- Compliance and performance should be improved.

In the current IACS, OTSC are based on a sampling rate of 5% of the farms which are actually controlled. This sampling method is fine for capturing stable land cover characteristics (surface), but seems to be too low to capture most of the temporal agronomic practices, farming activities and greening measures. Therefore the current OTSC workflow has to be redesigned and Sentinel 1&2 images are particularly relevant for that, as they provide continuous information over the whole crop season. With the monitoring approach, the “window” acquisition and time of sampling don’t have to be pre-defined in advance, thanks to Sentinel continuous observation.

For MS which will opt for the full monitoring approach, Copernicus’ benefit will be very significant for the monitoring of the CAP, as Sentinel will be the prime source of data (still complemented with VHR).

4.2.3.2.5.3 Better implementation of the Greening Measures

As mentioned above Copernicus Sentinels are able to detect activities on ground on a continuous time basis (Sentinel alert system). Hence they are particularly relevant for the controls relative to “greening measures”. The new CAP greening payments are additional to

¹²⁵ “Introduction of monitoring & investing in the future”, Arie Van der Gref, 2017 IACS Workshop, May 2017

the Basic Payment Scheme/SAPS. Each holding will receive a payment per hectare for respecting certain agricultural practices beneficial for the climate and the environment, under 3 basic set of rules on: maintaining permanent grassland, ensuring minimum crop diversification (depending on the size of their land, farmers must grow a certain number of crops) and maintaining Ecological Focus Area (EFA, 5% of the land dedicated to ecologically beneficial elements). Copernicus Land Service has developed a High Resolution Layers (Pan-European products) dedicated to Grassland. This is particularly relevant for the track of changes in the preservation of permanent grassland within the farmers declared areas.



Use Cases: Sentinel use for Greening measure implementation

We present below several examples where Copernicus data enabled a better implementation of the CAP greening measures:

- Permanent Grassland was declared but arable land was identified by the automated classification system developed by the Czech Paying Agency: it might present a potential risk for trying to avoid the conditions for maintaining the permanent grassland ratio. Focus should be put on this area for the OTSC¹²⁶.
- Fallow land was declared by farmer and accepted by CAPI (Computer-Assisted Photo Interpretation) at the beginning of the cropping season. But during the year Sentinel-2 time series show that tomatoes have eventually been planted. Visit on field confirmed that the plot was cultivated with tomatoes¹²⁷.
- Oats was declared and found by original CAPI, but NDVI evolution derived from Sentinel images acquired along the year, suggests that after harvesting Oats, the parcel had Maize as second crop¹²⁸, not compliant with diversification rules.

Without Copernicus these anomalies would not have been detected, therefore we can say that Copernicus has a real value added for Cap Greening measures implementation. It will result mainly in benefits for the EU and the MS Paying Agencies: cost reduction, better/easier implementation of the greening measures as Sentinel missions are well tailored and relevant for that, and overall more efficient monitoring system.

4.2.3.2.6 Ground elevation and ground motion monitoring

The monitoring of surface deformation is an important stake as current infrastructure may not be ready to face its consequences (e.g. if gas pipelines are damaged due to ground subsidence, it could lead to gas explosion). The use of Synthetic Aperture Radar (SAR) and Optical (multispectral) imagery is therefore key for ground observation and mapping. In the case of the ground elevation and ground motion monitoring impact driver, Copernicus can in particular be useful to support infrastructure management, facilities construction or tunnelling¹²⁹ thanks to its ability to track subsidence. Since their launch, Sentinel-1 and 2 have contributed to the monitoring of ground evolution thanks to their frequent revisit frequency (e.g. 6 days when both Sentinel-1A and 1B are in operation, 5 days for Sentinel-2A and 2B), their wide coverage (e.g. 250km swath width for Sentinel-1)¹³⁰ and good resolution (e.g. 5x20m for Sentinel-1). These two satellites are complemented by the Copernicus

¹²⁶ "Potential Use of Sentinels for the IACS purposes (Czech Agri Project)", SZIF, 2016

¹²⁷ "Effectiveness of current CwRS strategy, real cases examples", JRC, 2017 IACS Workshop, May 2017

¹²⁸ "Effectiveness of current CwRS strategy, real cases examples", JRC, 2017 IACS Workshop, May 2017

¹²⁹ Copernicus newsletter. (Online) Available at: <http://newsletter.copernicus.eu/article/successful-launch-sentinel-1-marks-beginning-new-era-copernicus-programme> (Accessed: July 26th 2017)

¹³⁰ ESA presentation, 20

¹⁶, Earth Observation products & services in support of the mining industry. (Online) Available at: <https://ec.europa.eu/growth/tools-databases/eip-raw-materials/sites/rawmaterials/files/2%202%20ESA%20EIP%20Raw%20Materials%2001%20Dec%20rev%202.pdf> (Accessed: July 26th 2017)

Contributing Missions, which enable Copernicus services to dispose of Very High Resolution (VHR) raw data for their products. Products necessary to these type of activities are mostly found on the Copernicus Land Monitoring service (CLMS) website (e.g. Corine Land Cover (CLC) or the European Settlement Map). As an example of the role Copernicus can play in ground motion monitoring, one of the first winners of the Copernicus Masters¹³¹ in 2014 was the Geomatic Ventures Limited company that is notably using Sentinel-1 data to produce land motion maps dedicated to environmental safety and security¹³².

The ability of Copernicus to provide accurate data on surface deformation can lead to several benefits (impacts) mapped in the impact pathway below:

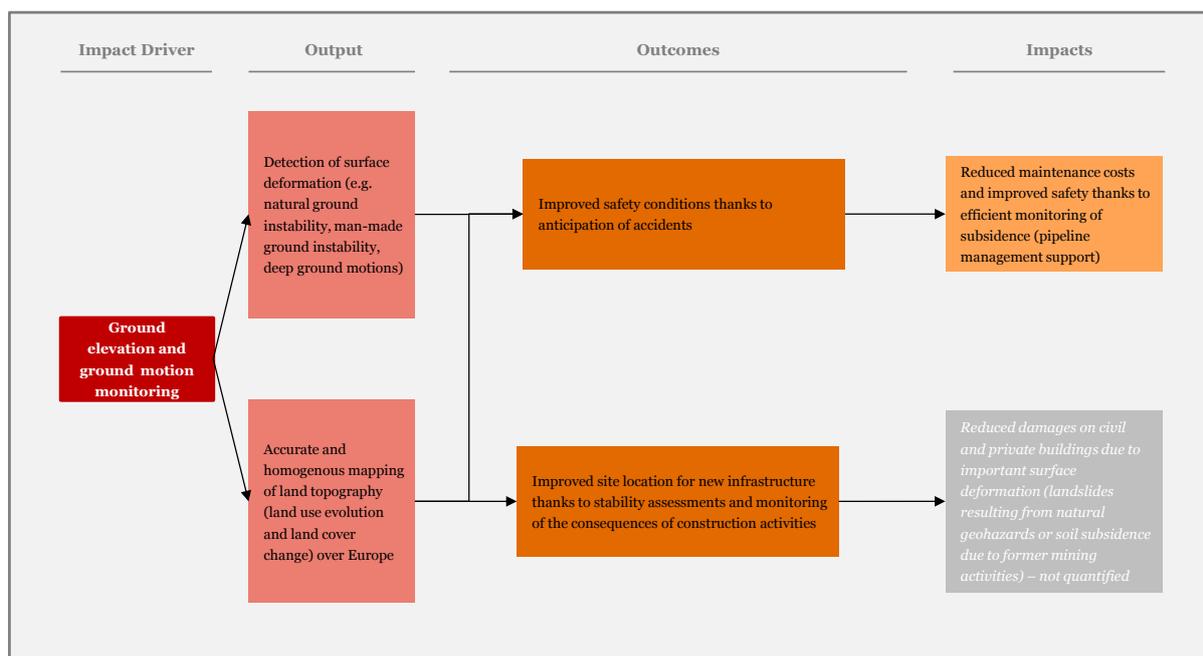


Figure 46 - Impact pathway for ground elevation and ground motion monitoring (Source: PwC analysis)

The monitoring of ground elevation and ground motion consists in two kind of activities related to one another: first, the detection of surface deformation and second, the development of precise mapping of land topography. These land motion maps highlight the different levels and speed of subsidence of the ground, whether due to natural land instability (e.g. landslide), man-made ground instability (e.g. underground construction) or deep ground motions (e.g. earthquake)¹³³. This mapping enables the improvement of several activities. Before the construction of civil facilities like dams, roads or bridges, or of new private buildings, radar imagery from Copernicus providing elevation information can be gathered in order to ease site selection processes or to determine the expected stability of an infrastructure. For instance, radar data enable to measure the impact of tunnelling in a city, which could result in ground subsidence. This results in an increased safety for citizens, who are less likely to face damages due to ground movements.

As a result of all these outcomes, the following impacts are expected:

131 <http://www.copernicus-masters.com/>

132 <https://www.geomaticventures.com/>

133 Copernicus user forum meeting, 2016, Integrated DInSAR-based National Ground Motion Service. (Online) Available at: http://www.copernicus.eu/sites/default/files/documents/News/Copernicus_GroundMotion_Mining_by_TLedge_2.pdf (Accessed: July 26th 2017)

- Reduced maintenance costs and improved safety thanks to efficient monitoring of subsidence (pipeline management support);
- Reduced damages on civil and private buildings and other infrastructure due to important surface deformation (landslides or subsidence resulting from natural geohazards or due to current or former mining activities, underground or open pits).

The quantification of the benefits mentioned above is as follows:

4.2.3.2.6.1 Reduced maintenance costs and improved safety thanks to efficient monitoring of subsidence (pipeline management support)

Avoiding pipeline incidents due to ground subsidence is a major stake considering the damages that could be caused by a gas pipeline break for instance. To help support pipeline management, the use of InSAR (Interferometric SAR) maps can be very useful. These maps are based on SAR (Synthetic Aperture Radar) images, such as images provided by Sentinel-1, which enable to detect the changes in height of the surface of the Earth and thus of ground movement. The map works as follows: each scene of satellite images contains points that have coherent reflections. The reflections remain the same in each radar image, no matter the time. As such, it is possible to compare the position of these points throughout time. This technique only works accurately if the images are less than 20 days apart. As such Sentinel-1 data provide a perfect revisit frequency, considering that from a 10-day revisit period, this technique of point comparison is considered optimum. However, Sentinel-1 data cannot be used alone to build such maps. Considering its resolution, 5x20m, it only enables to detect areas considered at risk and then Very High Resolution (VHR) data such as Radarsat-2 or TerraSAR-X, which has a 3x3m resolution are used to get more details on the hot spots. The two are fully complementary: Sentinel-1 gives information at the scale of a street, and VHR data at the scale of a building; Sentinel-1 has a wider coverage than VHR data (e.g. 10km for TerraSAR-X).



Methodological approach to value the reduction of maintenance costs and the improvement of safety thanks to the efficient monitoring of subsidence (pipeline management support)

Our model is based on the specific cases of water and gas pipeline management in the Netherlands. Direct and indirect benefits from improved pipeline management have been considered and further expanded to the European Union. The steps are:

1. Assess benefits of gas and water pipeline monitoring in the Netherlands
2. Expand these benefits to the European Union by doing a ratio between the share of gas and water consumed in the Netherlands and in the European Union
3. Isolate the share of companies using maps derived from Earth Observation data
4. Assess the contribution of Copernicus to these maps

Reduced maintenance costs and improved safety thanks to efficient monitoring of subsidence (pipeline management support)

Valuation approach

$$\text{Impact (EUR)} = \left(\begin{array}{l} \text{Benefits from the} \\ \text{monitoring of gas} \\ \text{pipelines thanks} \\ \text{to Earth} \\ \text{Observation} \end{array} + \begin{array}{l} \text{Benefits from the} \\ \text{monitoring of} \\ \text{water pipelines} \\ \text{thanks to Earth} \\ \text{Observation} \end{array} \right) \times \begin{array}{l} \text{Contribution of} \\ \text{Copernicus to} \\ \text{pipeline} \\ \text{management} \end{array}$$

The analysis is based on EARSC case study¹³⁴ which looks at the benefits of Copernicus to water and gas pipeline monitoring in the Rotterdam and Gouda area before expanding it to the whole of Netherlands. Several types of benefits are included: the benefits in terms of employment for the companies in charge of processing Copernicus data with other satellite data as well as the companies in charge of analysing these data; the benefits related to the reduction of costs linked to failures and replacements of pipelines; and the benefits for citizens, due to the fact of not being hassled for no reason by the replacement of a pipeline that was in fact working and due to the reduction of odds of major calamities. These benefits are then projected up to 2035: for gas pipeline monitoring, the projection takes into account the fact that the share of gas in the Dutch energy mix will decrease considering the objectives of the European Union in terms of increase in renewable energy (30.7% of gas in the Netherlands forecasted in 2035 for 37.9% in 2015¹³⁵); for water pipeline monitoring, the growth in water consumption is assumed to be proportionate to the growth of the EU28 population¹³⁶. These benefits are then expanded to all EU Member States by looking at the share of gas consumption as well as the share of water consumption of the Netherlands compared to the consumption in the European Union, making the assumption that gas and water infrastructure are similar in all countries.

As of today, and extrapolating EARSC data on the Netherlands to the whole of Europe, the uptake of Earth Observation-based deformation maps is of 43.3% and is assumed to increase up to 70% before the launch of the New Generation of Sentinels in 2030. This increase is assumed to be quite important as there are few players in the market (e.g. nine gas connections service providers in the Netherlands) with very different share of activity (approximately three major players, and smaller ones), so once a company decide to start using maps based on Earth Observation data, the percentage can strongly increase. According to EARSC case study¹³⁷, Sentinel-1 represented about 30% of the benefits from the use of soil deformation maps used for the monitoring of pipelines in 2015. This percentage is assumed to increase up to 35% in 2020 once Copernicus ground deformation maps will be available and will once again increase when these maps will be promoted in all European areas subject to pipeline maintenance issues, therefore reaching 37% from 2030 to 2035. Copernicus global contribution was therefore of 13% in 2015, rising to 25.9% in 2035.

As a result, benefits linked to Copernicus are expected to amount between EUR 30.5 M and EUR 36.6 M in 2017, rising to between EUR 50.2 M to EUR 60.3 M, with total cumulative benefits ranging from EUR 788.7 M and EUR 947.1 M (not discounted values).

The global trend over the period is illustrated in the chart below. The trend appears as almost linear. This is due to the fact that benefits from gas pipeline monitoring represent the biggest share of the total benefits presented below (about 90%) and the gas benefits will decrease concurrently with the increase in Copernicus contribution, resulting in such a curve.

¹³⁴ EARSC, 2016, Copernicus Sentinels' products economic value: A case study, Pipeline infrastructure monitoring in the Netherlands. (Online) Available at: <http://earsc.org/news/satellites-benefiting-citizens-the-case-of-pipeline-infrastructure-in-the-netherlands> (Accessed: July 26th 2017)

¹³⁵ National Energy Outlook 2016 (Online). Available at: <http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-2016-national-energy-outlook-2016.PDF> (Accessed: September 18th 2017)

¹³⁶ WorldBank data (Online) Available at: http://data.worldbank.org/indicator/SP.POP.TOTL?end=2016&locations=BD-NL&name_desc=false&start=2013 (Accessed: September 18th 2017)

¹³⁷ EARSC, 2016, Copernicus Sentinels' products economic value: A case study, Pipeline infrastructure monitoring in the Netherlands. (Online) Available at: <http://earsc.org/news/satellites-benefiting-citizens-the-case-of-pipeline-infrastructure-in-the-netherlands> (Accessed: July 26th 2017)

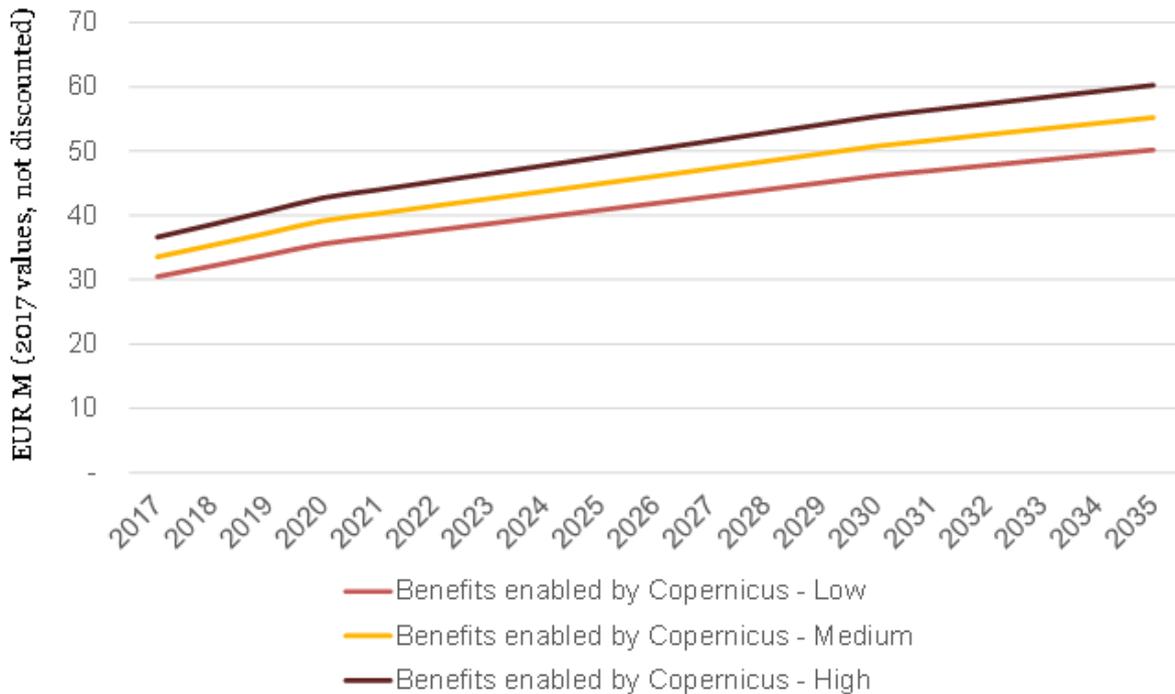


Figure 47 - Evolution of the Copernicus benefits for the impact “Reduced maintenance costs and improved safety thanks to efficient monitoring of subsidence (pipeline management support)” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The shutdown of all Copernicus assets in 2030 would have a major impact in the case of pipeline infrastructure management. First, by then, the share of companies relying on ground deformation maps notably based on Sentinel-1 data will have increased. Second, companies relying on Sentinel-1 can currently save about EUR 50 K out of EUR 140 K budget, hence a drop of about 1/3 of the budget, by focusing and limiting the purchase of commercial data, in particular TerraSAR-X data. Indeed, the use of lower resolution imagery, as previously mentioned, enables to give a first overview on the areas at risk and it is only for the previously detected areas at risk that Very High Resolution data will be bought. Without such free data, the use of ground deformation maps would potentially not be viable for the companies considering the cost per scenes of commercial satellite data and the large areas to be covered to prevent the occurrence of calamities¹³⁸. The existence of Sentinel-1 data is therefore crucial, as ground deformation maps providers will probably not risk producing a map too costly for any company to buy.

4.2.3.2.6.2 Reduced damages on civil and private buildings and other infrastructure due to important surface deformation (landslides or subsidence resulting from natural geohazards or due to current or former mining activities, underground or open pits)

As satellite radar imagery enables to detect changes in the ground surface such as landslides (i.e. all ground movement, such as rock falls, deep failure of slopes, and shallow debris flows¹³⁹) and land subsidence (i.e. the sinking of the Earth’s surface¹⁴⁰), it can be useful to anticipate where to locate new infrastructure so as to choose areas not at risk, or to track where ground movement is occurring in order to react before damages are too important. In

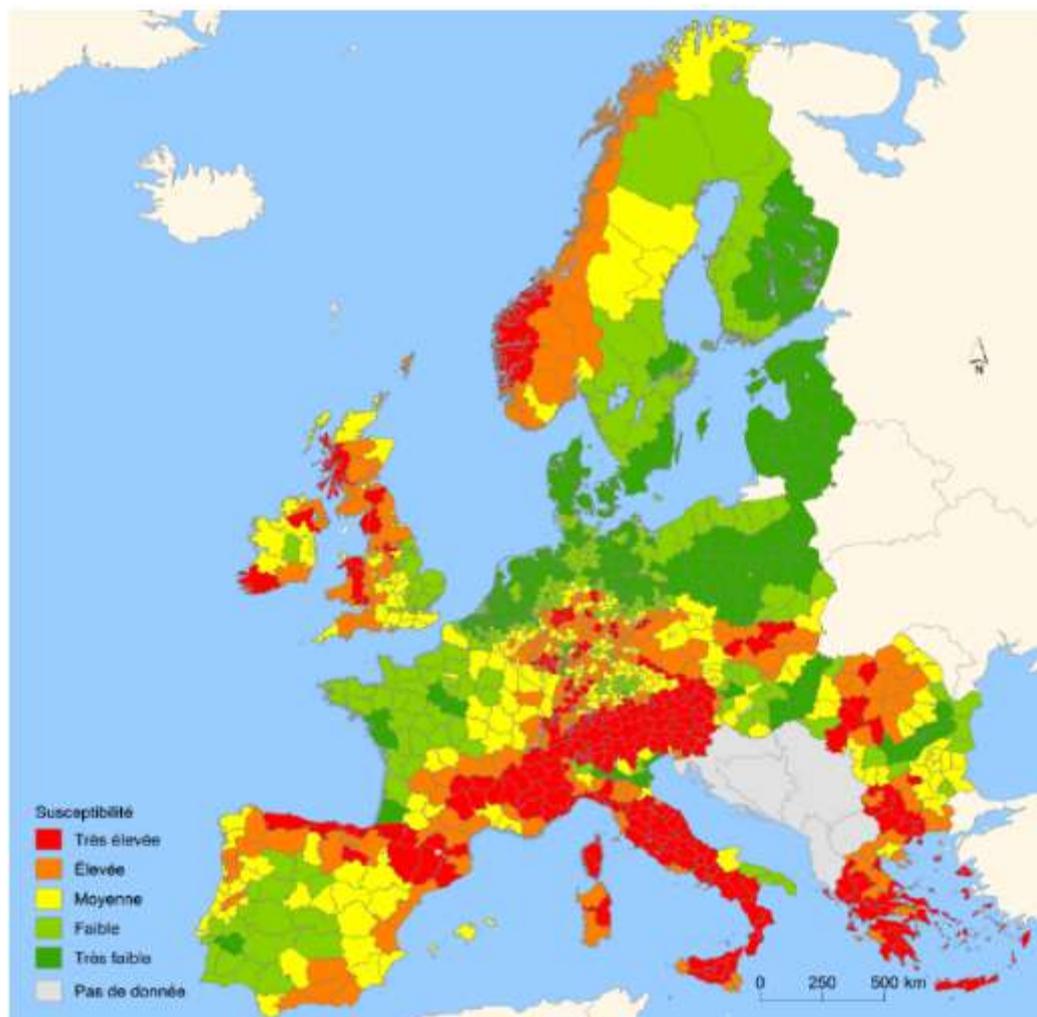
138 EARSC, 2016, Copernicus Sentinels’ products economic value: A case study, Pipeline infrastructure monitoring in the Netherlands. (Online) Available at: <http://earsc.org/news/satellites-benefiting-citizens-the-case-of-pipeline-infrastructure-in-the-netherlands> (Accessed: July 26th 2017)

139 USGS website (Online). Available at: <https://landslides.usgs.gov/learn/l101.php> (Accessed: 24th November 2017)

140 USGS website (Online). Available at: <https://water.usgs.gov/ogw/subsidence.html> (Accessed: 24th November 2017)

the case of Copernicus, Sentinel-1 is useful to develop ground motion maps. Indeed, Sentinel-1 enables to detect where the ground is stable, where it is moving and by how much¹⁴¹. The accuracy provided by Copernicus, far above what used to exist (currently a few millimetres and bound to decrease to only a millimetre in the next years), makes it a major asset in the development of ground motion maps that are to be used by public authorities for infrastructure management and by insurers for their insurance policy.

Landslides and subsidence may be of natural origin (such as geohazards, tectonics, etc.) or of anthropogenic origin (such as the consequences of mining activities on surrounding area)¹⁴². As such, not all European regions are affected in a similar way by both: France, the United-Kingdom, the Mediterranean and Central and Eastern Europe are the areas most exposed to soil subsidence¹⁴³; South of France, Italy, Slovenia, Austria and Greece are the areas most exposed to landslides as emphasized in the figure below.



Source : JRC, BGR, CNR-EOST, CNR-IRPI - ELSUS1000_v1, 2013 © Günther A., Reichenbach P., Malet J.-P., Van Den Eeckhaut M., Hervás J., Dashwood C., Guzzetti F.

Figure 48 - European areas subject to landslides (Source: Website of the Ministry of the ecological and solidarity transition)

141 ESA Website (Online). Available at: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Mapping_that_sinking_feeling (Accessed: September 18th 2017)

142 Copernicus Briefs. (Online) Available at:

http://www.copernicus.eu/sites/default/files/documents/Copernicus_Briefs/Copernicus_Brief_Issue31_Infrastructure_Sep2013.pdf (Accessed: August 9th 2017)

143 Swiss Re, 2011, The hidden risks of climate change: An increase in property damage from soil subsidence in Europe. (Online) Available at: http://media.swissre.com/documents/Soil_Subsidence_Publication_en_0718.pdf (Accessed: August 9th 2017)

In the case of man-induced ground motions, there is the example of the United-Kingdom where mining activities have always been important. This is why mining subsidence is a major issue as emphasized by the existence of the Coal Authority, a government body in charge of managing the effects of past coal mining¹⁴⁴. In Europe, some buildings and facilities are insured against the effects of ground subsidence but the uptake of satellite imagery by insurers is very small if not non-existent. Besides, data on losses related to ground subsidence are difficult to find and may strongly vary between countries in the European Union. In the United Kingdom, the cost of ground subsidence to the economy is estimated at £ 300 M per year¹⁴⁵. In France, it is estimated that damages due to soil subsidence, notably resulting from climate change in its broader sense, amount for about EUR 340 M every year¹⁴⁶. In the most exposed European regions, damages due to soil subsidence from climate change are set to increase by up to 50% for the period 2021-2040 compared to the 2011 results, taking into account that current results are already 50% higher than in the 1951-1970 period¹⁴⁷. These numbers show how useful ground motion maps are to prevent potentially dramatic damages.

As for landslides, there is, for instance, 18.47% of the French territory that is subject to “high” to “very high” risk of landslides¹⁴⁸. Though these landslides are not necessarily located in urbanised area (which account for 52.5% of the territory), this percentage is important enough to cause strong damages.

Considering the lack of use of Copernicus data by insurers handling ground subsidence and landslides damages and the diversity of the multiple areas concerned by the phenomenon, for which data cannot be obtained, this impact cannot be modelled. However, it should be noted that Sentinel-1 has only been launched in 2014 and archives might be needed by insurers to take adequate decisions: the development of standardised ground deformation information might be key. As such, it is assumed that the potential of Copernicus in this field is important.

4.2.3.2.6.3 Summary of Copernicus contribution to “Ground elevation and ground motion monitoring (support to raw material industry and civil engineering)”

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

<i>Copernicus EU benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	28.9	40.8	50.2	788.7
Medium estimate	33.6	44.9	55.2	867.9
High estimate	36.6	49.0	60.3	947.1

Table 15 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below. It corresponds to the benefits of “reduced maintenance costs and improved safety thanks to efficient monitoring of subsidence (pipeline management support)” with a trend almost linear.

144 Coal Authority website. (Online) Available at: <https://www.gov.uk/government/organisations/the-coal-authority> (Accessed: August 9th 2017)

145 Landmark Information Group, A Guide to Subsidence: Risk Assessment and Risk Management against Soil Shrinkage. (Online) Available at: <http://www.subsidence-support.co.uk/downloads/Property%20Assure%20Guide%20to%20Subsidence.pdf> (Accessed: August 9th 2017)

146 Swiss Re, 2011, The hidden risks of climate change: An increase in property damage from soil subsidence in Europe. (Online) Available at: http://media.swissre.com/documents/Soil_Subside..._Publication_en_0718.pdf (Accessed: August 9th 2017)

147 Swiss Re, 2011, The hidden risks of climate change: An increase in property damage from soil subsidence in Europe. (Online) Available at: http://media.swissre.com/documents/Soil_Subside..._Publication_en_0718.pdf (Accessed: August 9th 2017)

148 Ministère de la Transition Ecologique et Solidaire website. (Online) Available at: <http://www.statistiques.developpement-durable.gouv.fr/lessentiel/ar/2055/0/lalea-glissements-terrain.html> (Accessed: September 6th 2017)

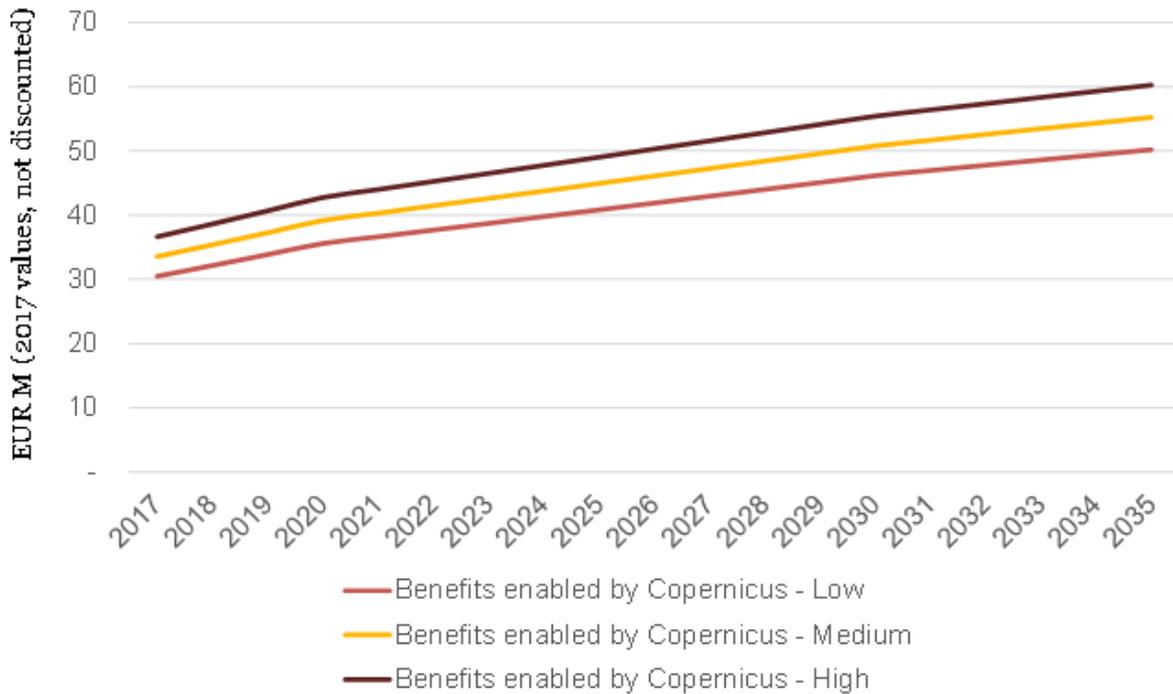


Figure 49 - Overall Copernicus D&I benefits from 2017 to 2035 (Source: PwC analysis)

4.2.3.2.7 Support to land mapping and cadastral surveying

As mentioned in introduction, the mapping of Land use/Land cover is one of the primary goals of Copernicus Land Services. Therefore National Mapping Agencies, Cadastral and Land registration authorities can be users of Copernicus products, as well as providers of data to enhance Copernicus Services (Mapping emergency service for example). A good example of this cooperation is the recent signature of a partnership between EEA (entrusted entity for Land services) and EuroGeographics (membership association, voice of the European Mapping and Cadastral agencies) which aims to foster knowledge exchange between the two organisations. Copernicus will have access to EuroGeographics data, produced using geospatial data from its members.

On the other hand, there are also projects developed by mapping agencies that use Copernicus data as inputs. They exploit the different Sentinel datasets and Copernicus Services to create their own individual land monitoring products. For example the Federal Agency for Cartography and Geodesy in Germany (Bundesamt für Kartographie und Geodäsie, BKG), is using Copernicus data for certain projects and tries to include it in its daily process¹⁴⁹. Sentinel 1 is particularly interesting for them, as it provides information on soil moisture, soil surface roughness and vegetation structure. These data are used to distinguish the different objects in an image and hence, the different land cover classes. Extracting major land cover classes is really useful to develop Digital Land Cover Model, and doing it with remote sensing is easier and less costly than sending surveyors on field. Sentinel 2 data are also being used as inputs data for Land Cover analysis in the frame of the LUCAS system (Land Use/Cover Area Frame Survey), which is used by Eurostat.

Concerning Cadastral update and upkeep, Cadastral agencies are using VHR ortho-imagery for their survey. But Copernicus can be a complementary source of data for them. Especially when it comes to change detection (new building, increase in agriculture parcel, etc.) or detection of illegal activities. Copernicus Land Services can support the transition to a more

¹⁴⁹ Copernicus – practice of daily life in a national mapping agency?, BKG, 2016

“dynamic” cadastral system (updated in “real” time), and to the digitalization of Land registration systems.

Copernicus can also support the INSPIRE directive as a complementary source of information.

The following impact pathway maps out the impacts of Land Mapping and Cadastral (impact driver) through the different derived benefits (impacts):

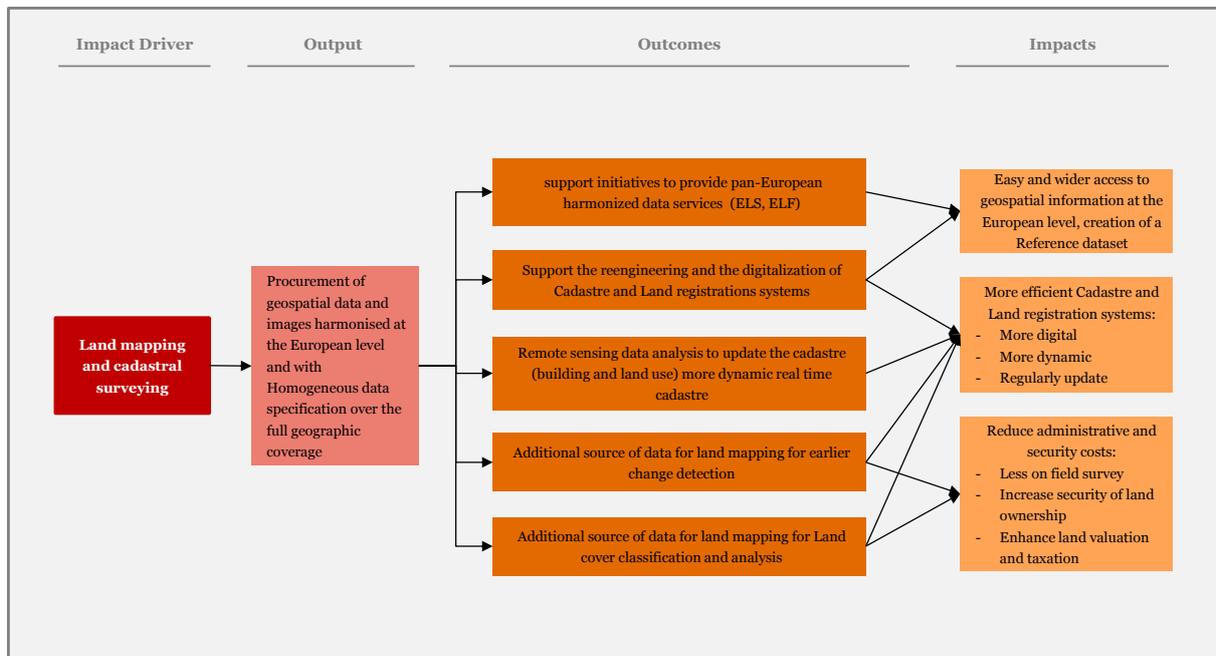


Figure 50 - Impact pathway for Support to land mapping and cadastral surveying (Source: PwC Analysis)

The major Copernicus benefit for Land Planning and Cadastral Surveying is the development of a reference data set for geospatial information in Europe. Copernicus could be the first access point of harmonised, pan-European, authoritative geospatial information and services, enabling cost reduction and efficiency gain. However, given the scarcity of quantitative data, it was not possible to monetise this impact.

4.2.3.3 Built environment

4.2.3.3.1 Urban Area Monitoring

In 2020, 80% of the EU population will be concentrated into urban areas as cities provide an access to dynamic job marketplaces, education, health services and infrastructure, daily consumption goods and shelter¹⁵⁰. The growth and densification of urban areas pose social, economic and environmental challenges as the health, comfort and consumption needs of city dwellers must be addressed while environmental damages caused by human activities and excessive resource consumption must be avoided. Such sustainable urban development can be reached by making cities smarter and by integrating the usage of information and communication technology into the decision making process of urban planning and development. The support of Earth observation and remote sensing technologies can facilitate the access to the necessary data enabling the analysis of urban drivers and the monitoring of the urban environment. The Copernicus programme has the capacity to provide such data, and represents an important component of the concept of smart cities as the usage of Copernicus data can improve the design of urban systems.

¹⁵⁰ Source: The European Environment, State and Outlook 2010, Urban Environment, EEA

Managed by the European Environmental Agency (EEA), the Copernicus Land Monitoring Service (CLMS) provides products and data such as HR and VHR satellite imagery, Land Cover, High Resolution Layers, and Land Surface Temperature which can be exploited to support several urban monitoring applications. The CORINE Land Cover inventory provides a wide range of information such as the composition of artificial areas which includes data related to urban fabric; industrial, commercial and transport units; mine, dump and construction sites; and artificial non-agricultural vegetated areas. The satellite data composing the CORINE Land Cover inventory was provided by several Copernicus contributing missions (Landsat-5, Landsat-7, Spot-4, Spot-5, IRS P6 and RapidEye). The Urban Atlas also provides land cover and land use information for major EU urban areas and is employed as a tool to analyse the social, economic and environmental trends and performances of urban areas.

The provision of the Copernicus products listed in the previous paragraph enables the mapping of urban deformation and urban sprawl, road extraction and Urban Heat Island monitoring. These activities enabled by Copernicus lead to the benefits mapped in the following figure:

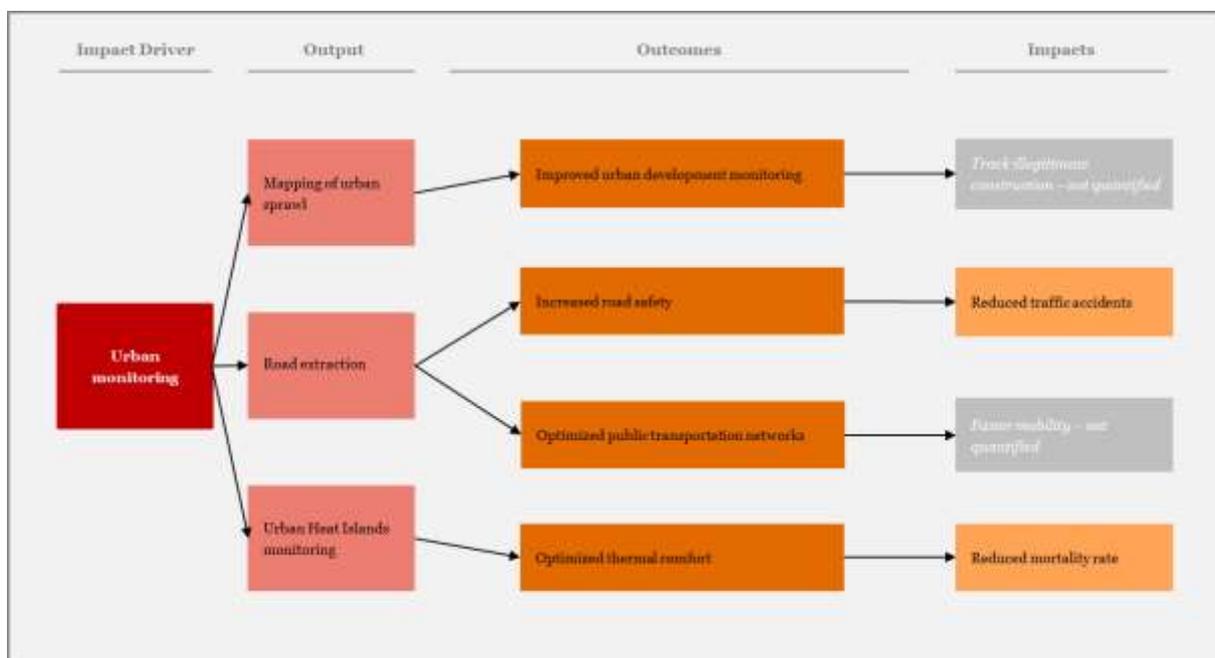


Figure 51 - Impact pathway for Urban Area Monitoring (Source: PwC Analysis)

As a result of the impact pathway for Urban Area Monitoring, the following benefits can be pointed out:

- Track illegitimate construction
- Reduced traffic accidents
- Faster mobility
- Reduced mortality rate caused by Urban Heat Islands

The processes leading to the quantification of benefits enabled by Copernicus for Urban Area Monitoring are provided in the following paragraphs:

4.2.3.3.1.1 Track illegitimate construction

The detection of the illegitimate construction of buildings reinforces public authorities in controlling urban sprawls. Uncontrolled and illegitimate construction of buildings can have severe consequences on the urban environment in which they occur. Indeed, these constructions can endanger the dwellers occupying the buildings as the buildings materials and construction techniques might not comply with legal standards, can participate to the increase of urban heat islands, and might be built upon areas subject to the risk of landslide hazards.

The Sentinel-2 satellites launched in 2015 (2A) and 2017 (2B) provide data with a minimum resolution of 10 metres. The Copernicus High Resolution Imperviousness Layer product supports the detection of illegitimate construction by regularly measuring the land cover and use of urban areas.

Due to the lack of quantified data on illegitimate construction, the impact of Copernicus could not be monetised.

4.2.3.3.1.2 Reduced road traffic accidents

Spatial imagery provided by Sentinel-2A, 2B and HR and VHR spatial imagery delivered by contributing missions belonging to Mission Group 2¹⁵¹ can support better decision making in designing and maintaining sustainable urban transportation.

The quantification approach developed to measure the benefits brought by the Copernicus programme to the reduction of traffic accidents is primarily based on the annual evolution of the number of road fatalities causing fatalities and serious injuries to EU citizens. As it is practically impossible to precisely estimate the yearly number of fatalities caused by road accidents until 2035, the compound annual growth rate of the number of people killed by road accidents in Europe since 1991 was calculated and applied to the forecasted period (2017 – 2035), the same compound annual growth rate was applied to forecast the evolution of the number of serious injuries caused by traffic accidents. The impact of Copernicus was then measured on the difference between two consecutive years of the number of fatalities. It is assumed that Copernicus plays a role in supporting the decision making process leading to different measures preventing road fatalities. Finally, the number of fatalities and serious injuries avoided thanks to Copernicus was converted into an economic value by using the statistical value of life (economic impact of an avoided fatality).

¹⁵¹ <https://spacedata.copernicus.eu/web/cscda/missions>



Methodological approach to quantify value enabled by Copernicus to the reduction of traffic accidents in urban areas

The model is based on the economic impact of the number of serious injuries and fatalities caused by road incidents in urban areas.

The steps are:

1. Assessment of the yearly evolution of the number of road accidents fatalities avoided in urban areas
2. Application of the average value of life for EU citizens to the results obtained from step 1
3. Assessment of the yearly evolution of the number of serious injuries road accidents avoided in urban areas
4. Application of the average cost for major incident for EU citizens to the results obtained from step 3
5. Assessment and application of the contribution of Copernicus to the aggregation of the results obtained in steps 2 and 4

Reduced Traffic accidents

Valuation approach

$$\text{Impact (EUR)} = \text{Contribution of Copernicus to the improvement of road security} \times \left(\text{Number of road accidents fatalities avoided in urban area} \times \text{Average economic impact of EU fatality} + \text{Number of road accidents fatalities avoided in urban area} \times \text{Average economic impact of EU fatality} \right)$$

Therefore, using the approach described above, the annual evolution of the number of road fatalities was estimated at 4.39%, which implies a continuous reduction of the number of people killed and seriously injured by traffic accidents until 2015. The statistics published by the European Commission in November 2016 in the Road Safety in the European Union report, indicate that 37% of traffic accidents occur in urban areas¹⁵². It is assumed that this percentage of traffic accidents occurring in urban areas stays constant during the quantified period.

As no quantitative data was found to establish the precise contribution of Copernicus on the reduction of fatalities caused by traffic accidents, the contribution was measured through the qualitative analysis of the value of Earth observation data among other elements enabling traffic accidents prevention. Literature review has indicated that the main factor triggering a reduction of traffic accidents is user's road behaviour, and that Copernicus plays a minor yet unneglectable role in informing road administration and policy makers in establishing sanctions preventing abusive and irresponsible road behaviour. It is worth mentioning the initiative lead by the SATURN EU Project, aiming at demonstrating the use of Copernicus data combined with GNSS data to enhance better mobility and improved road safety. The project included a demonstrator led by a Polish consortium composed of the Institute of Geodesy and Cartography and of HELLER Consult, aiming at developing an information tool enabling road administration to improve road safety and efficiency of maintenance. The demonstrator was based on Copernicus data providing information on land coverage, atmosphere and climate change which are useful to assess the impact of weather and land use on roads and better manage road maintenance to improve safety.

Built on the qualitative appreciation of the elements mentioned above, a range of three different scenarios (*low, medium and high scenario*) was modelled to measure the contribution of Copernicus on the reduction of fatalities caused by traffic accidents.

¹⁵² https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/vademecum_2016.pdf

Therefore, the impact of Copernicus on road safety and the avoidance of traffic accidents in urban areas leading to fatalities or serious injuries is comprised between **EUR 64 M** (low scenario) and **EUR 295.3 M** (high scenario) over the quantified period (2017 – 2035). The yearly evolution of the economic impact of Copernicus is illustrated in the following figure:

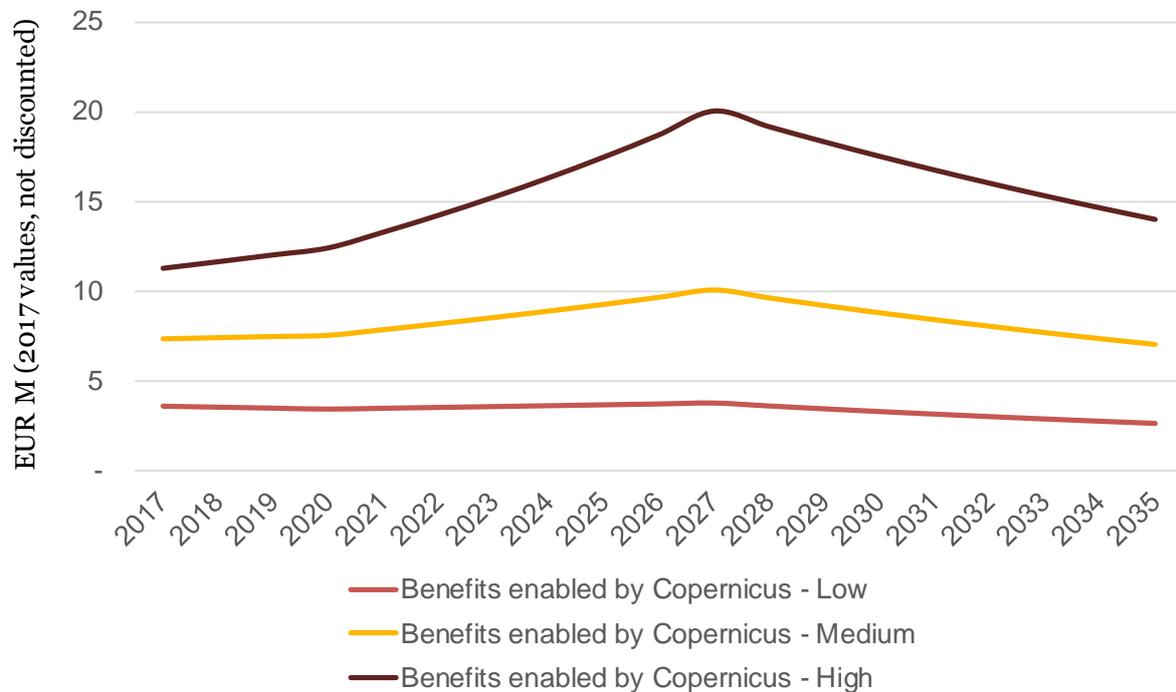


Figure 52 - Evolution of the Copernicus benefits for “reduced traffic accidents in urban areas” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

In 2014, road accidents killed 25,974 people and caused 135,000 people to suffer from serious injuries¹⁵³. Satellite imagery can support traffic management systems in increasing the level of road safety in urban areas by providing additional data on areas and road segments which are at risk for both road users and pedestrians. Furthermore, Copernicus data providing information on land cover, atmosphere and climate, combined with traffic, road and transport data represent an efficient tool for road administrations in charge of guaranteeing the monitoring and maintenance of road and transport infrastructures. SAR data provided by Sentinel-1 and Mission Group 1 spacecraft, can inform on the slow deformation of roads over several kilometres.

4.2.3.3.1.3 Faster mobility

European cities face the challenge of developing sustainable transportation and traffic networks to improve urban mobility while ensuring a continuous decrease of traffic congestion and accidents. Efficient and sustainable transport systems and networks can lead to many economic benefits as improved mobility is a natural growth enabler. In 2007, a green paper entitled “Towards a new culture for urban mobility” discussed several topics among which the definition of smarter urban mobility and urban transport systems. Following the outcomes of this paper, the European Commission adopted the Action Plan on urban mobility in 2009, which defined a set of twenty recommendations aiming at supporting the implementation of measures leading to sustainable urban mobility across

¹⁵³ https://ec.europa.eu/transport/road_safety/specialist/statistics_en ; https://ec.europa.eu/transport/sites/transport/files/road_safety/pdf/vademecum_2015.pdf

European cities. These recommendations encompass actions such as improved travel information, strengthened urban passenger rights, and enhanced transport system planning, development of greener transport by supporting the adoption of energy-efficient vehicles, and a better assessment and support of funding needs for urban mobility.

Remote sensing products can support the list of actions mentioned in the previous paragraph by offering key data feeding transportation modelling and hence support the planning process of future transportation infrastructures. Satellite imagery enables the identification and precise mapping of building and roads and improve road extraction initiatives.

The impact of Copernicus on urban mobility leads to a wide range of economic, environmental and societal benefits which are too complex to be quantified in a synthetic manner and be all included in the format of this study.

4.2.3.3.1.4 Reduce mortality rate caused by the effects of Urban Heat Islands

In summer 2003, a violent heat wave devastated Europe and caused 35,000 fatalities¹⁵⁴. Such excess mortality would have been significantly reduced with smarter cities designed to prevent heat from being accumulated in dense urban areas. This kind of event is most likely to repeat itself over the 2017 – 2035 period and therefore represents a threat that cannot be ignored.

Urban Heat Islands occur when air temperatures in urban areas are higher than in surrounding rural areas. Urban Heat Islands are mainly provoked by the density of buildings, the absence of green spaces and the accumulation of anthropogenic heat. Several Copernicus products provide data enabling the analysis of the factors listed above, a better understanding of Urban Heat Islands and therefore ways to design smarter cities which avoid the occurrence of this phenomenon.

Copernicus' participation to the reduction of mortality rate caused by Urban Heat Islands can be quantified by comparing the baseline scenario evolution of the number of fatalities caused by extreme heat temperatures with a mitigation scenario which comprises the stabilisation of global temperature change at 2 degrees Celsius above pre-industrial levels. The difference in terms of fatalities between the two scenarios is considered and it is assumed that Copernicus is included in the mitigation actions leading to the reduction of fatalities. The impact of Copernicus is then measured on the difference between the two scenarios. The number of fatalities avoided by actions supported by Copernicus data is converted into an economic value by using the statistical value of life (economic impact of an avoided fatality) for European citizens.



Methodological approach to value the contribution of Copernicus to the reduction of the mortality rate caused by Urban High Islands effects

The model is based on the economic impact of the number of fatalities caused by Urban Heat Islands.

The steps are:

1. Assessment of the potential number of fatalities caused by the effects of Urban Heat Islands in baseline scenario
2. Assessment of the potential number of fatalities caused by the effects of Urban Heat Islands in mitigation scenario
3. Assessment of the potential number of fatalities saved in mitigation scenario

¹⁵⁴ <https://www.newscientist.com/article/dn4259-european-heatwave-caused-35000-deaths/>

- when comparing it to the baseline scenario
4. Assessment and application of the contribution of Copernicus to mitigate the effects of Urban Heat Islands and to support the reduction of the number of casualties caused by Urban heat Island



In the baseline scenario projecting the annual excess mortality caused by extreme temperatures in the EU steadily climbs from 17,700 fatalities in 2016 to 57,000 fatalities in 2035. Whereas the mitigation scenario projects an evolution of the number of deaths caused by thermal discomfort progressing from 17,500 in 2016 to 50,000 in 2035¹⁵⁵. Compared to the baseline scenario, the mitigation scenario would enable the avoidance of 49000 excess deaths caused by extreme temperature in the EU. The impact of Copernicus was applied to the number of fatalities avoided in the mitigation scenario compared to the baseline scenario. The modelling of the contribution of Copernicus was nourished by the qualitative analysis of the impact of thermal remote sensing on urban heat islands and the Copernicus capabilities enabling thermal monitoring services. Such analysis revealed that the usage of thermal imagery and services, and in particular the Copernicus capabilities in this field had a rather modest impact on the reduction of UHI effects and thus the reduction of fatalities caused by thermal discomfort. Furthermore, since the development process of SMART cities enabling the reduction of UHI takes place over several decades, the user uptake increase slowly over the period but continues to grow post 2035. Hence, the impact of Copernicus on Urban Heat Island mitigation leading to the reduction of fatalities caused by extreme heat is comprised between **EUR 423M** (low scenario) and **EUR 1,732M** (high scenario) over the quantified period (2017 – 2035). The yearly evolution of the economic impact of Copernicus is illustrated in the following figure:

¹⁵⁵ http://www.climatecost.cc/images/Policy_Brief_ClimateCost_Draft_Final_Summary_vs_4.pdf

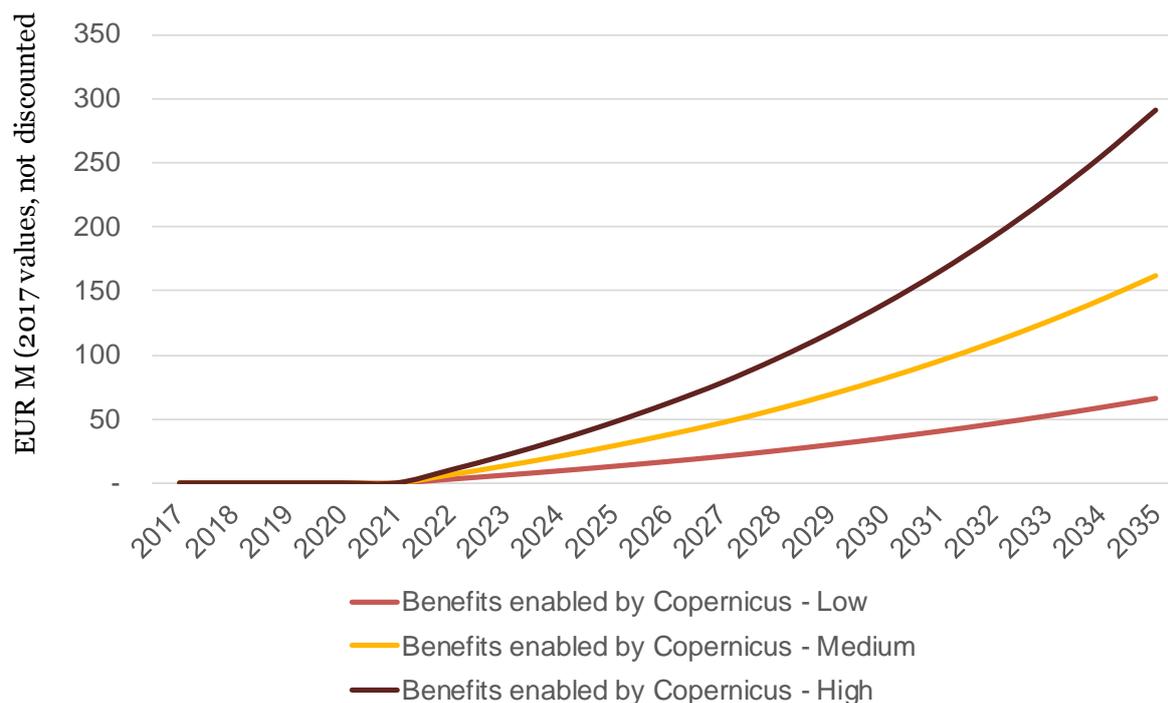


Figure 53 – Evolution of the Copernicus benefits for “reduced mortality rate caused by UHI” from 2017 to 2035 (Source: PwC analysis)

Funded by ESA, the Urban Heat Islands and Urban Thermography project uses various sensors from Copernicus contributing missions to demonstrate the use of satellite thermal sensors to better understand and prevent the impacts of Urban Heat Islands and support the definition of better energy efficiency policies in European urban areas. This project has demonstrated the added value of 18 different products supporting Urban Heat Islands monitoring.

Differentiation factor of EO and Copernicus D&I

Remote sensing thermal infrared data can be utilised to measure Land Surface Temperature (LST) in a much faster, simpler and more efficient way than non-space borne such as in-situ temperature sensors placed on tall towers, tethered balloons, aircraft sensors, etc. as a global view of concerned cities is allowed and leads to a faster mapping of urban hot spots. The Sea and Land Surface Temperature Radiometer (SLSTR) mounted on Sentinel-3 satellites provides a range of thermal measurements products enabling the detection and mapping of Urban Heat Islands.

4.2.3.3.1.5 Summary of Copernicus contribution to “Urban area monitoring”

The total not discounted benefits generated by Copernicus are expected to amount as presented in the following table:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	3.6	16.7	68.7	486.9
Medium estimate	7.3	38.2	168.9	1,156.6
High estimate	11.3	64.8	305.2	2,026.8

Table 16 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global evolution of benefits for urban area monitoring are illustrated in the chart below:

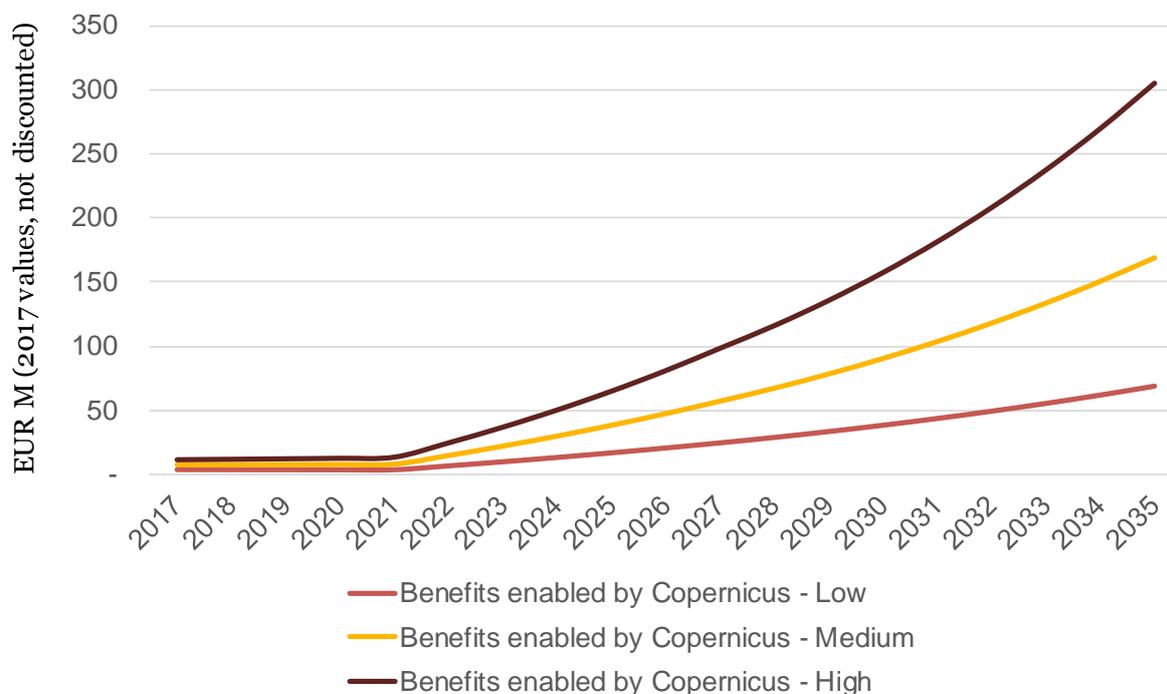


Figure 54 - Evolution of the Copernicus benefits for Urban Area Monitoring from 2017 to 2035 (Source: PwC analysis)

4.2.3.3.2 Offshore Wind Renewable Energy infrastructure management

According to the OECD's Ocean Economy Report¹⁵⁶, the offshore wind energy market holds high prospects for long-term growth.

The Copernicus Marine Environment Monitoring Service (CMEMS) is used to support the renewable wind energy industry and the building of its offshore farms. A dedicated tool from Copernicus 'MyOcean' provides users with ocean characteristics such as currents, sea level and sea surface temperature. Such measurements and following computations of the ocean conditions can be used during the exploration, exploitation, and environmental assessments phases of offshore wind energy production.

The Copernicus Climate Change Service (C3S) is used to support the renewable wind energy industry by providing up-to-date wind climatology that has been used by down-stream service providers to identify optimal sites for on and off-shore wind farms. C3S provides as well seasonal predictions (up to six months ahead) of the expected wind energy capacity factors. SAR data (Synthetic Aperture Radar) obtained from Copernicus contributing missions are used to extract wind data and calculate ocean wind speed. SAR data are retrieved in X-band from the Contributing Mission Cosmo-SkyMed and in C-band from

¹⁵⁶ OECD, 2016, The Ocean Economy in 2030 (Online). Available at: <http://www.oecd.org/sti/futures/the-ocean-economy-in-2030-9789264251724-en.htm>

ENVISAT and ERS, enabling the computation of instantaneous wind speed¹⁵⁷. Copernicus can thus give an informed optimized location for potential wind energy farm sites taking into account the amount of wind available, the wave height or the wind speed, weather conditions in the area of interest and whether they pose a risk on the infrastructure. This information can also be used to refine the design of offshore platforms so that they withstand weather conditions of the desired location, and to monitor and assess the Operations and Maintenance (O&M) costs of the wind farm, which represents 39% of the wind farm total costs.¹⁵⁸ As such, Copernicus would contribute to the reduction of offshore wind farms costs, while increasing the harnessing of wind and the energy production¹⁵⁹. Concurrently with the increased renewable energy production, fossil fuel energy production will decline. This, in turn, means displacing toxic emissions that fuel combustion produces (including CO₂, SO₂, and NO_x that have drastic effects on the environment and the public health).

The benefits of offshore wind energy infrastructure management described above can be portrayed in the following impact pathway.

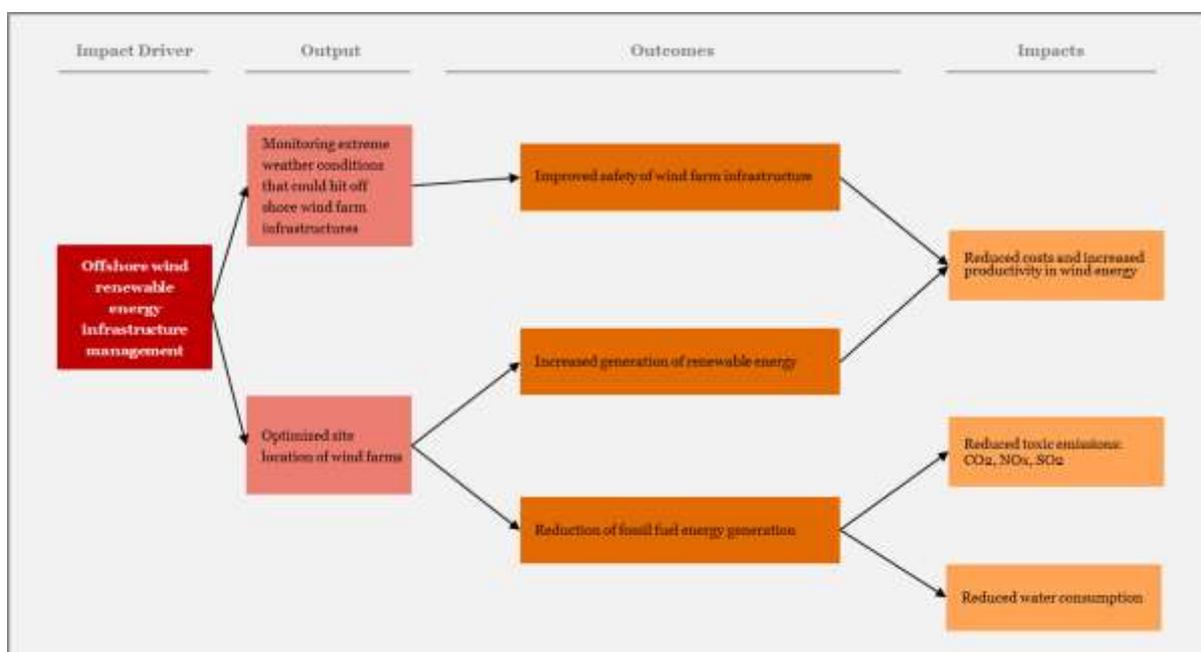


Figure 55 - Impact pathway of offshore wind energy infrastructure management (Source: PwC analysis)

As a result of the impact pathway for offshore wind renewable energy infrastructure management, the following benefits can be highlighted:

- Reduced costs and increased productivity in wind energy
- Reduced toxic emissions (CO₂, NO_x, SO₂)
- Reduced water consumption (renewable energy provided displaces fuel combustion which consumes a lot of water only for cooling purposes)

4.2.3.3.2.1 Reduced costs and increased productivity in wind energy

¹⁵⁷ Satellite Remote Sensing Applied to Offshore Wind Energy. Sara Venafra, Marco Morelli, Andrea Massini

¹⁵⁸ EC, 'Environmental Monitoring of Marine Renewable Energy Farms'. Copernicus User Uptake Information Sessions, Renewable Energies/Marine

¹⁵⁹ 'Space Supports Europe's Renewable Energy Future', September 2013.

Thanks to the optimized locations of wind farm sites and the assessments provided by Copernicus, higher production rates from farms can be expected leading to the required productivity of wind energy being achieved at smaller costs. Thus, the revenues of offshore wind renewable energy increase.



Methodological approach to value reduced costs and increased productivity in wind energy

Copernicus is expected to support the three phases of offshore wind energy production: exploration, exploitation, and environmental assessments. This support should in total increase the productivity of wind farms and reduce their costs. It is measured by the total increase in revenue that Copernicus stimulates:

1. Projection of expected installed capacity for offshore wind energy up to 2035 according to EU binding targets
2. Calculation of the revenues coming from these installations
3. Attribution of the Copernicus contribution to this increased revenue

Increased revenues due improved offshore wind energy production

Valuation approach



Most of the data used in this economic model was taken from EWEA (European Wind Energy Association)¹⁶⁰ and some proxies, derived from AWEA (American Wind energy Association)¹⁶¹, were used to complement the model.

EU climate and energy targets impose that, by 2030, 27% of EU's final energy consumption comes from renewable energy. In that case, wind energy is supposed to provide 21% of renewable energy. In order to meet EU 2030 energy targets, 66.5 GW of offshore wind energy need to be installed by 2030. This would enable to generate 245 TWh and should satisfy 7.7% of Europe's electricity demand¹⁶². The growth in offshore installed capacity is projected linearly from today's values up to 2030's targets.

This 66.5 GW target correspond to a central scenario. However, the European Wind Energy Industry predicts two other scenarios, one where the target was not achieved due to governance issues, another where the target is surpassed. The expected installations for each of these scenarios were projected in the model and used for the low and high scenarios.

The revenues are then calculated each year using the average wholesale market electricity price of the last three years, with the assumption that electricity prices are constant during that period of time.

The Copernicus contribution to the revenues described above is set at a range comprised between 0.3% and 2% in 2016 and increases to reach a range between 1,55% and 7% in 2035. These values are based on assumptions built upon the appreciation of qualitative elements

¹⁶⁰ Wind Energy Scenarios for 2030. A report by the European Wind Energy Association - August 2015

¹⁶¹ US Wind Industry 2016. Annual Market Update

¹⁶² EWEA

such as the comparison of services offered by Copernicus for Wind monitoring for farm sites location with what can be provided by meteorological organisations. In 2021, the contribution increase is foreseen to grow more rapidly due to the launch of Sentinel-6 in 2020 which can enhance and support this activity. A year is given for the user uptake.

Copernicus attribution to the increased capacity installation is then projected to 2035, as presented on the following model:

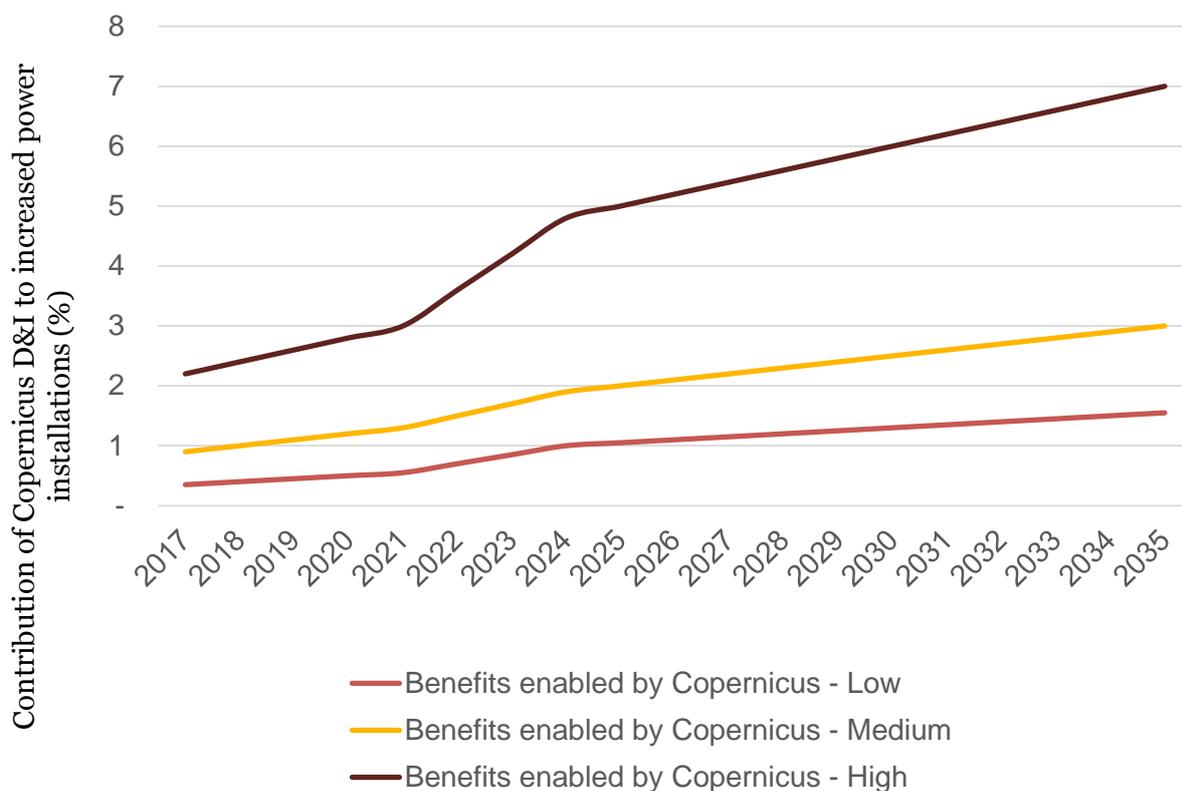


Figure 56 - Attribution of Copernicus to increased power installations (Source: PwC analysis)

It is important to mention that all costs implied by the installation of off shore wind energy infrastructures were not taken into account when modelling benefits generated by Copernicus. Indeed, as mentioned earlier in section 3.1.2 (Challenges in assessing the benefits from the Copernicus programme) implementation costs are not covered in this study.

Copernicus-enabled total economic benefits of offshore wind energy infrastructure management are presented in the graph below:

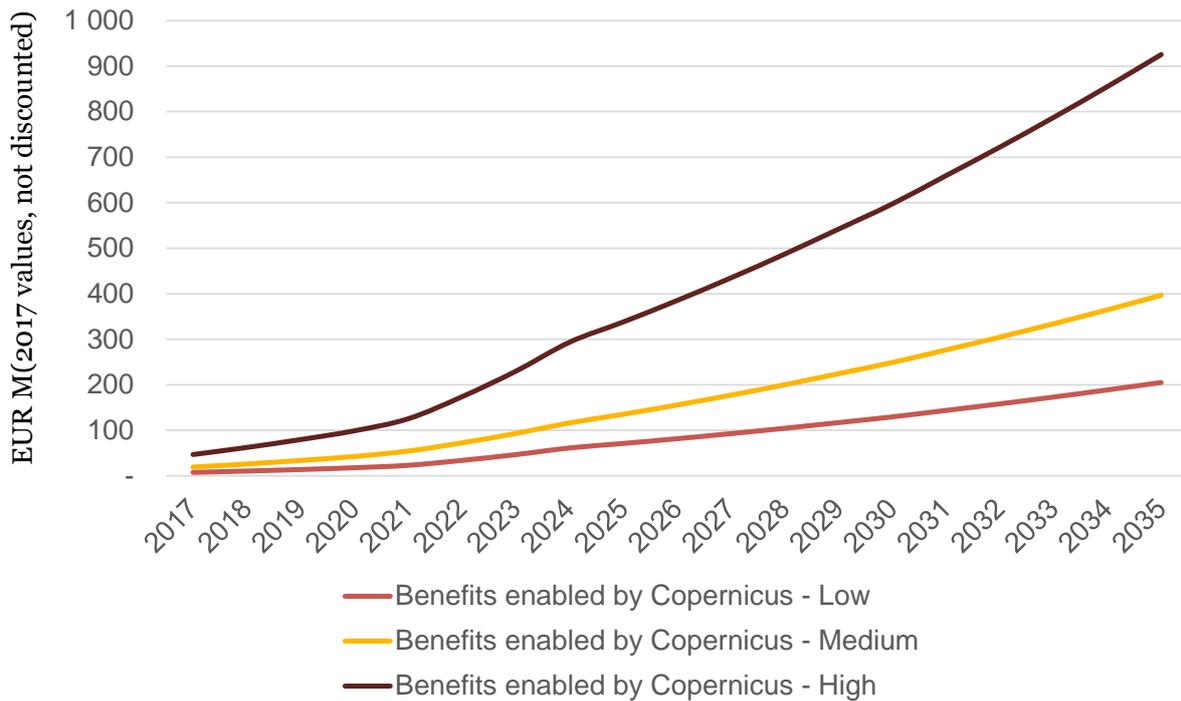


Figure 57 - Economic benefits of Copernicus for offshore wind energy (Source: PwC analysis)

4.2.3.3.2.2 Social and Environmental benefits: Reduced toxic emissions of CO₂, SO₂, and NO_x

When more of Europe’s need for generated power is satisfied by renewable energy sources, less generation from fossil fuels is required. Therefore, to look at the environmental benefits of offshore wind energy, the displaced toxic emissions of a KWh thanks to clean energy generated can be calculated from the difference with what a KWh of fossil fuel energy production emits. The toxic emissions looked at are CO₂, SO₂ and NO_x that are given a monetary value through valuation coefficients. The methodology behind the CO₂ valuation coefficient is presented more in depth in section 5.2.2 - Option 3A: Anthropogenic CO₂ emissions. As for SO₂ and NO_x, in order to get their valuation coefficient, we modelled the societal impacts of these types of pollution based on the methodology described in PwC (2015) Valuing corporate environmental impacts: Air pollution¹⁶³. This aims to cover the most significant impacts from each air pollutant.

- **Health impacts:** Societal cost of increased mortality and morbidity due to NO_x and SO₂ emissions, including the effects of secondary PM_{2.5} (fine particles) and O₃ emissions. Respiratory diseases lead to large societal costs from air pollution. These damages include increased incidents of chronic diseases such as asthma and bronchitis and, in some cases, premature mortality from cardiovascular diseases, pulmonary diseases and lung cancer;
- **Visibility impacts:** Air emissions, particularly PM and O₃ precursors, contribute to reduced visibility through the formation of smog. Reduced visibility affects various forms of navigation and also reduces people’s enjoyment of recreational sites and the neighborhoods where they live (i.e. disamenity);
- **Agricultural impacts:** Changes in the atmospheric concentration of certain gases can negatively impact the growth of crops leading to reduced yields. Acid rain can

¹⁶³ Available online at: www.pwc.com/naturalcapital. Full details of calculations and data sources for the health impact calculations are provided in PwC (PwC (2015) Valuing corporate environmental impacts.). Impacts to visibility and agriculture, as well as health impacts from secondary O₃ formation, were estimated using transfer functions as described in PwC (Ibid.)

damage crops directly and can also acidify soils with impacts on future growth.

The health impacts are by far the largest of these impacts in terms of social cost (impact to society). This was estimated at a country level as follows:

1. Estimate change in atmospheric concentration of pollutants, using air dispersion modelling;
2. Estimate change in health end-points from the change in pollutant concentration (mortality and morbidity) using dose-response functions;
3. Estimate WTP to avoid health impacts using VSL for mortality and WTP for reduced morbidity.

Similarly, the required cooling water for fossil fuel combustion that is saved can be determined.



Methodological approach to value reduced socio-environmental damages

The increased installations in offshore wind energy will lead to a decreased fossil fuel combustion and thus reduced toxic emissions and water consumed after for the cooling of the combustion. The steps to value this environmental benefits are:

1. Project the expected installed capacity for off shore wind energy up to 2035 according to EU binding targets
2. Calculate the displaced CO₂, NO_x, SO_x, and water gallons from the power provided by these installations
3. Multiply by the attribution of the Copernicus contribution to the installations
4. Multiply by the valuation coefficients of the toxic emissions and water waste on public health, morbidity and the environment

Reduced toxic emissions and avoided waste of water

Valuation approach



The displacement ratio of these emissions vary depending on several factors: from turbine technology, to grid efficiency, the types of fuel replaced fuel, etc.. The values used in the model were taken from AWEA for NO_x, SO₂ and water gallons, and from EWEA for CO₂. For the yearly generated power, the ratio is used to determine the displaced tons of CO₂, NO_x, and SO₂, and then the Copernicus attribution percentage is used to determine how much of these tons are saved due to Copernicus.

Valuation coefficients have been developed by PwC to determine how many euros 1 kg reduction of each of these gases saves in mortality, morbidity, visibility and agriculture. As

for the water gallons saved, the valuation coefficients determine their benefit on health and resources.

The cumulative benefits enabled by Copernicus for off shore wind energy are demonstrated in the graph above.

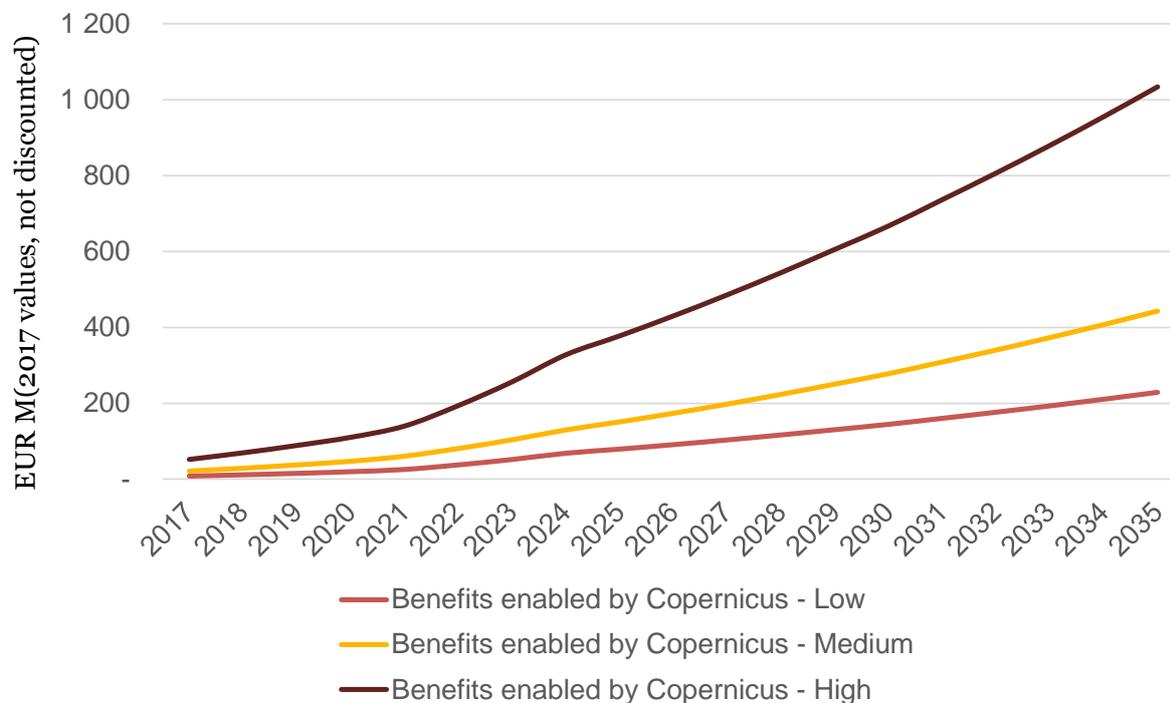


Figure 58 - Social and environmental benefits of Copernicus for off shore wind energy (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

EO data have proven useful for the offshore wind energy industry. Through desk research, it appears that comparisons between EO data and meteorological data concerning ocean characteristics give similarly accurate results. If Copernicus shuts down, the offshore wind industry will still expand however the data needed to support its exploitation and exploration will need to be taken from meteorological organizations and other EO space missions which do not offer open and free data, and thus cost will increase. The benefits due to Copernicus in productivity and cost effectiveness will decline to zero at the shutdown of the program.

4.2.3.3.2.3 Summary of Copernicus contribution to “Offshore Wind Renewable Energy infrastructure management”

The total benefits coming from Copernicus for offshore wind energy infrastructure are presented in the graph below:

<i>Copernicus EU benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	15.7	150.3	433.8	3,551.1
Medium estimate	40.4	286.2	839.8	6,923.4
High estimate	98.8	715.6	1,959.5	16,605.2

Table 17 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

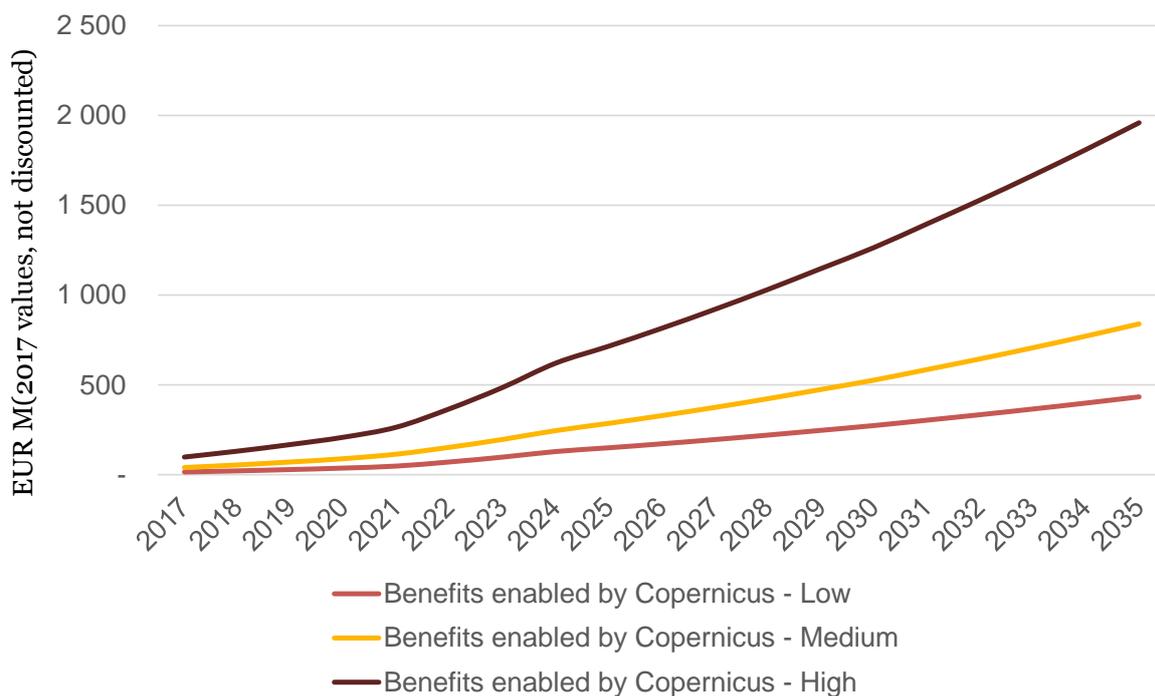


Figure 59 - Evolution of the Copernicus benefits in the field of Offshore Wind Renewable Energy Infrastructure Management (Source: PwC analysis)

4.2.3.3.3 Oil and Gas infrastructure management/development and exploration activities

The Oil & Gas industry has been using satellite-based imagery for more than a decade and recent initiatives, such as the Earth Observation for Oil & Gas (EO4OG), have stimulated dissemination of EO data and products in daily activities of O&G companies.

Imagery and GIS products are widely used in the O&G industry, mostly to support upstream activities for both on-shore (O&G activities performed on land) and off-shore (O&G maritime activities) activities, through 3D modelling and forecast. Upstream O&G activities are split between exploration, construction and maintenance of O&G infrastructure and production & drilling of crude oil. More details on the O&G industry (upstream, midstream and downstream) are available in Appendix, section 7.1.1.

Even if on-shore and off-shore activities drastically differ, in both cases the O&G upstream value-chain relies on the following applications:

- Early Exploration:** this first stage of the value chain relies on the monitoring of specific geographic areas to spot potential positions of petroleum deposits. Sentinels data alone enables the creation of very useful products to monitor large scale area compared to other tools. Copernicus products enable O&G actors to perform large scale prospection on a much more efficient way for both onshore and offshore exploration. Indeed, Copernicus products offer very large geographical coverage that cannot be achieved by helicopter, ground team and/or maritime survey, or at least not at the same cost per squared kilometre. Using satellite data is also way more discrete compared to sending helicopters or boats over specific areas of interest that can be seen by competitors. These products are specifically useful to monitor large off-shore and/or polar areas where companies are tracking oil seeps using radar

technologies (Sentinel 1 data). The presence of oil seeps is the mark of the existence of deep-water petroleum reservoirs in 80% of the cases. These early exploration activities can also be performed using helicopters or boats to survey large scale areas, quite often in remote areas, but the price per squared kilometre is way higher than the one related to Copernicus-based products. It is also less risky to use satellites data than boats or helicopters in harsh and remote geographic areas.

- **Seismic Survey:** the second stage of the value chain relies on more advance and precise surveys (when compared with early exploration) to analyse the different potential petroleum deposits pinpointed during early exploration. Survey activities are concluded by drilling exploration well to confirm the presence of a petroleum deposit. Copernicus data and information are very useful to support seismic planning and optimize the positioning of instruments for seismic survey. These products are also used for planning exploration and well construction. The access to an archive of satellites data of the area of interest can also be useful for in-shore survey because it can enable interesting cost reduction. As an example, if a given area is subject to flooding in spring each year over the last 5 years, seismic survey and exploratory drilling will be performed at another period, improving efficiency of survey activities and mitigating the risk of damages to the equipment. Once the seismic survey has been performed, Copernicus products are also useful to calibrate the results and check consistency of some results' parameters.
- **Appraisal:** if exploration activities were successful – which means a petroleum deposit has been identified – appraisal drilling has to be performed to assess the size and the extent of the reservoir but also the properties of the crude products. In this stage, Copernicus data and information are used mixed with other sources of imagery of higher spatial resolution and, in most of the cases, the final outputs used by the O&G end-user are GIS products. Indeed, the planning and construction of appraisal drilling are the first step of the development of production capabilities and many parameters need to be assessed to optimize this phase and the next ones.
- **Field Development and Monitoring:** field development occurs once exploration and appraisal activities were successful to prepare the full-scale production phase. Additional wells are usually drilled and construction of the entire supporting infrastructure (workers' infrastructure, roads, etc.) is performed. Copernicus data and information are again useful in this phase but they are usually integrated in larger GIS products to optimize drilling activities. However, Sentinel 2-based products are accurate enough to be used alone to plan road construction to access remote on-shore production sites. Fields monitoring activities are related to the facilitation of field activities, insuring security and safety for workers and equipment. This domain is critical for the O&G industry, especially for off-shore and polar activities in remote and harsh areas. Being able to monitor wave height, marine winds, icebergs, ice thickness, etc. is key to protect workers and equipment from natural hazardous. Satellites play a key role to increase safety in such activities. Copernicus products are used to forecast waves and winds and the potential impact on off-shore rigs. However, most of the satellite-based imagery used in field monitoring is related to very high spatial resolution and very high temporal resolution (near-real time).
- **Production:** once all the above activities have been performed, large-scale production can start, extracting crude oil (and gas) from the field developed. Copernicus products, and imagery of all type of resolution, are used within complex GIS products to analyse and optimize efficiency in production (injection rates, production volumes, etc.). The contribution and potential value of applications based

on Copernicus products are very small compared to other value chain's phases. Very high resolution imagery is more likely to be used in production phase.

- **Distribution and Pipeline:** pipeline and distribution road (land and/or sea) are planned during this phase to transport crude oil to refinery sites. Imagery, including Copernicus data & information, plays a significant role in pipeline planning and routing. Once built, pipelines can be monitored thanks to high resolution satellite-based imagery; in such type of applications, Copernicus is not offering a high enough spatial resolution to have a significant impact.
- **Environmental monitoring:** O&G activities have significant impacts on air quality and water quality that can be monitored by imagery-based products. Environmental monitoring of exploration and exploitation activities are receiving a growing interest within most of the applications mentioned above. Copernicus D&I play a role in mitigation and response to oil spills and air pollution monitoring and mitigation.

The importance of geospatial data and information in O&G activities varies extensively from one company to another. For some actors, geospatial information is a tool like many, whereas for others, EO leads to key competitive advantage on the market. Applications related to geospatial data vary extensively depending on the five main parameters of EO data: spatial resolution, temporal resolution, types of sensors, spectral resolution and archives vs. tasking activities.¹⁶⁴ O&G companies usually have strong in-house capabilities related to imagery processing and analysis to support exploration and exploitation, stimulating their interest for Copernicus data (i.e. Sentinel 2 data to support road and pipeline routing) and information (i.e. wind and waves forecasts for off-shore infrastructure planning). Nowadays, environmental monitoring activities have received a more and more important role within the O&G upstream industry. O&G companies are under scrutiny by NGOs and public authorities to reduce environmental impacts of O&G exploration activities and related disasters.

The impact pathway of “Oil and Gas activities” is summarized in the chart and the assessment of the benefits derived from Copernicus data and information is illustrated in the figure below.

¹⁶⁴ PwC, 2016. Copernicus Downstream Study. European Commission. Brussels, Belgium.

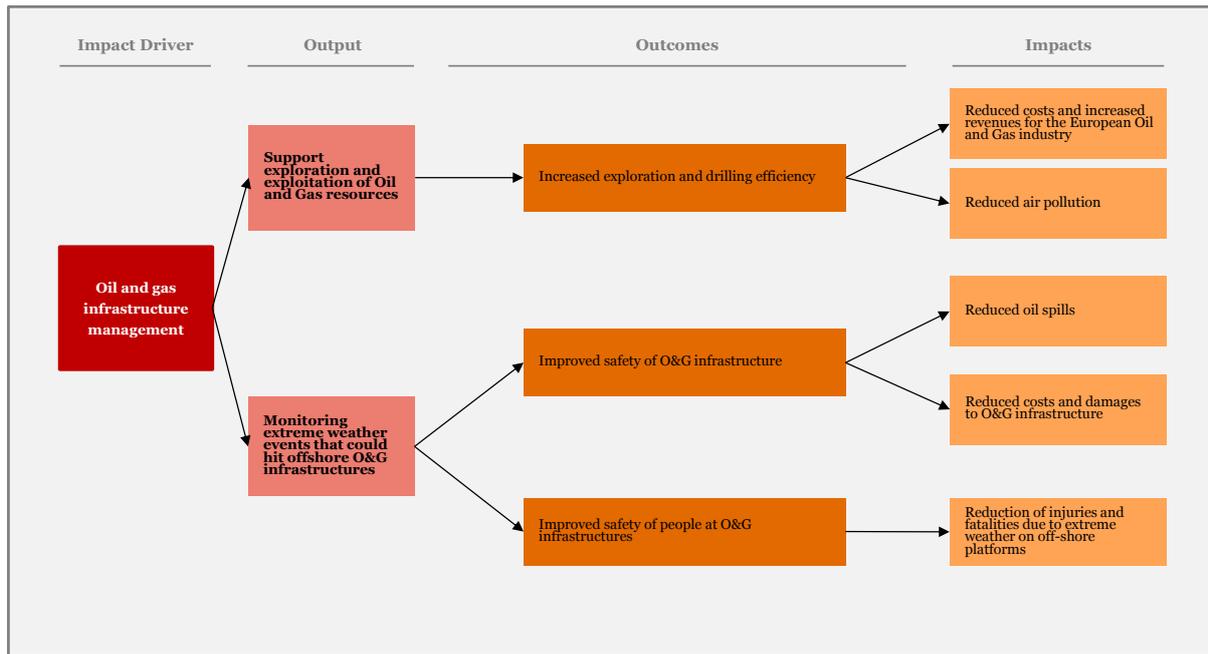


Figure 60 - Impact pathway for O&G activities (Source: PwC analysis)

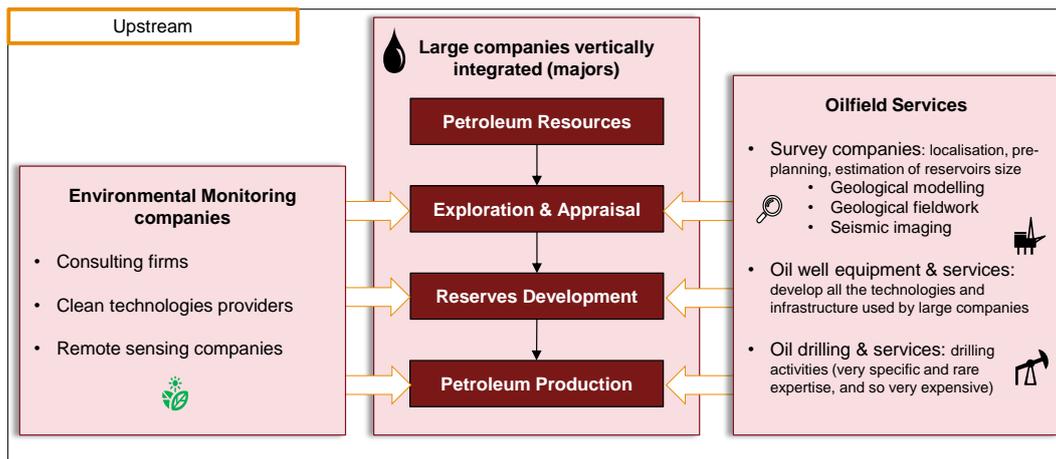
The first output is the support for exploration and exploitation O&G activities for European companies, which results in an increased exploration and drilling efficiency. The second output is the monitoring extreme weather events impacting offshore O&G infrastructure, which enables to improve both the safety of the O&G infrastructure and the safety of people working on-site.

As a result of these outcomes, the following benefits can be highlighted:

- Increased revenues and cost reduction for the European O&G industry;
- Reduced oil spills;
- Reduced air pollution;
- Reduced cost to off-shore infrastructure;
- Reduction of injuries and fatalities due to extreme weather on off-shore platforms.

4.2.3.3.3.1 Reduced costs and increased revenues for the European O&G industry

The analysis relies on the assessment performed in PwC (2016), updated with more recent data and extrapolated up to 2035. Such assessment is based on the structure of the O&G upstream industry which is mostly split between three types of companies as highlighted in the chart below. More details are available in Appendix, sections 7.1.2 and 7.1.3.



European environmental companies using EO data are already included in section 4.2.2 assessing EO downstream enabled revenues, so they were removed from this impact. Two separate assessments were performed on majors and oilfield services.

Copernicus D&I enables the O&G industry to save costs for the O&G sector, which makes it cheaper to supply O&G. The use of O&G has a negative impact on the environment so cheaper supply of O&G should have negative impact on the environment. Nevertheless, the O&G demand is completely inelastic, meaning that a lower or higher price of oil does not impact its level of consumption. In this context, having a cheaper supply of O&G thanks to Copernicus will not lead to additional negative externalities for the environment.



Methodological approach to value reduced cost and increased revenues for the European O&G industry

The assessment is performed on the two key type of companies on this market: the large integrated operators (majors) and oilfield services. The methodological approach is explained step by step:

1. Assessment of European majors and oil field services overall revenues (*for majors and oilfield services*)
2. Isolation of the split of revenues related to exploration and infrastructure development (*for majors only*)
3. Assessment of the share of exploration and infrastructure development revenues derived from geospatial data (*for majors and oilfield services*)
4. Among the revenues attributed to geospatial data, isolation of the split attributed to Copernicus data and information (*for majors and oilfield services*)
5. Assessment of the overall revenues enabled by Copernicus data and information using the following formula: (*for majors and oilfield services*)

Reduced cost and increased revenues for the European Oil & Gas industry Valuation approach

$$\text{Impact (EUR)} = \text{Overall exploration and infrastructure development revenues} \times \text{Share of revenues derived from geospatial D\&I} \times \text{Share of geospatial D\&I revenues attributed to Copernicus D\&I}$$

The first step aims to assess overall revenues, using Rystad Energy and Bloomberg data bases. Exploration revenues being fully driven by a highly volatile oil price, its evolution over the next 20 years (up to 2035) is impossible. More details on the specificity of the O&G industry are available in Appendix, section 7.1.4. We have decided to assess an average value over the last 5 years for majors and oilfield companies, and to use these values up to 2035. Exploration and upstream exploitation activities were then isolated for majors, using public information available in annual financial statements of companies such as BP, Statoil or Total.

Stakeholder consultations were then performed with majors and oilfield services¹⁶⁵ in order to understand the split of these revenues (including cost reduction) that can be attributed to geospatial data and information per main type of activities (seismic survey, appraisal, etc.). Nevertheless, for sensitivity reasons, the contribution of geospatial data was aggregated per type of company. In 2016, this split was ranging between 5% and 8% for majors and 2% and 5% for oilfield services. In both cases, these proportions are respectively expected to reach a maturity of 8–10% (majors) and 6–10% (oilfield services) by 2020, remaining constant up to 2035. This choice was motivated by the fact the use of geospatial data is already quite mature in the O&G industry and it is a complementary tool to drilling activities and infrastructure development. On this split of revenues based on geospatial data, stakeholders were asked to assess the contribution of Copernicus data and information among revenues attributed to geospatial data. For 2016, the assessment ranges between 4.25% and 6% for majors and 2% and 5% for oilfield services, respectively reaching:

- 6–8% for majors and 6–10% for oilfield services by 2020,
- 8–10% for majors and 10–13% for oilfield services by 2030, remaining constant afterwards.

Revenues over the period 2017 – 2035 are then obtained by multiplying all this information together for the majors and for the oilfield services companies.

Copernicus D&I are expected to range between EUR 131.6 M and EUR 360.0 M in 2017, increasing to between EUR 429.0 M and EUR 762.6 M in 2035 to lead to cumulative benefits ranging between EUR 6.9 B and EUR 13.0 B.

The overall reduced cost and increased revenues for the European O&G industry is illustrated in the chart below.

¹⁶⁵ Stakeholders were consulted for the Copernicus Downstream Study (PwC, 2016). For sensitivity reasons, those companies appear as anonym. Nevertheless, some names are available in the acknowledgments section of PwC (2016).

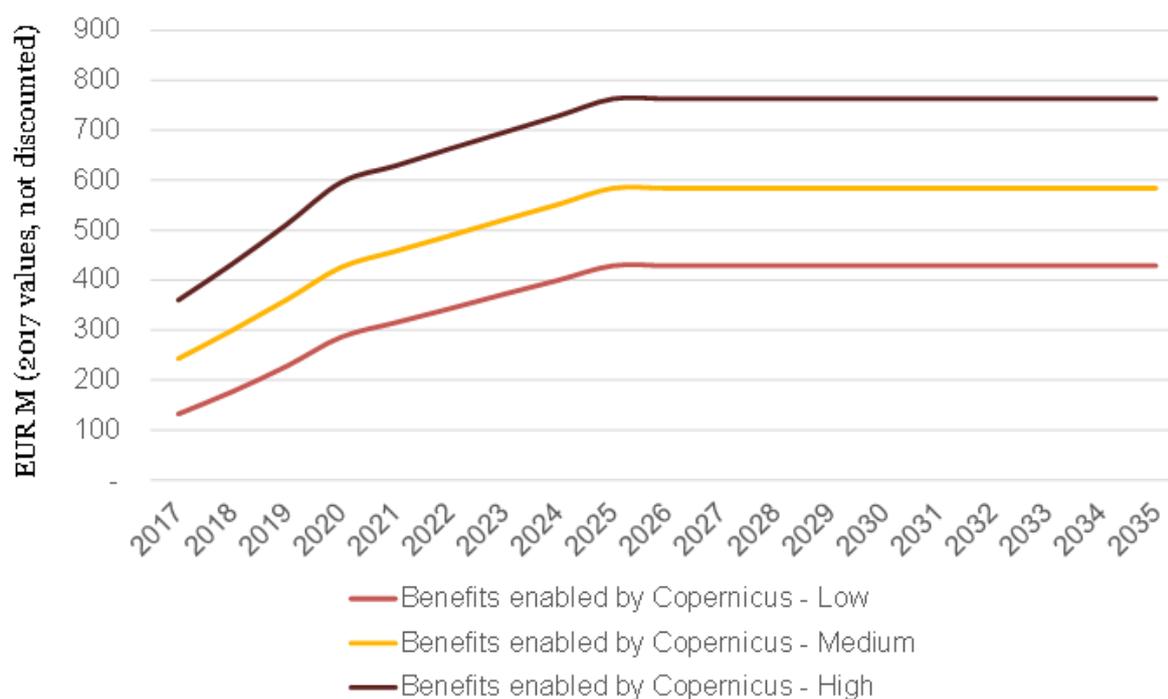


Figure 61 - Evolution of the Copernicus benefits for the impact “Reduced costs and increased revenues for the European O&G industry” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

For on-shore activities, Copernicus is expected to take over the utilisation of Landsat imagery, offering higher spatial and temporal resolution for optical data (Sentinel-2). This means that without Copernicus D&I freely available, O&G companies would be using Landsat imagery leading to a similar order of magnitude of benefits for on-shore activities. The delta between Copernicus D&I and Landsat is very small and is very hard to quantify, even if the first one offer higher spatial and temporal resolution.

For off-shore activities, Copernicus D&I, especially the one based on SAR (Sentinel-1), brings a new capability that was not previously available for free at a global scale, especially relevant for pre-planning survey and pre-planning infrastructure development. Access to this source of data for European company is a real value-added, without real counter factual for similar spatial and temporal resolution.

By considering the split of overall revenues for O&G exploration (HIS database):

- On shore: 70% of overall exploration
- Off-shore: 30% of overall exploration

If we consider that 95% of the on-shore activities could have been done using Landsat imagery (5% of added value from Copernicus D&I) and that almost 100% of off-shore activities enabled by Copernicus D&I do not have counterfactuals, the delta (value added of Copernicus D&I) could be assessed as followed for the period 2017 – 2035 (cumulative):

- Low estimate: EUR 2,335 M

- Medium estimate: EUR 3,273 M
- High estimate: EUR 4,357 M

4.2.3.3.3.2 Reduced oil spills

Reduced oil spills from off-shore platform are one among other sources of oil spills in Europe. The overall benefits related to Copernicus data and information to monitor and mitigate oil spills in Europe has been assessed and monetised in section 4.2.3.6.4 - Oil Pollution Monitoring.

4.2.3.3.3.3 Reduced air pollution

Benefits derived from reduced air pollution were already assessed and valued at a global level in section 4.2.3.1.1. The assessment performed in “Air quality and pollution” section includes all sources of air pollutant and so then including air pollution due to O&G activities.

4.2.3.3.3.4 Reduced costs and damages to O&G infrastructure

Among the most common disasters that could strike the offshore platforms are:

- On-board incidents: where high energy content such as hydrocarbon leaks could lead to disastrous explosions due to human error, or faulty design, or installation...
- External elements such as ship collisions which could lead to complete destruction of the structure
- Natural, or meteorological incidents whose effects are minor in general.

The first two are irrelevant under the scope of this impact driver as hydrocarbon leaks cannot be monitored by EO, and explosions cannot be predicted.

However as CMEMS provides ocean current and wind speed information helpful for exploration and exploitation phases of O&G, it is also important for environmental assessments during the operational phase of O&G offshore platforms. Therefore an impact pathway for these services previously done was warning offshore platforms of extreme weather events that could destroy platforms, break pipes, cause oil leaks and result in massive economic losses. Nevertheless, following desk research and consultation with Petroleum Safety Authority of Norway this appears like an impact that should not be quantified.

4.2.3.3.3.5 Reduction of injuries and fatalities due to extreme weather on off-shore platforms

The weather in northern European seas has long periods of bad conditions, but unlike the North American Oceans, they don't exhibit singular catastrophic events that could destroy the infrastructure. Therefore the EO and meteorological data and archives of European oceans are used for the phases of locating the platforms, and designing or engineering them so as to withstand the worst possible weather conditions in these oceans, which itself suppresses the need of monitoring events that could destroy the platforms as they are initially robust to any of these conditions. Bad weather conditions could of course lead to the evacuation of personnel if present on the offshore platforms(as precaution) in case of risk and maybe lead to shut down of production for a day or two but that has no economic consequences as the production could be compensated in following days.

4.2.3.3.3.6 Summary of Copernicus contribution to “Oil and Gas infrastructure management/development and exploration activities”

The total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus EU benefits –	2017	2025	2035	Cumulative
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EUR M				(2017 – 2035)
Low estimate	131.7	429.0	429.0	6,971.0
Medium estimate	242.5	583.9	583.9	9,771.4
High estimate	360.0	762.6	762.6	13,006.8

Table 18 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below (not discounted).

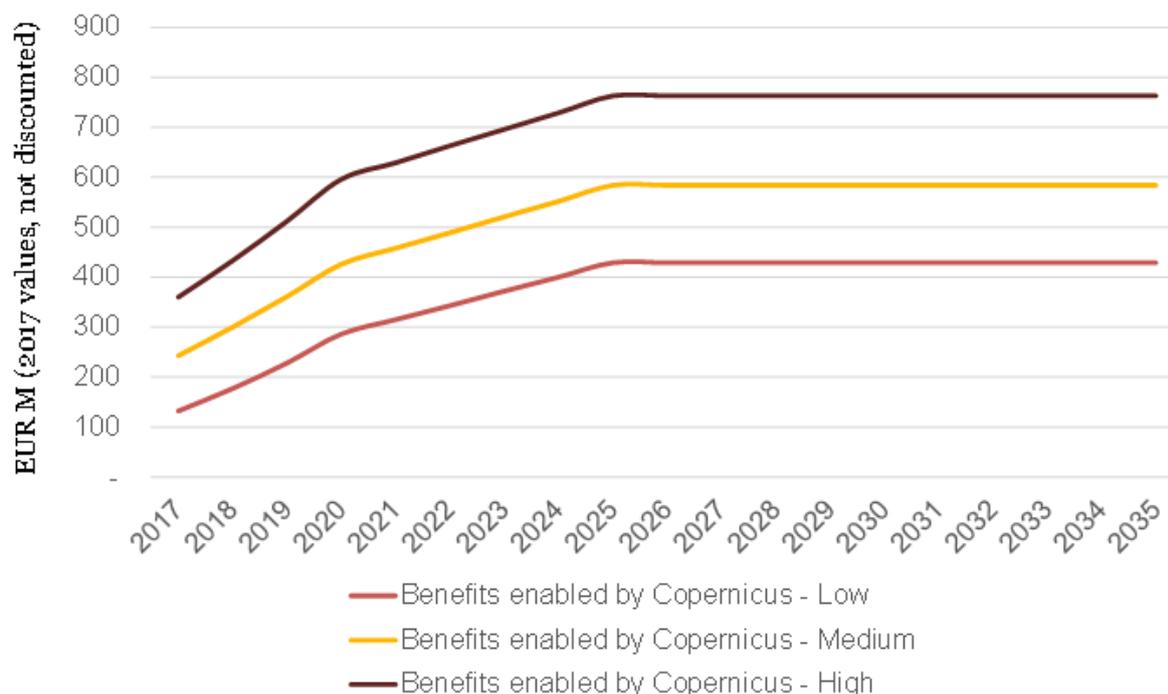


Figure 62 - Evolution of the Copernicus benefits for Oil & gas infrastructure management/development and exploration activities, from 2017 to 2035 (Source: PwC analysis)

4.2.3.3.4 Mining and quarrying: minerals and raw materials extraction

The mining and quarrying sector is considered one of the major sectors by the European Union, as emphasized by the EUR 180 M spent in Research & Investment for raw materials in the frame of the FP7 for the period 2007-2013 and the EUR 600 M invested in the frame of Horizon 2020 for the period 2014-2020¹⁶⁶. Indeed, in 2008, the European Commission launched the Raw Material Initiative (RMI) aimed at developing a European strategy as to the access and use of non-energy raw materials. Currently, Europe is almost self-sufficient for construction and industrial minerals, however, it is dependent on imports for metals¹⁶⁷.

Mining activities are composed of several stages: first, the prospection and exploration phase, which consists in searching for mineral deposits and determining the location of raw materials depending on mineral occurrence; second, the operation phase, which consists in the extraction of raw materials and the monitoring of activities, including extractive waste

¹⁶⁶ European Commission, 2016, Report : Copernicus for Raw Materials workshop (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/ajax/raw_materials_ws_report.pdf

¹⁶⁷ European Innovation Partnership on Raw Materials, 2016, Raw Materials Scoreboard (Online). Available at: <https://publications.europa.eu/en/publication-detail/-/publication/1ee65e21-9ac4-11e6-868c-01aa75ed71a1/language-en> (Accessed: November 24th 2017)

disposal and monitoring of the facilities to dispose the extractive waste; third,, the closure phase, which consists in all the activities surrounding the shutdown of mine sites and its impact and finally the post-closure and long term monitoring of the mining sites and, in particular, the extractive waste facilities (dams, heaps, ponds)¹⁶⁸. Several challenges faced by the mining sector are similar to the ones faced by the Oil & Gas sector, and as such, Earth Observation based products may be of use in both cases¹⁶⁹.

Considering the importance of the raw materials sector, Earth Observation and in particular Copernicus, has a strong role to play and can be useful during all phases of mining activities¹⁷⁰. Several environmental processes, necessary for the monitoring of mining activities, such as surface water, soil or vegetation evolution can be monitored with Earth Observation. The service supporting raw materials-related activities is the Copernicus Land Monitoring Service: from the prospection phase, to the fighting against illegal mining (mostly relevant outside Europe), to the monitoring of environmental from extraction activities and to post-closure¹⁷¹. More precisely, in the mapping phase, Copernicus, through Sentinel-2 data, can support mineral exploration through the modelling of mineral composition of potential mining areas. In the operation phase, Sentinel-1, thanks to its ability to provide processed Interferometric Synthetic Radar Aperture (InSAR) data, can be useful to support mining activities and in particular to prevent mining subsidence¹⁷² (see section 4.2.3.2.6.2 - Reduced damages on civil and private buildings and other infrastructure due to important surface deformation (landslides or subsidence resulting from natural geohazards or due to current or former mining activities, underground or open pits). However, currently, the potential of Earth Observation in the mining sector is considered under-exploited and Copernicus uptake is of reduced maturity: there are still some major gaps in the data and information currently available and these are expected to be solved by hyperspectral space borne sensors¹⁷³.

The ability of Copernicus to support mining and quarrying activities can lead to several benefits (impacts) mapped in the impact pathway below:

168 Benecke N. et al., 2012, GMES4Mining - Innovative Geoservices for Exploration and Monitoring of Mining Areas (Online); Available at: http://www.gmes4mining.info/public/AIMS2012_GMES4Mining_Benecke_et_al.pdf

169 Euromines website. (Online) Available at: <http://www.euromines.org/news/newsletters/3-2016/the-eu-copernicus-programme-and-the-raw-materials-sector> (Accessed: August 10th 2017)

170 European Commission, 2016, Report : Copernicus for Raw Materials workshop (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/ajax/raw_materials_ws_report.pdf

171 European Commission, 2016, Integrating the extractive industries value chain in Copernicus (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/form-ZpdWWke1Pspaj6_KXzsXFbLNWJoJ_DnBIyREBgIXAsY/diaz_pulido_-_dg_grow.pdf

172 Copernicus newsletter. (Online) Available at: <http://newsletter.copernicus.eu/article/successful-launch-sentinel-1-marks-beginning-new-era-copernicus-programme> (Accessed: July 26th 2017)

173 European Commission, 2016, Report : Copernicus for Raw Materials workshop (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/ajax/raw_materials_ws_report.pdf

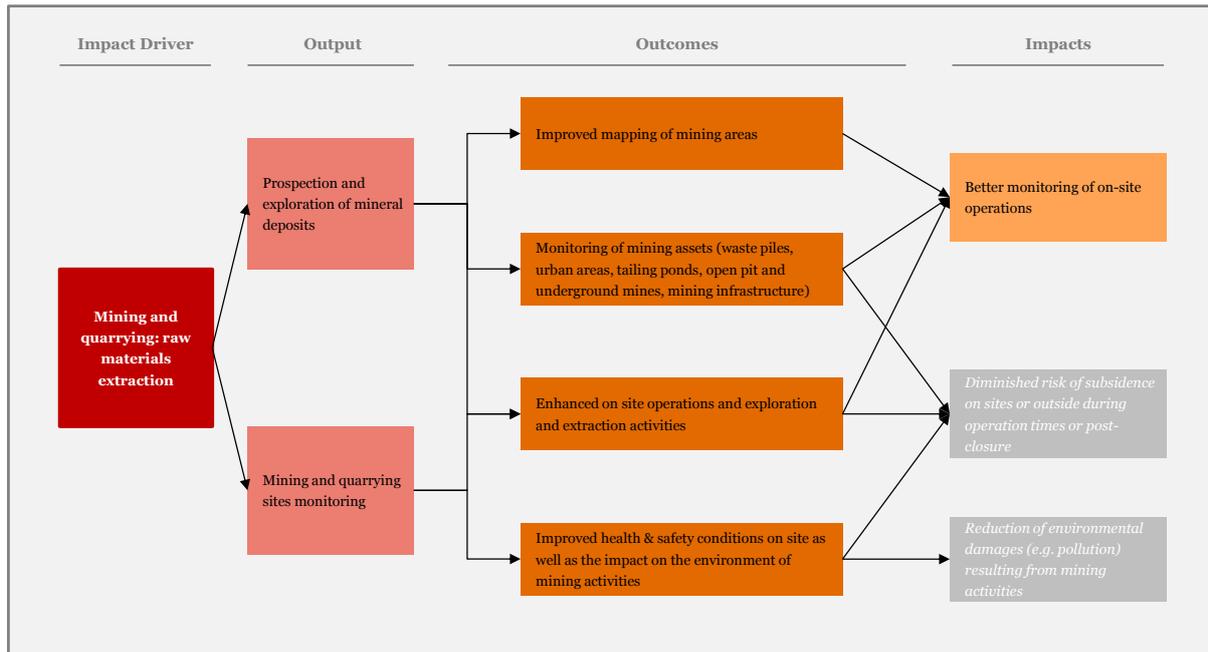


Figure 63 - Impact pathway for mining and quarrying: raw materials extraction (Source: PwC analysis)

Two main activities can be supported by Earth Observation and more precisely by Copernicus in the mining and quarrying sector: first, the prospection and exploration of mineral deposits (which consists in identifying the location and size of mineral deposits in order to determine the economic feasibility to exploit them), second, the mining and quarrying sites monitoring. Satellite images and derived products enable mining companies to detect areas that are inhabited and have a soil composition leading to expect the presence of ores and minerals. The outcomes include: a better knowledge of the mining areas thanks to the ability to dispose of precise mapping, an improved functioning of all extraction activities on site, a better surveillance of the evolution of all mining assets (e.g. displacement of waste piles), mostly enabled by radar imagery or an improved functioning of all extraction activities on site. Indeed, mines monitoring is facilitated by radar imagery, which impacts both the productivity on site and the conditions of workers on the mine. For instance, subsidence of pits, waste piles or tailings can lead to environmental or health and safety concerns such as issues for urban areas near mining extraction sites that are polluted or for workers subject to potential accidents on the mining site.

As a result of all these outcomes, the following impacts are expected:

- Better monitoring of on-site operations;
- Diminished risk of subsidence on sites or outside during operation times or post-closure;
- Reduction of environmental damages (e.g. pollution) resulting from mining activities.

4.2.3.3.4.1 Improved mine site surveying, resource reserves exploration and drilling and blasting leading to an increased output

In the past years, there have been few new mining projects in Europe. For instance, metal exploration activities in Europe are less numerous than in the rest of the world, partly because of policy frame constraints¹⁷⁴. This implies that most European projects are either in the operation phase or in the closure phase¹⁷⁵, which implies that Earth Observation-based applications useful for the mining sector in Europe mostly concern on-site activities and post-closure management. As such, products like land surface mapping, which, combined with geological models, enable to prospect mineral deposits, are currently of lesser importance in the current European context of mining and quarrying activities¹⁷⁶. Moreover, if, in the field of mining and quarrying applications, satellite data can prove really useful, it is mostly navigation data that are essential. Earth observation imagery is often only complementary to navigation data and is thus used in a limited number of applications (e.g. resource reserves exploration, mine site surveying and precise drilling and blasting, where satellite imagery is used for the development of maps enabling to detect specific areas)¹⁷⁷.



Methodological approach to value the improvement of monitoring operations

Our model is based on the Gross Value Added (GVA) of the mining and quarrying sector that is attributable to space activities and in particular to Copernicus. The steps are:

1. Assess the GVA of the mining and quarrying sector
2. Determine the share of the GVA that is generated thanks to space activities
3. Isolate, among space activities, the share that is due to Earth Observation
4. Assess the contribution of Copernicus to Earth Observation imagery used in the mining and quarrying sector

Improved exploration and extraction Valuation approach



In the last five years, the Gross value Added (GVA) has been constantly decreasing and has reached, in 2015, its lowest value since 2004¹⁷⁸. However, in the period before, the GVA has known highs and lows and can therefore be described as very volatile. As such, the projection of the GVA of mining and quarrying activities up to 2035 has been assumed to correspond to the average GVA of recent years and to remain constant over the period as there are major uncertainties for its evolution. 80% of this GVA has been generated thanks to the use of

¹⁷⁴ European Innovation Partnership on Raw Materials, 2016, Raw Materials Scoreboard (Online). Available at:

<https://publications.europa.eu/en/publication-detail/-/publication/1ee65e21-9ac4-11e6-868c-01aa75ed71a1/language-en> (Accessed: November 24th 2017)

¹⁷⁵ Benecke N. et al., 2012, GMES4Mining - Innovative Geoservices for Exploration and Monitoring of Mining Areas (Online); Available at:

http://www.gmes4mining.info/public/AIMS2012_GMES4Mining_Benecke_et_al.pdf

¹⁷⁶ Euromines website. (Online) Available at: <http://www.euromines.org/news/newsletters/3-2016/the-eu-copernicus-programme-and-the-raw-materials-sector> (Accessed: August 10th 2017)

¹⁷⁷ PwC, 2017, Dependence of the European Economy on Space Infrastructures: Potential Impacts of Space Assets Loss

¹⁷⁸ OECD, Mining and quarrying sector GVA https://stats.oecd.org/Index.aspx?DataSetCode=SNA_TABLE6A#

space-related applications for on-sites activities by mining companies¹⁷⁹. This number is also assumed to remain constant and not grow over the period though technology might evolve as on field work cannot always be replaced by space technologies. Among space applications, satellite imagery represents a minor part of the data used, between 0.1% and 0.2%¹⁸⁰. As such, Earth Observation data are responsible for the generation of between 0.08% and 0.16% of the mining and quarrying GVA.

As the contribution of Earth Observation imagery is already quite low and data with the higher resolution, hence mostly commercial data, are the most useful among satellite imagery used in mining and quarrying activities, the Copernicus contribution is low. As such, in 2015, Copernicus only contributed to 0.1% of Earth Observation data used, rising to 1.5% in 2020 and to 6% from 2030 on. This contribution of Copernicus is based on what is happening in the Oil & Gas sector (cf. section 4.2.3.3.3 – Oil & Gas infrastructure management/development and exploration activities): considering the mining Earth Observation market is not mature yet and that similar data and products are used both for the oil & gas sector and the mining sector, the contribution of Copernicus to Oil & Gas is used as a proxy to help determine the contribution of Copernicus to mining and quarrying activities. This increase in contribution by 2030 is due to the fact that Copernicus products including VHR data from Contributing Missions were either not released by the services or not used by Value Added Services (VAS) developers yet. Thanks to the free, full and open data policy of Copernicus, VAS developers seized the opportunity to create more products and services for a broader audience whereas products used to be tailored to a single customer because of their expensive costs linked to the reliance on commercial data only¹⁸¹. However, most products useful for mining companies are products targeting very specific and localised areas, hence there will always be a need of mining companies for products tailored to their need, hence based on VHR data.

As a result, benefits linked to Copernicus are expected to amount to between EUR 0.5 M and EUR 1.0 M in 2017, rising to between EUR 2.8 M and EUR 5.6 M in 2025 and to between EUR 4.5 M and EUR 8.9 M in 2035 for a total cumulative value ranging from EUR 54.9 M to EUR 109.8 M (not discounted values).

The global trend over the period is illustrated in the chart below. The benefits will increase concurrently with the Copernicus contribution up to 2030 and stagnate afterwards as the GVA and the user uptake will have reached maturity and remain constant.

¹⁷⁹ PwC, 2017, Dependence of the European Economy on Space Infrastructures: Potential Impacts of Space Assets Loss

¹⁸⁰ PwC, 2017, Dependence of the European Economy on Space Infrastructures: Potential Impacts of Space Assets Loss

¹⁸¹ Euromines website. (Online) Available at: <http://www.euromines.org/news/newsletters/3-2016/the-eu-copernicus-programme-and-the-raw-materials-sector> (Accessed: August 10th 2017)

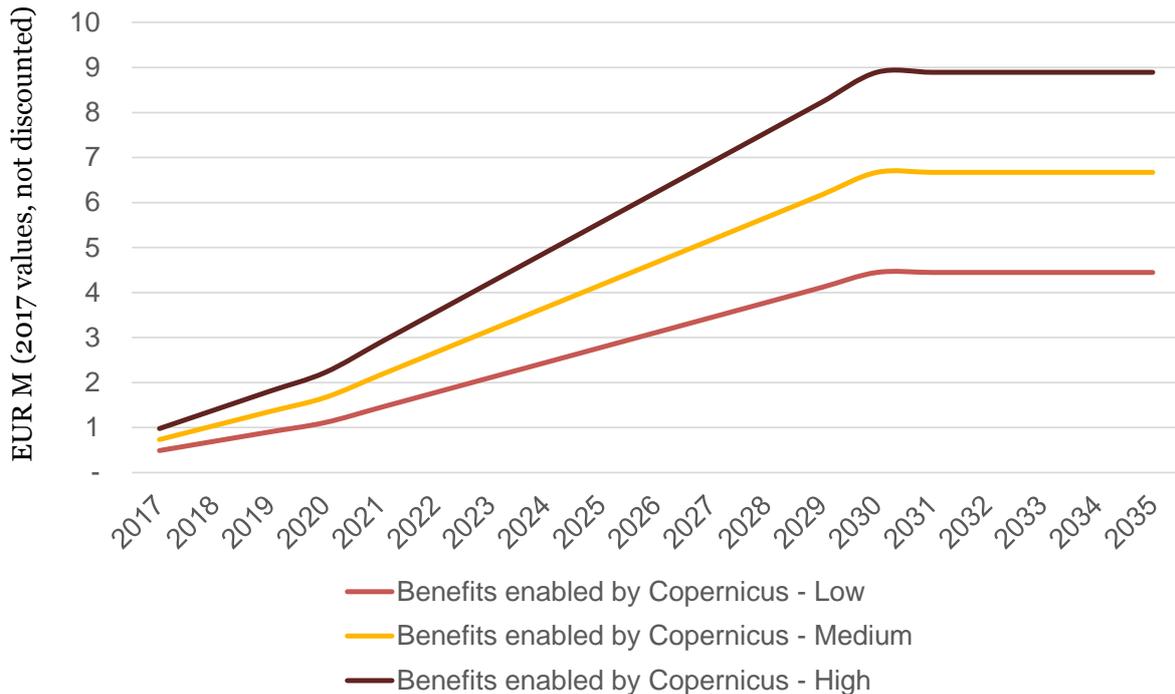


Figure 64 - Evolution of the Copernicus benefits for the impact “Improved mine site surveying, resource reserves exploration and drilling and blasting leading to an increased output” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Considering the very low impact of satellite imagery on the mining and quarrying activities, the shutdown of Copernicus assets in 2030 would not have enormous consequences as most satellite imagery currently used are not Copernicus D&I or are Contributing Missions data that would still exist without the Copernicus programme. As such, the major change would lie in the fact that satellite imagery used would become fee-based.

4.2.3.3.4.2 Diminished risk of subsidence on sites or outside during operation times or post-closure

Considering mining activities can lead to surface displacement, the use of satellite imagery and derived products can be useful to enhance mining safety¹⁸². Thanks to the Permanent Scatterer Interferometry (PSI) technique, ground deformation with a high spatial resolution over large areas can be perceived, with up to a millimetre accuracy. PSI notably requires the use of C-band SAR data, such as the ones provided by Sentinel-1¹⁸³. The only other satellite providing C-Band SAR data currently in orbit is Radarsat-2, whose revisit time is lower than the one of Sentinel-2 (24 days for Radarsat-2, 12 days for Sentinel-2, falling to 6 days when both Sentinel-2A and 2B are working)¹⁸⁴. This technique needs large sets of images, which gives Copernicus an advantage thanks to its free data policy. Not only can PSI monitor active mine activities (underground or open pit), but also abandoned mines and mining waste such

182 GMES4Mining, 2016, GMES-based geoservices for mining areas (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/form-ZpdWWke1Pspaj6_KXzsXFbLNWJoJ_DnBlyREBgIXAsY/muterthies_-_eftas.pdf

183 Crossetto, M., Monserrat, O., Jungner, A. & Crippa, B., 2009, Persistent Scatterer Interferometry: Potential and Limits http://www.isprs.org/proceedings/xxxviii/1_4_7-W5/paper/Crossetto-136.pdf

184 Colombo, D. & MacDonald, B., 2015, Using advanced InSAR techniques as a remote tool for mine site monitoring http://tre-altamira.com/uploads/2015_InSAR_mine-site_monitoring.pdf

as tailings¹⁸⁵. Considering the number of persons employed for mining and quarrying related jobs (over 560,000 in 2014¹⁸⁶) and therefore may have to be on-site, monitoring is important to prevent incidents (about 1,100 in 2014, not necessarily related to subsidence only¹⁸⁷). As such, the role of Copernicus in the reduction of mining-induced subsidence seems promising, however, this market is not mature yet and it is hard to currently quantify it.

This aspect is dealt with more in depth in section 4.2.3.2.6.2 – Reduced damages on civil and private buildings due to important surface deformation (landslides resulting from natural geohazards or soil subsidence due to former mining activities), which presents the impacts of landslides, including those resulting from past mining activities.

4.2.3.3.4.3 Reduction of environmental damages (e.g. pollution) resulting from mining activities

Mining activities can have a negative impact on the environment. For instance, tailings, which consists in storing the part of the extractive waste that have been gathered but are judged of poor quality and are not kept, can be damageable for the environment if not properly stored and continuous monitoring is needed, also during the post-closure phase. Indeed their mineralogical content may vary and contain residues of polluting elements that risk of being released in surrounding areas¹⁸⁸. It is therefore optimum to be able to track tailing, heap, pond and dam movements with SAR data such as those provided by Sentinel-1 in order to avoid damaging spreading. It is also necessary to be able to monitor their content in order to assess risks, which is feasible with multispectral imagery provided by Copernicus.

Mining activities can also impact air quality, as presented in section 4.2.3.1.1 – Air quality and pollution monitoring.

4.2.3.3.4.4 Summary of Copernicus contribution to “Oil and Gas infrastructure management/development and exploration activities”

The total not discounted benefits linked to Copernicus are expected to amount to:

<i>Copernicus EU benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	0.49	2.78	4.45	54.9
Medium estimate	0.73	4.17	6.67	82.3
High estimate	0.98	5.56	8.89	109.8

Table 19 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below.

185 EuroGeoSurveys, 2016, Earth Observation for Raw Materials (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/form-ZpdWWke1Pspaj6_KXzsXFbLNWJoJ_DnBiyREBgIXAsY/herrera_-_egs.pdf

186 ESTAT – Structural business statistics

187 ESTAT – Structural business statistics

188 GMES4Mining, 2016, GMES-based geoservices for mining areas (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/form-ZpdWWke1Pspaj6_KXzsXFbLNWJoJ_DnBiyREBgIXAsY/muterthies_-_eftas.pdf

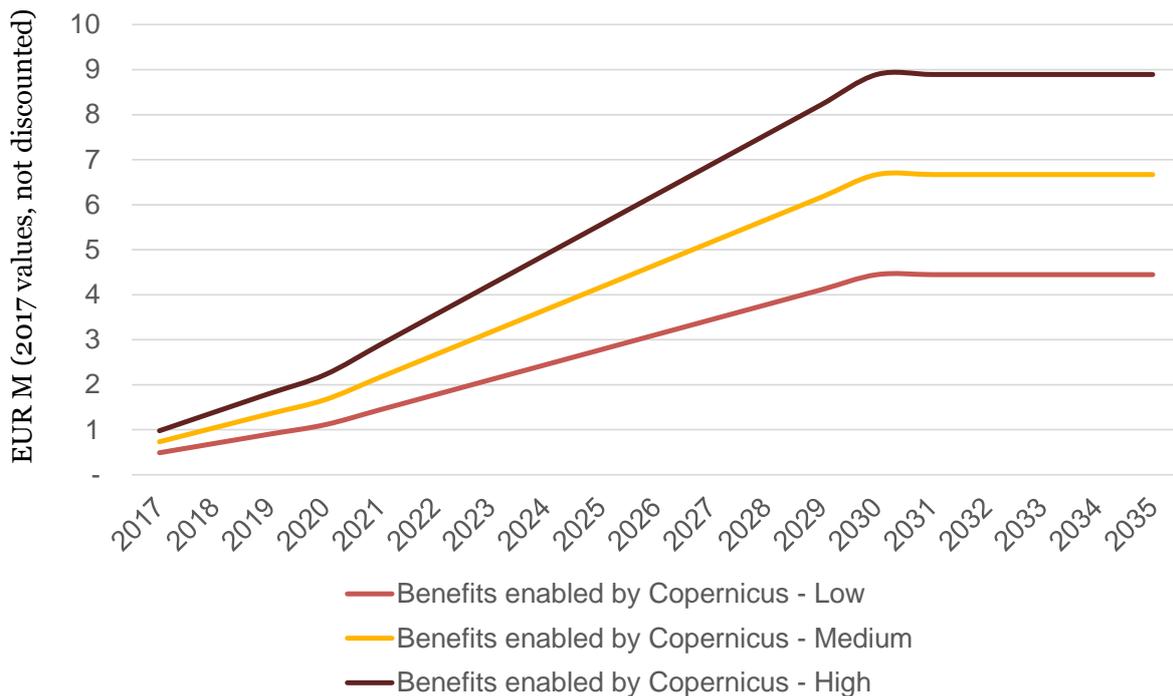


Figure 65 - Evolution of the Copernicus benefits for Mining and quarrying: minerals and raw materials extraction, from 2017 to 2035 (Source: PwC analysis)

4.2.3.4 Marine & ocean

4.2.3.4.1 Coastal area monitoring

Coastal area monitoring includes a broad range of interlinked challenges between urban and land areas and offshore maritime areas. Indeed, natural marine and environmental factors such as waves, winds, wind, tides, storms, currents, etc. have an impact on coastal land areas. In addition, human factors such as coastal urbanisation and economic activities are also included in the list of drivers contributing to coastal degradation.

The Copernicus Marine Environment Services (CMEMS) aim to provide marine observation and forecast information through a free and open service based on both satellite and in-situ data. Such data contributes to support coastal area monitoring activities in the different EU sea basins. These Copernicus services offer various sets of data on coastal marine activities and cover mainly the EU sea basins as well as the Pacific, Atlantic, Indian, Arctic and Antarctic Oceans¹⁸⁹. The launch of Sentinel-3A in February 2016, enabled the replacement and update of earth observation data collection that was until then supported by Envisat. Consequently, Sentinel-3A has allowed the Copernicus Marine Environment Services to widen and expand its range of Ocean missions. The Sentinel-3A's payload is composed of several instruments such as a Sea and Land Surface Temperature Radiometer, a synthetic Aperture Radar Altimeter, a Microwave Radiometer and an Ocean and Land Colour Instrument. These payloads enable the execution of missions such as sea-surface topography assessment, ocean temperature measurement, sea-water quality monitoring, ocean forecast, and climate monitoring and modelling¹⁹⁰. Furthermore, the launch of

¹⁸⁹ Copernicus Marine Service Catalogue Overview June 2017

¹⁹⁰ ESA's website: Sentinel-3A Mission Details - <https://earth.esa.int/web/guest/missions/esa-co-missions/sentinel-3>

Sentinel-3B in 2018 is expected to consolidate Copernicus' support to Coastal area monitoring by doubling the amount of collected data and thus improving the robustness of forecast models.

The numerous observation instruments mounted on Sentinel-2A/B and Sentinel-3A support Coastal area monitoring in shoreline monitoring and management activities. The following impact pathway maps the processes leading to the benefits (impacts) achieved through the use of Copernicus in support of Coastal area management:

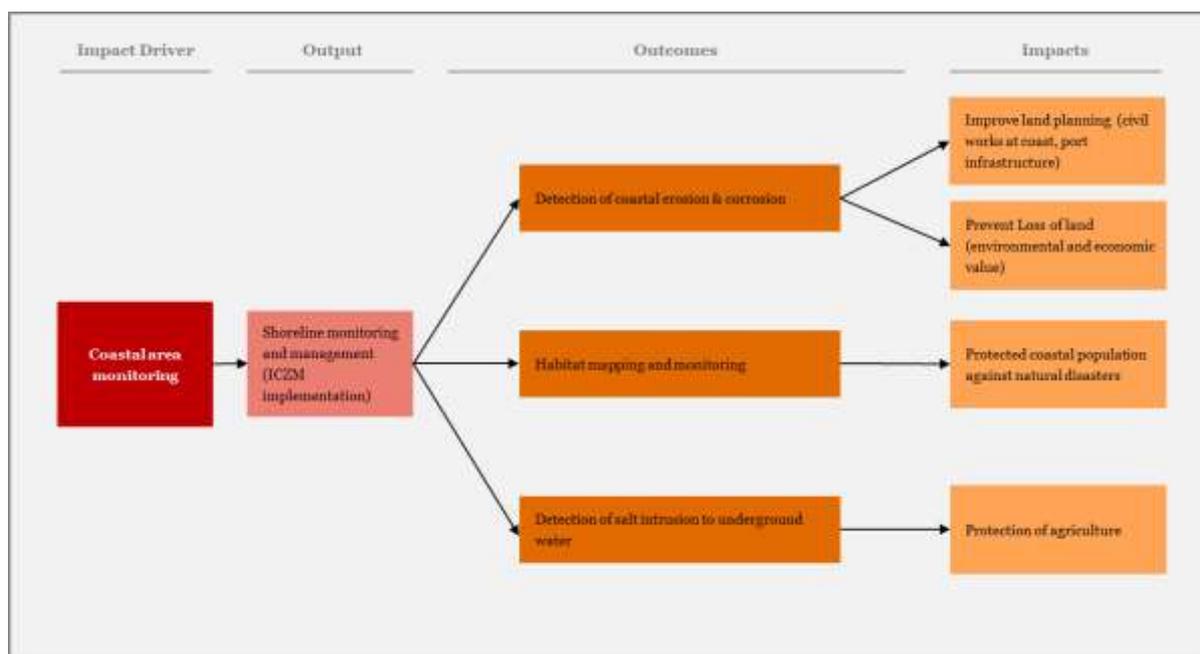


Figure 66 - Impact pathway for Coastal Area Monitoring (Source: PwC Analysis)

The EU Integrated Coastal Zone Management (ICZM) initiative and approach sets the best practices for risk prevention, better informed decision making, coastal environment protection and coastal infrastructure and sustainable planning. Copernicus products are relevant to all entities taking part in EU coastal zone management activities and bring added value for the detection of coastal erosion and corrosion, habitat mapping and monitoring and the detection of salt intrusion into underground water sources.

As a result of the impact pathway for Coastal Area Monitoring, the following benefits can be highlighted:

- Improve land planning (civil works at coasts, port infrastructure);
- Prevent loss of land;
- Protected coastal population against natural disasters;
- Protection of agriculture.

The processes leading to the quantification of benefits enabled by Copernicus are provided in the following paragraphs:

4.2.3.4.1.1 Reduce costs of land planning (civil works at coast, port infrastructure)

Early detection of erosion and corrosion is highly important to prevent the phenomenon from growing into an important threat to coastal infrastructures. The average annual public

expenditure dedicated to EU coastline protection is worth EUR 5 billion and is expected to reach EUR 7 billion by 2035¹⁹¹. Satellite imagery data is key in understanding the various trends of coastal erosion and accurately forecast its evolution. Therefore, better informed decision making is enabled thanks to Copernicus data, which leads to optimised expenditures dedicated to coastline protection.

The quantification approach employed to measure the benefits of Copernicus which enable the reduction of costs for land planning in coastal zones is built upon the assessment of the average annual public expenditure dedicated to coastline protection in Europe between 2017 and 2035. To this results has been applied the contribution rate of Copernicus to obtain the value the cost reduction of land planning in coastal areas.



Methodological approach to value reduced cost of land planning (civil works at coast, port infrastructure)

Our model is based on the quantification of savings enabled by Copernicus in the field of coastal land planning. The steps are:

1. Assess the average annual public expenditure dedicated to coastline protection in Europe
2. Apply the contribution of Copernicus through the different CEMS products enabling better decision making and therefore cost reduction of land planning

Reduce costs of land planning

Valuation approach



Copernicus data are not the only inputs that are required to optimise expenditure, as data from other sources, other technologies and human effort are also required. Conservatively assuming that Copernicus's contribution to the expenditure savings starts between 0,51% and 2% in 2016 and grows to reach between 0,61% and 2.43% in 2035¹⁹², the use of Copernicus is expected to reduce expenditures dedicated to coastline protection and thus enable expenditure savings of a total value ranging between EUR 764 M (Low scenario) and EUR 3,058 (High scenario).

191 EC – Results of the EuroSION study (2004) - http://www.euroSION.org/project/euroSION_en.pdf

192 PwC Assumption based on qualitative interview feedback

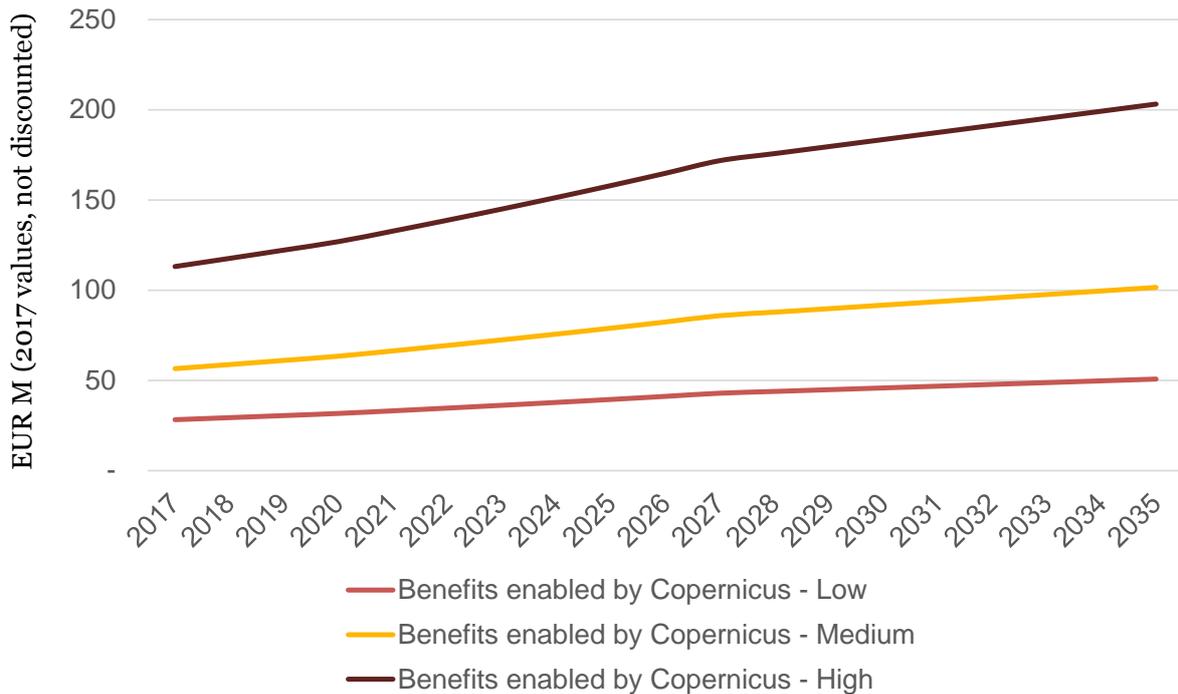


Figure 67 - Evolution of the Copernicus benefits for reduced costs of planning in Coastal areas (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The information provided by Copernicus data on coastal areas enable a fast analysis of areas concerned by coastal erosion and therefore represent a valuable input to better decision making when planning coastal protection actions. Compared to non-space borne data, Earth Observation and Copernicus data are much timely to collect and analyse when examining a wide area.

4.2.3.4.1.2 Prevent loss of land

Coastal erosion threatens 20% of the entire EU coastline and despite the protection efforts mentioned in the previous paragraph, the phenomenon leads to an average loss of 15km² of land per year¹⁹³. Such yearly loss implies that nearly EUR 900 M worth of EU coastal infrastructures are jeopardised by erosion. By supporting better decision making and planning measures for the protection of coastal infrastructure, Copernicus data allows the reduction or at least the containment of coastal loss.

193 EC – Results of the EuroSION study (2004) - http://www.euroSION.org/project/euroSION_en.pdf



Methodological approach to value the prevention of land loss due to coastal erosion

This model is based on the economic valuation of coastal land jeopardised by coastal erosion. The steps are:

1. Assess the average surface (km²) of coastal land lost due to coastal erosion
2. Apply the average value of land (km²) to the amount of coastal land lost due to coastal erosion
3. Apply the contribution of Copernicus to the prevention of coastal land loss to the actual value of land lost due to coastal erosion

Prevent loss of land

Valuation approach



The contribution of Copernicus on the prevention of coastal land loss was assumed to be comprised between 0.5% and 2.5% and reach between 1% and 4.4% in 2035. Such contribution values and evolution are built upon assumptions based on the analysis of several qualitative parameters such as the place of Copernicus data among the value chain of components leading to coastal erosion modeling. Thus when taking into consideration such assumptions, the Copernicus programme would enable a total cumulative value ranging between EUR 153.4M (low scenario) and EUR 766.9 M (High scenario) worth of EU land and coastal infrastructure (not discounted values).

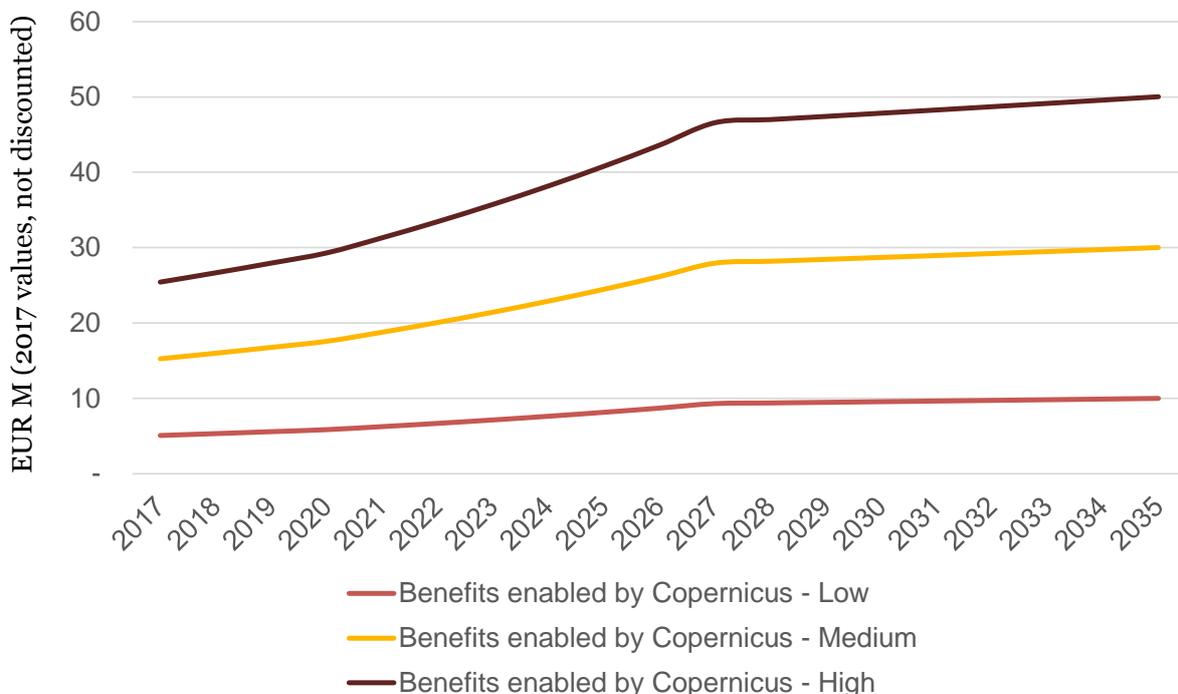


Figure 68 - Evolution of the Copernicus benefits for "Reduced loss of land" from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Similarly to the inputs brought to the reduction of coastal protection costs, the information provided by Copernicus data on coastal areas allow quicker and enhanced analysis of areas concerned by coastal erosion. Therefore, faster and better decision making is done when planning the construction of coastal infrastructures.

4.2.3.4.1.3 Protected coastal population against natural disasters

Coastal areas are considered to be part of the most productive zones in the world and are particularly exposed to environmental hazards and climate changes involving storms and floods. In 2016, it was estimated that one third of the total EU population was living within 50km of EU coasts¹⁹⁴. Considering the importance and vulnerability of coastal zones, efficient and performant means of protection must be put in place to sustain coastal productivity while preserving coastal ecosystems and their biodiversity.

Assuming that 30% of severe storms and floods occur in coastal regions¹⁹⁵, and taking into account that an average amount of 6 casualties befall during both severe storms and flood events¹⁹⁶, it was estimated that 94 people perished in environmental hazards occurring in EU coastal zones in 2016.



Methodological approach to value the protection of coastal populations against natural disasters

This model is based on the economic impact of fatalities caused by natural disasters in coastal zones. The steps are:

1. Assess the average number of fatalities caused by natural disasters in coastal areas
2. Assess the economic impact of these fatalities
3. Apply the contribution of Copernicus to the mitigation of fatalities caused by natural disasters in coastal areas

Protected coastal population against natural disasters

Valuation approach



Assuming that Copernicus data would have an impact rate of 1.5% in 2016 reaching 2.4% in 2035¹⁹⁷, a total number of 40 lives are estimated to be saved during the 2016 – 2035 period (medium scenario). Based on the average value of life of EU Member States citizens, the total number of fatalities avoided over the period represents an economic value ranging between **EUR 43.9 M** (Low scenario) and **EUR 175.8 M** (High scenario).

194 Copernicus' website – Climate Change impact on coastal areas sector - <https://climate.copernicus.eu/resources/information-service/climate-change-impact-coastal-areas-sector>

195 PwC Assumption based qualitative data collected through desk research

196 PreventionWeb – Europe Disaster Statistics - http://www.preventionweb.net/english/countries/statistics/index_region.php?rid=3

197 PwC Assumption based on qualitative interview feedback and desk research

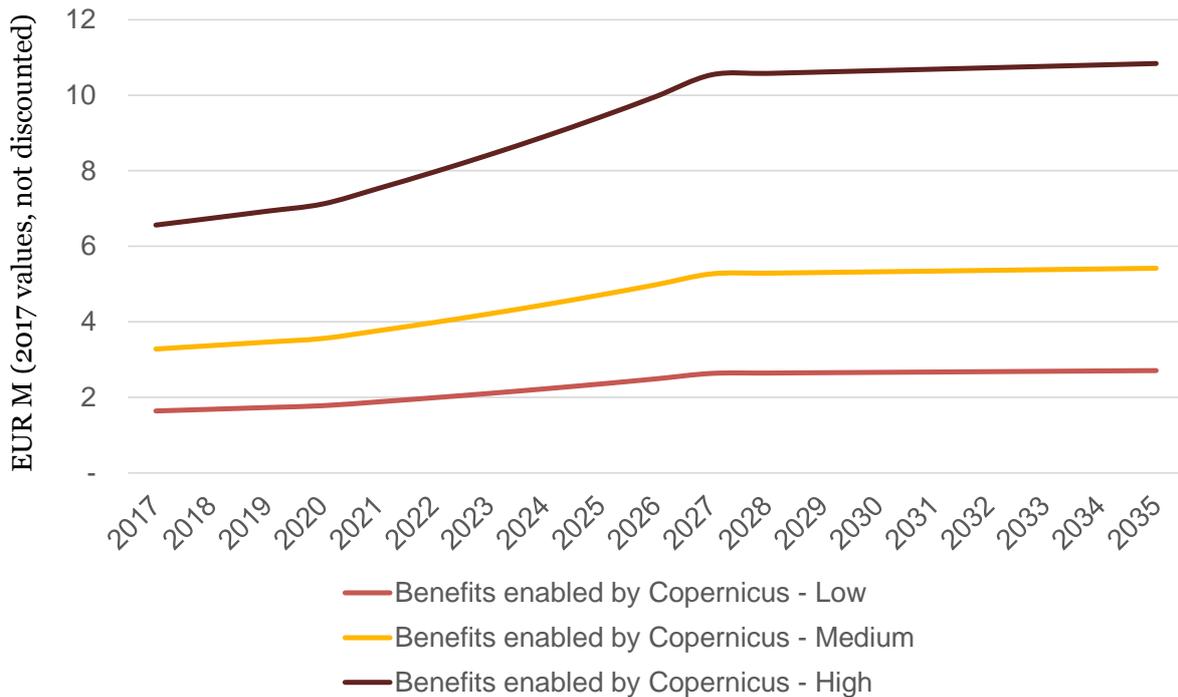


Figure 69 - Evolution of the Copernicus benefits for protected coastal population against natural disasters from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Copernicus data can contribute to the protection of coastal population against natural disasters by providing models on marine mechanisms such as sea level, wave intensity, drifts, and winds that lead to a better identification of specific areas exposed to floods and severe storms' direct effects and aftereffects.

4.2.3.4.1.4 Protection of agriculture

Marine activities and excessive exploitation of natural resources undermine coastal regions and lead to issues such as saltwater intrusion into groundwater sources. Today coastal agriculture is threatened by this issue as groundwater sources provide 41% of the water utilised for irrigation in Europe¹⁹⁸.

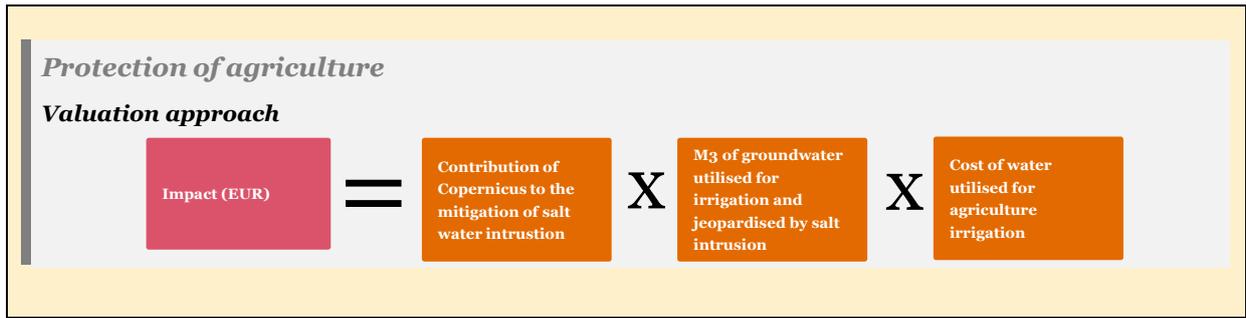


Methodological approach to value the protection agriculture

This model is based on the economic value of water contaminated by salt intrusion. The steps are:

1. Assess the percentage and amount (m3) of irrigation water coming from groundwater sources jeopardised by salt intrusion
2. Assess the cost of water utilised for agriculture irrigation (€/m3)
3. Apply the economic value of water utilised for irrigation to the amount of irrigation water coming from groundwater sources and jeopardised by salt intrusion.
4. Apply the contribution of Copernicus to the economic value of water threatened by salt intrusion

¹⁹⁸ Eurostat – water source used for irrigation (2010) - [http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Water_source_used_for_irrigation,_2010_\(%25_of_holdings_using_each_method\).png](http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Water_source_used_for_irrigation,_2010_(%25_of_holdings_using_each_method).png)



A study on groundwater sources utilised for irrigation in Spain points out that 10% of Spanish groundwater sources are contaminated by seawater. As it is challenging to compile and synthesise data concerning all MS and the European continent in general, this study focusing on Spanish groundwater was used as a proxy, as it appeared in preliminary researches that the case of Spain was quite representative of the rest of the EU continent. When extracting this trend and applying the same ratio for the rest of Europe, it appears that an average of EUR 291 M worth of groundwater is wasted due to saltwater intrusion.

Because of its indirect impact on seawater intrusion containment, the contribution of Copernicus for the protection of agriculture conducted in coastal area was estimated between 0.75% and 3% in 2016 raising between 1% and 3.5% in 2035¹⁹⁹. The value of groundwater preserved thanks to Copernicus over the total period ranges between **EUR 52.8 M** and **EUR 211.2 M**.

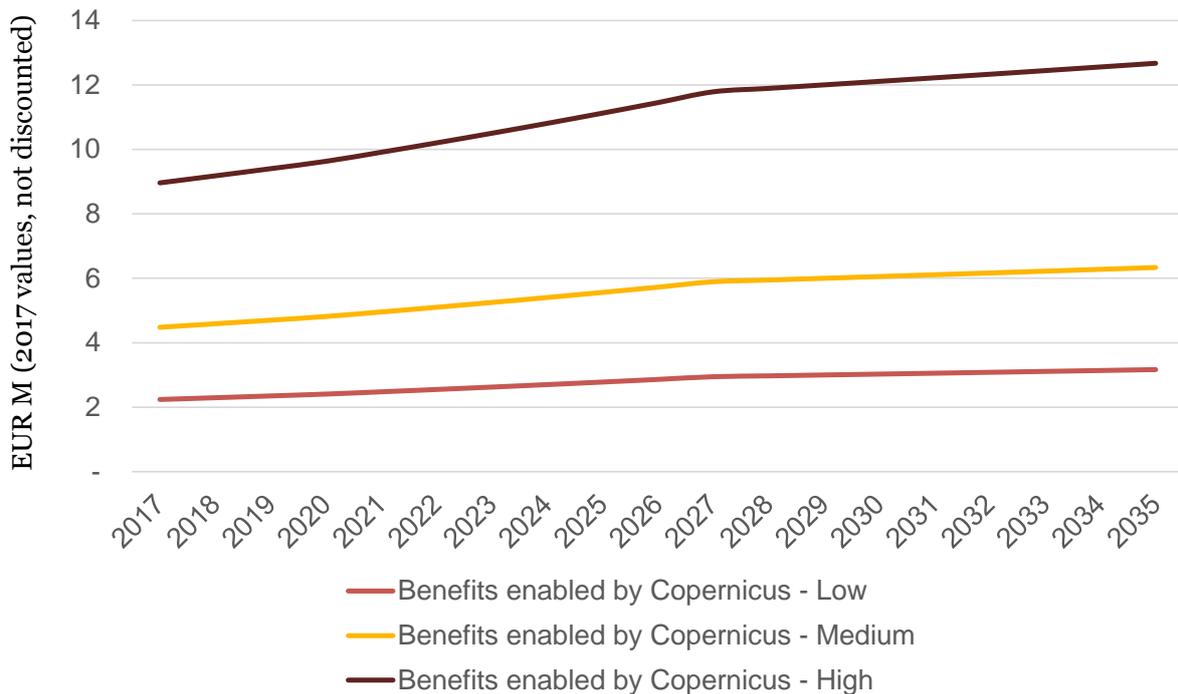


Figure 70 - Evolution of the Copernicus benefits for protection of agriculture from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

199 PwC Assumption based on qualitative interview feedback and desk research

Copernicus data supports the detection of saltwater intrusion into groundwater sources and helps researchers in understanding the occurrence of the phenomenon and therefore its containment and the reduction of its effects.

4.2.3.4.1.5 Summary of Copernicus contribution to “Coastal monitoring”

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

<i>Copernicus benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	37.2	52.8	66.6	1,014.1
Medium estimate	79.6	113.8	143.3	2,182.6
High estimate	154.1	219.4	276.7	4,211.8

Table 20 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below.

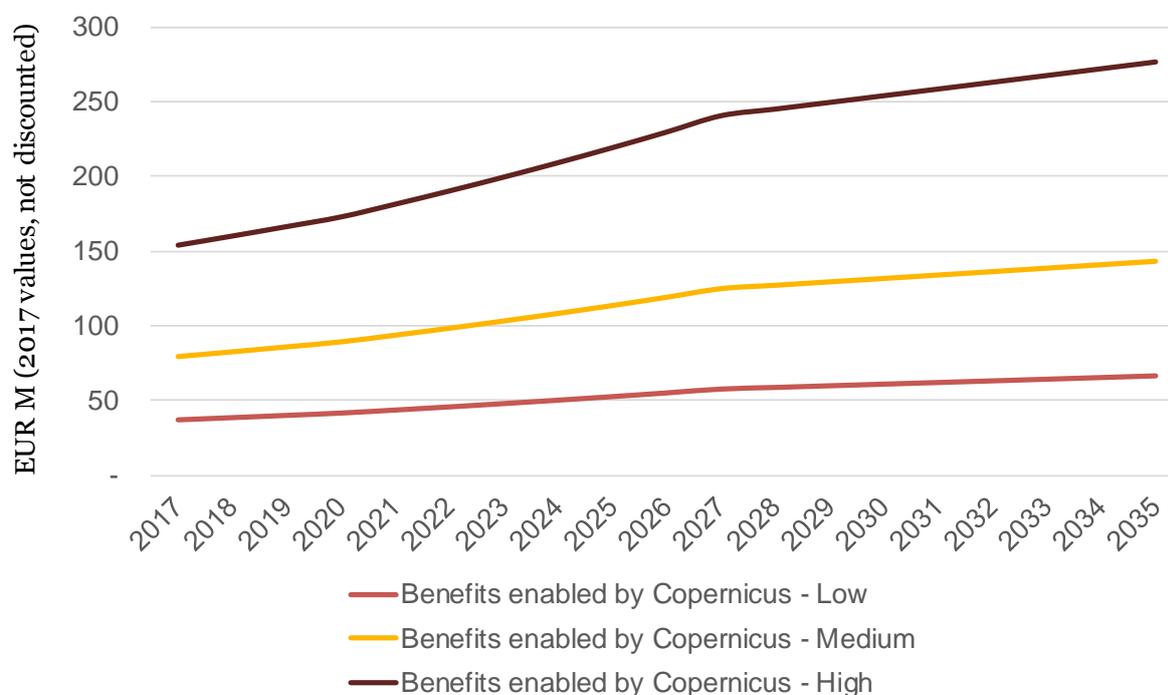


Figure 71 - Evolution of the Copernicus benefits for Coastal area monitoring from 2017 to 2035 (Source: PwC analysis)

4.2.3.4.2 Marine resources management

Marine resources management, including sustainable fishing, plays a key role in effectively managing the oceans, as we rely on our marine environment for food to support the growing human population.

Sustainable fishing is a key consideration for food security, as seafood plays a significant role in the human diet, both in Europe and worldwide, where approximately 20% of the global

population acquires at least 20% of their animal protein from fish²⁰⁰. As the population increases, pressure on aquaculture production will only grow. The wild catch of many species at sea have already exceeded sustainable levels, this need can only be met by expanding aquaculture. However, the sustainable management of aquaculture sites can be challenging, and requires continuous monitoring of local conditions. Monitoring of conditions can, for example, provide inputs to optimise site locations for both fish farmers and wild fishermen. Monitoring data also provide key inputs for fish stock modelling, which can be used to develop recommended quota levels for key fish stocks, and to forecast the evolution of fish stocks, including protected species. Therefore, the use of satellite imagery and modelled products and services are key to monitor conditions, support site optimisation and quotas, and improve practices for the protection of protected species.

Through the Copernicus Marine Environment service (CMEMS), data models and services are available on ocean temperature, currents, salinity and the chlorophyll content of the ocean's surface levels alongside other biogeochemistry factors associated with ocean colour. These services enable the analysis of the ocean to optimise both wild and fish farm sites, and the analysis of fish stocks. These have been used for a number of studies to monitor ocean conditions²⁰¹, however it is acknowledged that only 12-15% of Copernicus' users are using the CMEMS data to support sustainable fishing and marine resources management²⁰².

From a regulatory perspective, the availability of ocean monitoring data helps to identify potential fishing hotspots (e.g. areas of increased catch per unit of effort; areas with improved conditions for fish farming growth) and provides key inputs for fish stock monitoring, (e.g. informing debate on the EU total allowable catch) and recommendations for practices to protect protected species. This leads to the following impact pathway, which maps out the total impact of the marine resources management application (impact driver) through to the particular environmental, societal or economic benefits (impacts):

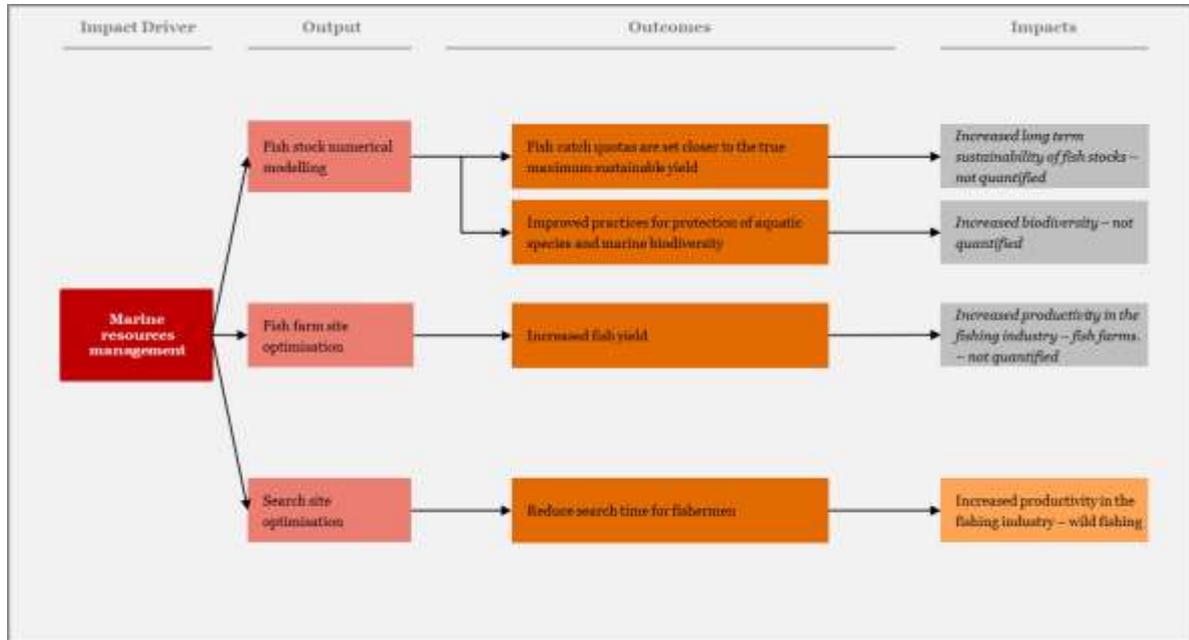


Figure 72 - Impact pathway for marine resources management (Source: PwC analysis)

²⁰⁰Copernicus Brief. (Online) Available at:

http://www.copernicus.eu/sites/default/files/documents/Copernicus_Briefs/Copernicus_Brief_Issue24_Aquaculture_Sep2013.pdf (Accessed: July 20th 2017)

²⁰¹ Copernicus case studies. (Online) Available at: <http://marine.copernicus.eu/benefits/marine-resources/downstream-use-cases/> (Access: July 20th 2017)

²⁰² Interview with Cécile Thomas-Courcoux, conducted on July 17th 2017.

We note that this is only a small section of the current impacts of Copernicus within the marine resources management, due to the scope of our study. We could not value the benefits for some important Copernicus outputs, for example, managing coral reef systems. Therefore this section should be read with the knowledge that this represents a small proportion of overall benefits.

From a commercial and broader scientific perspective, monitoring ocean conditions to support marine resources management enables fish stock modelling, fish farm site optimisation and wild fishing site optimisation. Primarily, fish stock modelling can be used to recommend quotas on key fish stocks. Fish stock numerical models, currently in place for the tuna population in the Western Pacific Ocean, map the changes in recruitment, mortality and migrations, and recommend quota levels to align with the maximum sustainable yield²⁰³. Furthermore, fish stock models can be used to recommend changes in practices within the fishing industry to improve the protection of protected species, in order to reduce bycatches, for example.

Secondly, more productive sites can be highlighted from analysis of ideal conditions for fish farms. This can lead to a potential increase in the health of the fish far produce, and hence an increase in the productivity of fish farmers, who choose sites more easily chosen thanks to knowledge of ocean conditions.

Thirdly, more productive areas of wild fish can be modelled using ocean data, which can be used by fishermen to increase their catch per unit effort. This allows fishermen to reduce their search time, increasing productivity within the fishing industry.

4.2.3.4.2.1 Increased long term sustainability of fish stocks

This benefit is associated with the output “fish stock numerical modelling”. It could not be quantified within the scope of this study, as there is a lack of available information on the associated long term benefit of setting quotas to align with the maximum sustainable yield, and limited information to construct an estimate for the potential contribution of Copernicus.

4.2.3.4.2.2 Increased biodiversity

This benefit is also associated with the output “fish stock numerical modelling”, because this output leads to improved practices for protection of aquatic species and marine biodiversity, such as sea turtles for example. This benefit could not be quantified within the scope of this study, as there is a lack of data on the natural capital valuation of these species and the associated benefits of the improved practices

4.2.3.4.2.3 Increased productivity in the fishing industry – fish farms

The benefits associated with fish farm site optimisation could not be quantified within the scope of this study. There is a lack of scientific studies on the productivity increase associated with optimising fish farm site location, particularly when associated with the application of satellite data. The additional benefit of Copernicus *a priori* is expected to be small, as fish farm sites are often considered optimised without using satellite data.

4.2.3.4.2.4 Increased productivity in the fishing industry – wild fishing

Fisheries and aquaculture directly employed over 56.6 million people globally in 2014, with over 65% employed as fishermen in wild fisheries²⁰⁴. The analysis to value this impact is based on productivity improvements in fishing harvests in West Bengal, India. Empirical evidence for this region has shown that satellite derived ocean colour (chlorophyll-a) and sea

²⁰³ Interview with Philippe Gaspar, conducted on August 25th 2017. Further information on the model can be found at www.spc.int/ofp/seapodym/.

²⁰⁴ Data available at The State of World fisheries and Aquaculture 2016, Table 10. Available at: <http://www.fao.org/3/a-i5555e.pdf> (Accessed: August 6th 2017)

surface temperature data can be used for prediction of Potential Fishing Zones (PFZ). The study elicits the benefits of satellite derived PFZ advisories using two identical fishing crafts. The benefits found were that search time to locate fish schools and associated mean catch per unit effort (CPUE) in PFZ areas was almost twofold in comparison to the CPUE of non-PFZ areas²⁰⁵. Therefore, should a similar approach be taken globally, the efficiency gains can be quantified by estimating the total cost savings by fisheries, specifically the labour and fuel costs of operations.

However, we recognise and note the limitations of transferability of this study, as a wider data set was not available. Recognising the limitations of transferability of this data, we have included a number of factors in our extrapolation and forecasting. Primarily, as the cost savings are calculated by the labour costs of operations, the results are influenced by the number of number of fish farmers in the region. The number of fishers in the EU has been on a downward trend²⁰⁶, in contrast to global fishers. This has influenced the labour cost savings estimate for the EU, and increases the difference between EU and global benefits. Furthermore, fuel costs of operations are influenced by the relative catch of motorised versus non-motorised vehicles. This is forecasted to fall globally, although within the EU this is forecasted to rise²⁰⁷. However these savings are reduced by the average fuel intensity in the EU (fuel consumed per tonne of fish landed) being relatively efficient. Due to these two factors, the value of the benefits associated with increased productivity in the EU are estimated to reach a plateau around 2030. Although out of core scope of the study, we have included the non-EU benefits for this impact for context.

The quantification of the increased productivity of the fishing industry by reducing search time for wild fisheries is detailed below.



Methodological approach to increased productivity associated with reducing search time

Our model is based on the calculation of the labour and fuel costs saved should the production associated with 50% of global fishing sites be optimised in line with the above study. The steps are:

1. Determine the labour costs associated with persons directly employed by wild fisheries and fuel costs associated with search sites, varying by region
2. Calculate the cost savings associated with increased productivity
3. Apply a roll out as the technology becomes more popular
4. Apply the contribution of Copernicus to this cost saving

Increased productivity associated with reduced search time Valuation approach



²⁰⁵ Based on the "Satellite based integrated potential fishing zone advisories: a feasibility analysis in the coastal water of West Bengal" study (online). Available at : <https://link.springer.com/article/10.1007/s12595-013-0088-x> (Access: July 21th 2017)

²⁰⁶ Data available at The State of World fisheries and Aquaculture 2016, Table 10. Available at: <http://www.fao.org/3/a-i5555e.pdf> (Accessed: August 6th 2017)

²⁰⁷ Data available at The State of World fisheries and Aquaculture 2016, Table 13, Figure 10. Available at: <http://www.fao.org/3/a-i5555e.pdf> (Accessed: August 6th 2017)

Due to lack of robust data on the proportion of benefits which could be associated to Copernicus satellites, we have assumed that the proportional contribution of Copernicus should be estimated to be between 6% and 12%. Due to the lack of robust data in the area, we have used the Copernicus EO revenue share for the ocean monitoring section as our baseline assumption on the proportion of benefits to be attributed to Copernicus²⁰⁸. However, we expect that as an open data product, the market share may underrepresent this proportion, and there may be advantages of Copernicus products compared to other providers not fully reflected in current market share. We have therefore assumed a 12% contribution of Copernicus as a high scenario.

Assuming that 50% of global fishing sites can be located and optimised using satellite derived data, total benefits for EU in terms of saved labour and fuel costs of operations from search site optimisation amount to between EUR 6.3 M to EUR 12.6 M in 2017, rising until between EUR 37.0 M and EUR 74.0 M per year by 2035, for a total cumulative value ranging from EUR 386 M to EUR 772 M (not discounted values).

Although not in the core scope of this study, total benefits for non-EU countries have been provided for context. These benefits amount to between EUR 324.9 M and EUR 649.9 M in 2017, rising to between EUR 2,422 M and EUR 4,845 M by 2035, for a total cumulative value ranging from EUR 23,886 M to EUR 47,773 M (not discounted values). The results are illustrated in the two charts below:

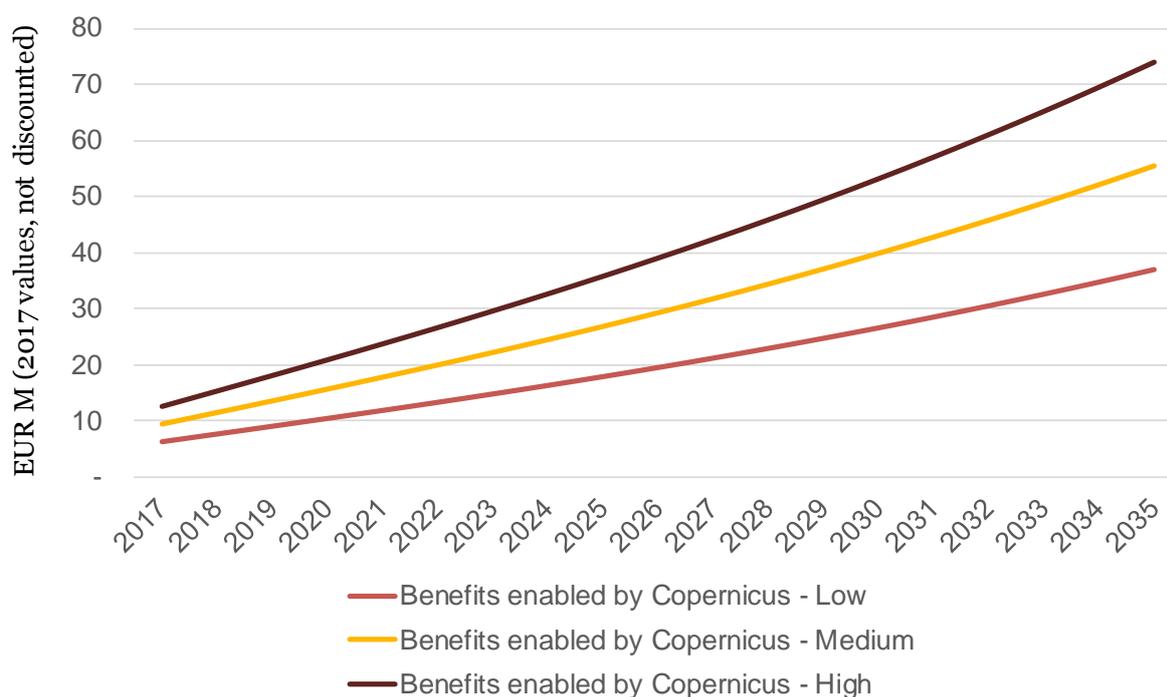


Figure 73 - Evolution of the Copernicus benefits for the EU for the impact “Increased productivity in the fishing industry from optimising search areas” from 2017 to 2035 (Source: PwC analysis)

²⁰⁸ Earth observation revenues for the ocean monitoring sector amounted to EUR 103.85 M in 2015, and among those, EUR 5.76 M can be directly attributable to Copernicus. Taken from the study to examine the socio-economic impact of Copernicus in the EU. Report on the Copernicus Downstream Sector and User Benefits.

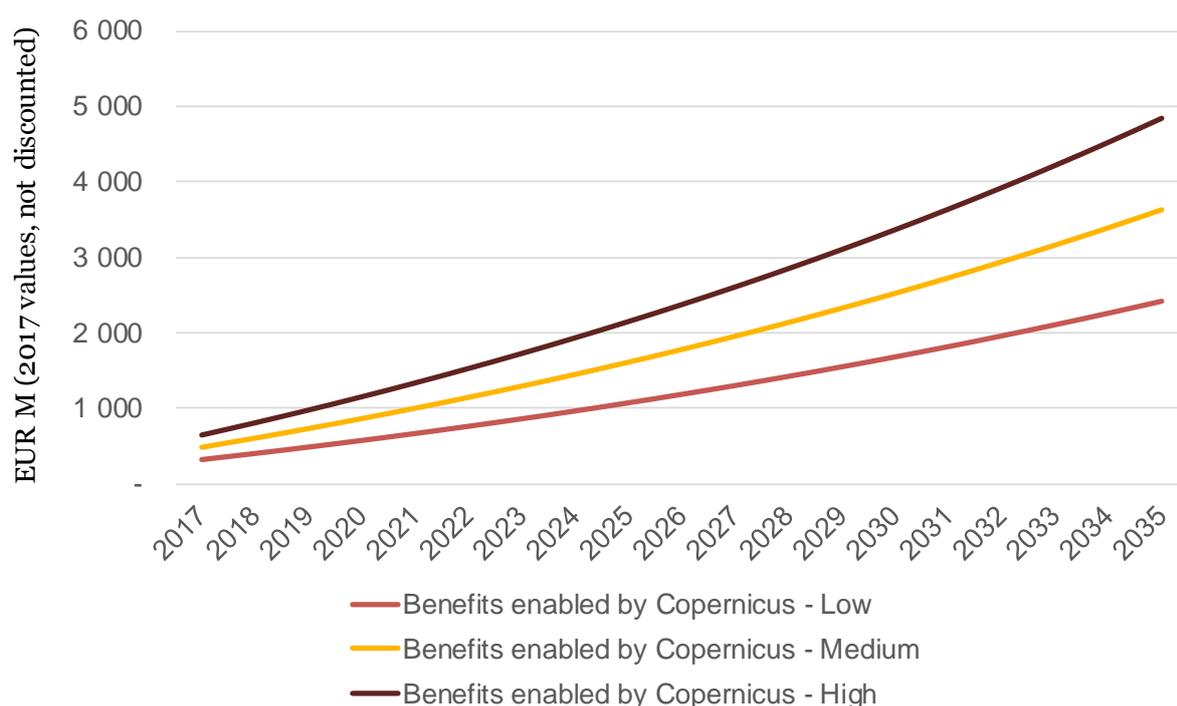


Figure 74 - Evolution of the Copernicus benefits for non-EU countries for the impact “Increased productivity in the fishing industry from optimising search areas” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Due to lack of robust data on the proportion of benefits which could be associated to Copernicus satellites, we have assumed that the proportional contribution of Copernicus should be estimated at between 6% and 12%. This is realistic, as satellite data is used in this area to provide key data sources however it is limited in its outreach as many users of Copernicus data do not use the data provided for sustainable fishing. If all Copernicus assets were shut down in 2030, other sources of satellite data could be used, but would be limited in the quality of results.

4.2.3.4.2.5 Summary of Copernicus contribution to “Marine resources management”

As a result, the total not discounted benefits linked to Copernicus for non-EU countries are expected to amount to:

<i>Copernicus Global benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	324.9	1,076.6	2,422.7	23,886.5
Medium estimate	487.4	1,614.9	3,634.1	35,829.8
High estimate	649.9	2,153.2	4,845.5	47,773.1

Table 21 - Copernicus total Global benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The total not discounted benefits linked to Copernicus in the EU are expected to amount to:

<i>Copernicus EU benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
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Low estimate	6.3	17.9	37.0	386.2
Medium estimate	9.4	26.9	55.5	579.2
High estimate	12.6	35.8	74.0	772.3

Table 22 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below, calculated by summing both the EU and non-EU benefits. It matches the curve of the non-EU graph as the contribution of this quantified benefit is much larger and has therefore more impact on the total benefits.

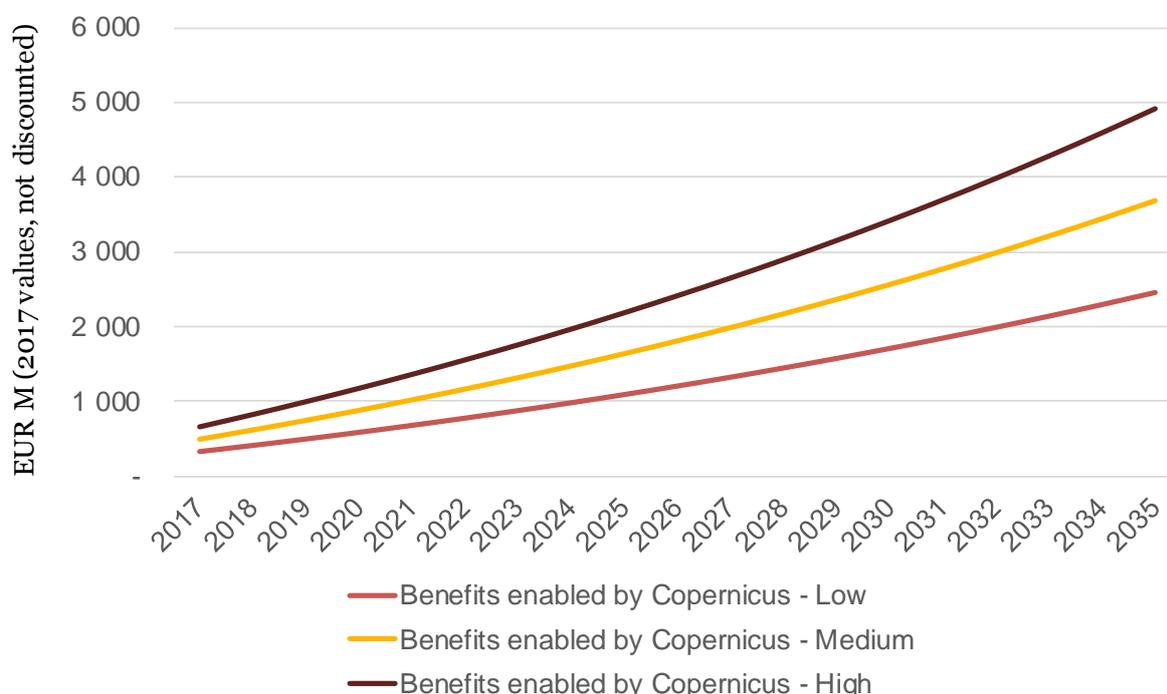


Figure 75 - Evolution of the total Global Copernicus benefits for Marine resources management from 2017 to 2035 (Source: PwC analysis)

4.2.3.4.3 Water quality monitoring

Water quality monitoring provides information to support public policy and regulatory decisions on health and environmental issues, which can assess and prevent damages to ecosystems and coastal communities and economies. Monitoring of ocean conditions can, for example, detect potential hazards to fish stocks such as harmful algal blooms. Once detected, increased testing of aquaculture stocks can reduce the levels of toxins in food destined for human consumption. Jellyfish blooms can also be monitored through ocean analysis, which can affect tourism in coastal environments, and have implications for healthcare provision. The data provides key inputs into monitoring, modelling and forecasting these hazards, which can be used to develop guidance on bathing in coastal environments, and inform fish farmers' decisions on their fish stocks. Additionally, ocean current analysis is a key input into the monitoring of plastic waste in the oceans, particularly the North Pacific Gyre. Therefore,

the use of satellite imagery is key to monitor conditions and support the modelling of key water quality hazards.

Through the Copernicus Marine Environment service (CMEMS), Copernicus is providing data, models, products and services on sea surface temperatures, sea surface salinity, sea level, ocean currents, ocean colour, art, dissolved oxygen, nutrients and sea ice amongst others. Data and products are provided on ocean temperature, currents, and the chlorophyll content of the ocean's surface levels alongside other biogeochemistry factors associated with ocean colour, that enable the analysis of algal and jellyfish blooms. Furthermore, ocean current models enables the search areas of plastic pollution to be optimised, a subject which is receiving increasing attention.

Combining these issues leads us to define the following impact pathway, which maps out the total impact of the water quality monitoring application (impact driver) through to the particular environmental, societal or economic benefits (impacts):

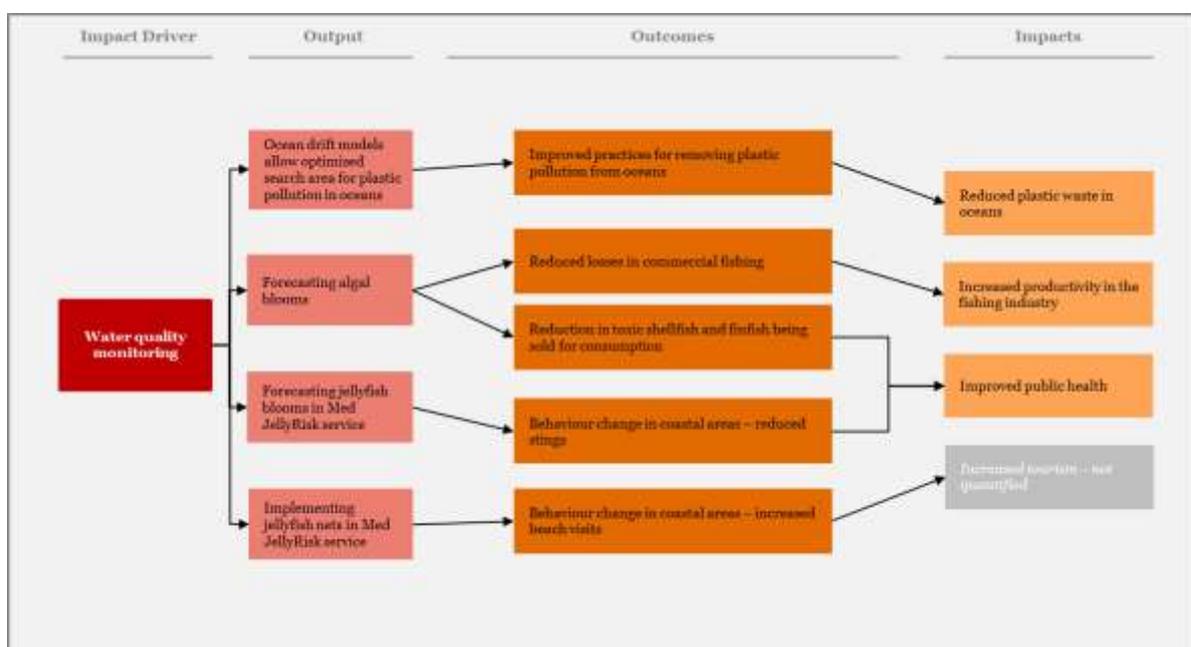


Figure 76 - Impact pathway for water quality monitoring (Source: PwC analysis)

We note that this is only a small section of the current impacts of Copernicus within water quality management, due to the scope of our study. We could not quantify the benefits for some potentially important Copernicus outputs, for example, boundary conditions to coastal models delivered by national agencies. Therefore this section should be read with the knowledge that the quantified benefits shown here may not represent the full benefits of Copernicus's water quality management applications.

Indeed, the monitoring of ocean conditions to support water quality monitoring enables modelling and forecasting of various ocean hazards. It is possible to model harmful algal blooms, leading to forecasts of a harmful algal bloom event. Harmful algal blooms occur when colonies of algae grow out of control while producing toxic or harmful effects on people, fish, shellfish, marine mammals, and birds. The human illnesses caused by harmful algal blooms, though rare, can be debilitating or even fatal. Several decades ago, relatively few countries appeared to be affected by harmful algal blooms, but now most coastal countries are threatened, in many cases over large geographic areas and by more than one harmful or toxic species. The provision of accurate harmful algal bloom forecasts has enabled fish farmers to increase their productivity by approximately 5%, by optimising harvesting schedules and installing appropriate aeration systems. Indeed, an early warning

system for blooms gives producers the chance to change their practices by, for example, installing oxygenation systems, moving their stocks, and harvesting their fish earlier²⁰⁹. Forecasting algal blooms can also lead to potential increases in water sampling and testing for the presence of biotoxins in the growing areas, leading to a reduction in toxic foods being sold for consumption, and eventually reducing the costs associated with illnesses and lost productivity due to illness.

Within the Mediterranean area, Med-JellyRisk, a project assessing the socio-economic impacts of jellyfish blooms and the implementation of mitigation countermeasures, currently uses Copernicus data to monitor jellyfish blooms, and assigns beaches and coastal areas a green/yellow/red rating based on jellyfish presence²¹⁰. This is communicated to beach users through its mobile app, which we expect will reduce the number of jellyfish stings. Further mitigation measures implemented by Med-JellyRisk included installing jellyfish nets on beaches at risk of jellyfish blooms, which we expect to increase tourism at these beaches. Finally, ocean current models can be used to optimise practices to remove plastic waste from the oceans, as marine waste often converges at optimisation points and collects in large gyres. Using satellite data, plastic waste can be removed from the ocean more effectively.

Following the logic for the outputs developed above, Copernicus products could lead to four benefits:

- Reduced plastic waste in oceans
- Increase productivity in the fishing industry
- Improved public health
- Increased tourism

We have been able to value three out of the four outputs presented in the impact pathway.

4.2.3.4.3.1 Reduce plastic pollution in the oceans (economic impact)

The total natural capital cost to marine ecosystems of plastic littering per year is estimated to be between USD 650 and USD 1,300 per tonne²¹¹. As a result of ocean currents, plastic pollution often converges in accumulation zones known as gyres. Using data on ocean currents and ocean current models, surface plastic pollution can be identified and removal mechanisms more effective.

Over two thirds of plastic litter ends up on the seabed, with half of the remainder washed up on beaches. The remaining half is floating on or under the surface, according to a report from UNEP²¹². Our analysis focuses on these surface marine plastics, due to limited data in this area. It is estimated that the current global mass of floating plastic is 500,000 tonnes²¹³, however there is significant uncertainty on the amount of marine surface plastics. We recognise that these estimates may be conservative, particularly our current analysis does not take into consideration any year on year increase in global surface plastics. Should there be robust data available, incorporating this growth would further increase the benefits associated with this impact.

209 Copernicus Market Report. (Online) Available at: http://www.copernicus.eu/sites/default/files/library/Copernicus_Market_Report_11_2016.pdf (Accessed: August 6th 2017)

210 Med-JellyRisk. (Online) Available at: <http://jellyrisk.eu/en/project-results/mitigation-tools/medjelly-mobile-app/> (Accessed: August 6th 2017)

211 Valuing Plastic, 2014. Available at <https://wedocs.unep.org/rest/bitstreams/16290/retrieve>. (Accessed September 7th 2017)

212 Valuing Plastic, 2014. Available at <https://wedocs.unep.org/rest/bitstreams/16290/retrieve>. (Accessed November 7th 2017)

213 How the oceans can clean themselves: a feasibility study. Available at: https://www.theoceancleanup.com/fileadmin/media-archive/Documents/TOC_Feasibility_study_lowres_V2_o.pdf. (Accessed November 7th 2017)

Major marine plastic pollution removal organisations expect that due to the available technologies, including ocean current models, schemes involving plastic pollution collection barriers can remove plastics at an effectiveness of 4.2% annually. Current models assume a clean-up start date of 2018, with full implementation in 2020. Therefore, for the purpose of this study, analysis was conducted on the global surface plastics to forecast the total tonnage to be removed and the respective natural capital costs saved. The natural capital cost is an estimate of the damage caused by annual plastic pollution to the marine environment, which we used to derive a value per tonne of plastic pollution.

We note that the systems described above can currently only remove surface plastics, and the benefits associated with surface plastics are conservative. Additionally, there are a large amount of plastics which are not subject to our analysis. There are also additional impacts, in particular of plastic waste reaching the ocean when littered, which have not been analysed due to the absence of robust data and scientific research, for example around the impact of microplastics. Estimates on the natural capital cost to marine ecosystems may also be conservative, as the amount, behaviour and impact of plastics in the marine environment is not well known. Direct industry damage in the APEC region is calculated to be USD 1.265 billion per year, with 140,000 tonnes of plastic in the region, giving an estimated cost per tonne of plastic of USD 9,000. This figure was not used in our analysis, but is provided as a demonstration of the wider impacts of plastic pollution.

In summary, the true impact of Copernicus on plastic pollution is expected to be much higher, but due to the scope of the study we could not quantify the additional benefits as described above.



Methodological approach to value the economic impact of reduced plastic pollution in the oceans

Our model is based on the natural capital cost to marine ecosystems of plastic pollution, and the associated reduction in accumulation zones. The steps are:

1. Determine the annual plastic pollution able to be removed with current technologies
2. Calculate the reduction in plastic pollution using these technologies
3. Calculate the natural capital cost associated with the removed plastics
4. Apply the contribution of Copernicus to this cost saving

Reduced plastics in the oceans Valuation approach



Due to lack of robust data on the proportion of benefits which could be associated to Copernicus satellites, we have assumed that the proportional contribution of Copernicus should be estimated at 6%²¹⁴. As a result, assuming a clean-up start date out in 2018, and full

²¹⁴ Earth observation revenues for the ocean monitoring sector amounted to EUR 103.85 M in 2015, and among those, EUR 5.76 M can be directly attributable to Copernicus. Taken from the study to examine the socio-economic impact of Copernicus in the EU. Report on the Copernicus Downstream Sector and User Benefits.

implementation in 2020²¹⁵, benefits amount to between EUR 386K and 778K per year by 2035, reaching a peak of between EUR 735K and 2.4M in 2020. We note that the effectiveness of the plastic collection barriers is very high after installation, as the majority of surface plastics are then collected into the devices. The benefits then fall as less and less plastics are removed per year, as the surface plastics become more dispersed and the plastic collection barriers remove the remaining plastics less efficiently.

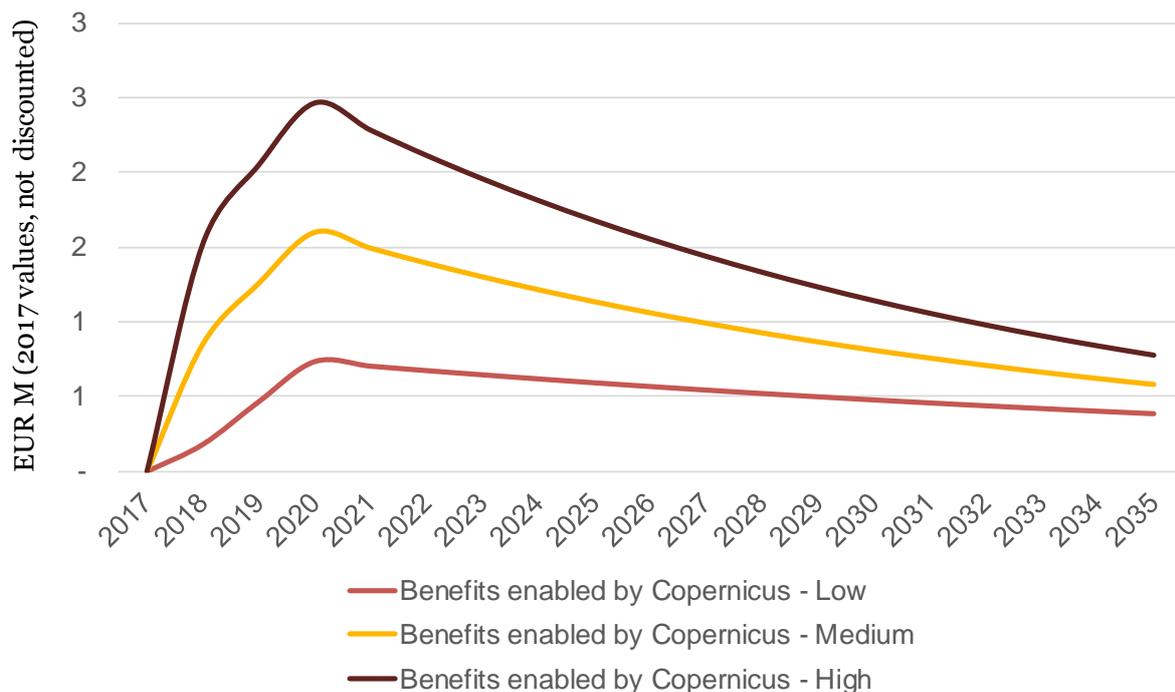


Figure 77 - Evolution of the Copernicus benefits globally for the impact “Reduced plastics in the oceans from optimising removal sites” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Due to lack of robust data on the proportion of benefits which could be associated to Copernicus satellites, we have assumed that the proportional contribution of Copernicus should be estimated at 6%. This is realistic, as satellite data is used in this area to provide key data sources however it is limited in its outreach as many users of Copernicus data do not use the data provided for water quality management. If all Copernicus assets were shut down in 2030, other sources of satellite data could be used, but would be limited in the quality of results.

4.2.3.4.3.2 Increased productivity in the fishing industry associated with harmful algal bloom forecasts:

The analysis is made on Portugal, France, Spain, Ireland and Scotland which account for 25% of the EU’s aquaculture production and 1% of the world’s production by weight²¹⁶. The benefits are then extrapolated to the EU and the world by aquaculture production, with the assumption that the same factors play a similar part in the other countries.

²¹⁵ How the oceans can clean themselves: a feasibility study. Available at: https://www.theoceancleanup.com/fileadmin/media-archive/Documents/TOC_Feasibility_study_lowres_V2_o.pdf. (Accessed September 7th 2017)

²¹⁶ PwC analysis.

However, we recognise and note the limitations of transferability of this study, as a wider data set was not available. For these five countries, a study was conducted showing that access to the harmful algal bloom forecasts gave a direct benefit of 5% productivity increase in the affected farmers, with the aim of a 12.5% productivity increase should the necessary technologies be implemented across the farms, such as oxygenation systems²¹⁷.

From consultation with experts, it was suggested that Copernicus data provides a 25% increase in quality compared to other available sources. Therefore we have assumed a proportional contribution of Copernicus to achieving this benefit of 25%. User uptake was modelled as proportional to the user uptake as demonstrated in the original case study²¹⁸.

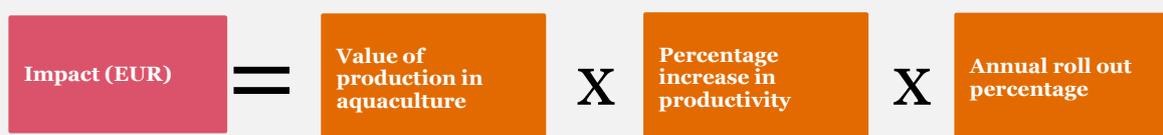


Methodological approach to value the economic impact of increased productivity associated with harmful algal blooms

Our model is based on the increase in productivity and the value of additional production. The steps are:

1. Determine the tonnage of production in aquaculture
2. Calculate the value of the additional production associated with increased productivity
3. Apply a roll out as technology becomes more popular and available
4. Apply the contribution of Copernicus to this cost saving

Increased productivity associated with harmful algal blooms Valuation approach



Assuming an EU roll out in 2017, total benefits for EU in terms of increased productivity from algal bloom forecasts amount to between EUR 33,900 and EUR 84,800 per year by 2035. Although outside the scope of our study, we have provided the global benefits for this impact for context. Assuming a global roll out in 2020, total benefits for non-EU countries in amount to between EUR 229,800 and EUR 574,700 per year by 2035. The results are illustrated in the two charts below:

²¹⁷ Study conducted using Copernicus data (Online). Available at: http://cordis.europa.eu/result/rcn/149876_en.html Accessed July 20th 2017

²¹⁸ Study conducted using Copernicus data (Online). Available at: http://cordis.europa.eu/result/rcn/149876_en.html Accessed July 20th 2017

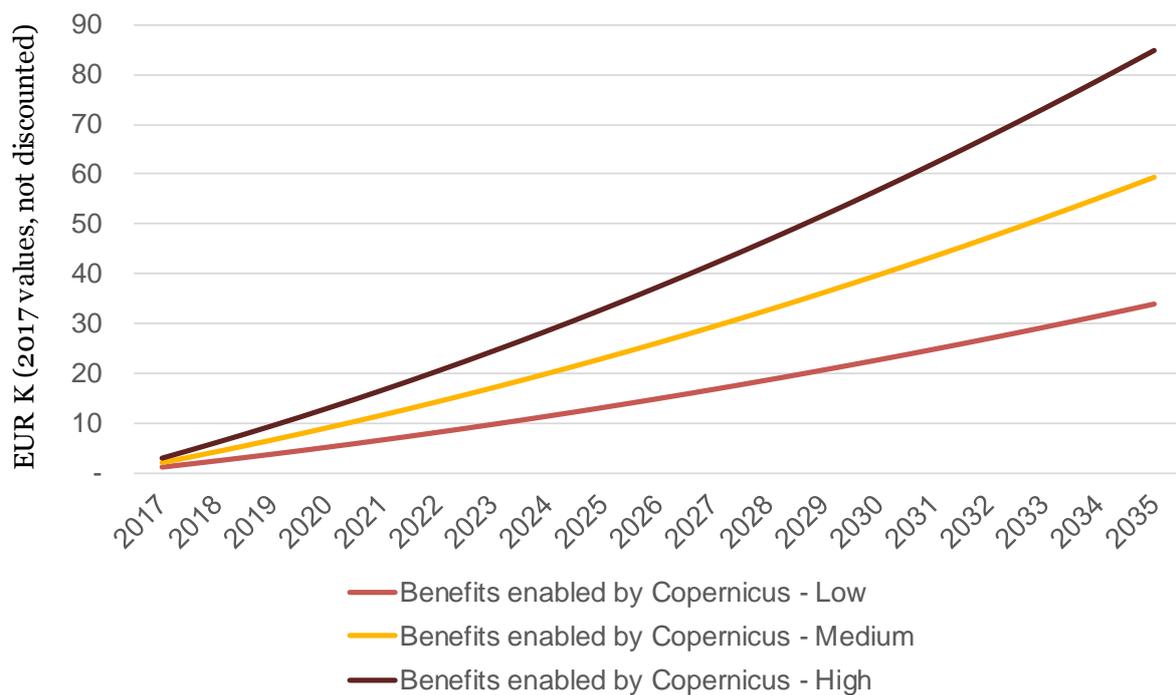


Figure 78 - Evolution of the Copernicus benefits for the EU for the impact “Increased productivity in the fishing industry from forecasting harmful algal blooms” from 2017 to 2035 (Source: PwC analysis)

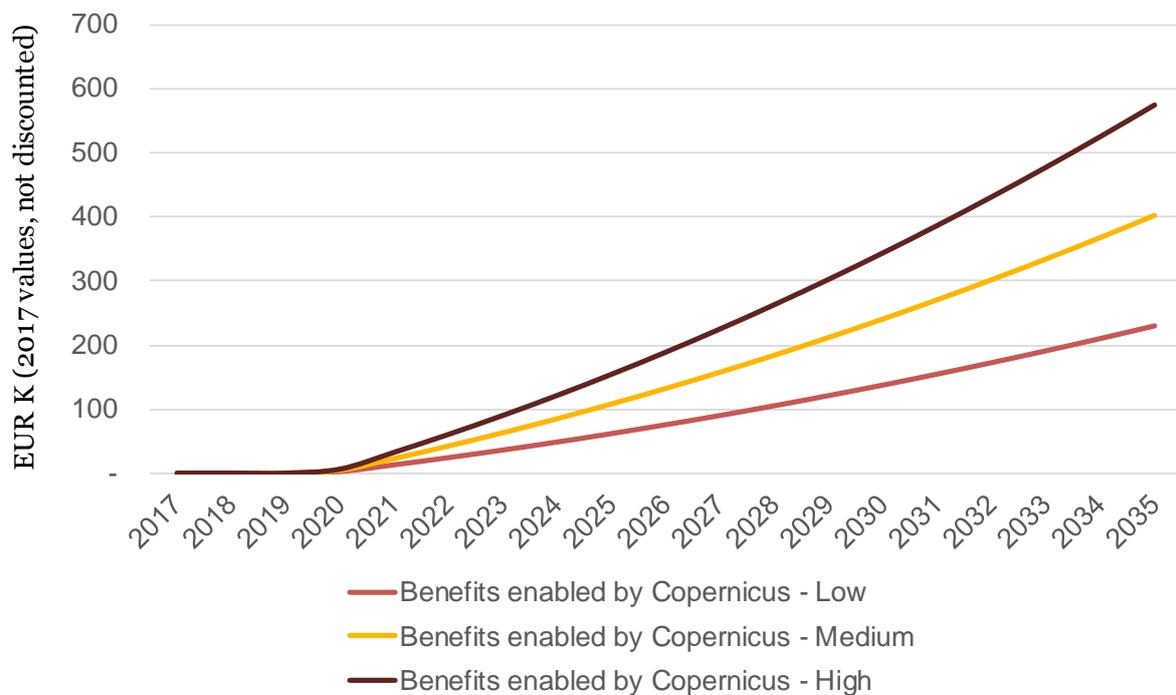


Figure 79 - Evolution of the Copernicus benefits for non-EU countries for the impact “Increased productivity in the fishing industry from forecasting harmful algal blooms” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Due to lack of robust data on the proportion of benefits which could be associated to Copernicus satellites, we have assumed that the proportional contribution of Copernicus should be estimated at 25% based on expert stakeholder consultation. This is realistic, as satellite data is used in this area to provide key data sources however it is limited in its outreach as many users of Copernicus data do not use the data provided for water quality management. If all Copernicus assets were shut down in 2030, other sources of satellite data could be used, but would be limited in the quality of results.

4.2.3.4.3.3 Improved public health

4.2.3.4.3.3.1 Economic impact of reduced harmful algal bloom related illnesses

The analysis for this impact area is underpinned by studies in the US, where it has been estimated that the annual economic impact of harmful algal blooms on public health is approximately USD 20 million²¹⁹. The studies calculate the economic impact of harmful algal bloom illnesses using both the treatment costs and productivity decrease due to toxic finfish and shellfish consumption. The impact is then extrapolated to the EU and worldwide, to assess the impact by region. As harmful algal bloom related illnesses are transmitted by consumption of seafood, this was a factor in our modelling. In order to correctly scale associated treatment costs and productivity decreases, healthcare and labour costs were also key modelling inputs. We also note that user uptake was modelled as proportional to the user uptake as demonstrated in the study.

An expert in the field expects that upon receiving an algal bloom forecast showing imminent contamination, testing would occur daily rather than weekly²²⁰, and so additional toxic finfish and shellfish would be diverted from being sold for consumption. Due to this increase in testing, the consumption of toxic seafood is expected to fall, and so a reduction in the annual treatment costs and losses from reduced productivity occurs. From research in the field and consultation with experts, it is expected that Copernicus data provides a 25% increase in quality compared to other available sources. Therefore we have assumed that the proportional contribution of Copernicus should be estimated at 25%.

²¹⁹ Estimated Annual Economic Impacts from Harmful Algal Blooms (HABs) in the United States. Available at : <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.693.5018&rep=rep1&type=pdf> Accessed July 20th 2017

²²⁰ Marine researcher, specialising in algal blooms. Interview conducted on 22nd August 2017.



Methodological approach to value the economic impact of reduced harmful algal bloom related illnesses

Our model is based on the economic impact of harmful algal blooms, associated with treatment costs and lost time. This was extrapolated from the US by seafood consumption and healthcare costs by country, and the associated fall in illnesses calculated in line with increased testing. The steps are:

1. Determine the economic impact of harmful algal blooms in the US
2. Scale the economic impact to develop a global economic impact
3. Calculate the associated reduction in illnesses (and associated impact) as a result to increased testing
4. Apply a roll out as technology becomes more popular and available
5. Apply the contribution of Copernicus to this cost saving

Reduced illnesses associated with harmful algal blooms **Valuation approach**



Assuming an EU roll out of a forecasting system in 2017, total benefits for EU in terms of saved treatments costs and losses from reduced productivity costs from algal bloom forecasting amount to between EUR 7.0 million and EUR 8.6 million per year by 2035.

Although outside of the scope of our study, we have included the global benefits for this impact for context. Assuming a global roll out in 2020, total benefits for non-EU countries amount to between EUR 4.5 million and EUR 5.5 million per year by 2035.

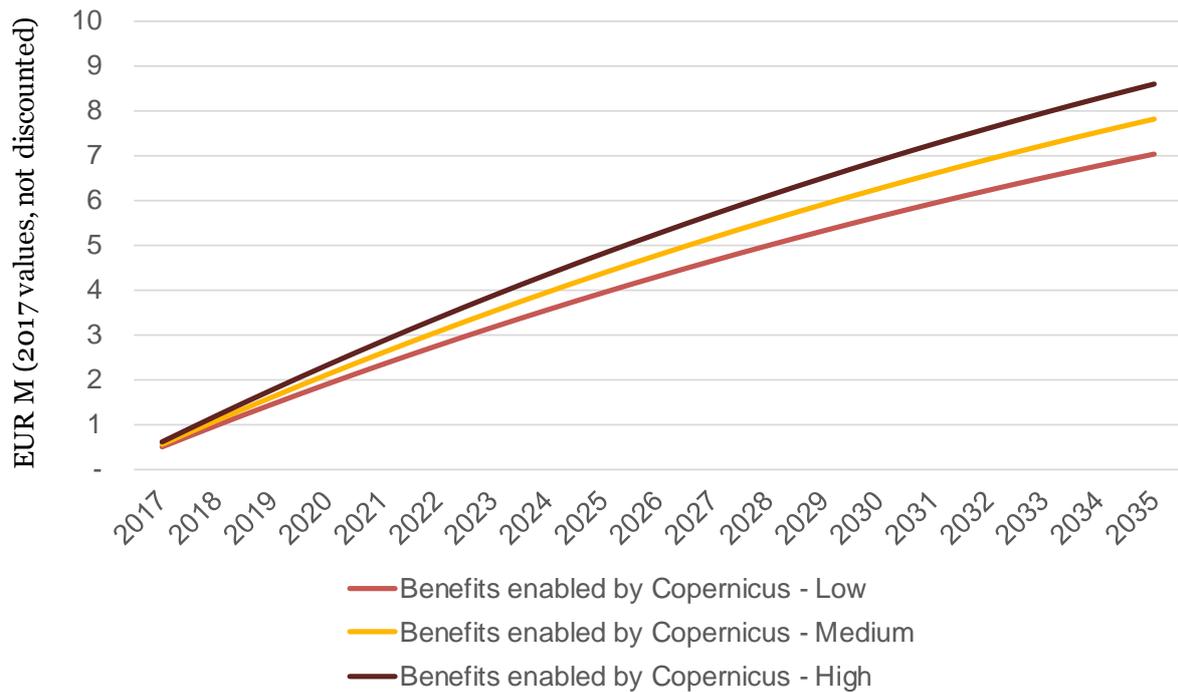


Figure 80 - Evolution of the Copernicus benefits for the EU for the impact “Reduced impacts on human health from forecasting harmful algal blooms” from 2017 to 2035 (Source: PwC analysis)

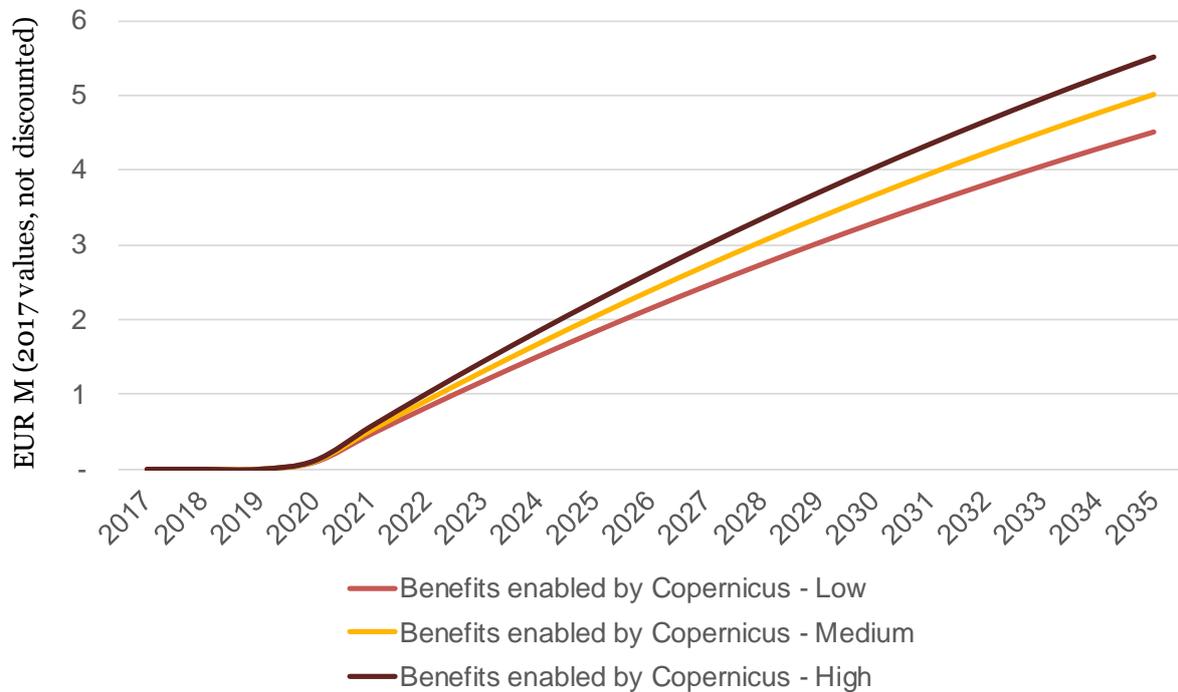


Figure 81 - Evolution of the Copernicus benefits for non-EU countries for the impact “Reduced impacts on human health from forecasting harmful algal blooms” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Similar to previous paragraph.

4.2.3.4.3.3.2 Economic impact of reduced jellyfish stings

Med-JellyRisk, a project assessing the socio-economic impacts of jellyfish blooms and the implementation of mitigation countermeasures, addresses an integrated coastal management approach into 10 Marine Coastal Zones faced with increased jellyfish proliferations. In these areas, jellyfish outbreaks represent a growing threat for humans and coastal activities (including leisure and aquaculture).

Using Copernicus data, the Med-JellyRisk project monitors jellyfish risk at beaches, and communicates this to beach users through its mobile application. Analysis was conducted on a study of the South Italian Coast, which estimates the costs associated with jellyfish stings to the Italian Health Service²²¹. The study estimates a cost of EUR 225 to national health services per instance of medical assistance sought due to a jellyfish sting. To extrapolate the economic impact to the EU, predicted jellyfish stings are modelled to increase the costs proportionately. Furthermore, due to the differing healthcare costs in EU countries, the National Health Service healthcare costs were used to adjust the economic impacts on healthcare by country. Following the scaling of the impacts by predicted jellyfish stings and healthcare costs, the impact of jellyfish stings in the EU can be modelled.

However, due to a lack of data on the reduction of stings associated with using the application, we have assumed a reduction in stings of 5% due to an expected reduced number of bathers entering waters with a red rating of jellyfish.



Methodological approach to value the economic impact of reduced jellyfish stings

Our model is based on the economic impact of jellyfish stings, associated with first aid treatment costs. This was extrapolated from the South Italian Coast by coastal tourism visitors and healthcare costs by country, and the associated fall in stings calculated in line with increased awareness. The steps are:

1. Determine the economic impact of jellyfish stings in the South Italian Coast
2. Scale the economic impact by healthcare costs to develop an EU-wide economic impact
3. Calculate the associated reduction in stings (and associated impact) as a result of increased awareness
4. Apply a roll out as technology becomes more popular and available
5. Apply the contribution of Copernicus to this cost saving

Reduced treatment costs associated with jellyfish sting Valuation approach



221 Impact of Stinging Jellyfish Proliferations along South Italian Coasts: Human Health Hazards, Treatment and Social Costs. Available at <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3986988/>. (Accessed September 7th 2017)

As with other marine benefits, there is a lack of data on the proportion of benefits which could be attributed to Copernicus satellites, however given that the Med-JellyRisk project names Copernicus, we have assumed that the proportional contribution of Copernicus should be estimated at 50%. As a result, assuming an EU-wide roll out in 2020 of the mobile application, total benefits for EU in terms of saved treatments costs from jellyfish monitoring amount to between EUR 801 K and EUR 980 K per year by 2035.

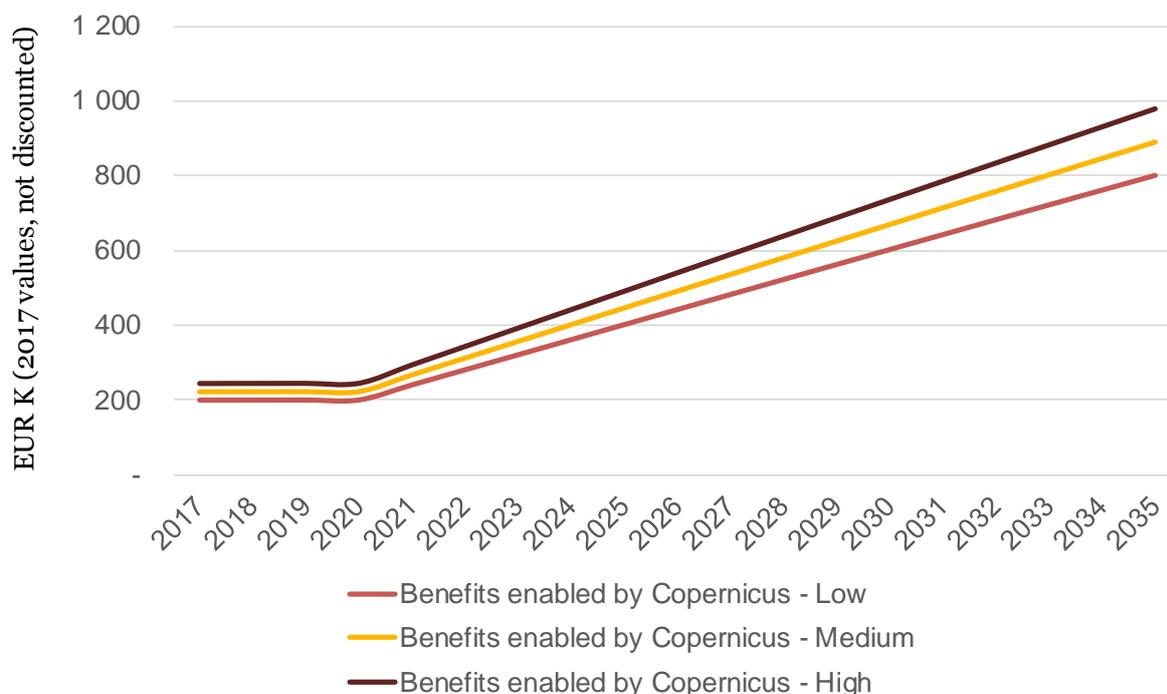


Figure 82 - Evolution of the Copernicus benefits for the EU for the impact “Reduced impacts on human health from alerting bathers to the presence of jellyfish” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Due to lack of robust data on the proportion of benefits which could be associated to Copernicus satellites, we have assumed that the proportional contribution of Copernicus should be estimated at 50% based on expert stakeholder consultation.

4.2.3.4.3.4 Increase Tourism, by implementing jellyfish nets in the Med JellyRisk service

The benefits associated with reduced tourism losses could not be quantified, as there is insufficient data to extrapolate the benefits of jellyfish nets, and the willingness to pay associated with reduced risk of jellyfish blooms.

4.2.3.4.3.5 Summary of Copernicus contribution to “Water quality monitoring”

As a result, the total not discounted EU benefits linked to Copernicus are expected to amount to:

Copernicus Global benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	0.8	2.5	5.1	50.1
Medium estimate	1.7	3.3	6.0	65.4

High estimate

0.8

2.5

5.1

50.1

Table 23 - Copernicus total global benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below.

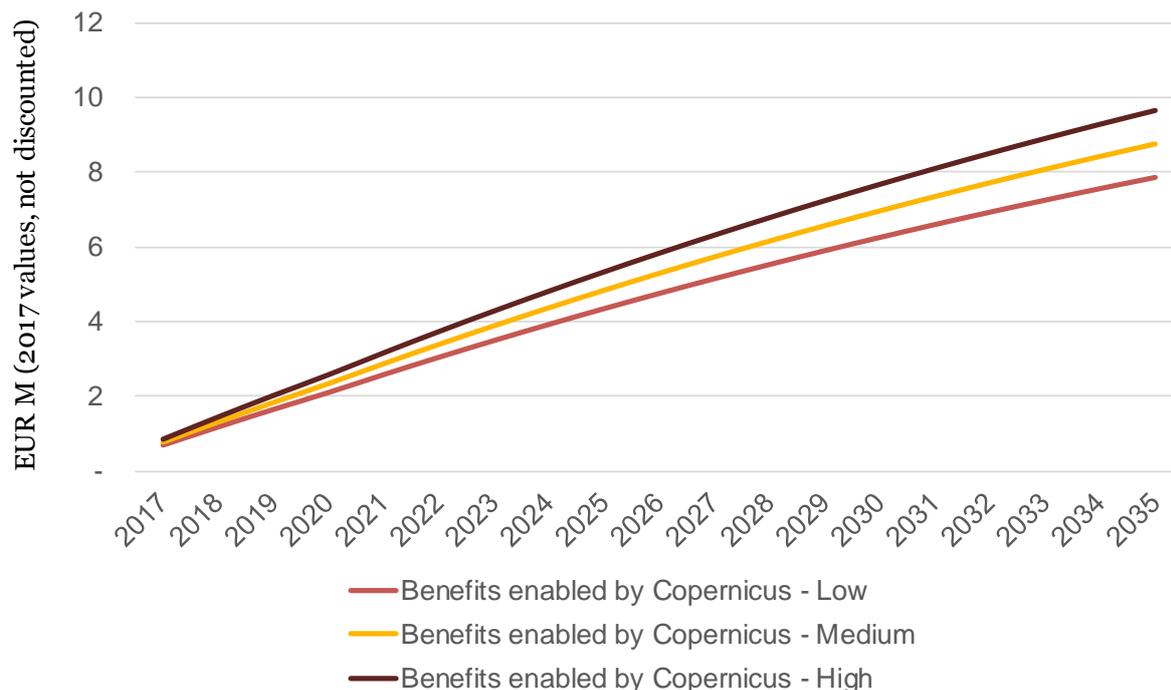


Figure 83 - Evolution of the total EU Copernicus benefits for Water quality monitoring from 2017 to 2035 (Source: PwC analysis)

4.2.3.4.4 Ice monitoring to support (winter) navigation/ship routing

Sea ice evolution is a complex and variable phenomenon. From a year to another, throughout a season or from one region to the other, sea ice conditions are completely different. The use of satellite imagery is therefore crucial to track these evolutions and support winter navigation.

Through the Copernicus Marine Environment service (CMEMS), Copernicus is providing data and products on sea ice extent, thickness, concentration, motion and ridges in the Northern seas that enable the monitoring and forecasting of sea ice conditions through the publication of sea ice maps²²². Those products results from Copernicus data that is essential for real-time mapping and from modelling based on this data that is crucial for forecasting. Previously, RADARSAT-2 as well as Envisat (whose mission ended in 2012) data were used to monitor sea ice evolutions in the region. Since the launch of Sentinel-1 in 2014, it has become the main source of satellite imagery enabling this mapping²²³. Sentinel-1 presents several advantages: a high revisit time, a large geographical coverage, data deemed reliable, of good quality, rapidly disseminated and more importantly costless (compared to RADARSAT-2 that is a commercial satellites). Indeed, thanks to its C-band SAR, Sentinel-1

²²² CMEMS portal. (Online) Available at : <http://marine.copernicus.eu/training/education/ocean-parameters/sea-ice/> (Accessed: July 19th 2017)

²²³ EARSC case study. (Online) Available at : <http://earsc.org/news/copernicus-sentinels-products-economic-value-study> (Accessed: July 19th 2017)

can monitor sea ice conditions irrespective of cloud cover and light conditions²²⁴ and sea ice information are delivered 30 minutes after data have been received from the satellite²²⁵.

The availability of precise sea ice mapping helps to identify risks (e.g. drifting ice patches, icebergs leading to accidents) and opportunities (e.g. new, faster shipping lanes) for winter navigation of commercial vessels and passenger ships. This leads to the following impact pathway, which maps out the total impact of the ice monitoring to support navigation application (impact driver) through to the particular environmental, societal or economic benefits (impacts):

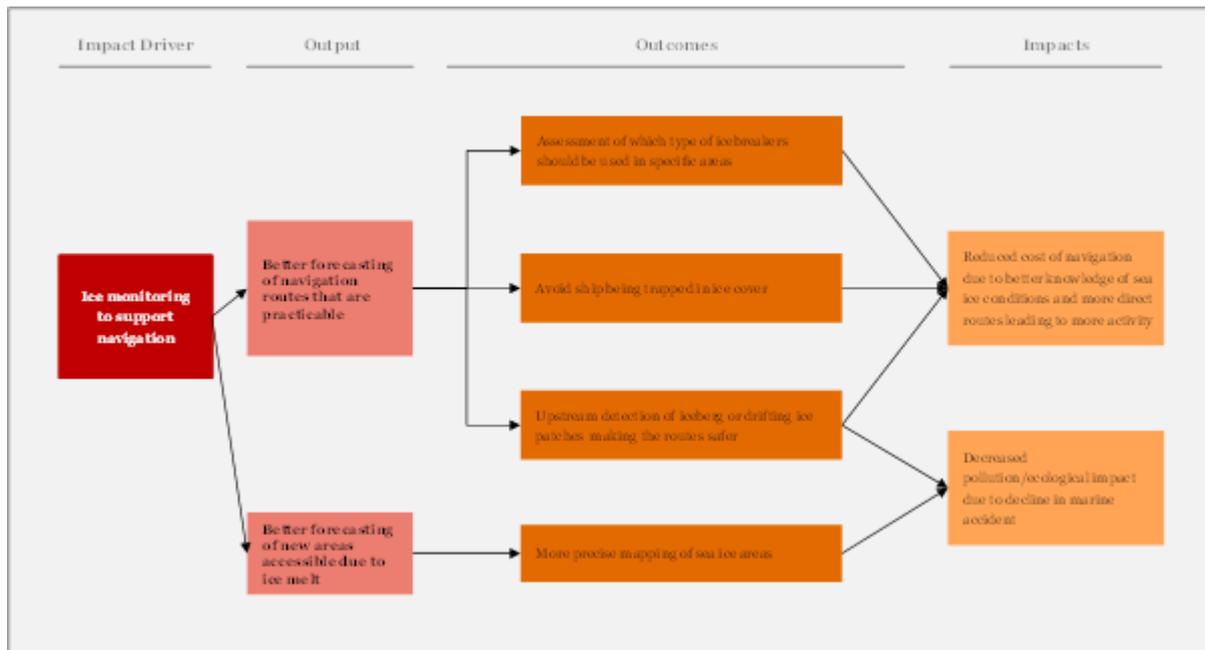


Figure 84 - Impact pathway for ice monitoring to support navigation (Source: PwC analysis)

Indeed, the monitoring of sea ice in support of navigation enables practicable navigation routes to be better forecasted. As such, the right type of icebreaker can be more easily chosen thanks to knowledge of ice thickness; ships have less risk to be trapped in ice cover thanks to frequent ice mapping and large geographical coverage; and routes are made safer thanks to upstream detection of icebergs or drifting ice patches. Moreover, new areas accessible due to ice melt can be more easily spotted. This leads to a more precise knowledge and mapping of sea ice areas. As a result of all these outcomes, icebreakers can plan faster, safer and more efficient shipping routes, which leads to:

- Reduced cost of navigation through decreased fuel consumption, shorter transit times and faster routes;
- Avoided ecological impact/marine pollution due to reduced CO₂ emissions from fuel combustion as well as decreasing number of accidents requiring repairs;

The quantification of the benefits mentioned above is as follows:

224 ESA website. (Online)<https://sentinel.esa.int/web/sentinel/thematic-areas/marine-monitoring-content/-/article/sentinel-1-data-advance-sea-ice-monitoring> (Accessed: July 19th 2017)

225 Copernicus Briefs. (Online) Available at:

http://www.copernicus.eu/sites/default/files/documents/Copernicus_Briefs/Copernicus_Brief_Issue5_SeaIce_Sep2013.pdf (Accessed: July 19th 2017)

4.2.3.4.4.1 Reduced cost of navigation through decreased fuel consumption, shorter transit times and faster routes

Satellite imagery have been used to improve navigation routes that icebreakers are supposed to make safe. Before the availability of satellite imagery, icebreakers used to rely on helicopters that would provide several pictures of the sea and detect potential ice charts to warn the icebreaker. However, these helicopters had a cost and the reliability was not entirely guaranteed: the helicopters could not fly when the weather was too bad nor at night (whereas Sentinel-1 can provide data under all weather conditions and at night); they provided several pictures that needed to be analysed altogether (instead of a single global map as Sentinel-1 can provide); and the limited speed of helicopters made it possible for weather conditions to change before the icebreakers could be warned and react. Before Sentinel-1, SAR imagery was already used through Envisat or Radarsat-2 to pave the way for icebreakers, though Copernicus provide better data quality than Envisat, whose mission was older and has currently ended. However, satellite imagery is not sufficient in itself and needs to be complemented by on-field expertise of icebreaker captains. Moreover, during summer, there are few ice navigation issues due to the melting of ice but, in winter, weather conditions might change and routes might remain open for only few hours after the icebreaker passed. As such, the more often satellite images are taken, the better the quality of the information provided will be. Currently, images are taken every two or three days but optimally, it should be every day at the same time to gain in accuracy. The launch of Sentinel-1C might help attain this goal.



Methodological approach to value reduced cost of navigation decreased fuel consumption, shorter transit times and faster routes

Our model is based on the specific cases of navigation costs reduction in Finland and Sweden. Direct and indirect benefits from improved navigation routes have been considered and further expanded to the whole Baltic region. The steps are:

1. Assess the benefits of improved navigation routes in Finland and Sweden
2. Expand these benefits to the Baltic Region by doing a ratio between the share of container port traffic in Sweden and Finland and the whole Baltic region
3. Isolate the share of companies using Earth Observation data for ice navigation
4. Apply the contribution of Copernicus to Earth Observation imagery used in ice navigation activities

Reduced cost of navigation through decreased fuel consumption, shorter transit times and faster routes

Valuation approach



The analysis is based on EARSC case study on winter navigation in the Baltic²²⁶, which looks at the benefits from Copernicus derived from improved navigation in the Baltic Sea. The case focuses on Finland and Sweden, which account for about 20% of the commercial traffic in

²²⁶ EARSC case study. (Online) Available at : <http://earsc.org/news/copernicus-sentinels-products-economic-value-study> (Accessed: July 19th 2017)

the Baltic region²²⁷ and are the second and third countries with the biggest container port traffic behind Germany. For these two countries, Copernicus has direct and indirect benefits²²⁸: the former consist in the upper part of the value chain with fuel savings for icebreakers and ship operators, the removal of helicopters (that used to provide the information now provided by satellite imagery but with a less good quality) and the reduction of operational costs due to time gains; the latter consist in the benefits for the lower part of the value chain, from the arrival of the ships to the port, to the goods being supplied to the general public. Considering that Sweden and Finland combined represent approximately one fifth of the container port traffic in the Baltic region and that similar navigation behaviours are to be found in every country, the Finnish and Swedish benefits have been scale up to the Baltic region countries.

Copernicus has a major role to play in ice navigation. However, Sentinel-1 images have only been available since 2014, and former satellite imagery that could provide similar information came from commercial satellites. As such, and conversely to the case of Finland and Sweden where the full transition from helicopters to Earth Observation images occurred at the beginning of the 21st century, thanks to supportive public authorities facilitating the uptake of satellite data, it is not necessarily the case in the whole Baltic region countries; as such, the uptake of satellite data for ice navigation is assumed to be of 70% at the time of the launch of Sentinel-1 and is expected to increase to 90% in 2035, once all Sentinel-1 (C and D) will be operational. As for the Copernicus contribution for users of Earth Observation imagery, it is assumed to be of 0.5% in 2014 as Sentinel-1 would barely have been launched, drastically increasing up to between 40% and 90% in 2030 when user uptake is complete²²⁹. This increase is indeed quite high but can be explained. In 2014, the uptake is very small as the Sentinel-1 satellite has barely been launched. However, Sentinel-1 data are sufficiently satisfying for ice navigation: knowing this element and that Copernicus data is free, uptake could theoretically reach 100%. As other sources of data can still be used when specific sea ice information are needed (such as Very High Resolution (VHR) data or tailored sea ice modelling), Copernicus contribution is not of 100% but is expected to be between 40% and 90% although Sentinel-1 data are sufficiently satisfying for ice navigation. The low scenario corresponds to ships that have very specific needs for their navigation hence need to complement Sentinel-1 data by other data; the high scenario corresponds to a theoretical best case scenario where ships would not have specific needs.

As a result, benefits linked to Copernicus are expected to amount to between EUR 2.4 M and EUR 9.6 M in 2017, rising to between EUR 79.1 M and EUR 185.8 M in 2035 for a total cumulative value ranging from EUR 684.2 M to EUR 1.76 B (not discounted values).

The global trend over the period is illustrated in the chart below. For this benefit, the medium scenario does not correspond to the average of the two other scenarios. Indeed, the high scenario corresponds to the hypothetical case where the uptake of Copernicus data from satellite imagery users would be almost absolute as Sentinel-1 data are considered sufficient for ice navigation activities. The two other scenarios correspond more to practical reality. The three major steps of the uptake are reflected here.

227 World Bank data; PwC analysis

228 EARSC case study. (Online) Available at : <http://earsc.org/news/copernicus-sentinels-products-economic-value-study> (Accessed: July 19th 2017)

229 PwC analysis

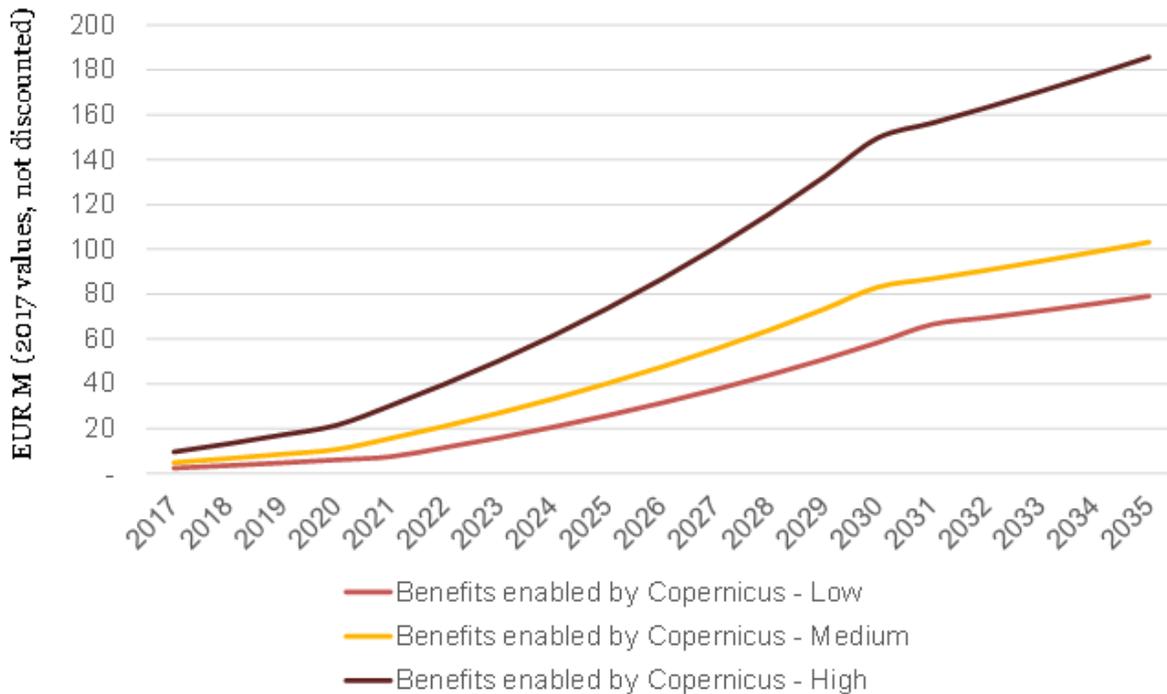


Figure 85 - Evolution of the Copernicus benefits for the impact “Reduced cost of navigation through decreased fuel consumption, shorter transit times and faster routes” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

In case of shutdown of all Copernicus assets in 2030, there would be two possibilities for ice navigation. First, going back to the use of helicopters that would provide icebreakers with pictures of ice conditions. This would have several consequences: conversely to Sentinel data, helicopters have a consequent cost; accuracy would be diminished as helicopters are less precise and cannot function under all weather conditions nor at night; and the gain in time (5 to 8 hours per journey) would be lost once again. Second, keep using satellite imagery but rely on commercial data such as RADARSAT-2. The gain in time and accuracy would therefore not be lost but the cost per scene of satellite images, superior to the cost necessary to use helicopter, would make it financially way less interesting.

4.2.3.4.4.2 Avoided ecological impact/marine pollution due to reduced CO₂ emissions from fuel combustion as well as decreasing number of accidents requiring repairs

The analysis mostly rely on CO₂ emissions reductions due to decrease in fuel consumption from icebreakers and ship operators. As for marine accidents requiring repairs, their number had already decreased since the introduction of satellite imagery for ice navigation and the resulting products on winds, currents or waves for instance: about 100 accidents at the beginning of the 21st century for about 10 accidents a decade later²³⁰. Having a low number of accidents associated with the inability to judge on the ecological impact of each accident, which may drastically vary, led this factor considered negligible in comparison to CO₂ emissions from fuel combustion of vessels.

Satellite imagery involved in fuel reduction, and thus CO₂ emissions reduction, is exactly the same as for the previous benefit. Indeed, it is because of the gain in timer of 5 to 8 hours per journey that fuel consumption is reduced.

²³⁰ EARSC case study. (Online) Available at : <http://earsc.org/news/copernicus-sentinels-products-economic-value-study> (Accessed: July 19th 2017)



Methodological approach to value avoided ecological impact/ marine pollution as well as decreasing number of accidents requiring repairs

Our model is based on the specific cases of navigation costs reduction in Finland and Sweden. Fuel consumption reduction is used to calculate CO₂ emissions that were prevented. The steps are:

1. Assess the benefits of improved navigation routes in Finland and Sweden in terms of cost reduction of fuel spending
2. Expand these benefits to the Baltic Region by doing a ratio between the share of traffic in Sweden and Finland and the whole Baltic region
3. Convert monetary value of fuel consumption avoided into volume of CO₂ emissions avoided, thanks to the cost of a ton of fuel in the maritime transport industry
4. Isolate the share of companies using Earth Observation data for ice navigation
5. Apply the contribution of Copernicus mentioned in the previous benefit

Avoided ecological impact/marine pollution due to reduced CO₂ emissions from fuel combustion as well as decreasing number of accidents requiring repairs
Valuation approach



The analysis is based on fuel reduction of icebreakers and ship operators thanks to the improvement of navigation routes as presented in the previous benefit. Navigation routes have been optimized thanks to satellite imagery, leading to ships gaining between 5 and 8 hours during a journey. As such, it implies fuel consumed is decreasing. After having calculated how much money can be saved by not buying fuel²³¹, this monetary value is transformed into the volume of fuel it corresponds to by taking into account the yearly evolution of fuel prices in the maritime transport industry. The volume of fuel that should have been consumed is then converted into the energy generated by ships in MWh (12.2 MWh are generated by a ton of fuel) and into CO₂ that is emitted by this amount of energy (0.264 kg of CO₂ is emitted per KWh of fuel generated²³²). This value is then multiplied by a valuation coefficient which gives the value in terms of environmental benefits to the economy per kg of CO₂ emissions not generated²³³. The Copernicus contribution is then applied to these values.

As CO₂ emissions reduction is directly to the fact that faster routes are taken, the Copernicus contribution is the same as in the previous benefits. What differs between the two benefits is that, here, it is an environmental benefit that is presented whereas it was an economic one in the previous case.

231 EARSC case study. (Online) Available at : <http://earsc.org/news/copernicus-sentinels-products-economic-value-study> (Accessed: July 19th 2017)

232 Energie pour demain website (Online). Available at : <http://energiepourdemain.fr/energie-et-emissions-de-co2-par-les-combustibles/> (Accessed: September 19th 2017)

233 PwC analysis

As a result, benefits linked to Copernicus are expected to amount to between EUR 0.2 M and EUR 0.4 M in 2017, rising to between EUR 5.5 M and EUR 12.4 M in 2035 for a total cumulative value ranging from EUR 51.1 M to EUR 117.5 M (not discounted values).

The global trend over the period is illustrated in the chart below. The trend quite similar to the previous benefit as the contribution is the same. The main difference is in the order of magnitude of CO2 emissions reduction benefits, which are much smaller.

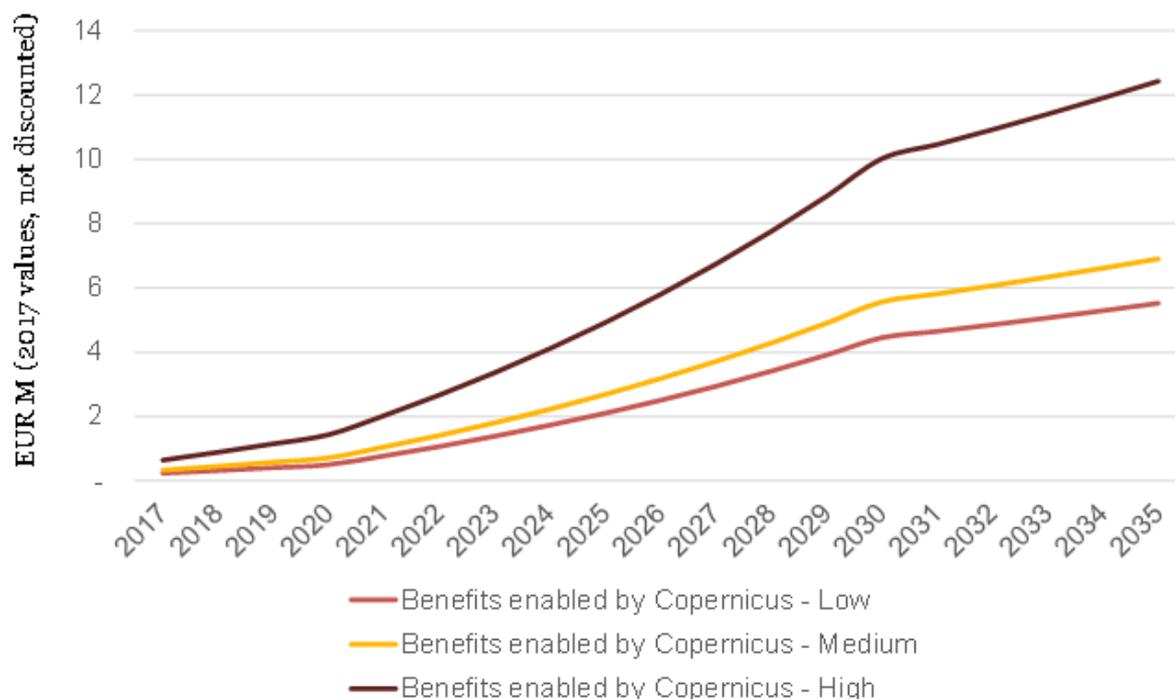


Figure 86 - Evolution of the Copernicus benefits for the impact “Avoided ecological impact/marine pollution due to reduced CO2 emissions from fuel combustion as well as decreasing number of accidents requiring repairs” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Similarly to the previous benefits, the shutdown of all Copernicus assets would lead either to the use of commercial satellite imagery or to going back to helicopters. Considering the cost of commercial satellite images, it can be assumed that this option would be chosen by a minority, hence all environmental benefits of Copernicus would be lost as the journey time will increase with helicopters.

4.2.3.4.4.3 Summary of Copernicus contribution to “Ice monitoring to support (winter) navigation/ship routing”

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	2.6	28.0	84.6	735.4
Medium estimate	5.3	42.8	110.1	1,031.0
High estimate	10.3	78.5	198.3	1,874.1

Table 24 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below. It matches the curve of the two benefits it is composed of, as they were both structured in a similar manner.

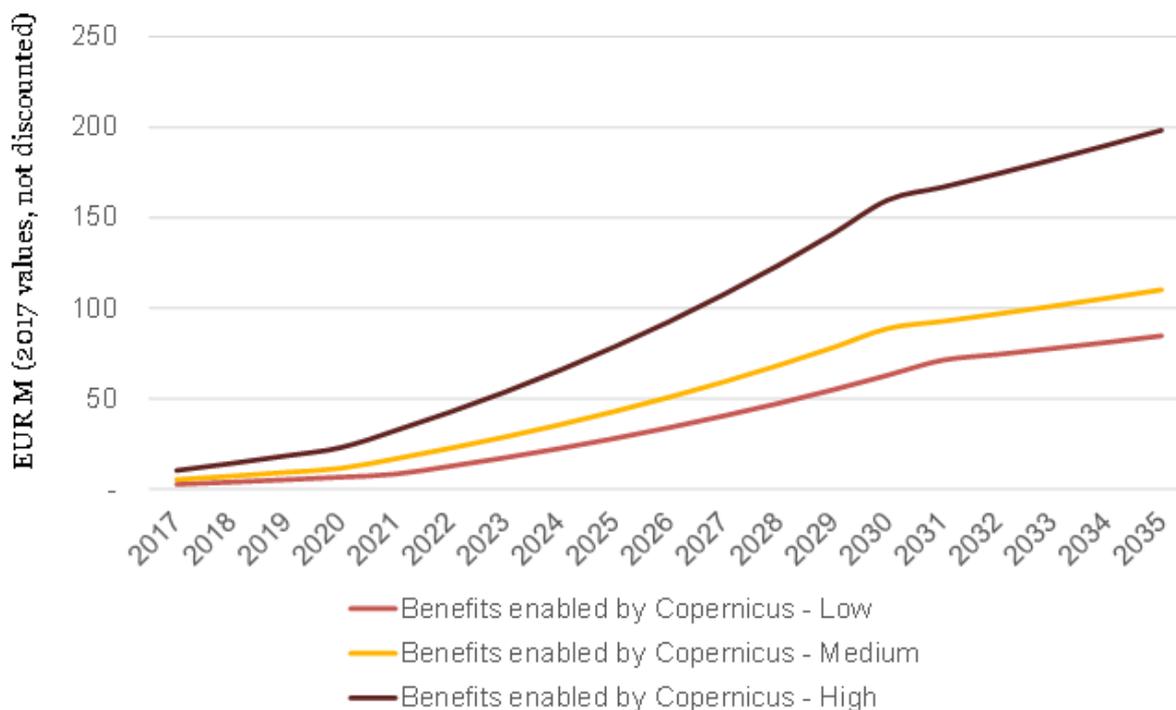


Figure 87 - Evolution of the Copernicus benefits for Ice monitoring, from 2017 to 2035 (Sources: EARSC, 2015; PwC analysis)

4.2.3.4.5 Maritime Navigation

As more than half of intra and inter EU trades is carried by sea, maritime transport has a great impact on the health of the global and EU economy²³⁴. Navigation plays an important role in maintaining and reinforcing the safety of can jeopardise and/or delay cargo ships operations. Indeed, wind, waves and heavy weather conditions can greatly affect cargo ships expeditions.

The Sentinel-1 satellites as well as contributing mission spacecraft belonging to mission group 1, providing SAR (Synthetic Aperture Radar) data, combined with altimetry data provided by Sentinel-3 satellites and mission group 3 contributing missions, produce information on ocean wind fields, ocean wave spectra and surface radial velocity that can be exploited to feed marine forecast models. Therefore, Copernicus participates to the identification of safer and faster routes for carrying vessels. As described in the following impact pathway, Copernicus products enable the improvement of traffic management and thus the avoidance of lost containers during cargo ship expeditions, and lead to the optimisation of navigation routes enabling the reduction of fuel consumption.

234 Source: Eurostat, newsrelease, September 2016 - <http://ec.europa.eu/eurostat/documents/2995521/7667714/6-28092016-AP-EN.pdf>

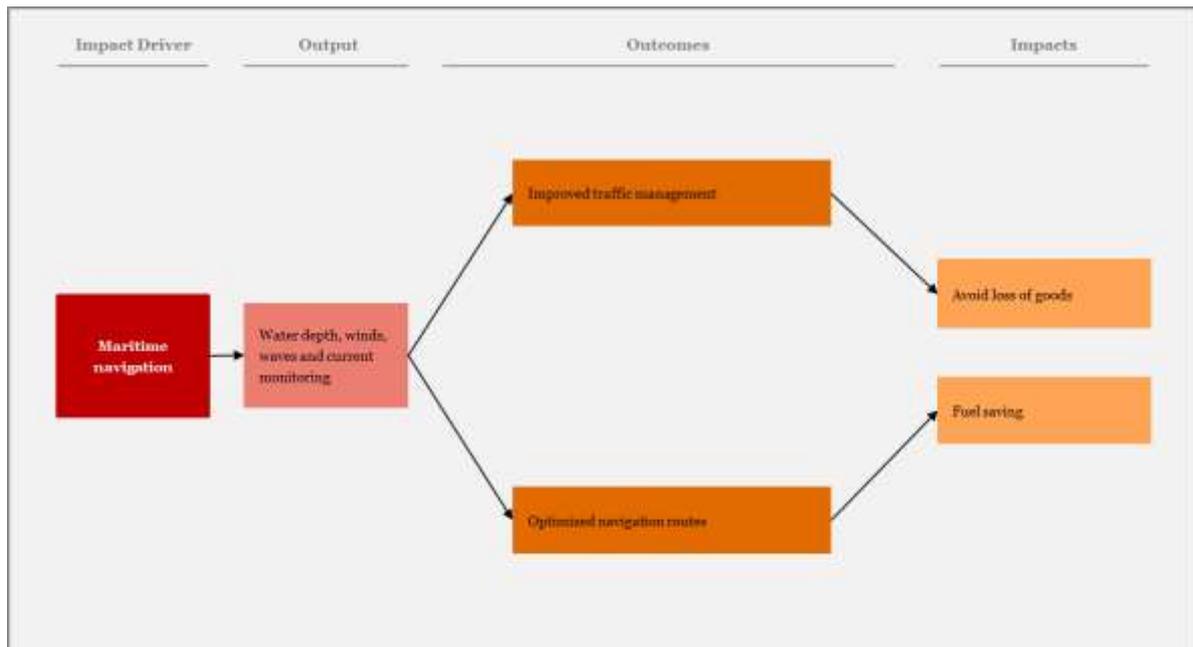


Figure 88 - Impact pathway for Maritime Navigation (Source: PwC analysis)

This impact pathway leads to two benefits:

- Avoid loss of goods
- Fuel saving

The approaches utilised to quantify these benefits enabled by the Copernicus programme for Maritime Navigation are described in the following sections:

4.2.3.4.5.1 Avoided loss of goods

Cargo ships are often confronted to difficult sea and weather conditions which in some cases may result in violent rolling, pitching and heaving motion of ships which greatly endangers the containers carried on board. The European Maritime Safety Agency (EMSA) has stated in its annual overview report of marine casualties and incidents issued in 2015, that 3% of casualties at sea were caused by environmental conditions and that 3% were caused by a lack of safety and environment management²³⁵.

To estimate the impact of Copernicus Maritime Safety products on the reduction of goods lost at sea, the annual value of goods lost at sea due to environmental issues and to a lack of safety and environment management was calculated over the period of 2016 to 2035. To reach this data, the average value of goods carried cargo vessels was quantified and multiplied by the percentages of severe casualties caused by environmental conditions (3%) and by poor safety management (3%). The contribution rate of Copernicus on the reduction of maritime casualties leading to the loss of containers is assumed within a range of three scenarios: a *low scenario* assuming a rather modest contribution (1% in 2016) and a timid annual user uptake until 2035 (0,20% annual growth from 2016 to 2020, 0,75% from 2021 to 2027 and 0% from 2028 to 2035); a *high scenario* based on an optimistic assumption of Copernicus' contribution (5% in 2016) with a dynamic user uptake (1% between 2016 and 2020, 3% from 2021 to 2027 and 0% from 2028 to 2035); and a *medium scenario* based on a moderate assumption of Copernicus' contribution (3% in 2016) and a steady user uptake (0,5% from 2016 to 2020, 1,5% from 2021 to 2027 and 0% from 2028 to 2035).

²³⁵ Source: EMSA, Annual Overview of Marine Casualties and Incidents 2015



Methodological approach to value the contribution of Copernicus to the definition of safer maritime routes

The model is based on the quantification of the value of goods threatened by at sea during cargo vessels journeys. The steps are:

1. Assess the average value of goods transported at sea (€/Twenty Foot Equivalent Unit)
2. Assess the evolution of the annual average amount of Twenty Foot Equivalent of goods lost at sea
3. Apply the contribution of Copernicus to safer maritime routes detection

Avoid loss of goods

Valuation approach



The impact of Copernicus on the reduction of goods lost at sea thanks to improved maritime safety management is comprised between **EUR 44.6 M** (low scenario) and **EUR 141.1 M** (high scenario) over the quantified period (2017 – 2035). The yearly evolution of the monetary impact of Copernicus is illustrated in the following figure:

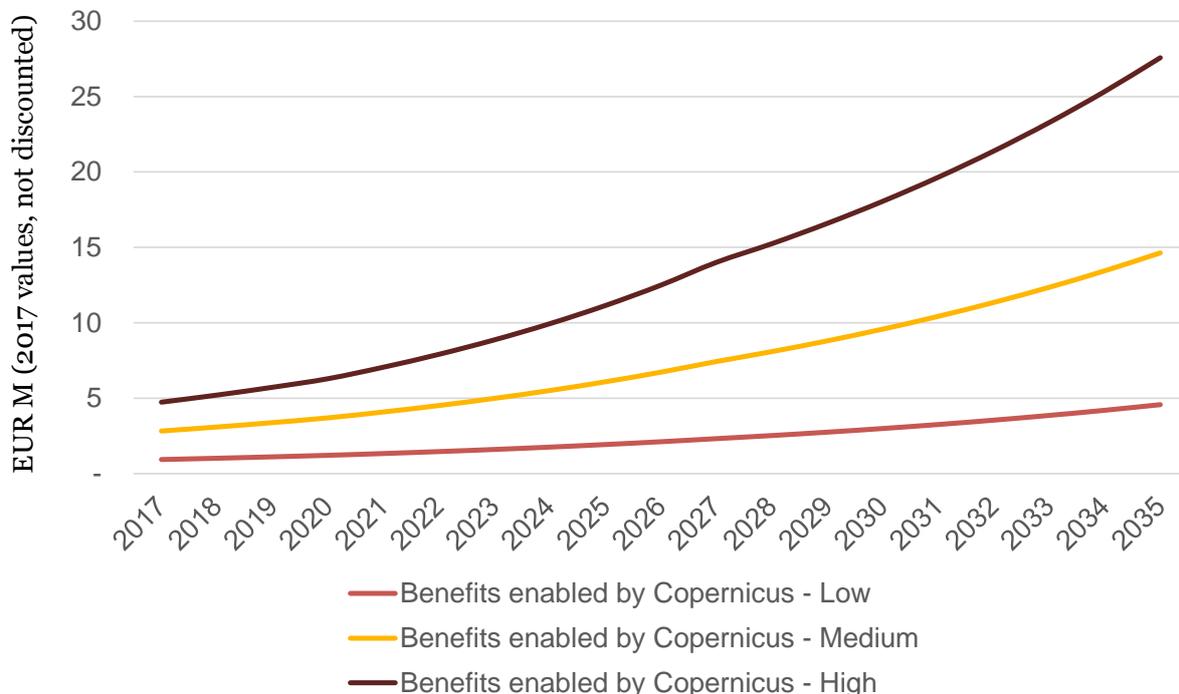


Figure 89 - Evolution of the Copernicus benefits for Avoided loss of goods from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

Information on ocean wind fields, ocean wave spectra and surface radial velocity provided by Copernicus can be exploited to build marine forecast models. By detecting and forecasting sea areas that would endanger carrying vessels on their journey, Copernicus enables the definition of safer maritime routes.

4.2.3.4.5.2 Fuel savings reached through optimised navigation routes

Shipping companies have an economic interest in reducing the fuel consumption of their cargo ships fleet. The forecast of marine currents can enable cargo ships to use current routing for their voyage and therefore reduce their fuel consumption.

The average level of savings reached by current routing is estimated at 0.4% which corresponds to 24 000 tons of fuel²³⁶. The improvement of current forecasts modelling should lead to an average level of fuel savings of 1% by 2020 and represent 60 000 tons of fuel saved annually (in the model developed to quantify the benefits of Copernicus on fuel savings, this trend stays constant between 2020 and 20135). As it is difficult to estimate the precise annual price of fuel in the maritime transport industry until 2035, the average fuel price in USD per ton between 2004 and 2017 was utilised as constant (418,42\$/ton) to simulate a value utilised in this model. Thus, the amount of tons of fuel saved thanks to current routing was multiplied by the average annual price of fuel to obtain a monetised value. The impact of Copernicus on fuel savings reached through optimised navigation routes was assumed to be comprised between 6% (low scenario) and 12% (high scenario) as CMEMS data account for approximately one tenth of the range of elements which are combined to define optimised shipping routes.



Methodological approach to value fuel savings reached through optimised navigation routes

This model examines the amount of fuel that can be yearly spared thanks to the identification and use of current routes for cargo ship journeys.

The steps are:

1. Assess the yearly amount of fuel (tons) saved when using currents routes for cargo ships journeys
2. Forecast the average annual cost of fuel (€/ton)
3. Apply the contribution of Copernicus to the identification of current routes enabling fuel saving

Fuel savings reached through optimized navigation routes

Valuation approach

$$\text{Impact (EUR)} = \text{Contribution of Copernicus to the identification of current routes} \times \text{Yearly amount of fuel saved thanks to current routes (ton)} \times \text{Average annual cost of fuel (€/ton)}$$

The user uptake applied to calculate the growth of Copernicus's contribution is based on the analysis of the evolution of the number of CMEMS subscribers since 2013. In four years (2013 – 2016) the average number of annual CMEMS products subscribers has ranged between 1560 and 2250 and is estimated to keep the same pace until 2028. The partial extraction of this trend was then used to estimate the user uptake for CMEMS products utilised to define current routes and combined with the evolution forecast of the number of vessels taking international routes up to 2035.

²³⁶ Source: http://www.iserd.org.il/_Uploads/dbsAttachedFiles/4_Cristina_Ananasso_Copernicus_Maritime_Domains_v2.pdf

Based on the quantification approach described above, the cumulated economic benefits of the Copernicus programme on fuel savings for maritime cargo vessels between 2016 and 2035 is estimated between **EUR 25.6 M** (low scenario) and **EUR 58.9 M** (high scenario). The annual evolution of this forecast is provided in the following figure:

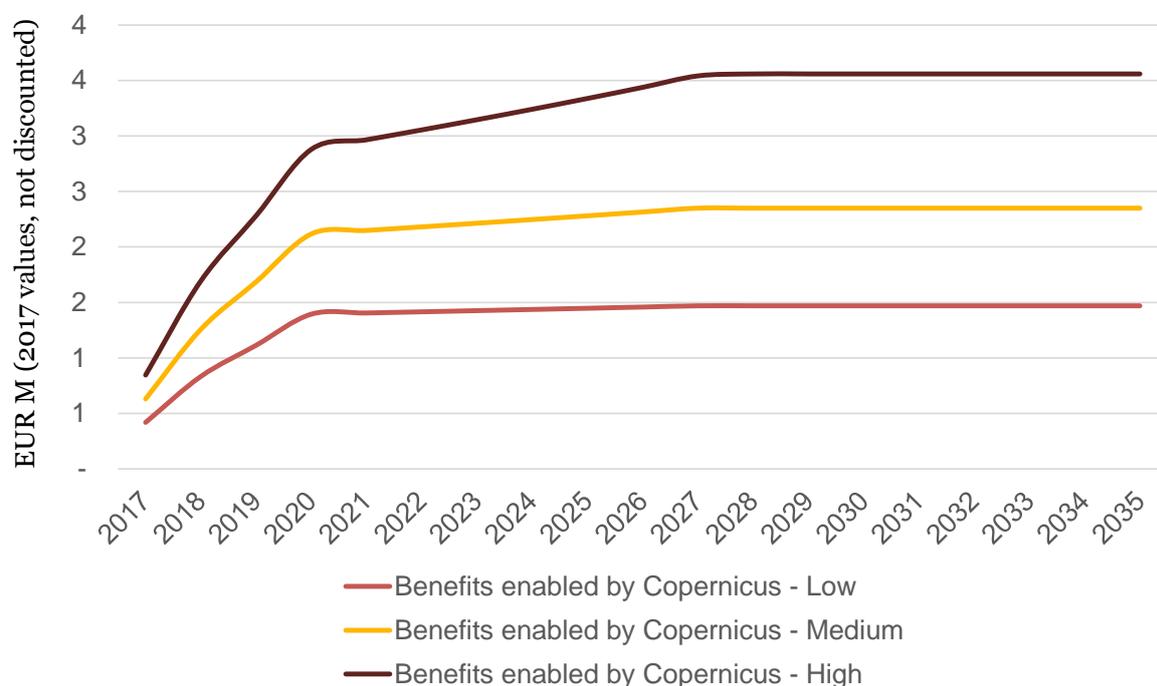


Figure 90 - Evolution of the Copernicus benefits for Fuel savings reached through optimised navigation routes from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The identification of current routes is reached by the utilisation of meteorological and oceanography data. CMEMS products providing information on winds, waves and drifts, support currents modelling forecasts which can be exploited by shipping companies to define economical routes.

4.2.3.4.5.3 Summary of Copernicus contribution to “Maritime navigation”

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

<i>Copernicus EU benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	1.4	3.4	6.0	70.2
Medium estimate	3.5	8.4	17.0	181.3
High estimate	5.6	14.5	31.1	319.4

Table 25 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below.

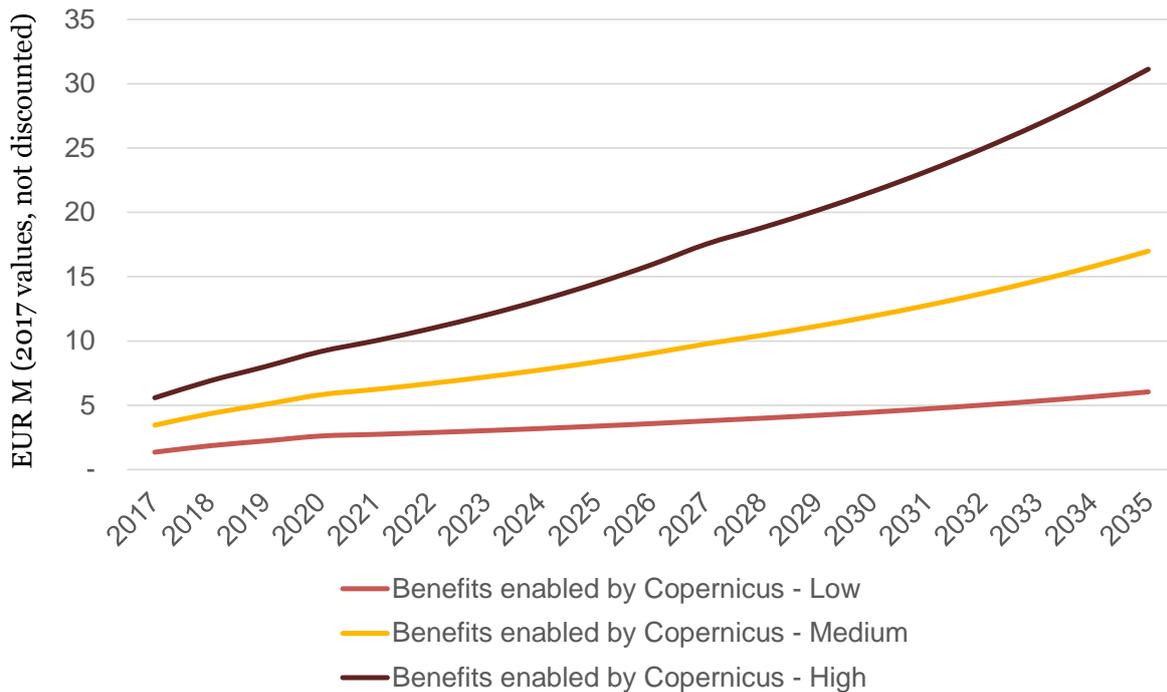


Figure 91 - Evolution of the Copernicus EU benefits for Maritime Navigation, from 2017 to 2035 (Source: PwC analysis)

4.2.3.5 Disasters and geo-hazards

Due to the developments of new disaster management techniques, the global increase in disaster awareness, the emergence of new tools, trainings and international partnerships built to strengthen resilience and reduce disaster risks, natural disasters and their effects tend to decrease with time. However, in some cases this trend is violated and takes the opposite direction as a result of many external factors. This violation manifested in the year 2015, and broke the continuous yearly disaster damages decrease and witnessed 22,765 fatalities worldwide, affected 110.3 million people and caused economic damages worth 70.3 billion USD.²³⁷ These numbers are expected to start increasing yearly when projected up to 2050 or further driven mainly by climatological or socio-economic growth. Such disasters are meteorological, geophysical, accidental or deliberate, humanitarian or technical. All the same, they need to be managed in the best possible way to minimize casualties and damages.

Disaster management is a full cycle. First, it depends on building preparedness and mitigation measures to prevent or reduce disaster risks, then it requires timely effective response to the disaster, and finally it enhances the recovery phase with minimal losses and interruptions to everyday life.

One of Europe's good tools that incorporate science and technology in the fight against disaster risks is Copernicus Emergency Management Services (EMS). Copernicus EMS uses Earth observation data from satellites and in situ measurements to provide national humanitarian aid, civil protection or authorities products that support them in the different steps of emergency management.

Copernicus EMS products are three: Mapping services for any type of disaster anywhere around the world, and two dedicated early warning systems for Europe : European Flood Awareness System (EFAS), European Forest Fire Information System (EFFIS).

²³⁷ Guha-Sapir, Hoyois, and Below, 2015. Annual Disaster Statistical Review 2015 The number and trends. Centre for Research on the Epidemiology of Disasters (CRED), Université Catholique de Louvain.

Mapping services of Copernicus EMS are international and can be used for any type of disaster. To access them, an authorized user (which is a national or a European focal point) must activate the service which offers two types of services: Rapid Mappings and Risk & Recovery Mapping. The rush mode reference, delineation, and grading maps are those requested immediately following a disaster. They are provided within hours to days of the activation and aim to support the on ground response to the disasters. The risk and recovery maps however address the other phases of emergency management from prevention to recovery and are provided within weeks or months to the user.

EFFIS services were established in 2003 but only became part of the Copernicus EMS in 2015. EFFIS provides historical information on the forest fire status over Europe and the MENA region (Middle East and North Africa), as well as data for the full fire cycle pre and post a fire. It provides daily updated fire danger maps and forecasts up to 6 days in advance of fires, and near real time mappings of burnt areas. For fire detection services that are only available in Europe through EFFIS (i.e. no European country has the national capacity to detect fires), it performs 6 revisits per day. Otherwise for monitoring the burnt areas it performs 3 revisits per day. Thanks to the resolution of the sensors it uses, EFFIS has the capacity to monitor all large fires in Europe (>30 ha) which represent around 80% of total burnt areas in Europe. It also has the capacity to perform fire damage assessments such as soil and vegetation damage assessments.

EFAS services had been under development since 2003 following the catastrophic Elbe and Danube floods, and they became part of Copernicus EMS in 2011 to become fully operational in 2012. EFAS provides European countries with flood early warnings and forecasts up to 10 days in advance. Other than the flood historic data and information, it also provides real time mapping and monitoring of floods all around Europe.

Copernicus EMS impacts will be calculated only for fires and floods as they have dedicated systems (EFFIS and EFAS) as for the mapping services, in Europe the highest number of activations of the rush mode mappings are for Floods then fires (<http://emergency.copernicus.eu/mapping>)²³⁸ therefore the greatest impact of Copernicus EMS would be on these two particular disasters.

4.2.3.5.1 Fire detection and monitoring

In Europe, forest fires mostly concern five countries: Portugal, Spain, Italy, Greece and France²³⁹. Indeed, these countries account for 85% of the European burnt areas. In this Mediterranean region, almost all fires (95.3 %) are man-made whether deliberate or not and 80% of burnt areas are due to large fires (over 30ha of burnt areas at once)²⁴⁰. Fires don't necessarily affect the same type of areas, meaning the impact varies accordingly (e.g. destruction of crops or trees). Using statistics from Forest Fire Reports published by EFFIS, the types of burnt areas in the five European countries mentioned above is distributed as follows:

²³⁸ Priolo, 2014. Copernicus Emergency Service Overview and Success Stories. 25 March 2014, Sofia.

²³⁹ San-Miguel-Ayanz and EFFIS Team, 2015. The European Forest Fire Information System

²⁴⁰ Jesús San-Miguel-Ayanz, Tracy Durrant, Roberto Boca, Giorgio Libertà, Francesco Boccacci, Margherita Di Leo, Jorge López Pérez, Ernst Schulte; Forest Fires in Europe, Middle East and North Africa 2015; EUR 28158 EN; doi:10.2788/914

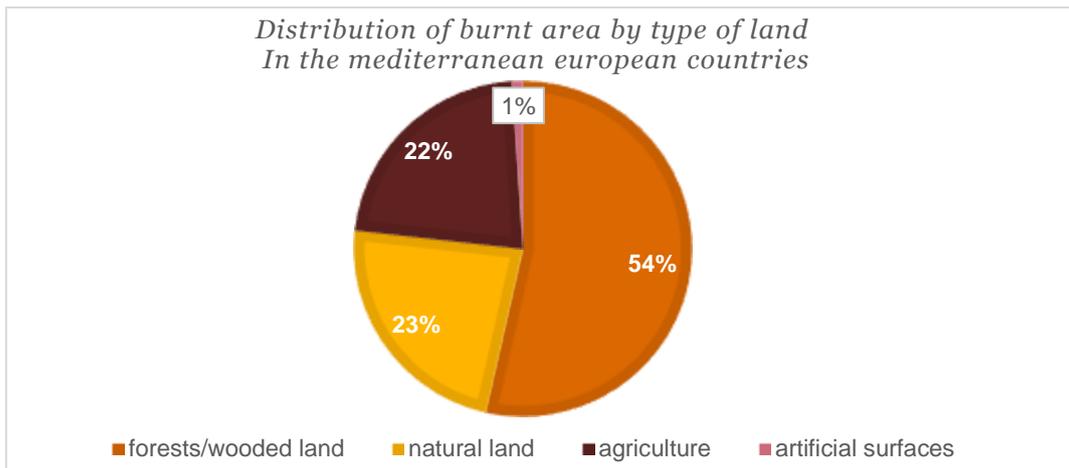


Figure 92 - Type of burnt areas in the European Mediterranean Region (Source: San-Miguel-Ayanz et al., 2015)²⁴¹

Even though the burnt areas in Europe have decreased in the past years due to better fire management, a growth of burnt areas is foreseen in the coming years due to climate change and weather conditions, notably warmer and dryer weather, but also due to economic growth. If no adaptation steps nor measures to these conditions are taken, burnt areas in Europe are expected to increase by 150 - 220% in 2090 compared to 2000²⁴², with a steep increase expected to start around 2050. However, with different fire prevention strategies and disaster preparedness or mitigation techniques, the total burnt area in 2090 could be significantly inferior to what is currently projected. The adaptation scenario simulated in *Forest fires and adaptation options* (Khabarov et al., 2014)²⁴³ emphasizes that through the use of prescribed burning (i.e. the process of planning and applying fire to predetermined areas, under specific environmental conditions, for the purpose of mitigating the effect of bushfire or maintaining biodiversity for instance), it is possible to limit the impact of fires.

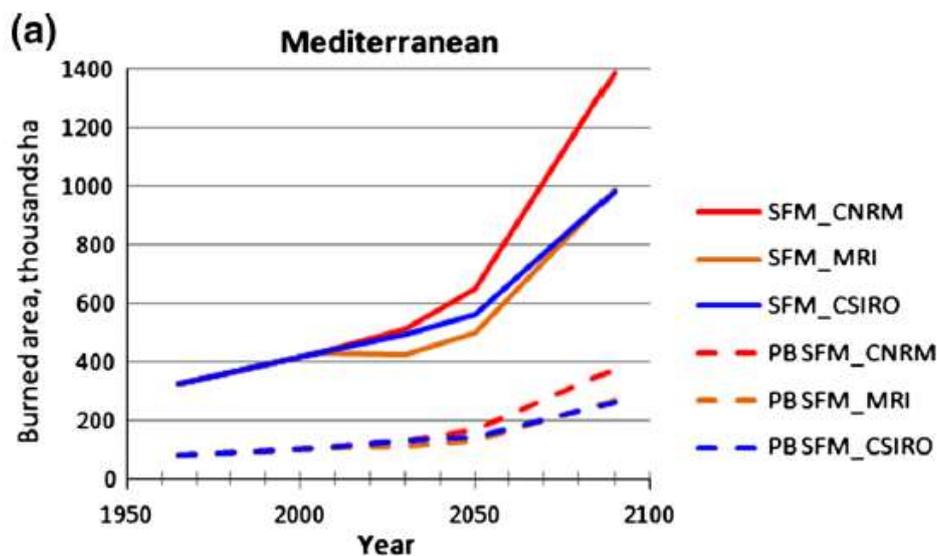


Figure 93 - Burnt area under 'no adaptation' scenario (SFM) and 'prescribed burnings' scenario (PB SFM) (Source: Khabarov et al., 2014)

241 Jesús San-Miguel-Ayanz, Tracy Durrant, Roberto Boca, Giorgio Libertà, Francesco Boccacci, Margherita Di Leo, Jorge López Pérez, Ernst Schulte; Forest Fires in Europe, Middle East and North Africa 2015; EUR 28158 EN; doi:10.2788/914

242 Khabarov et al., 2014. Forest fires and adaptation options in Europe

243 Khabarov et al., 2014. Forest fires and adaptation options in Europe

The Copernicus service in charge of fire detection and monitoring is the Emergency Management Service (EMS), in particular through its mapping service, the Global Wildfire Information System (GWIS) and the European Forest Fire Information System (EFFIS). As only European wildfires are concerned here, EFFIS is the entity that provides relevant data and information to fight forest fires. Through its fire detection capacity enabling to map forest fires in a timely manner, its fire forecasting capacity enabling fire prevention and preparedness (EFFIS has the capacity to detect a fire as soon as it starts, which is a feature that no European member States possesses yet), and its strategic role in spreading awareness among European countries on the importance of fire mitigation and in contributing to the EU strategy and policy framework of building fire resilience and disaster risk reduction. As for the Copernicus EMS mapping service, its on-demand rapid mapping services are delivered in relatively timely manner (24-48h after a user's request), with the capability to provide different types of post-crisis maps for the entire area of interest. As such, they can be very important for fire suppression and mitigation planning.

The impact pathway below presents the economic, social and environmental benefits that Copernicus EMS generates through EFFIS thanks to fire detection and monitoring.

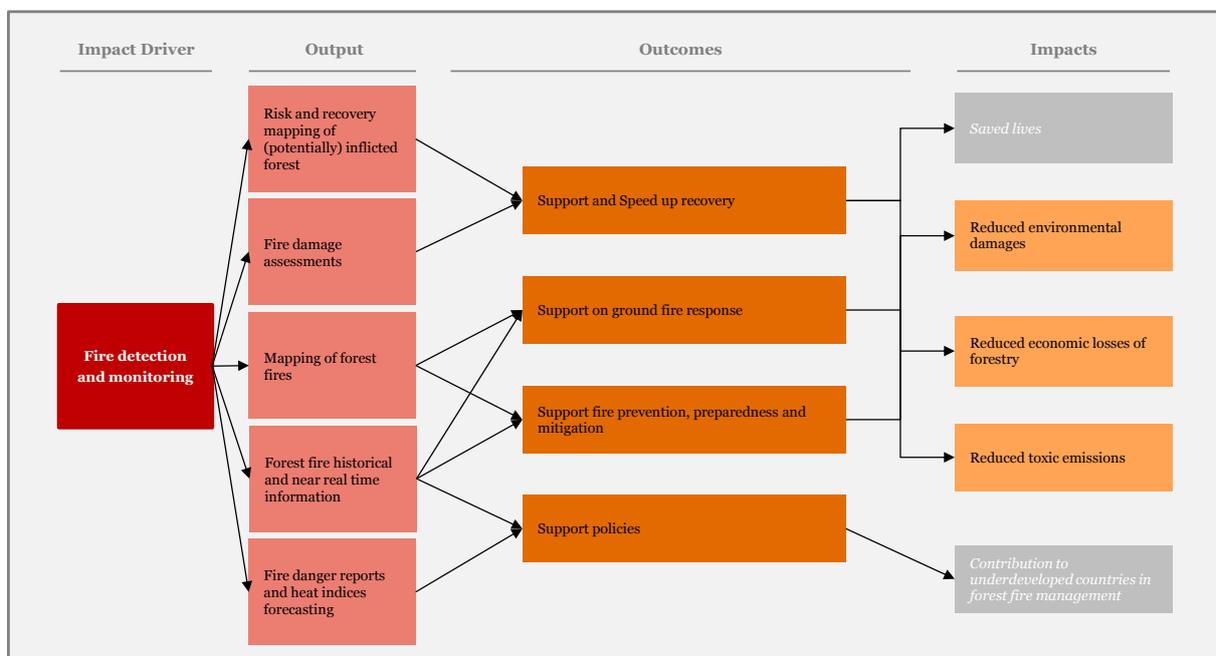


Figure 94 - Impact pathway of fire detection and monitoring (Source: PwC analysis)

Several activities are undertaken by the Copernicus EMS mapping service and EFFIS to provide actors with forest fire information and fire danger indices, supporting them in taking necessary measures to reduce fire risks. First, risk and recovery mapping of areas potentially at risk combined with fire damage assessments are supporting actors in assessing the extent and severity of forest damages in order to build recovery maps of forests and to enable to speed up this recovery. Second, EFFIS and the Copernicus EMS mapping service provide mapping of forest fires, which are supplemented by forest fire historical and near real time information that help on ground fire response but also support fire prevention, preparedness and mitigation. Indeed, this facilitates logistics for fire responders and leads to improved, better informed response plans that will thus support fire suppression, reducing the time it takes to put down the fire. The historical and near real time information on forest fires are also used by public authorities with fire danger reports and heat indices forecasting made available by EFFIS in order to support the development of new policies aiming at preventing forest fire occurrences. The different outcomes enable the following benefits:

- Reduced environmental damages;
- Reduced toxic emissions;
- Reduced economic losses due to loss of forestry;
- Contribution to underdeveloped countries in forest fire management.

The benefits are quantified as follows:

4.2.3.5.1.1 Reduced environmental damages

The first benefit of detecting and monitoring fires consists in the protection of the environment. The different varieties of land have different values to the ecosystem. This value comes from non-market services such as recreation, watershed, soil protection, biodiversity, pollination, etc. As presented above, different types of land are affected by fires: as such, the loss of forest does not have the same environmental consequences as the loss of artificial surfaces for instance.

Copernicus has a double contribution in the fight against environmental damages consequential to fires: first, the prevention and mitigation of fires and second, the preparedness and response to fires through mapping. The first activity is exclusively undertaken by EFFIS, whereas the second activity is undertaken both by EFFIS and by the Copernicus EMS mapping service.



Methodological approach to value to socio-environmental benefits of reduced forest fire areas

The assessment consists in looking at the areas saved from burning thanks to EFFIS and the Copernicus EMS mapping service and to analyse the environmental value that was prevented from being lost.

The steps are:

1. Determine the size of the areas that could theoretically be saved from fire burning thanks to fire prevention strategies and preparedness in five countries (Portugal, Spain, Italy, Greece and France²⁴⁴).
2. Expand the size of the areas saved to the whole of Europe by doing a ratio between burnt areas in Europe and in these five countries.
3. Take into account the 10-year recovery rate of burnt areas.
4. Apply a valuation coefficient to each type of areas that was not burnt and that has not recovered yet, which corresponds to the value that each type of land provides to the ecosystem.
5. Apply the contribution of Copernicus EMS mapping service and of EFFIS.

Social and environmental benefits due to reduced forest fire area Valuation approach



244 San-Miguel-Ayanz and EFFIS Team, 2015. The European Forest Fire Information System

In order to be representative of global trends in the forest fire sector, yearly averages for burnt areas over an 8 to 10 year span are taken: indeed, there can be major fluctuations of burnt areas between two consecutive years. According to Khabarov et al. predictions, without any adaptation such as fire prevention methods and techniques, the burnt areas in Portugal, Spain, Italy, Greece and France are expected to increase by about 6.38% between the yearly average of 2017-2025 and the yearly average of 2026-2035²⁴⁵. However, in reality, the share of actual burnt areas is decreasing as fire mitigation techniques are implemented and preparedness and responses are improving: in 2017-2025, 58.5% of the planned burnt areas are expected to actually burn, for 52% in 2026-2035, according to the trend of previous years²⁴⁶. After an extrapolation to the whole of Europe, based on the fact that burnt areas in these countries account for 85% of the European burnt areas, hence saved areas are similarly proportional, it appears that the yearly average of saved areas is 229,412 ha in 2017-2025 and 282,353 ha in 2026-2035. Besides, in order to get a sense of the environmental cost of forest fires, it is not sufficient to simply look at yearly burnt areas. Indeed, it takes time for burnt areas to regrow and regenerate. Recovery time of forests and land differs greatly depending on the type or size of trees, on their location and on the environmental conditions. However, in the model the regeneration period was assumed to be 10 years²⁴⁷. Therefore, the ecosystem damages count for every year the value of saved land plus the value remaining from saved land in previous years. These total saved areas are then applied different valuation coefficient corresponding to the cost of preserving the ecosystem for each type of area. The repartition of the different types of burnt areas, as presented above, enables to attribute each type of land the right valuation coefficient²⁴⁸.

Once the benefits of saving areas from fires thanks to adaptation has been calculated, the contribution of Copernicus to this adaptation is extracted. Two services play a role in this adaptation: EFFIS and the Copernicus EMS mapping service. As for EFFIS, it contributes to prevention and mitigation of forest fires and is assumed to be responsible of between 10% and 15% of the saved areas over the 2017-2035 period²⁴⁹. EFFIS also contributes to preparedness and response through mapping of large forest fires (above 30 ha), which represent 80% of the fires that occur²⁵⁰. Its contribution ranges between 0.5% and 0.75% in 2017-2025 to between 1% and 1.5% in 2026-2035 of the areas saved from large fires. This contribution is calculated by taking into account the fact that by increasing the probability of fighting down a fire in just one day by 10%, it would lead to saving 30% of the burnt areas in 2090²⁵¹. As for the Copernicus EMS mapping service, which also contributes to preparedness through mapping of large fires, its contribution is of 0.31% in 2017-2025, increasing to 1% in 2026-2035 of the areas saved from large fires. This contribution is also based on the boosting of the probability of putting out a fire within a day and on the solicitation of the mapping service by users. The activations of the on-demand rapid mappings covered 24% of the total burnt area from large fires in the five European countries mentioned above in 2015, and these activations are expected to reach 100% in the next ten years.

As a result, in 2017, the non-discounted benefits of Copernicus's fire detection and monitoring on the ecosystem are between EUR 23.4 M and 34.9 M and are expected to increase and reach between EUR 67.6 M and EUR 98.9 M in 2035. The evolution of these benefits is depicted in the following graph:

245 Khabarov et al., 2014. Forest fires and adaptation options in Europe

246 PwC analysis

247 Bartels et al., 2016. Trends in post-disturbance recovery rates of Canada's forests following wildfire and harvest. *Forest Ecology and Management*. Vol. 361, p. 194 – 207.

248 Jesús San-Miguel-Ayanz, Tracy Durrant, Roberto Boca, Giorgio Libertà, Francesco Boccacci, Margherita Di Leo, Jorge López Pérez, Ernst Schulte; *Forest Fires in Europe, Middle East and North Africa 2015*; EUR 28158 EN; doi:10.2788/914

249 Expert consultation

250 Jesús San-Miguel-Ayanz, Tracy Durrant, Roberto Boca, Giorgio Libertà, Francesco Boccacci, Margherita Di Leo, Jorge López Pérez, Ernst Schulte; *Forest Fires in Europe, Middle East and North Africa 2015*; EUR 28158 EN; doi:10.2788/914

251 Khabarov et al., 2014. Forest fires and adaptation options in Europe

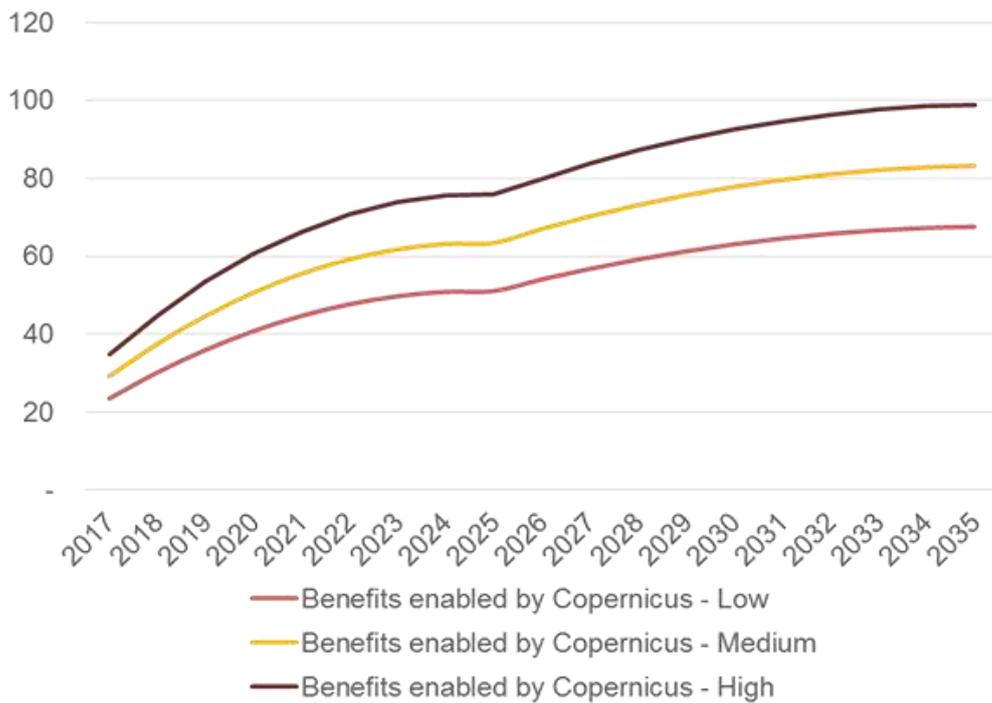


Figure 95 - Increased benefits to the ecosystem due to reduced forest fires in all of EU (Source: PwC analysis)

4.2.3.5.1.2 Reduced toxic emissions

The second benefits consists in the reduction of carbon emissions released by fire events. By saving areas from burning, it is possible to avoid the release of several toxic emissions. Similarly to the previous benefit, Copernicus has a double contribution through its two services, EFFIS and the mapping service.



Methodological approach to value the benefits of reduced toxic emissions due to reduced burnt area

The assessment consists in looking at the areas saved from burning thanks to EFFIS and the Copernicus EMS mapping service and to analyse the environmental value that was prevented from being lost. The steps are:

1. Determine the size of the areas that could theoretically be saved from fire burning thanks to fire prevention strategies and preparedness in five countries (Portugal, Spain, Italy, Greece and France²⁵²).
2. Expand the size of the areas saved to the whole of Europe by doing a ratio between burnt areas in Europe and in these five countries.
3. Apply a CO₂ valuation coefficient based on the CO₂ mass that is emitted per ha of forest.
4. Apply the contribution of Copernicus EMS mapping service and of EFFIS.

Environmental benefits due to reduced forest fire area Valuation approach



A methodology similar to the one of the previous benefit is applied here. The same size of saved areas is considered, however, the recovery is not taken into account: indeed, toxic emissions only happen once, when forest is burning but does not have longer term impact in terms of emissions. On a yearly average computed between 1980 and 2008, it appeared that 13.6 Mt of CO₂ were emitted from around 480,000 ha of burnt area²⁵³. From these values, an estimate of emitted CO₂ from 1 ha of burned forest fire can be calculated. This value is then multiplied by the total saved area from forest fires.

The contribution of Copernicus is then applied. This contribution is therefore similar to the one mentioned in the previous benefit as it is the same kind of contribution that is provided by EFFIS and the Copernicus EMS mapping service: prevention, preparedness and improved response.

As a result, the non-discounted benefits from reduced toxic emissions amounted to between EUR 54.7 M and EUR 81.2 M in 2017 and is expected to reach between EUR 72.4 M and EUR 106.0 M in 2035 as shown in the following graph:

²⁵² San-Miguel-Ayanz and EFFIS Team, 2015. The European Forest Fire Information System

²⁵³ Terhi Vilen, Paulo M. Fernandez, 2011. Forest Fires in the Mediterranean Countries : CO₂ emissions and mitigation possibilities through prescribed burnings

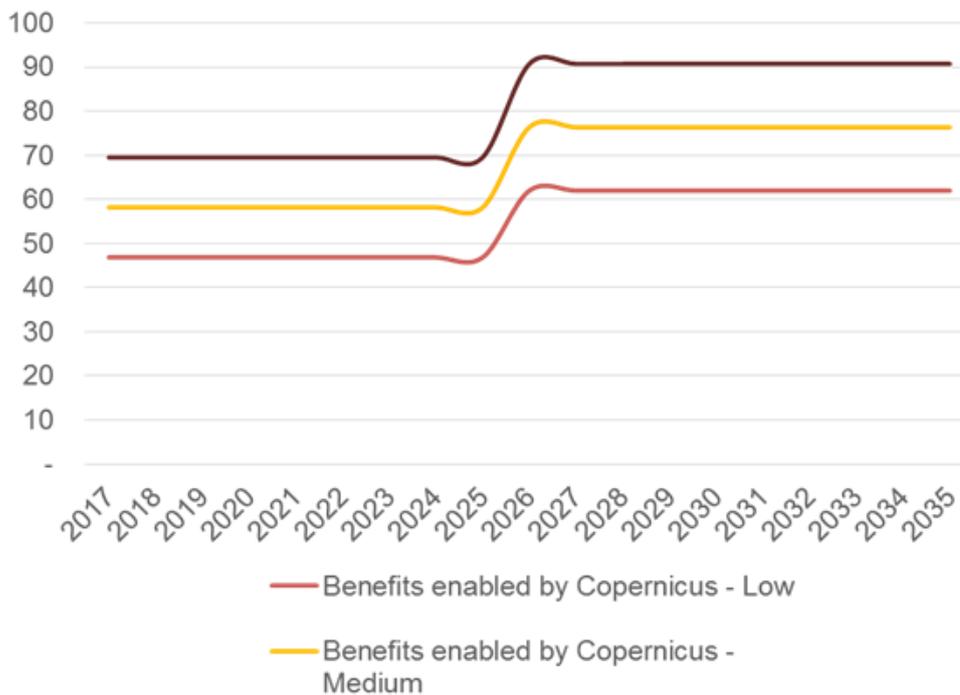


Figure 96 - Value of displaced CO2 emissions due to reduced forest fires thanks to Copernicus (Source: PwC analysis)

4.2.3.5.1.3 Reduced economic damages in forestry

Besides environmental damages linked to toxic emissions and damages to the ecosystem, forest fires also have an economic impact: for instance, there is an impact on wood production or on hunting activities²⁵⁴. Economic damages of forest fires in Europe have already been estimated for a yearly average of EUR 2.7 B²⁵⁵ in terms of forest reconstruction value after a fire. However, the size of burning areas can be really changing and is not always proportionally linked to the economic damages. The estimated economic damages in Europe are presented below:

²⁵⁴ Di Fonzo M., P.M. Falcone, A.R. Germani, C. Imbriani, P. Morone, F. Reganati (2015). The Quantitative and Monetary Impacts of Forest Fire Crimes. Report compiled as part of the EFFACE project, University of Rome “La Sapienza”, www.efface.eu.

²⁵⁵ San-Miguel-Ayaz and EFFIS Team, 2015. The European Forest Fire Information System

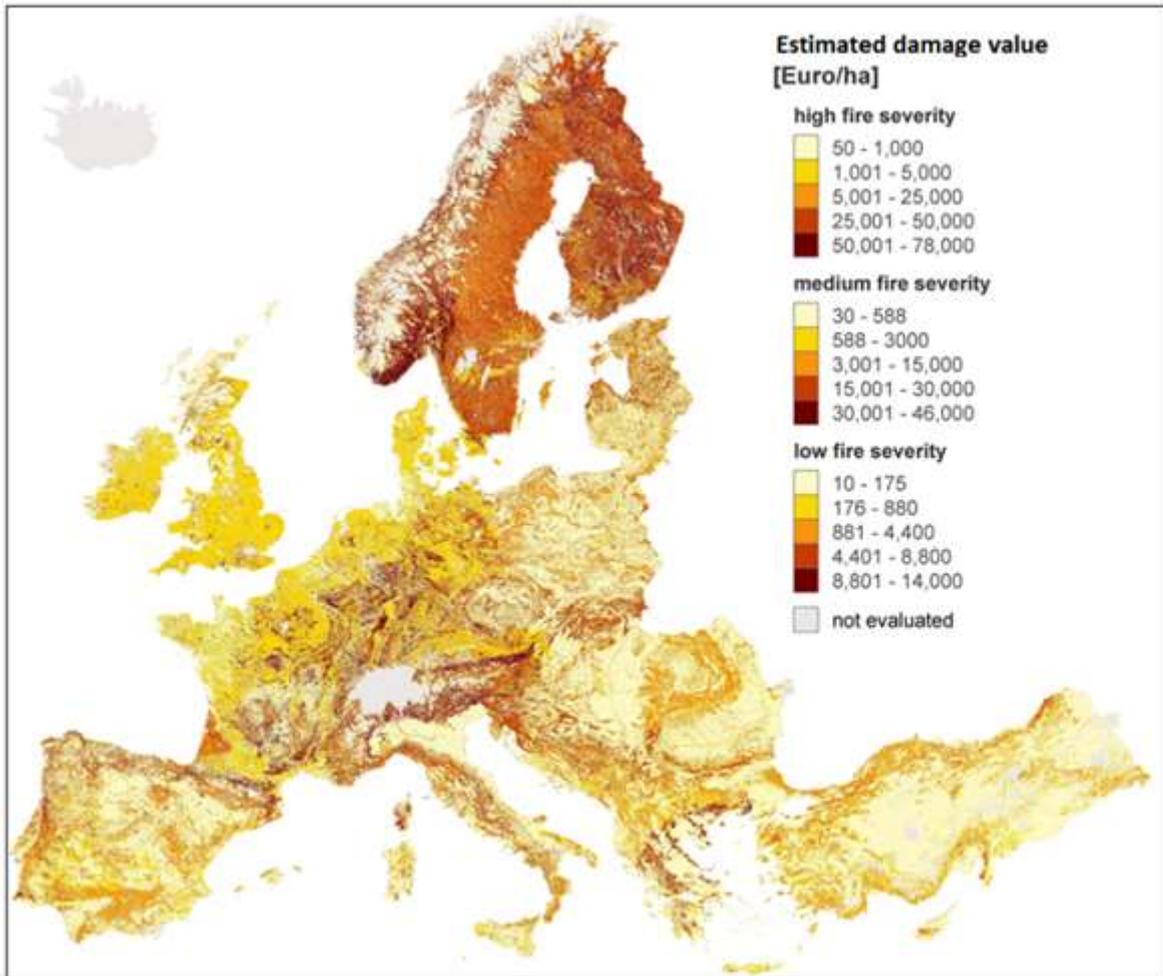


Figure 97 - Estimated economic damages of wildfires in Europe (Source: A. Camia, G. Libertá, J. San-Miguel-Ayanz, 2017²⁵⁶)

²⁵⁶ Camia Andrea, Libertá Giorgio, San-Miguel-Ayanz Jesús(2017). JRC Technical Report, "Modelling the impacts of climate change on forest fire danger in Europe"



Methodological approach to value economic benefits due to reduced forest fire area

The assessment consists in looking at the areas saved from burning thanks to EFFIS and the Copernicus EMS mapping service and to analyse the environmental value that was prevented from being lost. The steps are:

1. Determine the size of the areas that could theoretically be saved from fire burning thanks to fire prevention strategies and preparedness in five countries (Portugal, Spain, Italy, Greece and France²⁵⁷).
2. Expand the size of the areas saved to the whole of Europe by doing a ratio between burnt areas in Europe and in these five countries.
3. Apply the economic cost of a hectare of forest lost.
4. Apply the contribution of Copernicus EMS mapping service and of EFFIS.

Economic benefits due to reduced forest fire area

Valuation approach



The methodology applied here is similar to the one of the previous benefit. The same size of saved areas is considered, without taking into account the recovery time: indeed, economic damages are calculated for each new hectare lost but cannot be applied twice to the same area. Based on the estimated economic damages presented on the map above, a value was extracted for economic damages: these are estimated at EUR 9,020 per hectare in 2017 ²⁵⁸. This value is then multiplied by the size of the areas that were saved.

The contribution of Copernicus is then applied. This contribution is therefore similar to the one mentioned in the previous benefit as it is the same kind of contribution that is provided by EFFIS and the Copernicus EMS mapping service: prevention, preparedness and improved response.

As a result, the non-discounted benefits from reduced toxic emissions amounted to between EUR 225.8 M and EUR 335.1 M in 2017 and is expected to increase to between EUR 298.8 M and EUR 437.2 M in 2035. The trend is presented in the graph below:

²⁵⁷ San-Miguel-Ayaz and EFFIS Team, 2015. The European Forest Fire Information System

²⁵⁸ Based on the map above. assuming an equal distribution among fire severity and economic damages cost. We took medium fire severity and the average of the middle value range of damages (3001 – 15000) was computed = 9000 euro/ha, updated in EUR 2017

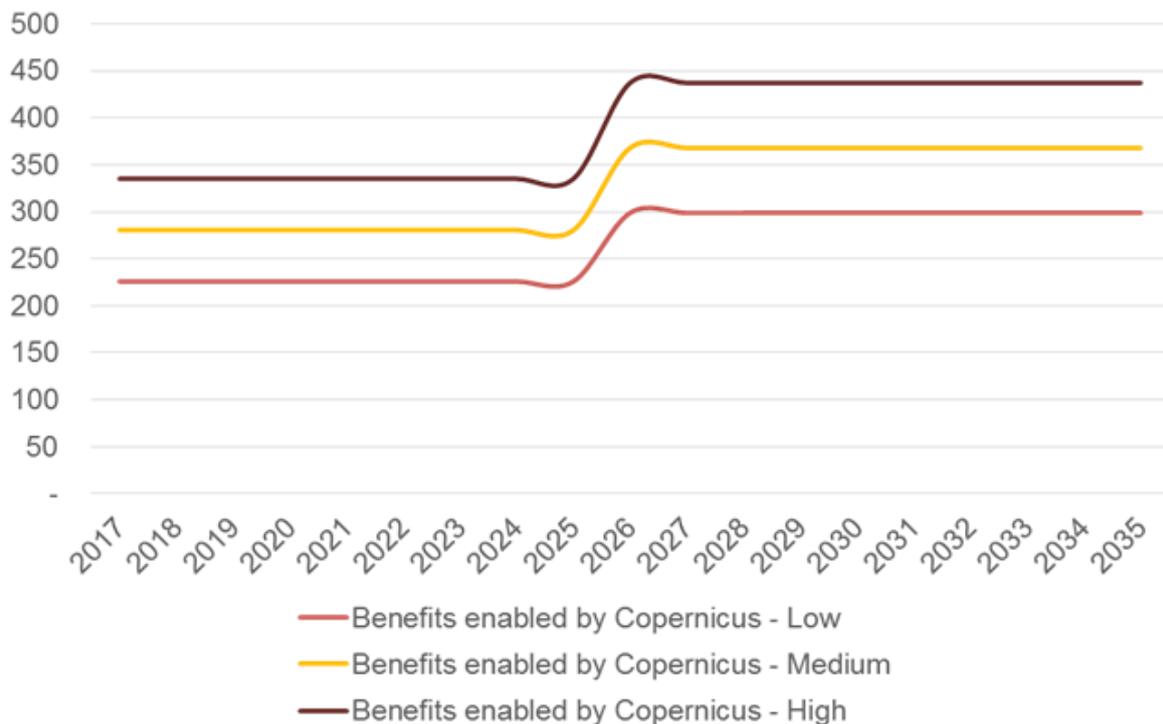


Figure 98 - Saved economic costs due to reduced forest fires in the EU (Source: PwC analysis)

4.2.3.5.1.4 Saved lives

The value of saved lives thanks to Copernicus fire monitoring and detection applications was not calculated in this model. The reason for that is the large uncertainty of quantifying fatalities in fires. There is no particular trend or estimation to the number of fatalities per fire. For most fire occurrences, no life is lost, particularly when fires are in forests and far from residential areas, and the easiness to evacuate people in fire prone regions also helps avoid fatalities. Of course, there is always an occasional fire that claims lives such as the exceptional case in Portugal last June when around 64 people died due to a wildfire. However even for such cases, allocating a contribution to Copernicus for the lives saved is farfetched, and would be highly uncertain.

Differentiation factor of Copernicus and EO

Despite the importance of EFFIS, the entity is still facing many challenges: for example, the absence of a European forest policy, which would include coordination among Member States and facilitate fire management. Copernicus EMS is a great networking tool that is currently working to achieve higher level disaster coordination and communication among European countries. A shutdown of these services will leave hollower the void on the level of communication and coordination and lead to greater difficulties in facing disasters in Europe, and in responding to the EU strategy and policy framework of building fire resilience and disaster risk reduction with synchronization.

As for the improved fire response and preparedness, although there are some products that offer mapping services of disasters such as the international charter, fire detection services in Europe does not exist elsewhere. Countries will have to depend on their own capacities for fire and heat indices forecasting and monitoring while others would have to buy the other available services.

4.2.3.5.1.5 Summary of Copernicus contribution to “Fire detection and management”

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	304.0	331.6	438.8	7,238.3
Medium estimate	377.6	441.9	540.4	8,946.2
High estimate	451.3	492.1	642.0	10,654.2

Table 26 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below. It matches the increase in likelihood of putting a fire out in a day set for 2026.

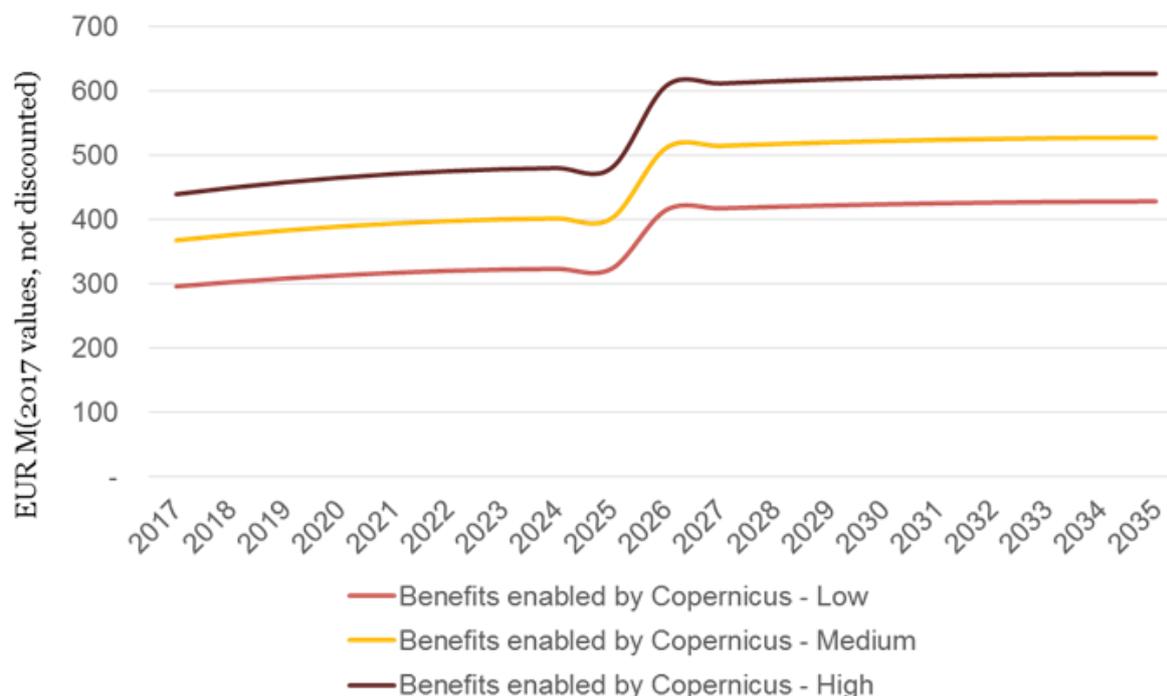


Figure 99 - Total benefits of Copernicus on fire detection and monitoring in Europe (Source: PwC analysis)

4.2.3.5.2 Flood monitoring and forecasting

Floods are the most recurring disasters in Europe, and claim the highest number of victims and economic damages on yearly averages than any other disaster. Flood damages do not only consist of destroying property or land, but have long term effects as well as they leave people homeless and injured, cause disruptions in daily utilities such as electricity and water. Destruction of schools could interrupt access to education for weeks. Access to proper and necessary medical care post floods could be compromised due to destruction of hospitals. On another, level floods could lead to the contamination and chemical poisoning of crops and vegetation, or of the drinkable water and cause more serious long term health problems that would not be detected immediately after the flood²⁵⁹.

To minimize these effects as much as possible the most important thing is to be aware of the dangers of floods. That being achieved vulnerabilities and risks can be identified, action plans can be put in place and preparedness augmented so that all the needs before, during, and after the flood are met with the minimum of losses. As a matter of fact studies have

259 Guha-Sapir, Hoyois, and Below, 2015. Annual Disaster Statistical Review 2015 The number and trends. Centre for Research on the Epidemiology of Disasters (CRED), Université Catholique de Louvain

shown that spending EUR 1.75 B on flood risk reduction today (2017) will reduce by 2050 the estimated annual flood losses by EUR 7 B²⁶⁰.

EFAS is the European Flood Awareness System. It is an operational service under the umbrella of the Copernicus Emergency Management Service. As the first operational European system monitoring and forecasting floods across Europe, it provides complementary, flood early warning information to its partners. Copernicus Mapping Services and EFAS create strategic networking among European Member States on disaster risk reduction which is a main tool to spread awareness among them, and let them motivate each other to improve their resilience to disasters. They play a direct role in fighting flood risks.

By warning entities of flood risks before they occur, EFAS provides the chance to prepare for the flood, evacuate the areas and take necessary mitigation measures. EFAS historical and continuous flood information increases awareness about areas of high risks and vulnerability, and therefore allows authorities to make better informed decisions on socio-economic growth favorable to flood risk reduction, which on a long run, will reduce the economic damages due to floods. By providing on-demand Rapid Mapping services, Copernicus can deliver support to on ground response within the first hours or days of the flood occurrence be a key component of emergency response and operations strategy. Risk and Recovery Mapping provides geospatial information supporting related entities in preparing for flood risks or in planning recovery. These mappings will lead to more efficient response plans, and mitigation measures.

The benefits derived from the use of Copernicus Mapping Services and EFAS for flood monitoring and forecasting, are presented in the impact pathway below:

²⁶⁰ May 2014. "Science for environmental Policy": European Commission DG Environment News Alert Services, edited by SCU, the University of West England, Bristol

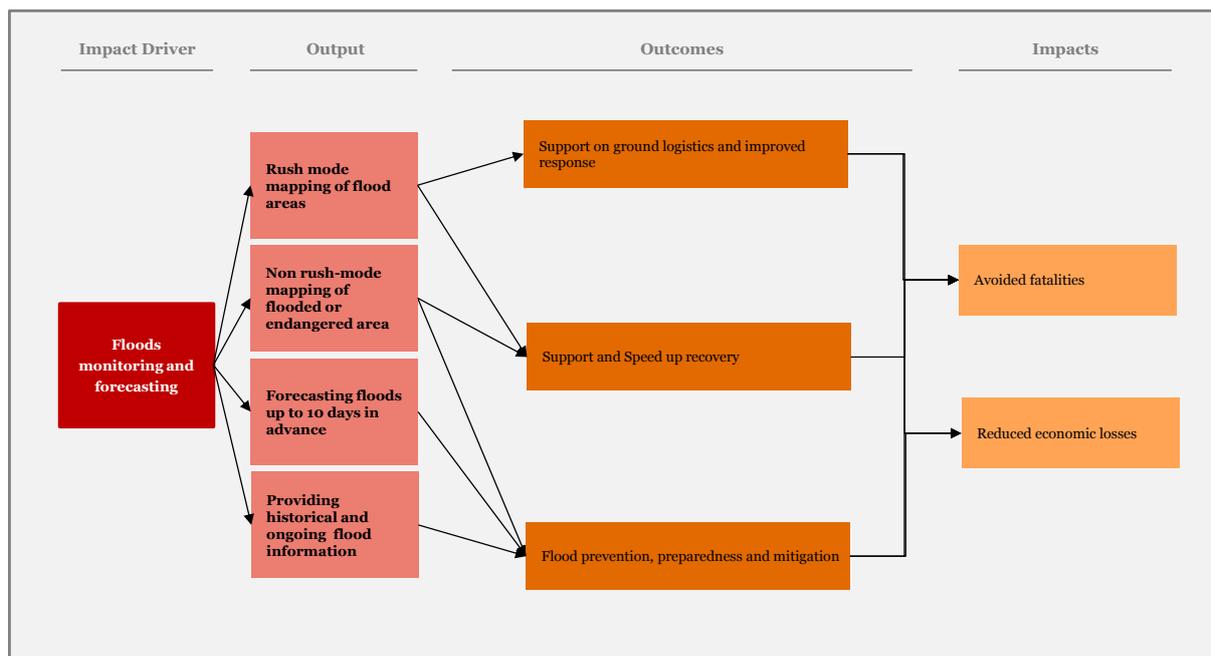


Figure 100 - Impact pathway of flood monitoring and forecasting (Source: PwC analysis)

As a result of all these outputs several benefits can be pointed out:

- Avoid fatalities and injuries in the population (Societal benefit)
- Reduced economic losses (Economic benefit)

4.2.3.5.2.1 Reduced economic losses (Economic benefit)

The benefit of reduced economic losses due to floods, comes from the two main outcomes resulting from Copernicus use:

- The flood prevention, preparedness and mitigation
- The support to on ground logistics and improved response

Calculation and methodological approach were based on this two outcomes, both leading to two main benefits: “Reduced economic losses” and “Avoided fatalities and injuries” (see next paragraph).

4.2.3.5.2.1.1 Thanks to flood preparedness, prevention and mitigation

Several studies have been performed on the methods of reducing disaster risks, and the most efficient was found to be flood forecasting. The value of the economic damages caused by floods over the past 5 years were collected from the EM-DAT data bases²⁶¹. Computations of the future trend of floods estimate that, by 2050 the insured economic losses due to floods will reach EUR 23.5 B yearly. It is important to mention that two-thirds of these losses would be driven by socio economic growth, and one-third by climatic changes. Having the amount of annual insured economic losses due to floods in 2017 (EMDAT database) and in 2050 (EUR 23.5 B, see estimation above), the growth between 2017 and 2050 is assumed to be linear and so we computed the annual values of economic losses from 2017 to 2035. Details of the model developed to quantitatively assess the benefit of forecasting, can be found in the box below:

²⁶¹ EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium



Methodological approach to value reduced economic damages from floods thanks to prevention and forecasting

This assessment is done based on the paper of Pappenberger et al.(2015) to determine how much benefits EFAS and Copernicus mapping services will give for flood monitoring and forecasting services. It is done by:

1. Determining annual insured economic losses due to floods from 2017 (using EMDAT database) up to 2035 (using computations that account for climate and socio-economic growth)
2. Estimating the economic damages that can be avoided thanks to early warning
3. Filtering that value by EFAS penetration ratio based on its performance and efficiency
4. Attributing a percentage of dependency on EFAS for that filtered value based on different scenarios

Reduced economic damages thanks to flood forecasting Valuation approach



Early warning of floods could reduce up to almost 32.85%²⁶² of the economic damages of a flooding event. Therefore with a perfect forecasting system for all the floods of Europe, the economic damages would be reduced by 32.85% every year up to 2035. Hence the value of economic damages in Europe would be estimated to EUR 2 B in 2017 up to EUR 5 B in 2035, in the case where 100% of flood events are correctly forecasted. But EFAS is not able to forecast 100% of flood events. So the reduction in economic damages must be multiplied by the EFAS “success rate” or “efficiency rate”. This is defined as the number of hits EFAS had over the total number of hits and misses, which is 55% in 2015²⁶³ (i.e. the percentage of times it managed to forecast a flood from all the times there was a flood risk). Naturally with the continuous improvement of EFAS has and the follow up of the service and its efficiency, its performance will improve over time and is calculated to improve by 20 to 30% every 10 years²⁶⁴.

However, even when EFAS is able to forecast the flood event, the resulted reduction in damages due to early warning, cannot be totally attributed to EFAS. Assessing to what extent Europe depends on EFAS for its flood forecasting is still difficult. Especially with EFAS’s contribution to different types and sizes of floods through the offering of different services and assessments (such as flash flood indices and medium-range forecasts). In Europe some countries / regions have their own complex flood forecasting systems (e.g. the Netherlands), and therefore do not need or use EFAS for early warning purposes, others do have national capacities but use EFAS rather as a complement to their capacities and for particular services, data, or information that complement their own (e.g. Spain) and the rest fully and completely depends on EFAS for the lack of any national similar systems (e.g. Ireland).

To estimate the percentage of EFAS data used in the forecasting of flood events among European countries, 3 scenarios were taken into account:

- The low scenario: by 2035, 50% of the European regions and river basins depend completely on EFAS. This is assumed to be parallel to the assumption that all the flood prone regions with no national capacities (assumed to be 50% of European

²⁶² Pappenberger et al., 2015. The monetary benefit of early flood warnings in Europe

²⁶³ Pappenberger et al., 2015. The monetary benefit of early flood warnings in Europe

²⁶⁴ Pappenberger et al., 2015. The monetary benefit of early flood warnings in Europe

flood prone regions) will be fully dependent on EFAS by 2035. This scenario attributes to Copernicus around EUR 97 M saved from ensured economic damages in 2017 and EUR 1.7 B in 2035.

- The high scenario: by 2035, around 75% of the European regions and river basins fully depend on EFAS for flood forecasting for the early warning of floods. This assumes that between 2017 and 2035, EFAS services would develop rapidly, reinforcing its role in the networking among European countries and spreading awareness on the need to join efforts to fight flood risks. It should motivate European countries with already strong national flood forecasting capacities, to partner with and join EFAS. Nonetheless EFAS will still use national weather forecasts, and data from different agencies. This scenario attributes to Copernicus around EUR 200 M in 2017 saved from ensured economic damages and EUR 3.4 B in 2035.
- The medium scenario, average of the two others, attributes to Copernicus 146 M in 2017 saved from ensured economic damages and EUR 2.5 B in 2035.

The growth rate over the period is derived from the registered number of users in EFAS up to 2035. The same pattern of growth was taken between 2012 (start of EFAS operations under Copernicus) up to 2017. The growth of the number of users was fitted into a quadratic growth curve, and the same trend was used to extrapolate the dependency on EFAS for each scenario. However after 2017, a slower increase is expected therefore the extrapolation from 2017 is linear and not quadratic. Linear projection is adapted and assumed over the period 2017-2030 and the 2030-2035 (smaller slope).

4.2.3.5.2.1.2 Thanks to the support of on ground logistics and improved response

Through the rapid, risk areas and recovery maps provided by Copernicus Mapping Services, on-ground authorities and entities responding to floods will be more informed on a larger picture and will be able to create better and more efficient response plans and strategies. These maps can be critical for civil protection entities to intervene and rescue people for most endangered areas, to know the extent of the damages and not overlook or miss certain areas where help might be needed. Such mapping services help entities to plan their logistics, locate their evacuation areas, deploy first aid tents, or settle temporary medical care areas. Beforehand or after a disaster, they are used for several purposes such as improving preparedness to potential events, or supporting the recovery and reconstruction phase.

Details of the model developed to quantitatively assess this economic benefit can be found in the box below:



Methodological approach to value reduced economic damages from floods thanks to improved response and on ground logistics

This assessment is done for the Copernicus mapping services enabling the reduction of flood

1. Determining annual insured economic losses due to floods from 2017 (using EMDAT database) up to 2035 (using computations that account for climate and socio-economic growth)
2. Estimating the economic damages that can be avoided due improved response
3. Filtering these values by Copernicus EMS - mapping services penetration ratio based

Reduced economic damages thanks to improved response

Valuation approach



The value of the annual economic losses due to floods is the same as explained in the previous model (for flood forecasting)

From the reduction in economic losses due to floods, a very small percentage is considered rescuable due to improved response, however data for a precise value was not found, and it is thus assumed to be a 0,5% decrease in damages.

The contribution of Copernicus mapping services was determined by the percentage of flood events that authorized users requested to map, out of the total amount of flood events in Europe. The values were taken from EMDAT bases²⁶⁵ and the Copernicus mapping services web portal²⁶⁶. This value averaged over the past 3 years was 78% and projected to become 100% in 2035. Therefore the contribution of Copernicus Mapping services to flood monitoring can be calculated and applied on both the economic and societal benefits (see below). Then we multiplied the three figures.

As a result, not discounted economic benefits linked to Copernicus for response to flood disaster, are expected to amount EUR 24.7 M in 2017, rising to EUR 313.0 M in 2035, for a total cumulative value of EUR 2.3 B.

4.2.3.5.2.1.3 Total benefits: reduced economic losses

Derived from the two outcomes: flood preparedness, prevention and mitigation and support of on ground logistics and improved response; the total benefits in terms of reduced economic losses due to floods are presented here. They are expected to amount between EUR 122.6 M and EUR 220.5 M in 2017, rising to between EUR 2,023.6 M and EUR 3,734.2 M in 2035, for a total cumulative value ranging from EUR 17.2 B to EUR 32.1 B.

²⁶⁵ EM-DAT: The Emergency Events Database - Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

²⁶⁶ <http://emergency.copernicus.eu/mapping/#zoom=2&lat=29.42903&lon=-27.48695&layers=00BoT>

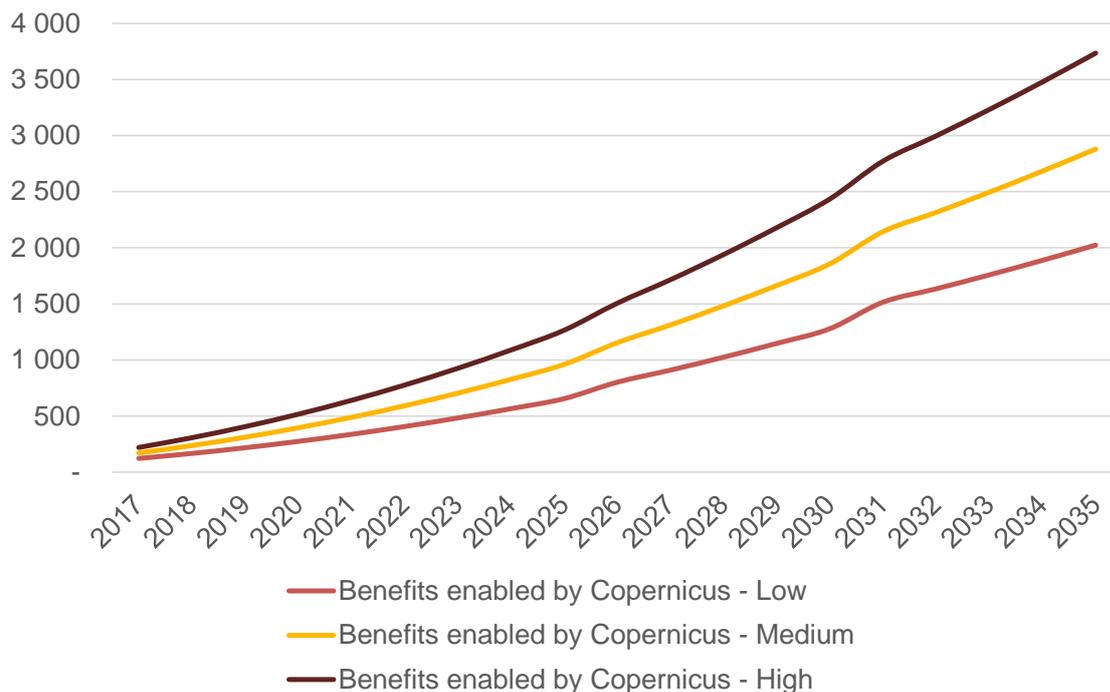


Figure 101 - Evolution of the Copernicus benefits for the impact “reduce economic damages due to floods” from 2017 to 2035 (Source: PwC analysis)

4.2.3.5.2.2 Avoided fatalities and injuries in the population (Societal benefit)

4.2.3.5.2.2.1 Thanks to flood preparedness, prevention and mitigation

The number of injured people and fatalities caused by floods over the past 5 years were collected from the EM-DAT. In the future the number of casualties and fatalities is expected to increase due to climate change and population growth²⁶⁷. If no adaptation measures are taken to cope with floods, severe damages will be caused in 2050 and the societal cost linked to the number of affected people (from injured, homeless, evacuated etc.) would reach between EUR 775 K and EUR 5.5 M yearly, by 2085. Whereas with improved mitigation and preparedness, this economic impact would range between EUR 22 K and EUR 40 K²⁶⁸. This represents almost a 99% decrease of the number of people affected by floods.

As Copernicus Mapping Services and EFAS contribute to a better preparedness and early warning system for floods, we can say that Copernicus enable to avoid fatalities and injuries in case of flood event. Details of the model developed to quantitatively assess this benefit can be found in the box below:

²⁶⁷ May 2014. “Science for environmental Policy”: European Commission DG Environment News Alert Services, edited by SCU, the University of West England, Bristol

²⁶⁸ Floods in the WHO European Region : Health Effects and their Prevent⁴: World Health Organization, edited by Bettina Menne and Virginia Murray



Methodological approach to value avoided fatalities and injuries of floods thanks to prevention and forecasting

This assessment follows the assumptions taken in the previous part to attribute these benefits to Copernicus.

1. Determining annual fatalities and injuries from flood events up to 2035
2. Estimating the percentage of casualties that can be avoided due to early warning and projecting to be 67% in 2035 (which is taken from a linear growth to achieve the computed 99% in 2085)
3. Filtering that value by EFAS penetration ratio based on its performance and efficiency
4. Attributing the percentage of dependency on EFAS for that filtered value from the same scenarios as in the previous part
5. Valuation of the avoided fatalities and injuries thanks to EFAS using the PwC developed valuation coefficients

Avoided fatalities and injuries thanks to flood forecasting Valuation approach

$$\text{Impact (EUR)} = \text{Fatalities and injuries avoided thanks to early warning} \times \text{\% success of EFAS in forecasting floods} \times \text{\% of EFAS data used among other sources} \times \text{Valuation coefficient of avoided fatalities and injuries}$$

To calculate the number of fatalities and injuries over the years 2017 – 2035, we estimate the number of floods events in 2035 (based on the volume of economic damages expected in 2035), and multiplied it by the average amount of fatalities and injuries per flood event. Hence having the number of fatalities and injuries for the year 2035 and in 2017 (EM-DAT data bases), a linear growth was assumed between 2017 and 2035.

As mentioned earlier the percentage of reduction among the number of fatalities and injuries thanks to preparedness and early warning, can be estimated at 99% decrease per year in the number of people affected by floods²⁶⁹. Then the number of avoided fatalities and injuries thanks to early warning and adaptation, is multiplied by the EFAS success rate, and by the percentage of dependence on EFAS (depending on scenario, see above) to get a final attributed value to Copernicus EMS. Valuation coefficient were used to monetize the benefit of an avoided fatality (statistical value of life) and of avoided injuries (hospitalization costs avoided).

Thus not discounted societal benefits thanks to Copernicus application for improved response to flood disaster, are expected to amount between EUR 1.8 M and EUR 3.7 M in 2017, rising to between EUR 115.7 M and EUR 173.5 M in 2035, for a total cumulative value ranging from EUR 0.8 B to EUR 1.5 B.

4.2.3.5.2.2.2 Thanks to the support of on ground logistics and improved response

As for societal benefits, the contribution of mapping services to damage reductions can be applied on fatalities and injuries. This will give the number of saved lives and avoided injuries thanks to the service and multiplying it by the valuation coefficients for fatalities and injuries (hospitalization costs and statistical value of life), we end up with the monetization of the benefit.

²⁶⁹ Floods in the WHO European Region : Health Effects and their Prevent⁶: World Health Organization, edited by Bettina Menne and Virginia Murray



Methodological approach to value avoided fatalities and injuries of floods thanks to improved response

This assessment follows the assumptions taken in the previous part to attribute these benefits to Copernicus.

1. Determining annual fatalities and injuries from flood events up to 2035
2. Estimating the percentage of casualties that can be avoided due to early warning and projecting to be 67% in 2035 (which is taken from a linear growth to achieve the computed 99% in 2085)
3. Filtering that value by EFAS penetration ratio based on its performance and efficiency
4. Attributing the percentage of dependency on EFAS for that filtered value from the same scenarios as in the previous part
5. Valuation of the avoided fatalities and injuries thanks to EFAS using the PwC developed valuation coefficients

Avoided fatalities and injuries thanks to improved response
Valuation approach

$$\text{Impact (EUR)} = \text{Number of fatalities and injuries due to floods} \times \% \text{ reduction in casualties due to improved response} \times \% \text{ of flood events mapped with Copernicus} \times \text{Valuation coefficient of avoided fatalities and injuries}$$

Similarly as for the economic benefit, we calculated the number of fatalities and injuries over the years 2017 – 2035. Then we multiplied this annual amount by the percentage of avoided (reduction) fatalities and injuries due to improved response, which is assumed to be 0.5% decrease in casualties.

The percentage of floods events mapped with Copernicus services represents the Copernicus contribution to this benefit and amounts to 78% in 2017 up to 100% in 2035. The total is then multiplied by the valuation coefficient attributed to one person injured or dead (PwC methodology based on statistical value of life and hospitalization costs).

Thus not discounted societal benefits thanks to Copernicus application for improved response to flood disaster, are expected to amount to EUR 0.9 M in 2017, rising to EUR 17.0 M in 2035, for a total cumulative value of EUR 116 M.

4.2.3.5.2.2.3 Total benefits: avoided fatalities and injuries in the population

Derived from the two outcomes: flood preparedness, prevention and mitigation and support of on ground logistics and improved response; the total benefits in terms of avoided fatalities and injuries due to floods are presented here. They are expected to amount between EUR 2.6 M and EUR 4.4 M in 2017, rising to between EUR 132.7M and EUR 248.4 M in 2035, for a total cumulative value ranging from EUR 0.9 B to EUR 1.7 B.

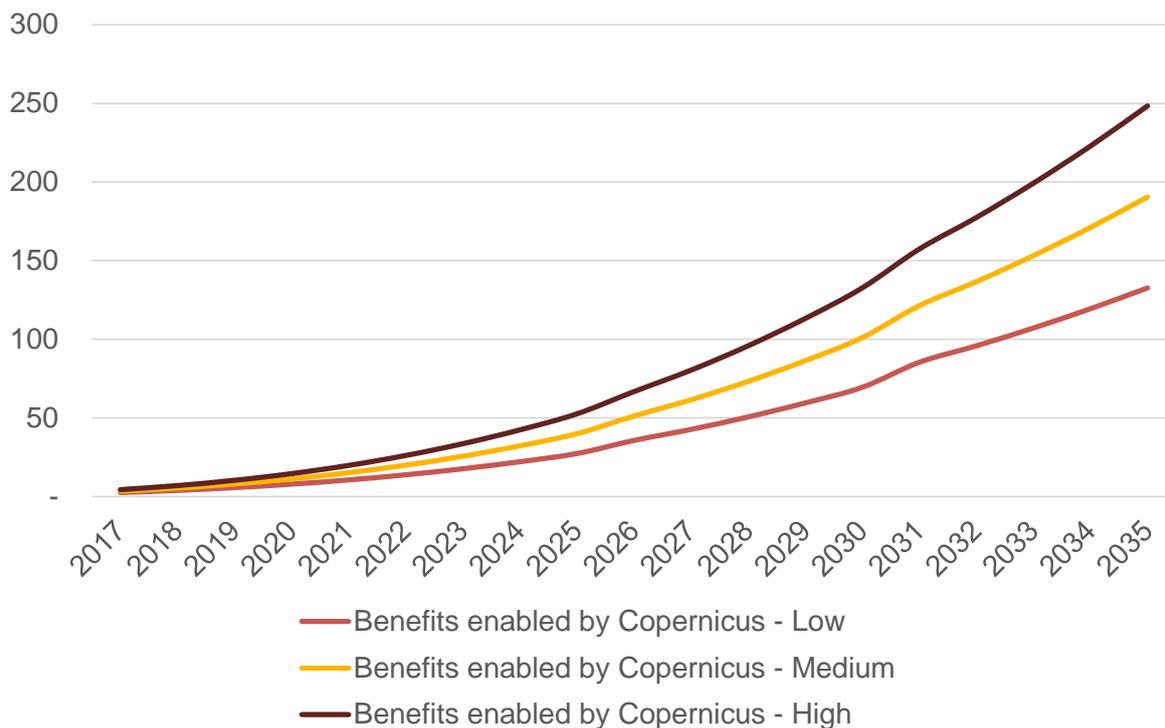


Figure 102 - Evolution of the Copernicus benefits for the impact “Avoid fatalities and injuries due to floods” from 2017 to 2035 (Source: PwC analysis)

Differentiation factor of Copernicus and EO

Copernicus EMS plays a strategic role in networking the European countries and unifying their efforts to fight floods. It provides countries with no national capacities for disaster risk reduction the tools to build disaster resilience and strengthen their vulnerabilities. Without Copernicus EMS on the level of flood monitoring and forecasting European MS can still seek alternative help such as the international charter for rush mode and non-rush mode mappings. As mentioned previously, some MS have very strong national capacities for flood forecasting so they would not be affected by a shutdown in another than on a coordination level. Other countries that only use particular products of EFAS can still find or develop such products elsewhere, but might not be able to openly and freely reach such data. As for countries that have been fully dependent on EFAS, a shutdown of the program will definitely have a strong impact on their preparedness and ability to efficiently respond to flooding events

4.2.3.5.2.3 Summary of Copernicus contribution to “Flood monitoring and forecasting”

The total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	125.2	682.8	2,156.3	18,122.6
Medium estimate	175.1	1,000.0	3,069.4	25,978.6
High estimate	225.0	1,317.3	3,982.6	33,834.6

Table 27 - Copernicus total EU benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period is illustrated in the chart below (not discounted).

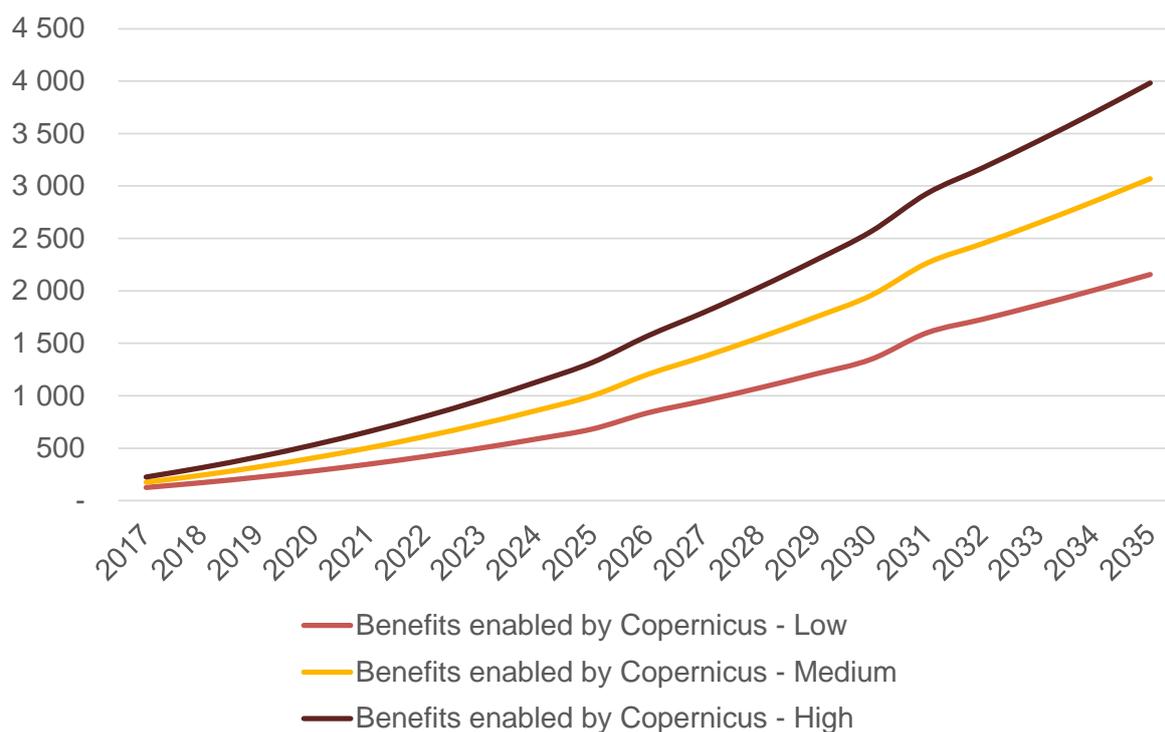


Figure 103 - Overall Copernicus D&I benefits for Flood monitoring and forecasting, from 2017 to 2035 (Source: PwC analysis)

4.2.3.5.3 Pandemic monitoring

This section is only composed of qualitative information on pandemic monitoring. Considering the diversity of diseases that can affect humans, livestock and crops and the lack of precise information gathered through interviews and desk research on the Copernicus contribution, no economic modelling has been performed in this section. However, the data presented below enable the reader to get a sense of the potential use of EO and of Copernicus for pandemic monitoring.

In a global context where borders are more and more crossed, the spread of pandemics appears as a major risk difficult to control (e.g. tourists bringing back diseases from the country they had travel to) The use of several Copernicus products that collect various sets of environmental data such as land cover, vegetation cover, water bodies, winds, dust movement, etc.²⁷⁰ can support the monitoring of pandemics. Indeed, the models and studies assessing the different correlations between environmental factors (physical factors such as temperature or humidity, biological readings, health data, socioeconomic data, etc.) and the development of infectious diseases are more and more using Earth Observation data to complement their research²⁷¹. This is called tele-epidemiology and relies specifically on land use data, climate data or meteorological data. The analysis of data collected by Copernicus can support the surveillance of trends affecting the creation, development and spreading of diseases: the currently launched Sentinel (Sentinel-1, Sentinel-2, Sentinel-3) as well as the

²⁷⁰ Copernicus Brief (Online). Available at:

http://copernicus.eu/sites/default/files/documents/Copernicus_Briefs/Copernicus_Brief_Issue47_Ebola_October2014.pdf (Accessed September 8th 2017)

²⁷¹ Using Space to Fight Disease (Online). Available at: http://eoedu.belspo.be/en/profs/Epidemio_A4_EN-small.pdf (Accessed September 8th 2017)

future Sentinels (Sentinel-4 and Sentinel-5 for atmospheric data affecting climate) can be particularly useful. The different Copernicus products derived from this imagery and utilized to support such outcomes are Land Surface Cover, Land Surface Temperature (LST), Vegetation Index, OLCI Water & Atmosphere or Sea Surface Temperature (SST). Copernicus Contributing Missions also play an important role as Very High Resolution (VHR) imagery is essential for the mapping of pandemics (e.g. WorldView2 data that have a resolution of less than 5m can prove very efficient to anticipate infection zones). As such the Copernicus services providing the right products are the Emergency Management service (for diseases affecting humans through their Early Warning system)) and the Land Monitoring and Atmosphere Monitoring services (for all types of disease monitoring).

The ability of Copernicus to provide accurate data on environmental factor that favour the emergence of a disease can lead to several benefits (impacts) mapped in the impact pathway below:

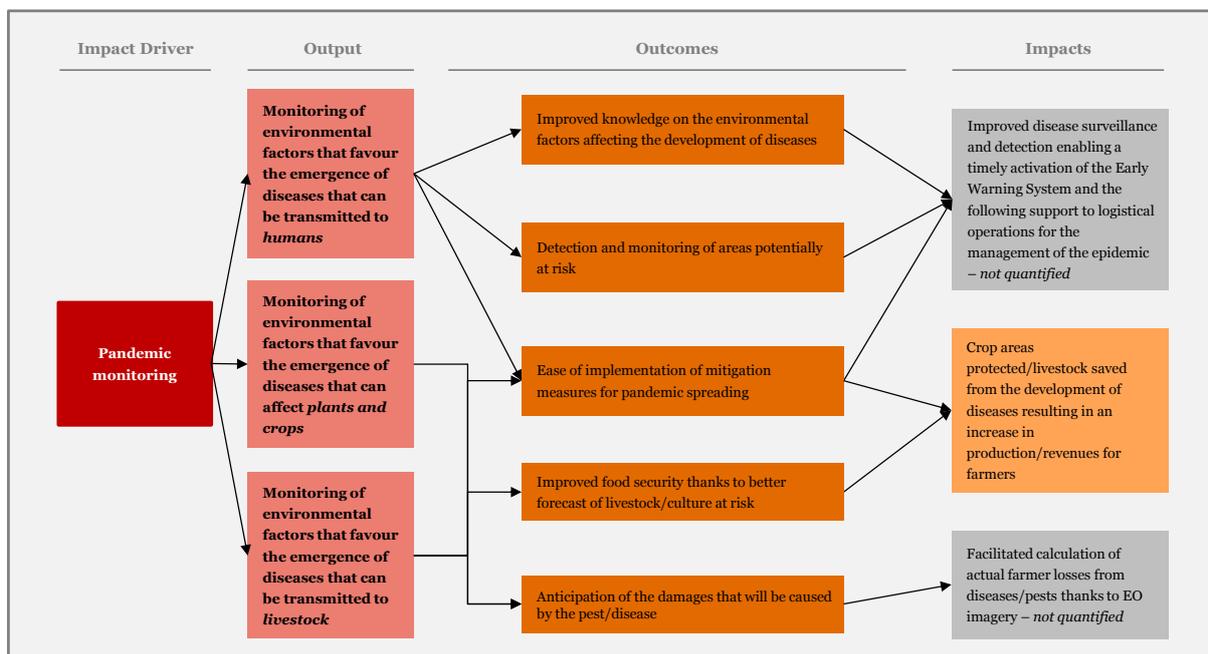


Figure 104 - Impact pathway for pandemic monitoring (Source: PwC analysis)

Copernicus data can be used for three types of pandemics: the ones that affect humans, the ones that attack livestock and finally the ones that destroy crops and plants. Being able to monitor the different environmental factors mentioned in the paragraph above enables several kind of benefits. By enabling a better understanding of how diseases develop, satellite imagery can help identify areas where infectious diseases are nesting or might nest (e.g. the West Nile virus is a mosquito-borne disease that is spread in most part of the world and causes neurological disorders among humans as well as animals. Satellite data similar to what Copernicus can provide, such as Land Surface Temperature (LST) or Normalized Difference Vegetation Index (NDVI), are used in the United States to develop forecast models of areas where disease transmission might occur²⁷²). Once an epidemic outbreak has occurred, Copernicus data can support logistical operations for emergency management by providing dynamic mapping of areas hit by the disease and help forecast and contain the short term geographic evolution of the pandemic event. As such, damages can be anticipated and preventive mitigation measures can be taken in order to reduce the impact of the disease (e.g. the 2006 INSPIRE EPISTIS project, dedicated to the development of tools for spatial veterinary epidemiology using Earth Observation data, offered a tool called Space-Time

272 R. Singh, K. Ranjan & H. Verma, 2015, "Satellite Imaging and Surveillance of Infectious Diseases", Journal of Tropical Diseases

Information System (STIS) aimed at supporting decision-making in case of spread of disease, as well as propagation models helping to estimate potential consequences of the spread²⁷³). This ability to monitor the trend in disease spreading as well as the anticipation of the damages thanks to predictive models is also key for food security.

As a result of all these outcomes, the following impacts are expected:

- Improved disease surveillance and detection enabling a timely activation of the Early Warning System and the following support to logistical operations for the management of the epidemic
- Crop areas protected/livestock saved from the development of disease resulting in increase in revenue for farmers
- Facilitated calculation of actual farmer losses from diseases/pests thanks to EO imagery

The quantification of the benefits mentioned above is as follows:

4.2.3.5.3.1 Improved disease surveillance and detection enabling a timely activation of the Early Warning System and the following support to logistical operations for the management of the epidemics

Surveillance and detection of diseases affecting humans can be facilitated by the use of satellite data combined with environmental knowledge leading to disease vector prediction models: areas prone to the emergence or spread of diseases can be mapped. Indeed, Sentinel-1, with its C-band SAR data, can help mapping water bodies; Sentinel-2 can help mapping land use and land use change; and Sentinel-3 can help mapping photosynthetic activities or land surface temperature²⁷⁴. These elements are key as most diseases are carried by insects (e.g. mosquitoes) that have very specific living and breeding conditions. The combination of knowledge on the vectors habitats and satellite data can therefore help track where the disease comes from and where it could spread: for instance, satellite data have been used to track mosquito-borne disease such as dengue or chikungunya fever in Europe and to establish predictive distribution models²⁷⁵.

The Copernicus Emergency Management service is not only in charge of disasters, but also of all kind of biogenic events that might occur such as disease spreading. The service guarantee supports to logistics by providing maps through their Early Warning System that enable to detect areas where outbreaks have occurred. For instance, at the time of the Ebola outbreak in 2014, the Copernicus Emergency Management service had published a map of the area where the disease originated from²⁷⁶.

However, today, there is little information on the extent to which Copernicus contributes to the prevention and spreading of disease outbreak. Moreover, satellite data are especially useful to track epidemics that go cross border; for national issues, local data are mostly

273 Using Space to Fight Disease (Online). Available at: http://eoedu.belspo.be/en/profs/Epidemio_A4_EN-small.pdf (Accessed September 8th 2017)

274 Copernicus Briefs (Online). Available at:

http://www.copernicus.eu/sites/default/files/documents/Copernicus_Briefs/Copernicus_Brief_Issue23_Malaria_Sep2013.pdf (Accessed September 19th 2017)

275 Nichols G.L., Andersson Y., Lindgren E., Devaux I. & Semenza J.C., 2014, "European Monitoring Systems and Data for Assessing Environmental and Climate Impacts on Human Infectious Diseases", *International Journal of Environmental Research and Public Health*, vol. 11, no. 4, pp. 3894-3936 (Accessed September 19th 2017)

276 Copernicus News (Online). Available at: <http://www.copernicus.eu/main/public-health>

used²⁷⁷. This implies that Copernicus may have a strong role to play on diseases spreading at a wider scale. It can also be expected that, as Copernicus data are free and of good quality, national authorities will not rely only on local data anymore in case of an epidemic not crossing borders.

4.2.3.5.3.2 Crop areas protected/livestock saved from the development of disease resulting in increase in revenue for farmers

The spreading of diseases among crops and plants, as well as among livestock is a major source of loss for farmers and can lead to endangered food security. Depending whether the target is vegetal or animal, the diseases vary, but their consequences remain dramatic.

Loss in livestock:

Animal diseases, such as Malaria, Lyme disease, the common liver fluke, bluetongue disease, etc., are gaining ground every year and spreading more and more. This is mostly consequential to climate change. Indeed, insects such as ticks or mosquitoes are the vectors of these diseases and they can only live and breed under specific climate conditions. With global warming, areas where these can nest have proliferated, leading to a spread in areas that can be infected²⁷⁸. The combination of satellite data providing analysis on the state of the environment combined with knowledge on areas where vectors are most likely to spread and contaminate livestock enables a better mapping of areas at risk and the implementation of preventive actions, when possible. However, as diseases affecting livestock differs in terms of consequences (long vs. short term consequences, fatality or temporary unavailability of livestock, punctual vs. recurring infections, different spatial repartition, etc.) it is hard to assess the benefits of satellite data, and in particular Copernicus, in Europe as a whole.



Use case: liver flukes

Liver flukes are bacteria that, once swallowed by the herds, impact their dairy production. This bacteria is transported by snails and transmitted to animals through the grass they eat and on which the snail has left traces contaminated by the bacteria²⁷⁹. What can be detected by satellite data is Small Water Bodies (SWBs), wetland areas which are the vectors' habitat²⁸⁰. These areas, because of their small size, are often not mapped. Several types of satellite data can be useful in the mapping of these areas: radar imagery (what Sentinel-1 could provide) that is active under all weather conditions; radar altimetry imagery (what Sentinel-3 could provide) that enables water depth detection; and optical imagery (what Sentinel-2 could provide) that enables cartography. Previous studies on liver flukes have indeed relied on Landsat imagery or data with less precise resolution which can lead to the assumption that Copernicus data, which are of better quality than Landsat data, would perfectly fit in. However, precise VHR optical data with a resolution lower than 5 meters are needed to go a step further than detecting SWB and map the snails' real habitat (in this case, WorldView 2 images, a Copernicus Contributing Missions, can be used)²⁸¹ as emphasized in the map below developed by the Belgian app VECMAP in the frame of the EU FP7 GLOWORM project.

²⁷⁷ Nichols G.L., Andersson Y., Lindgren E., Devaux I. & Semenza J.C., 2014, "European Monitoring Systems and Data for Assessing Environmental and Climate Impacts on Human Infectious Diseases", International Journal of Environmental Research and Public Health, vol. 11, no. 4, pp. 3894-3936 (Accessed September 19th 2017)

²⁷⁸ Using Space to Fight Disease (Online). Available at: http://eoedu.belspo.be/en/profs/Epidemio_A4_EN-small.pdf (Accessed September 8th 2017)

²⁷⁹ VECMAP website. (Online) Available at: <http://www.vecmap.com/stories/From-continent-to-field-tracking-down-Liver-Fluke> (Accessed September 8th 2017)

²⁸⁰ P.J. Skuce & R.N. Zadoks, 2013, "A Growing Threat to UK Livestock Production", Cattle Practice, vol. 21, pp. 138-149

²⁸¹ R. Singh, K. Ranjan & H. Verma, 2015, "Satellite Imaging and Surveillance of Infectious Diseases", Journal of Tropical Diseases

The impact of liver fluke on cattle is a reduced milk production and a reduced milk fat content and estimation of economic losses ranges from EUR 6 to EUR 250 per cow²⁸². However, the impact on sheep slightly differs as sudden death or development of critical diseases occur, leading to a reduction of meat that can be sold. Global annual losses for livestock and food industries in general is estimated at EUR 2.5 B and encompasses the diminution of milk and meat production. In recent years, liver fluke infections have increased up to 12 times in some EU Member States, hence a necessity to monitor this virus²⁸³. For instance, in Flanders alone, losses due to liver fluke is estimated at EUR 8.2 M per year. Considering the distribution map of the disease and the strong economic impact on the Flanders region, total European would be of a consequent amount.

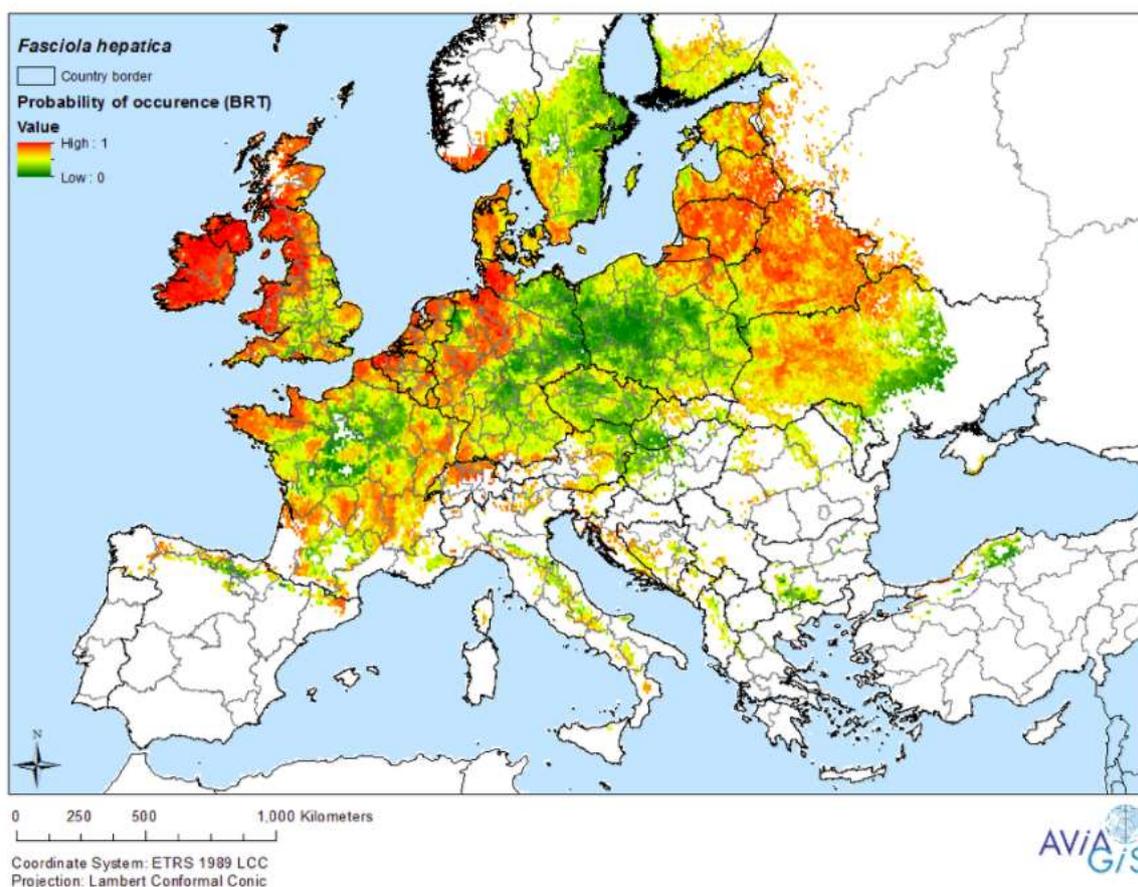


Figure 105 - Likelihood of liver fluke disease in Europe (Source: VECMAP)

As emphasized by the case of the liver fluke virus, there are important amounts involved in the monitoring of pandemics and a substantial part of these benefits are linked to the use of satellite data. As for Copernicus, it is currently not possible to quantify its contribution to pandemic monitoring considering the small if not non-existent use that is made of its data but it can be assumed that the capabilities of the current constellation are more than sufficient to consider Copernicus will play a role in the future.

²⁸² P.J. Skuce & R.N. Zadoks, 2013, "A Growing Threat to UK Livestock Production", Cattle Practice, vol. 21, pp. 138-149

²⁸³ Animal health Ireland (AHI), 2011, Liver Fluke – the facts (Online). Available at:

http://www.agritrading.ie/files/Farm_Focus_PDFs/Animal_Health_Ireland-Guide_to_Liver_Fluke.pdf (Accessed September 8th 2017)

Loss in crops:

Crop losses results from two types of factors: abiotic ones such as droughts, water issues, etc. (previously dealt with in the crop monitoring section for food security); and biotic ones such as weeds, animal pests and pathogens²⁸⁴. These biotic factors could, in a worst case scenario, lead to an estimated loss of 67.4% of the attainable crop production worldwide every year (average percentage of production tonnage lost), with 31.8% due to weeds, 17.6% to animal pests and 18% to pathogens²⁸⁵. In reality, losses account for about 32% of the attainable production tonnage, hence about 50% of the potential losses are prevented. Indeed, the influence of these biotic factors can surely be reduced thanks to mechanical, biological or chemical factors (e.g. the use of adequate pesticides), however, disposing of a means to monitor crops in a continuous and precise manner could help reduce these losses even more²⁸⁶. Sentinel-1 and 2 could be particularly useful in agricultural monitoring of biotic factors²⁸⁷ (e.g. Sentinel-2 can monitor plant health)²⁸⁸. Considering their recent launch, it is difficult to assess their contribution to loss reduction. Moreover, the types of diseases affecting crops may strongly vary and some might be easier to monitor through Copernicus than others.



Use case: wheat crop losses

As for any kind of crops, wheat are subject to several diseases that can hinder production. Among the diseases that can affect cereals, there are wheat rusts that used to be monitored by Landsat-2 when the satellite was active more than three decades ago²⁸⁹, and by SPOT 5 (currently part of Copernicus Contributing Missions)²⁹⁰. Landsat-2 had a multispectral capacity, just like Sentinel-2 though the Sentinel-2 satellite, as a more recent satellite, has an improved multispectral mission compared to the Landsat series²⁹¹, hence an enhanced ability to monitor diseases such as rusts.

Wheat crop losses due to biotic factors were estimated at 28.2% of the average production tonnage in the 2001-2003 (for a potential loss of 49.8%)²⁹². Making a conservative assumption that this percentage has remained constant since then and is similar for all kinds of cereals, it would imply that, in 2017, the harvested cereals areas without diseases affecting crops would have been of 34,632 1000ha instead of the actual 27,325 1000ha, hence a loss of 7,308 1000ha of production²⁹³. Making a conservative

284 Moore D., Robson G.D. & Trinci A.P.J., 2011, 21st century guidebook to fungi (Online). Available at:

http://www.davidmoore.org.uk/21st_Century_Guidebook_to_Fungi_PLATINUM/Ch14_01.htm (Accessed September 8th 2017)

285 Oerke E.C., 2006, "Crop losses to pests", The Journal of Agricultural Science, vol. 144, no. 1, pp. 31-43

286 Huang W. et al., 2012, Crop disease and pest monitoring by remote sensing, pp. 32-73

287 SRUC, 2016, Agri-food and Satellite applications: Challenges in crops, livestock and aquaculture (Online). Available at: <https://sa.catapult.org.uk/wp-content/uploads/2016/04/SRUC-CatapultRoadshow-2016.pdf> (Accessed September 8th 2017)

288 ESA Website (Online). Available at: http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-2/Plant_health (Accessed September 8th 2017)

289 Nagarajan S., Seibold G., Kranz J., Saari E.E. & Joshi M.L., 1983, Monitoring Wheat Rust Epidemics with the Landsat-2 Satellite (Online). Available at: https://www.apsnet.org/publications/phytopathology/backissues/Documents/1984Articles/Phyto74n05_585.PDF (Accessed September 8th 2017)

290 Prospects of satellite remote sensing in cereal disease monitoring and precision crop protection for food security enhancement in Pakistan (Online).

Available at:

[https://www.google.fr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0oahUKEwjZoYaBv6LWAhWODBoKHHexeCpAQFggsMAA&url=http%3A%2F%2Fwww.suparco.gov.pk%2Fdownloadables%2FProspects%2520of%2520satellite%2520remote%2520sensing%2520in%2520cereal%2520disease%2520\(1\).ppt&usq=AFQjCNHY9aFTOQoiFZL3-oiTU5JtnAwyqg](https://www.google.fr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0oahUKEwjZoYaBv6LWAhWODBoKHHexeCpAQFggsMAA&url=http%3A%2F%2Fwww.suparco.gov.pk%2Fdownloadables%2FProspects%2520of%2520satellite%2520remote%2520sensing%2520in%2520cereal%2520disease%2520(1).ppt&usq=AFQjCNHY9aFTOQoiFZL3-oiTU5JtnAwyqg) (Accessed September 8th 2017)

291 Sentinel-2 ESA's Optical High-Resolution Mission for GMES Operational Services (Online). Available at:

https://sentinel.esa.int/documents/247904/349490/S2_SP-1322_2.pdf (Accessed September 8th 2017)

292 Oerke E.C., 2006, "Crop losses to pests", The Journal of Agricultural Science, vol. 144, no. 1, pp. 31-43

293 Eurostat data on cereals production tonnage and harvested areas (Online). Available at:

<http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do> (Accessed September 8th 2017)

assumption on wheat crops margins at EUR 200 per ha, which corresponds to the 2014 value, considered as a bad year, it leads to a potential loss of EUR 1.5 B of gross margins in a year. This yearly amount is all the more significant as wheat crop production is increasing every year and Copernicus D&I could contribute to its reduction by enabling to take mitigation measures.

As emphasized in the case of wheat crops, the capabilities of Sentinel-2 combined with the important losses due to pests could lead to the assumption that Copernicus D&I could play an important role in crops and plants pandemic monitoring once the uptake of satellite data will have started.

Loss in plants and forests:

Current satellite imagery technology seems to have little added value for the monitoring of pests affecting plants and trees. What is needed is the ability to detect pest symptoms early, before its consequences become visible. This is enabled by examining very specific elements of the trees and plants individually and requires a close look at the tree branches to detect discoloration for instance. It appears that Copernicus cannot currently provide such level of details and that the process used for pest detection is rather performed by airborne technology such as helicopters and drones which provide high and very high resolution images (the resolution used to detect pest is currently of 15cm)²⁹⁴ or by humans directly sent on the field to do some testing. Therefore, at this time, Copernicus is not considered as an effective option to perform the monitoring of pests affecting trees and plants.

4.2.3.5.3.3 Facilitated calculation of actual farmer losses from diseases/pests thanks to EO imagery

Similarly to what is explained in the crop monitoring section on food security, satellite imagery can be useful to insurers as it enables them to have a quicker view of the damages affecting a herd or a crop. As such, reimbursement delay and accuracy of payments to be made should be facilitated. However, and conversely to the US Multiple Peril Crop Insurance (MPCI) which covers all types of events that could affect crops, plant diseases and plagues are often not covered by insurers in Europe²⁹⁵. Indeed, in the US, premiums asked for to insure crops against disease cost between 5% and 20% of the amount insured, making it unaffordable for most farmers²⁹⁶. This is similar for livestock insurance in most European countries that do not cover the consequences of an epidemic²⁹⁷. As such, if Copernicus data could theoretically help facilitate the calculation of losses, insurers have neither started to insure crops and livestock against epidemic nor to use satellite imagery.

However, some Members States are entitled to give funding (called calamities funds) to farmers that endure crop or livestock losses due to diseases. Having a European Union programme that enables to monitor the evolution of the disease can help in decision-making for mitigation measures as well as in assessing the subsidies that should be given to farmers.²⁹⁸

²⁹⁴ Interview with DG SANTE

²⁹⁵ Agricultural Insurance Schemes (Online). Available at : https://ec.europa.eu/agriculture/sites/agriculture/files/external-studies/2006/insurance/summary_en.pdf (Accessed September 8th 2017)

²⁹⁶ The World Bank, 2009, Agricultural Insurance (Online). Available at:

http://siteresources.worldbank.org/FINANCIALSECTOR/Resources/Primer12_Agricultural_Insurance.pdf (Accessed September 8th 2017)

²⁹⁷ Michael Rüegger, 2006, Trends in Agriculture Insurance in the European Union (Online). Available at:

<http://www.microinsurancecentre.org/resources/documents/products/agriculture-incl-index/trends-in-agricultural-insurance-in-the-european-union.html> (Accessed September 8th 2017)

²⁹⁸ Agricultural Insurance Schemes (Online). Available at : https://ec.europa.eu/agriculture/sites/agriculture/files/external-studies/2006/insurance/summary_en.pdf (Accessed September 8th 2017)

4.2.3.6 Security

The security benefits rely on the assessment of **the impacts** of data and information derived from the Copernicus security service **that can be monetized**. It is worth noting that the nature of security benefits can sometimes be hard to monetize, such as geopolitical and strategic impact. As for the Global EU strategy, EU Space Strategy and European Defence Action Plan, the scope of the study – assessing economic, societal and environmental spillovers derived from Copernicus D&I – cannot take those documents directly into account since their impacts cannot be turned into monetary terms. For instance, the notion of autonomy is key for the strategic objectives of the EU, as stated in the three past mentioned document, but cannot be valued in monetary terms. Moreover, the notion of creating more synergies between civilian and military is not in the scope of this particular study.

It is important to note again that this study is only an input of the future EC impact assessment on the evolution of the Copernicus programme with a particular scope focusing only on benefits that can be monetized.

4.2.3.6.1 The Copernicus Security Service

As stated in the Copernicus regulation, the Copernicus Security service aims at providing information in support of the civil security challenges of Europe improving crisis prevention, preparedness and response capacities. In particular, it should support border and maritime surveillance, but also support for the Union's external action, without prejudicing to cooperation arrangements which may be concluded between the Commission and various Common Foreign and Security Policy bodies, in particular the European Union Satellite Centre. This service is the most recent of the Copernicus services, with a signature of the first Delegation Agreement (DA) by the end of 2015 and a beginning of operations in 2016²⁹⁹. To tailor the service offering to the various environments involved, the provision of the Security service relies on 3 entrusted entities: Frontex, EMSA and SatCen.

Contrary to the other agencies, the entrusted entities for the security service are EU agencies, which already existed prior to the Copernicus programme. Their involvement in the programme aims at including space data into the operational activities already provided within their respective mandate, improving the results of the operations already delivered by the entities.

4.2.3.6.1.1 Frontex

The European Border and Coast Guard agency (renamed in 2016³⁰⁰, usually designated as Frontex) is in charge of the surveillance of European external borders, which includes both land and sea borders. The agency works extensively with EU Member States on joint operations, providing situation intelligence of external borders and risk analysis of the areas and events potentially having an impact on EU borders. These operations are conducted in the frame of the EUROSUR³⁰¹ regulation, which establishes the framework for cooperation between the MS and Frontex on activities aiming at “detecting, preventing and combating illegal immigration and cross border crime and contributing to ensuring the protection and saving the lives of migrants”.

The Delegation Agreement for the border surveillance service was signed in late 2015, and operational activities started in 2016. The border surveillance component provided by Frontex is structured along 8 services:

299 European Commission, 2017, Annex to the Commission Implementing Decision on the adoption of the 207 Copernicus Work Programme

300 European Parliament and European Council, Regulation (EU) n° 2016/1624, 14 September 2016

301 European Parliament and European Council, Regulation (EU) n° 1052/2013, 22 October 2013

Service	Description
S1 – Coastal monitoring	This service supplies the National Coordination Centres (NCC) and Frontex with surveillance information on specific external coastal borders of third countries on a regular, reliable and cost-efficient basis. Punctual and ad-hoc imagery analysis reports, vectorised data and imagery of coastal strips (beaches and ports) identified through risk analysis to support the operational assessment of irregular migration and cross-border crime related activities.
S2 – Pre-frontier monitoring	This service supplies the NCC and Frontex with surveillance information on the pre-frontier area (focused on the land portions of the pre-frontier area) on a regular, reliable and cost-efficient basis. Punctual and ad-hoc imagery analysis reports, vectorised data and imagery of the pre-frontier area identified through risk analysis to support the operational assessment of irregular migration and cross-border crime related activities.
S3 - Reference Imagery/ Mapping	Very High Resolution (VHR) satellite imagery and vectorised data covering large (50 km x 50 km max.) specific third country areas identified through risk analysis. This imagery is required for current and future analysis of irregular migration and cross-border crime related activities.
S4 - Maritime Surveillance of an Area of Interest	The service provides monitoring of designated maritime areas to detect, identify and track Vessels of Interest by using Earth Observation data combined with In-Situ Data provided by open source, and by platforms and sensors in a defined area over a period of time. The service aims at achieving the highest possible level of situational awareness in a given and predefined area.
S5 - Vessel Detection Service	Vessel detection service aims at detecting objects of interest (sea craft) at sea using Synthetic Aperture Radar on-board satellites. Objects detected are then correlated with available collaborative data from AIS and LRIT with the aim to categorize automatically as much detection as possible. For the correct implementation and exploitation of the Vessel Detection Service (VDS), each activation will be adequately planned and complemented with inspection with aerial or naval assets.
S6 – Vessel Tracking and Reporting Service	This service provides a coherent and complete situational picture of the commercial fleet according to internationally agreed frameworks based on collaborative data. The service is ensured through combined terrestrial, satellite AIS, LRIT and VMS feed. It provides users with information required to monitor and track vessels of interest (collaborative). The operational objective is to support the users with all the information available in Frontex systems related to commercial and fishing vessels fleet.
S7 - Vessel Anomaly Detection Service	The service is addressed to stakeholders in the MS interested in activities of a specific vessel (collaborative) or within a specific maritime area. The service provides a detection of atypical and suspicious behaviour of vessels. The service alerts are generated automatically and emitted to users whenever an anomaly is detected.
S8 - Environmental	Meteo service generates information about current and forecasted

Assessment – for Risk Analysis	weather conditions and state of the sea. The service provides detailed data of atmospheric and oceanographic conditions for the indicated areas. Environmental information service aims to support operational planning, decision-making processes, and satellite acquisition planning.
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Table 28 - Overview of Frontex services provided in the frame of the Copernicus border surveillance (Source: Frontex³⁰²)

In addition to the service provided now on a continuous basis, in 2017 Frontex is introducing 4 new operational services:

Service	Description
Multi-sensor monitoring service	Multi-sensor monitoring is to be delivered through the tasking and acquisition of satellite data over an area during a single day from multiple platforms (satellite). This service aims to provide for better activity analysis, through various acquisitions, which slightly differ in acquisition time and possible fusion of SAR with optical data. The key objective is to identify human activity within the area of interest and/or changes in the AOI.
Large Area Pre-frontier Monitoring service	This service aims to provide for a fusion of Pre-Frontier (both coastal and inland) monitoring with OSINT exploitation. It is planned to be delivered through imagery analysis based monitoring of specific areas within both archive and new imagery.
Earth Observation (EO) Recon service	The Earth Observation (EO) Recon service is expected to deliver an initial assessment and identification of specific areas and objectives of interest within large areas. The identified areas and objects will be validated by the requestor and, if required, further analysed with regular monitoring services.
Cross border crime surveillance service	The service will aim at determining potential locations for cross border crime activities, using both optical and SAR imagery - e.g. change detection. This service is designed in cooperation with experts from the National Coordination Centres and it expected to be used to find evidence for places particularly suited to cross border crime activities.

Table 29 - New services provided by Frontex in 2017 in the frame of the Copernicus border surveillance (Source: Frontex³⁰³)

The main end users of Frontex services provided for border surveillance are the Member States, which beyond EO-based products, also benefit from trainings and operational exercises. For instance in 2016, 3 exercises related to vessel detection, vessel monitoring and tracking, and anomaly detection have been conducted within the Copernicus framework, in Setubal (Portugal), Kolobrzeg (Poland) and Toulon (France).

Overview of EO acquisition for the border surveillance service

The acquisition of EO products and services by Frontex is achieved through Service Level Agreements (SLA) with SatCen and EMSA, and is completed with data from MeteoGroup S.A. Polska for the provision of the environmental service. EMSA supports Frontex in conducting its operations on irregular migration and cross-border crime along European

³⁰² Frontex, 2017, Copernicus border surveillance security service, 2016 semestrial implementation report (Q3 & Q4)

³⁰³ EC, 2017, Annex to the Commission Implementing Decision on the adoption of the 2017 Copernicus Work Programme

maritime borders, through the services S4 to S7. The existing service level agreement between Frontex and EMSA was renewed in 2016 for an additional three years. This agreement defines the conditions of the services provided to Frontex, including support for the implementation of the European Border Surveillance System (EUROSUR). SatCen supports Frontex in the monitoring changes of European neighboring areas through pre-frontier analysis and reference mapping (services S1 to S3), while commercial suppliers such as MeteoGroup contribute to the environmental service (S8).

In 2016, under the SLA with SatCen, 107 requests were sent (56 for coastal monitoring, 40 for pre-frontier monitoring and 11 for reference mapping). In 2016, under the SLA with EMSA, 234 EO optical service images and 376 vessel detection service images³⁰⁴ were delivered. The images for these services (S4 and S5) came from various satellites, including Pléiades, Radarsat, Woldview, Deimos or TerraSAR-X. It should be noted that the Copernicus funding to satellite and optical imagery only began under the new EMSA SLA (as of 1st of May 2017). It is important to stress the fact that non EU providers are usually used, especially when it comes to VHR.

4.2.3.6.1.2 EMSA

The European Maritime Safety Agency (EMSA) is in charge of the Copernicus Maritime Surveillance (CMS) component. Its missions is to provide support to the security challenges related to crisis prevention, preparedness and response activities (in particular for Search & Rescue and oil pollution). To achieve its mission EMSA provides monitoring and detection capacities for trans-regional threats, early warning, risk assessment and mapping of border areas.

The Delegation Agreement for the CMS service was signed in late 2015. In this frame, EMSA provides services and support for the following activities:

- Fisheries control
- Maritime safety and security (traffic safety, support to Search & Rescue, ice and icebergs monitoring etc.)
- Law enforcement (drugs smuggling, immigrant trafficking, illegal oil exploration etc.)
- Customs
- Marine environment which largely includes oil pollution monitoring
- Others (anti-piracy, defence etc.)

The two other operational axis for the maritime surveillance service include the development of the user uptake and the anticipation of the evolution of the service.

³⁰⁴ Frontex, 2017, Copernicus border surveillance security service, 2016 semestrial implementation reports (Q1 & Q2 ; Q3 & Q4)

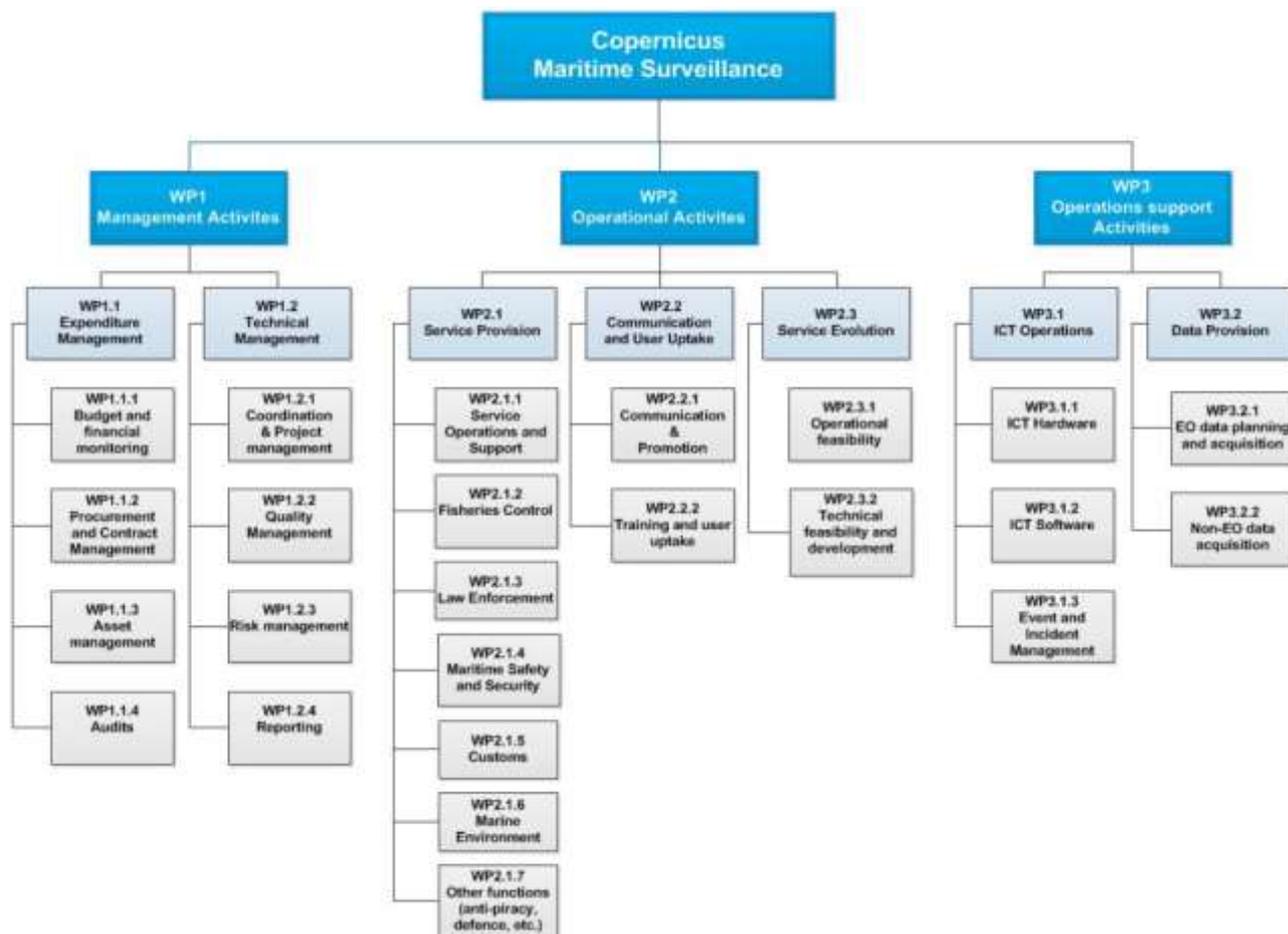


Figure 106 - Structure of the Maritime Surveillance service (Source: EMSA³⁰⁵)

Activities began following the approval of the Annual Implementation Plan 2016 on 20 May 2016 and the first fully operational services were delivered in September 2016³⁰⁶. These services were provided first to selected users from the Maritime Analysis and Operation Centre – Narcotics (MAOC-N) for law enforcement, and from the European Fisheries Control Agency (EFCA) for fisheries control. The deployment of the other services has continued on a nominal pace since then, along with the “usual” technical actions to allow the integration of EO images to operational processes (identification of satellite missions, feasibility assessment, satellite image conflict assessment, ordering process, validation of delivered products and services etc.).

Overview of EO acquisition for the CMS service

By the large areas they represent, oceans and seas require high scale monitoring means and capabilities. The use of satellite images is particularly suitable to have access to a global picture and to be able to obtain information on any given location in a limited time.

EMSA mandate existed prior to the CMS service, and EMSA was acquiring EO data on its own before the Copernicus programme. Today EMSA continues to procure satellite data through its own providers. The signature of the DA mainly reinforced EMSA’s purchasing capacity (among others, as for instance it also gave them access to new customers beyond EU seas), and in parallel enabled the improvement of some existing EO-based products by integrating Sentinel data in it. As an example, the CleanSeaNet component now strongly

305 EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

306 EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

relies on Sentinel 1 data but existed before the Copernicus DA. As a result, if the scope of the CMS service may be defined as the scope of activities financed by the DA, the reach of Copernicus within EMSA mandate is wider. In addition, the data from Earth observation is combined with a wide range of other data such as maritime traffic information in order to be valuable. Thus, the Copernicus component brings value to existing maritime surveillance activities, and in the same time, it provides its full benefits when used in combination with other EMSA activities.

The maritime environment, contrary to the land environment, is changing continuously even at small time intervals, and seas are not subject to change monitoring. Some comparison activities that can be led on land for change analysis for instance are not applicable to maritime environment, in which the traces of vessels activity, most of the time, have completely disappeared after few hours or minutes. Satellite data needs to be available, for most of the products, in Near-Real Time (NRT) that is to say in less than 30 minutes. This constraint often leads EMSA to procure satellite images through direct contracts with commercial providers (rather than using the Copernicus data dissemination infrastructure).

In terms of nature of the data, the seas environment makes radar images very useful for detection of surfaces, hence serving many maritime applications exploiting vessel detection or oil spills detection. Optical images are also used, usually to complement radar images, or for identification of vessels for instance. In the case of optical images however, most of the applications demand Very High Resolution (VHR) data. In the frame of the Copernicus DA, EMSA procures its EO data through satellite licenses with various providers, such as Airbus DS Geo, MDA Geospatial Services or European Space Imaging. Through these licences, EMSA has access to Radarsat (which is the main source of images, with more than 90% of the products delivered), TerraSAR-X/TandDEM, Pléiades, Deimos, as well as satellite services (Collecte Localisation Satellites, Edisoft, E-Geos, EUSI etc.)³⁰⁷. In 2016, 300 products were delivered by EMSA, with a large majority (277) for fisheries control purpose, to EFCA and the United Nations Office on Drugs and Crime (UNODC).

The budget of the CMS service was EUR 6.5 M in 2016 and is also EUR 6.5 M for 2017³⁰⁸. Out of the 2016 budget, EUR 4.4 M were committed from which EUR 2.45 M for satellite licenses and services. Over 2016, the payments for satellite licenses and services totalled EUR 687 k (out of which EUR 524 k for Radarsat licenses), and data for fisheries control represented 86% of the expenses with EUR 590 k, followed by law enforcement with 11% of the spending (EUR 77 k)³⁰⁹.

The gap between the financing received and actual costs is mainly due to the late start of the setup activities with consequent postponement of initial operations (started in September 2016), as well as the lower than expected consumption in initial operational phases.

4.2.3.6.1.3 EU Satellite Centre (SatCen)

The EU Satellite Centre, also known as SatCen, is part of the entrusted entities for the operations of the Copernicus services supporting Maritime Surveillance, Border Surveillance and primarily EU External Action. By coordinating the Copernicus service in support to EU External Action (SEA), SatCen assists the EU and third countries in dealing with external crisis situations or emerging crises. On October 6th 2016, a delegation agreement between SatCen and DG GROW was signed to support EU external actions with satellite data imagery. The beginning of the services is scheduled in the DA for April 2017.

307 EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016 ; EUSI, 2013, <http://www.euspaceimaging.com/category-news/item/european-space-imaging-s-optical-satellite-services-help-keep-the-seas-safe-and-clean>

308 EC, 2017, Annex to the Commission Implementing Decision on the adoption of the 2017 Copernicus Work Programme

309 EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

The Copernicus SEA services provide support to key application domains such as monitoring and surveillance of Political and Armed Conflicts, Situation Awareness, Humanitarian Support, Border Survey and Activity Monitoring.

Through the provision of Earth Observation data, the Copernicus SEA services are composed as described in the following table:

Service	Description
Reference Map	Reference Maps are produced with optical imagery delivering high quality cartographic products as well as a wide range of observable features. This service is used for crisis and preparedness modes and provides several types of information layers such as transportation networks, populated areas, hydrography, topography, land cover and use, administrative boundaries, etc. The observation mode for this service is available on demand.
Road Network Status Assessment	Road network status assessments are obtained with optical and SAR imagery. This data supports in-field logistic operations planning by providing information layers on road network, populated areas, road blocks, bridges, wat season impact, etc. The observation mode for this service is available on demand.
Conflict Damage Assessment	Based on change detection, conflict damage assessment products provide visual interpretation of transportation networks, populated areas, distribution of damage, operational statuses of points of interests, and damage on sites of cultural heritage. The observation mode for the Conflict Damage Assessment service is available on demand.
Critical Infrastructure Analysis	Critical infrastructure analysis services are based on SAR and/or Optical Imagery. It identifies the relevant components of key infrastructures such as power plants, industrial facilities, transportation networks, etc. This service provides information layers on Critical Infrastructure Operational elements, Transportation Network, Enclosure and security measures, populated areas and changes in infrastructure. The observation mode for this service is available on demand and for monitoring activities.
Support to Evacuation Plan	Based on SAR and/or Optical imagery, the Support to Evacuation Plan service produces geospatial information to support evacuation operations of EU citizens from crisis areas. The service reaches information layers such as transportation network, points of interest, evacuation routes, potential helicopter landing areas, gathering areas, road blocks, and tools for setting Rally Points and generating evacuation routes. The observation mode for this service is available on demand and for monitoring activities.
Non-EU Border Map	The non-EU border map service informs users on specific features such as transportation network, industrial facilities, administrative boundaries, hydrography, built up areas, points of interest, and Land cover and use to support decision making processes concerning non-EU border issues. This service is based on optical imagery and is available on demand.
Camp Analysis	The Camp Analysis service supports decision making concerning

	displaced population. It can be employed within EU borders as well as internationally. For this service, optical imagery is used to collect information layers such as camp dwellings, camp non-dwelling buildings, trends in population changes, enclosure, hydrography, urban areas and land use and cover. The observation mode for this service is available on demand and for monitoring activities.
Crisis Situation Picture	Crisis Situation Picture is a service enabling the overall assessment of the severity of consequences caused by conflicts and crises. Freely available ancillary information and optical imagery is used for this service. The information layers collected through this service are Human Geography layers, administrative boundaries, land cover and use and ancillary data concerning transportation network, industrial facilities, hydrography, etc. The observation mode for this service is available on demand and for monitoring activities.
Activity Report	Based on SAR and Optical imagery, and on pre and post event data, the Activity Report service supports the analysis of any given human activity. It provides information layers such as indicators of the observed activity, areas under construction, areas abandoned, change detection, etc. The observation mode for this service is available on demand and for monitoring activities.

Table 30 - Copernicus SEA services

The list of SEA services described above provide strategic support to EU External Action Security stakeholders such as central operational entities and Operations Headquarters. Products are provided to all Member States in order to simplify cooperative decision-making in the field of the CFSP and CSDP.

Overview of EO acquisition for the SEA service

As mentioned above, SatCen has a Service Level Agreement with Frontex and EMSA for the acquisition of EO images. SatCen supports Frontex in the monitoring changes of European neighboring areas through pre-frontier analysis and reference mapping.

SatCen uses primarily commercial and governmental providers to collect and have access to satellite imagery data. Data is collected on a case-by-case basis depending on the needs and nature of the mission. SatCen intends to privilege the use of European space assets when the quality of the data required, the reactivity of the data provision and the cost of the data meet the SatCen standards. Regarding Optical imagery, SatCen is increasingly using Pléiades imagery as a source of data. The Pléiades and Spot 6/7 sensors enable the generation of DEMs which can be used for several services.

In 2016, 40 requests were sent for pre-frontier monitoring and 11 for reference mapping and a total number of 1910 space-borne images were collected for SatCen supported missions, covering 264083 square km³¹⁰. Among these images, 88 were collected with SAR sensors, 20 with High Resolution sensors, and 1804 with Very High resolution sensors. These numbers show that the majority of the missions supported by the SEA service require VHR data. It is important to stress the fact that non EU providers are usually used, especially when it comes to VHR.

³¹⁰ EU SatCen Annual Report – 2016

4.2.3.6.2 Control of Illegal, Unreported and Unregulated (IUU) fishing activities in the EU

4.2.3.6.2.1 Context and role of EO

Illegal, Unreported and Unregulated (IUU) fishing represents a threat for the fishing economy in Europe and has a negative impact on the marine ecosystem. IUU fishing is estimated to reach between 11 million and 26 million tons of fish worldwide per year, representing between USD 10 B and USD 23.5 B of losses for the fishing industry³¹¹. The European fishing industry represents a substantial market with around 5 million tons of reported catch per year (mostly fished in large Atlantic) plus 1.2 million ton from aquaculture³¹², to which IUU fishing activities have to be added, representing around 15% additional catch.

The health of the fishing industry is closely related to the amount of fish resources available and harvested, making IUU fishing a threat for regular anglers. The negative impacts of IUU fishing affect both on the short and medium term on the reduction of fishing industry revenues, and for the preservation of the marine ecosystem and the renewal of species on the long term. The description quantification of these impacts are detailed in the following sections.

Earth Observation contributes to different types of activities in the fight against IUU fishing in Europe:

- Routine monitoring of fishing ground

The fight against IUU mainly relies on terrestrial monitoring systems required on vessels for navigation purposes such as the Automatic Identification System (AIS) and the Vessel Monitoring System (VMS) to provide a real time maritime awareness picture. However these systems do not allow the monitoring of non-reporting targets (not 100% of the fishing boats are equipped, and some outlaw anglers may use alternative small vessels) and are inefficient during non-reporting intervals. Satellite images are a mean to detect these vessels, in particular radar (MR and HR) images. They add a critical component to integrated services by correlating the position of the boats with their identification, and by providing this information in near-real time to the relevant fisheries authorities.

As of today the overall contribution of EO to the monitoring of fishing grounds is estimated to be medium³¹³. Satellites however have intrinsic advantages regarding the large areas that can be covered and the low cost of acquisition in remote areas (compared to aerial means for instance). They offer a very high potential in the future and could become a key data provider if current limitations improve: the availability of satellites missions is not always ensured, which is important when requiring images of a vessel during a non-reporting interval for instance, and a higher revisit time would support the adoption of satellites, in the ideal case allowing multiple passes per day.

- Specific fisheries species monitoring operations

This activity can involve the identification of non-cooperative targets, on which EO brings a lot of benefits, in particular in remote areas, where conventional monitoring means such as aerial surveillance are not able to operate, or are very expensive. In addition, EO enables the coverage of larger areas, which is very valuable in maritime high seas environment. For these

311 Agnew et al., 2009, Estimating the worldwide extent of illegal fishing

312 Eurostat, Fishery statistics, accessible at http://ec.europa.eu/eurostat/statistics-explained/index.php/Fishery_statistics#Catches ; European Commission, 2016, Facts and figures on the common fisheries policy

313 Stakeholder consultation

support operations, both radar images (MR and HR) and optical images (HR and VHR) are exploited.

The contribution of EO to specific operations is medium as Copernicus data remains mostly used for remote areas and its usage is limited near the coasts. The potential use in the future could be high if, similarly to the monitoring of fishing grounds, the number of satellites available and the revisit time improve. It can be noted that the improvement of these aspects would also benefit maritime surveillance in general.

- Monitoring of fish cages and traps

On the same logic as the monitoring of fishing grounds, satellites support the routine monitoring of fish cages and traps, both by spotting illegal cages and traps and by detecting vessels activities in these areas. They complete aerial means depending on the location of the cages, and support the identification of vessels by combining radar images and optical HR/VHR images. The same evolutions as other outputs could contribute to increase the adoption of satellite data, however with slightly less added value expected (from medium to medium/high).

- Monitoring of fishing ports

The routine monitoring of fishing ports is another activity that helps fighting IUU fishing, through the monitoring of IUU listed vessels in third countries ports. Satellite images can be used to ease this surveillance; however, the identification of the vessels requires VHR optical data and remains a challenging task. At the time of writing, the contribution of EO to this activity remains low, and the ensuing impact is too limited to be quantified.

Through its contribution to the routine monitoring of fishing grounds, of fish cages and support to specific operations, EO supports the spotting of illegal activities and the identification of thieves, therefore contributes to the progressive reduction of IUU fishing activities in Europe. A more efficient control system creates a dissuasion effect, and the negative consequences of illegal fishing are reduced over time, which can be reflected through 3 impacts:

- Upstream the dissuasion effect, the repression of IUU fishing leads to fines and financial sanctions inflicted by the involved MS to the thieves;
- Following the dissuasion of IUU fishing activities, the amount of fish available to regular anglers is higher (as regular and illegal anglers often draw from the same stocks), enabling higher revenues for the regular industry;
- On the longer term, the preservation of the livestock has an impact on the renewal of species and therefore on the sustainability of resources.

These activities are summarised in the following impact pathway, and the quantification of the three resulting impacts are detailed in the following sections.

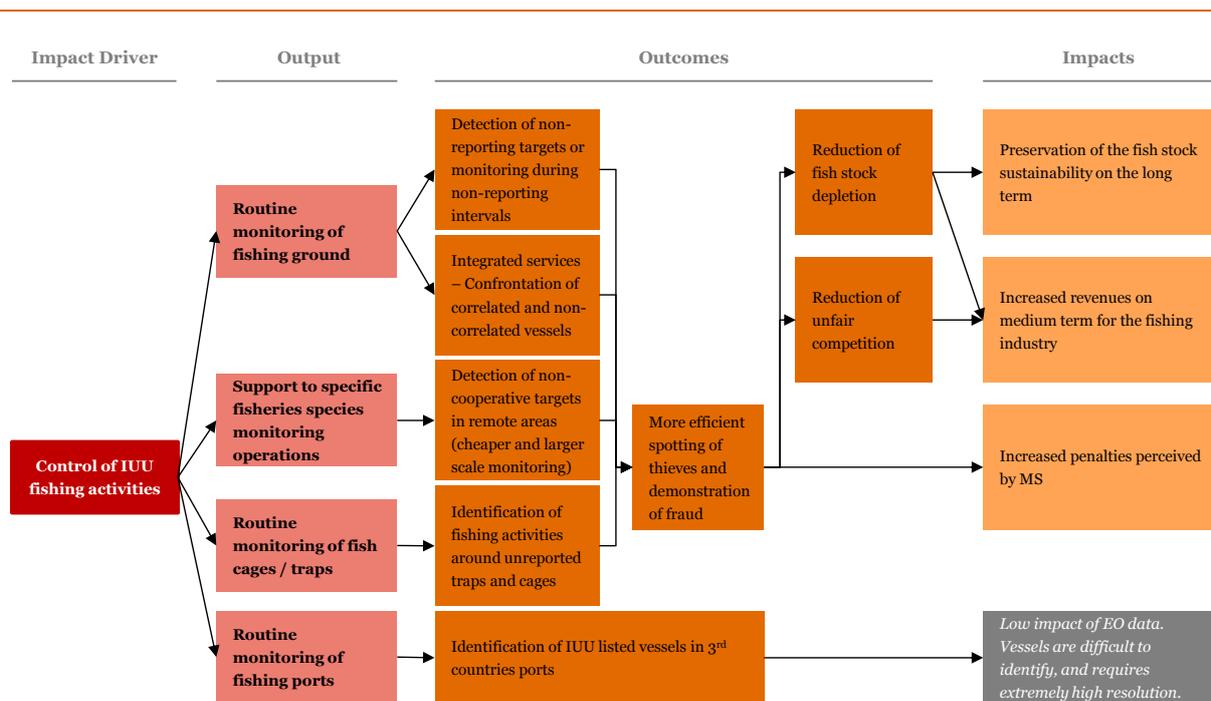


Figure 107 - Impact pathways for the impact driver “Control of IUU fishing activities” (Source: PwC analysis)

Examples of use cases

The usefulness of EO data against IUU fishing has been demonstrated through past projects, such as the SEAS (Surveillance de l’Environnement Assistée par Satellite – Satellite Assisted Environmental Surveillance) deployed in French Guyana (SEAS-Guyanne) in 2005 and in the Indian Ocean (SEAS-OI, based in the Reunion island) in 2012³¹⁴. They consist in ground stations receiving and broadcasting satellite images for various sectors including fishing, urban development, coastline management, transports etc. They rely on both radar images (Radarsat, Envisat) and optical images (SPOT, Pleiades). Copernicus is also a contributor to the EO capabilities of the DOLPHIN project which aims at improving the tools for maritime surveillance, regarding for instance small vessels detection or recognition of abnormal behaviours at sea³¹⁵. This research project foresees several technological steps (use of polarimetry and multi-channel SAR processing to detect small vessels, use of advanced single channel SAR processing to better detect small and fast targets, use of feature extraction for instance to detect manoeuvring vessels etc.). It should produce 25 software tools and three decision support modules that will be used by end users in their monitoring operations³¹⁶. The DOLPHIN project contributed to an exercise within the Bluefin tuna campaign in 2013 led by the International Commission for the Conservation of Atlantic Tuna (ICCAT) in cooperation with EFCA and the Italian coast guards, which demonstrated the added value of EO, in particular in areas with limited data coverage such as between Libya and Malta.

Expected uptake of EO and Copernicus (baseline)

In the future, the contribution of Copernicus within EO data is expected to increase, for several reasons. In the short term, the uptake of Copernicus by end users should improve as

314 <http://www.seas-oi.org/web/guest/accueil> ; [http://ec.europa.eu/regional_policy/sources/policy/themes/ outermost-regions/pdf/project_guyane_seas_fr.pdf](http://ec.europa.eu/regional_policy/sources/policy/themes/outermost-regions/pdf/project_guyane_seas_fr.pdf)

315 The Parliament Magazine 337, DOLPHIN : Development of pre-operational services for highly innovative maritime surveillance capabilities, Accessible at: http://www.gmes-dolphin.eu/sites/gmes-dolphin.eu/files/dolphin_Parliament_Mag.pdf

316 Copernicus newsletter, Copernicus projects : providing added-value to the EU fisheries control campaigns, Accessible at: <http://newsletter.copernicus.eu/article/copernicus-projects-providing-added-value-eu-fisheries-control-campaigns>

their awareness of the CMS products grows and the dissemination process reaches maturity. In the medium term, the launch of the remaining Sentinel units (C & D) should improve the amount of images available with better timeliness, which is a key expectation from the users. The gain in timeliness and availability of images, which is also supposed to be improved with EDRS, should enable national agencies to progressively replace their commercial images with this free data, using paying data only to complete their needs, in short term notice for instance. As the contribution of EO to fighting IUU fishing activities is expected to grow significantly in the future according to stakeholders (from “medium” to “very high” for routine monitoring for instance), we assume Copernicus data will follow a similar trend within EO data, starting from an average of 2% contribution in 2017 to reach 22% from 2022.

4.2.3.6.2.2 Increased revenues for the fishing industry



Methodological approach to value the increased revenues for the fishing industry

The valuation of increased revenues for the fishing industry assumes it is equal to the current shortfall due to IUU fishing. This shortfall relies on the valuation of the average ton of catches (meaning the revenues associated to the sale of the catches) and on the “dissuasion effect”, meaning the decrease of IUU fishing volumes due to IUU fishing repression.

Increased revenues for the fishing industry *Valuation approach*



Description of the impact

The first effect is the impact on the fishing industry revenues on medium term. IUU fishing implies the harvesting of livestock resources which abundance directly affects the revenues accessible to anglers. In addition to depriving regular anglers from their source of revenues, illegal fishing often relies on minimal cost approaches (exploitation of forbidden but more attractive fishing areas, forbidden fishing methods etc.). Catches from IUU fishing can be sold at lower prices, generating unbalanced competition. The repression of IUU fishing activities dissuades illegal anglers, progressively leading to increased revenues for the industry. As it relies on a dissuasion effect rather than a direct mitigation (illegal catches seized cannot be saved and returned to sea when fishes are dead), the actual benefits for the industry materialise after few years, as the difference between the theoretical revenues with no IUU fishing fighting and the actual revenues. In the current exercise, it has been assumed that it takes 3 years for the dissuasion effect to materialise.

Data for impact valuation

The yearly volume of reported fishing activities (catches and aquaculture) in the EU varies around 6.2 million tons³¹⁷, which enables to estimate the total volume of IUU catches for the EU around 620,000 tons per year³¹⁸.

When considering the evolution of the ratio of IUU catches versus overall catches, it can be estimated that since 1990 this ratio dropped from 21% down to 15%³¹⁹, representing an average decrease of 0.28 point per year (equivalent to 1.14% of the yearly IUU catches). Taking into account that the overall EU reported catches is constant over the past decade, this decrease in the share of IUU fishing with respect to the overall fishing activity represents the dissuasion effect attributed to IUU fishing repression. The model assumes that from 2015 to 2020 the rate of decrease of IUU fishing continues at this pace, leading to a yearly volume of fish stock saved from IUU fishing of about 17,700 tons. It should be noted that the 3 years delay between the repression actions and the actual IUU fishing reduction (cf. Impact description) are taken into account in the distribution of the Copernicus contribution.

The revenues for the fishing industry can then be derived based on the average value of the ton for catches landed. Over the past decade, IUU fishing stocks are valued around EUR 827 M per year³²⁰, leading to a price of EUR 1,281 per ton.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on increased revenues for the fishing industry relies on the following assumptions.

- The volumes of reported catches within the EU remains constant (oscillating around 6 million tons per year), following the trend of the past decade.
- The ratio of volume of IUU fishing to the volume of reported catches will keep decreasing (dissuasion effect) up to 2035. For 2015-2020 the pace of decrease will be the same as the average of past 25 years (0.28 points per year) and will progressively slows down, to 0.2 point for 2020-2025, 0.16 for 2025-2030 and 0.14 for 2030-2035. This attenuation of the pace of decrease aims at taking into account that it is not realistic to assume a total eradication of IUU fishing activities. By 2030 – 2035, the volume of fish stock saved from IUU fishing every year reaches 8,700 tons. It should be noted that the IUU fishing volumes considered represent a conservative position as the shares retained correspond to the values for Northeast Atlantic, which has the lowest shares of IUU fishing (worldwide) but does not necessarily includes all the fishing areas for EU players.
- The valuation of landed catches remains constant, equal to EUR 1,281 per ton.

Results

Under the assumptions described above, the benefits of Copernicus to the increase of the fishing industry revenues is the following. The first graph describes the benefits of Copernicus in terms of volume, and the second graph describes the monetised benefits associated to these volumes.

³¹⁷ EC, 2016, Facts and figures on the Common Fisheries Policy ; Eurostat, 2016, Fish catches and aquaculture production V2 – accessible at http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Fish_catches_and_aquaculture_production_V2.png

³¹⁸ Based on average share of IUU fishing volume for Northeast Atlantic of 10%. Source: EFTEC, 2008, Costs of illegal, Unreported and Unregulated (IUU) fishing in EU fisheries

³¹⁹ Agnew et al., 2009, Estimating the worldwide extent of illegal fishing

³²⁰ EFTEC, 2008, Costs of illegal, Unreported and Unregulated (IUU) Fishing in EU fisheries. Price adjusted to 2017 EUR.

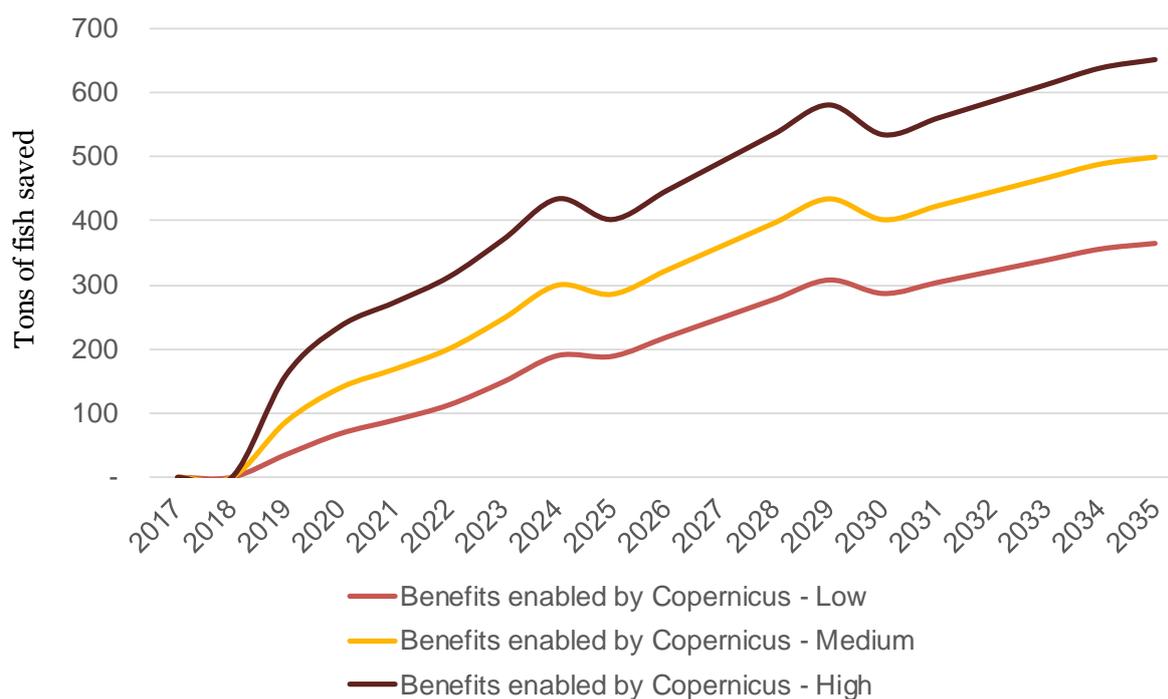


Figure 108 - Evolution of Copernicus benefits (tons of fish saved) for the impact “Increased revenues for the fishing industry” between 2017 and 2035 for Europe (Source: PwC analysis)

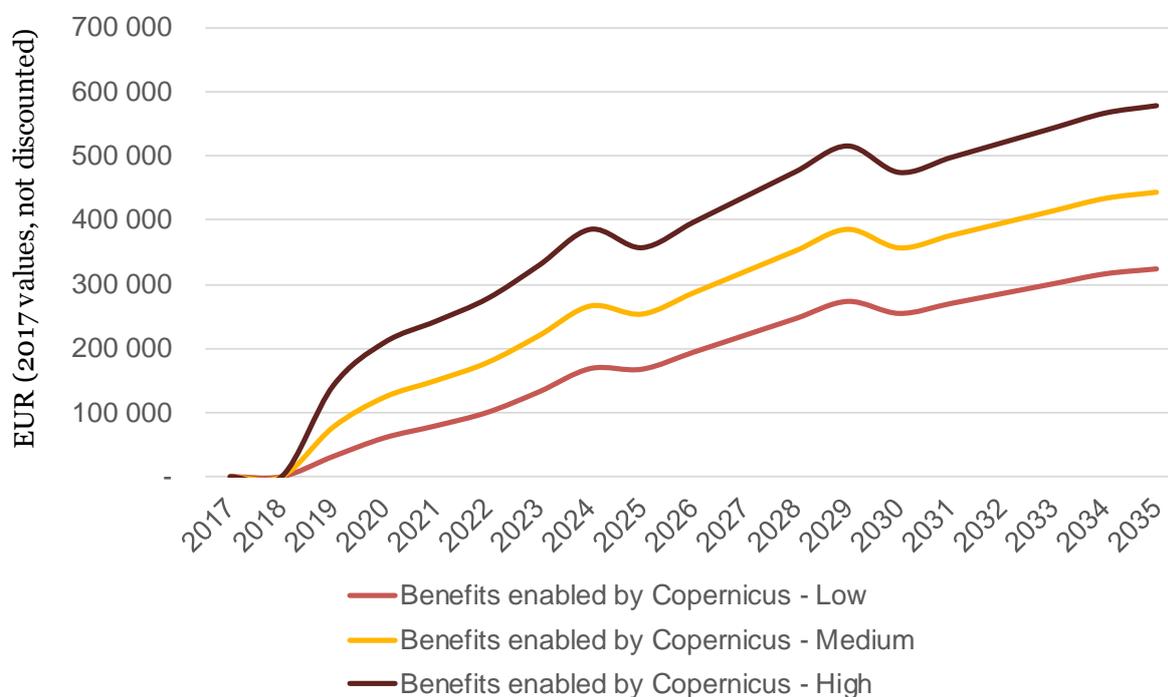


Figure 109 - Evolution of Copernicus benefits (EUR) for the impact “Increased revenues for the fishing industry” between 2017 and 2035 for Europe (Source: PwC analysis)



Methodological approach to value the preservation of fish stock sustainability on the long term

Fish stock sustainability is quantified based on the value of a fish when it is alive, as it is able to grow and reproduce. The reduction of IUU fishing saves fishes, which are able to renew the stock. The benefits materialise on medium to long term, as it takes into account the time of the reproduction cycle.

Preservation of fish stock sustainability on the long term *Valuation approach*



Description of the impact

The second impact of IUU fishing is linked to the uncontrolled depletion of the ecosystem livestock. It appears more on the long term, as depending on the species, the reproduction cycle takes between 3 to 10 years. An over-exploitation of fish livestock implies a reduced stock to ensure the renewal of the species. This slower renewal leads to smaller amounts of resources in the future and maintains the level of fish in a low-value state. Past studies have assessed that for species on which we have data, 68% are over-exploited, showing high risks of depletion, and that in 88% of the cases a reduction of fishing volumes would enable higher amounts of catches in the future³²¹.

If ultimately, the insufficient renewal of fish stock would have an impact on the revenues of the fishing industry, this impact differs from the previous one (section 4.2.3.6.2.3 “Increased revenues for the fishing industry”) as we consider here the threat on the environmental point of view. While illegal fishing has an immediate effect on industry revenues (each ton illegally fished is taken from regular fishing), this impact materialises on the long term, and characterises the ability of stocks to sustain, with all the consequences it implies. Fishing industry revenues are only one of these consequences, among others such as size-related impacts (evolutionary pressure towards earlier sexual maturity), unbalancing of predators-prey equilibrium, extinctions of certain species, etc.

Data for impact valuation

The logic to quantify this impact relies on the same principle of the IUU fishing dissuasion effect (with the same 3 years delay between repression and actual decrease of IUU fishing). Hence the same values are used: 620,000 IUU fishing volume per year, representing 10% of the EU catches. The dissuasion effect leads to a reduction of this share by 0.28 point per year up to 2020, and a slowdown of this effect by 0.05 point every 5 years up to 2035³²².

The difference with the industry revenues impact lies in the valuation of the fish stock saved. Its value (per ton) is not the same as the commercial value used for the shortfall for the

³²¹ European Commission, 2008, Communication on Fishing opportunities for 2009, Policy statement from the European Commission

³²² Cf. previous impact (Increased revenues for the fishing industry) for details.

industry, but instead it takes into account the prospective value of the fish, as being alive, for the ecosystem and the future fishing activities. It is difficult to put an economic value on this, but 2 main factors enter into consideration: on one hand a fish alive is more valuable than landed catches as it still has the potential to grow, reproduce, and create more fishes; on the other hand there are costs associated to its capture and to land it. In a past study this approach led to a valuation of the preserved livestock around 1,077 EUR per ton³²³.

Evolution up to 2035

The projection of the baseline up to 2035 of the impact of Copernicus on the preservation of fish stock sustainability relies on the following assumptions.

- The volumes of reported catches within the EU remains constant (oscillating around 6 million tons per year), following the trend of the past decade.
- The ratio of volume of IUU fishing to the volume of reported catches will keep decreasing (dissuasion effect) up to 2035. For 2015-2020 the pace of decrease will be the same as the average of past 25 years (0.28 points per year) and will progressively slow down to 0.2 point for 2020-2025, 0.16 for 2025-2030 and 0.14 for 2030-2035. This attenuation of the pace of decrease aims at taking into account that it is not realistic to assume a total eradication of IUU fishing activities. By 2030 – 2035, the volume of fish stock saved from IUU fishing every year reaches 8,700 tons. It should be noted that the IUU fishing volumes considered represent a conservative position as the shares retained correspond to the values for Northeast Atlantic, which has the lowest shares of IUU fishing (worldwide) but does not necessarily include all the fishing areas for EU players.
- The valuation of landed catches remains constant, equal to EUR 1,077 per ton.

Results

Under the assumptions described above, the contribution of Copernicus to the preservation of fish stock sustainability is the following.

³²³ EFTEC, 2008, Costs of illegal, Unreported and Unregulated (IUU) Fishing in EU fisheries

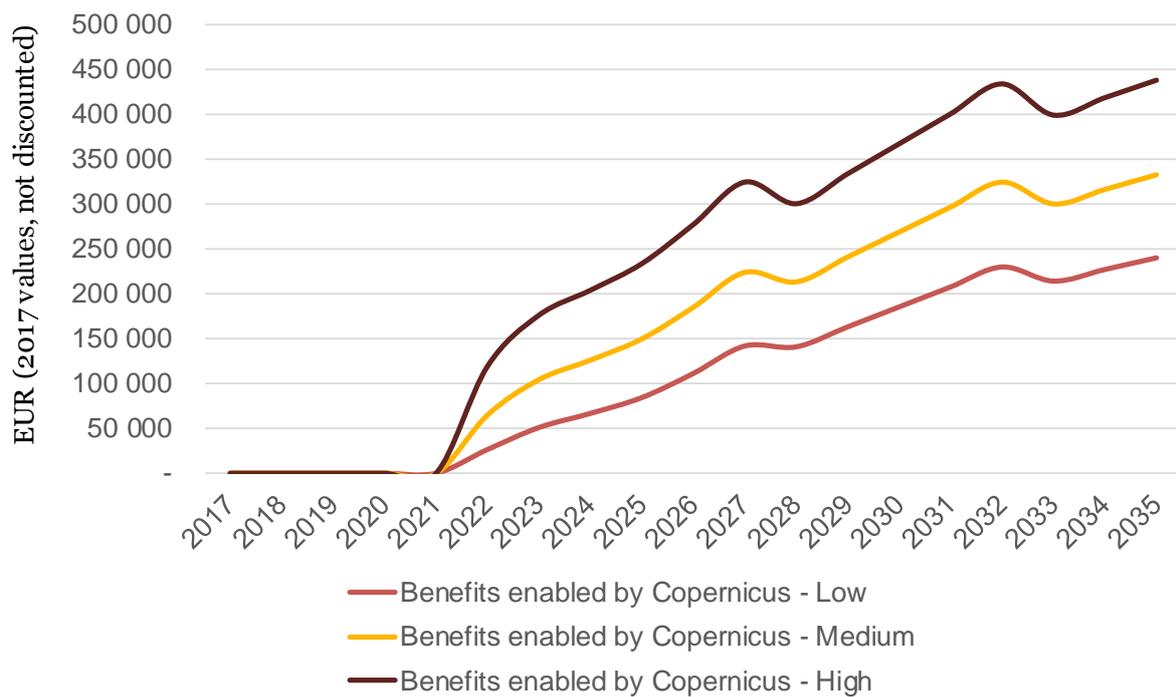


Figure 110 - Evolution of Copernicus benefits (EUR) for the impact “Increased revenues for the fishing industry” between 2017 and 2035 for Europe (Source: PwC analysis)

4.2.3.6.2.4 Increased penalties perceived by MS for law infringements



Methodological approach to value the increased penalties perceived by MS

The most immediate impact of the detection of IUU fishing activities is the penalty inflicted to the fraudsters, as it is not linked to the dissuasion effect. 4 categories of infringements are considered for this impact: unauthorised fishing, fishing without a licence, failure to comply with remote transmission of vessel movements and tampering of the satellite based VMS. These infringements are selected for they have a more direct link with the use of satellite data.

Increased penalties perceived by MS **Valuation approach**



Description of the impact

The monitoring of IUU fishing leads to economic sanctions for the illegal fishers, inflicted and perceived by the MS. The contribution of Copernicus to IUU fishing monitoring leads to more opportunities to intercept fraudsters, therefore to additional sanctions. It should be noted that sanctions remain a point of heterogeneity between the MS which do not all have the same levels of penalties³²⁴. The European Commission has identified some room for improvement in the rigor and harmonisation of the practices in term of law enforcement.

Data for impact valuation

MS are imposed by Council Regulation (EC) n° 1447/1999 to report on a yearly basis to the European Commission the serious infringements to the Common Fisheries Policy detected, and the associated penalties imposed. This regulation establishes 19 types of breaches, out of which 4 are considered for the quantification of this impact:

- “C1 - fishing without holding a fishing licence, fishing permit or any other authorisation required for fishing”
- “D5 – Unauthorised fishing”
- “E2 - Tampering with the satellite-based vessel monitoring system”
- “E3 - Deliberate failure to comply with the Community rules remote transmission of movements of fishing vessels”

When analysing all the potential breaches listed, these 4 infringements represent roughly one-third of the total fines perceived by MS (mostly from C1 and D5). Though no recent exhaustive data is available on the fines perceived by MS, the figures from 2004 to 2006³²⁵ provide an average of EUR 4.3 M per year (adjusted to 2017 euros).

Evolution up to 2035

The amount of fines perceived by MS related to these infringements is assumed to be constant in the future.

Results

Under the assumptions described above, the contribution of Copernicus to fines perceived by MS for IUU fishing is the following.

³²⁴ European Commission, Communication to the Council and the European Parliament, Reports from Member States on behaviours which seriously infringed the rules of the Common Fisheries Policy in 2005

³²⁵ European Commission, 2004, 2005 and 2006, Reports from Member States on behaviours which seriously infringed the rules of the common fisheries policy

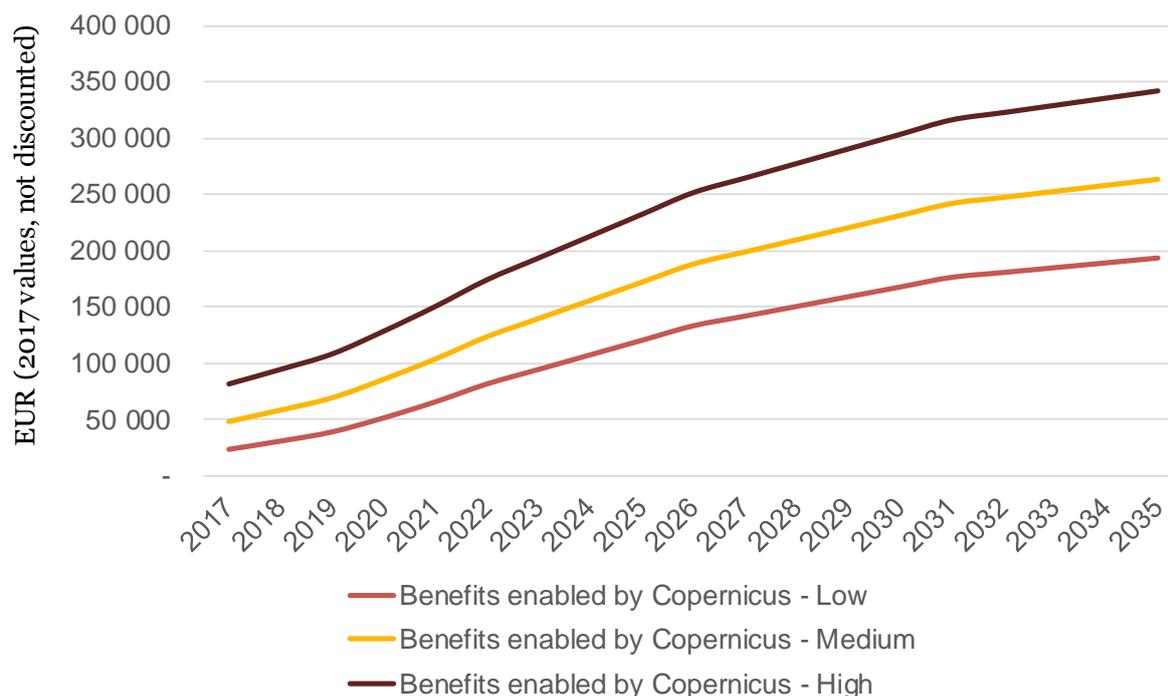


Figure 111 - Evolution of Copernicus benefits (EUR) for the impact “Increased penalties perceived by MS” between 2017 and 2035 for Europe (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

It is a delicate exercise to attribute a share of the operational results to the use of EO because the value chain involves many steps and actors, which can all have a critical role to play. Considering the overall value chain for IUU fishing mitigation activities, from the detection of fraudsters, to their identification and their actual interception by authorities, and based on the qualitative assessment from stakeholder consultation (who estimated the role of EO at “medium”), the contribution of EO to the repression of IUU fishing is assumed to be between 5% and 10%. This relatively low value is explained by the fact that EO mostly helps to identify additional fraudsters, improving the efficiency of the mechanism. In other terms, the sudden loss of satellite images would degrade the amount of IUU fishing intercepted, while other activities such as identification of vessels (AIS) or the interception of the vessels are critical for the results, meaning their sudden loss would lead to a total inability to intercept targets. In addition, this contribution of EO tends to be conservative as satellite data is now an indispensable mean for MS to implement effective control of IUU fishing far from coasts and overseas. If there are some alternatives near the coasts, EO remains the only tool to fight IUU fishing in remote areas.

The contribution of Copernicus within the EO data used for fighting IUU fishing is estimated to be moderate. EMSA provides some maritime surveillance pictures to the European Fisheries Control Agency (EFCA) through the CMS service, as well as to MS national fisheries authorities. However, it does not constitute the only source of satellite data for the agencies. For instance, since 2003 the French agency (Direction des Pêches Maritimes et de l’Aquaculture – DPMA) has ordered between 10,000 and 20,000 satellite images from Radarsat and Envisat every year. As a comparison, the CMS service has delivered 280 products in 2016 for fisheries control purposes³²⁶. For the few MS having a substantial

³²⁶ EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

fishing industry and control means relying on satellite data (France, UK, Spain, Italy, Denmark), the impact of Copernicus is substantial, reflected through both the direct use of the CMS service and the order of additional satellite data to commercial providers, based on CMS data. These countries EEZ (about 20 M km²) represent 11% of the world total maritime area under jurisdiction, and 70% of the EU maritime area under jurisdiction. A conservative approach is adopted, using the value for the global share (11%) as the EEZ of France and UK typically include external territories. The contribution of Copernicus can be conservatively estimated in the order of magnitude of 10% to 20%. This contribution materialises as an enabler to use of satellite images by MS, which allows a scaling up of monitoring means at much lower cost than traditional aerial and ground means (aircraft, drones, vessels etc.).

4.2.3.6.2.5 Summary of Copernicus contribution to fighting of IUU fishing

The following table summarises the overall impact of Copernicus for the support to the repression of IUU fishing in the EU, under the assumptions described above.

<i>Copernicus benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	0.023	0.372	0.758	7.81
Medium estimate	0.048	0.575	1.04	11.5
High estimate	0.081	0.823	1.36	15.8

Table 31 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

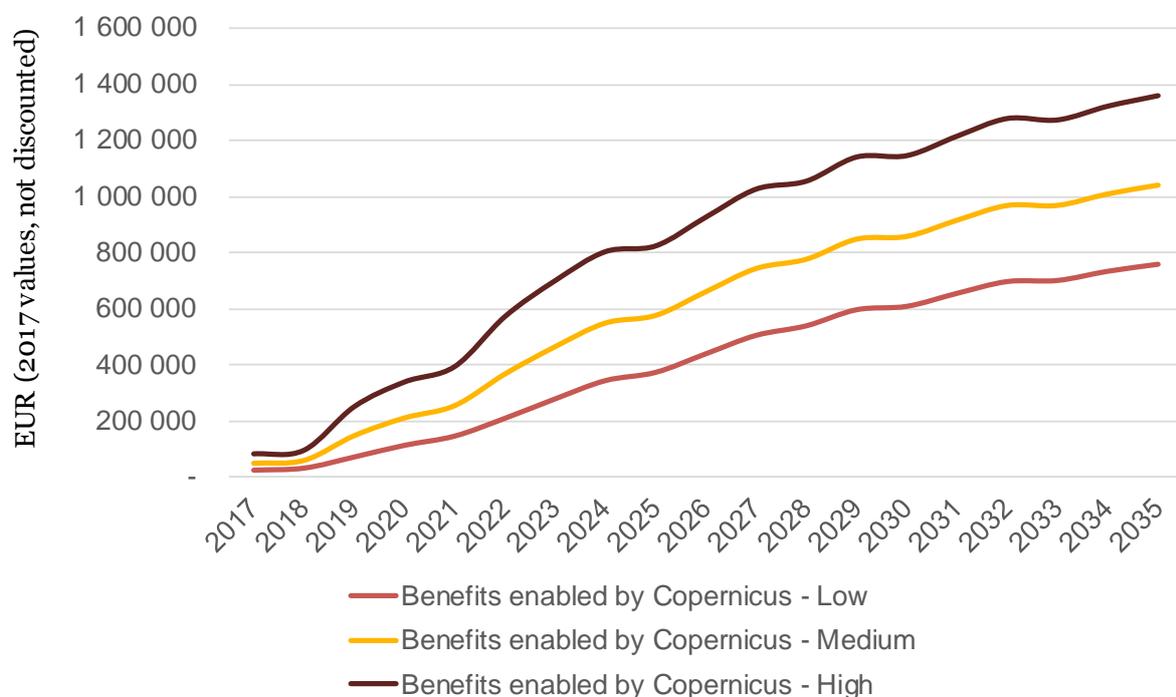


Figure 112 - Summary of Copernicus benefits (EUR) to the impact driver "Control of IUU fishing activities" between 2017 and 2035 for Europe (Source: PwC analysis)

4.2.3.6.3 Maritime safety - Search & Rescue

4.2.3.6.3.1 Context and role of EO

The hostility of maritime environment implies high risks for lives involved in incidents at seas. Search & Rescue (S&R) missions are critical across both the detection phase to spot the vessels in distress and the intervention phase to rescue the passengers. While S&R missions commonly refers to the rescue of vessels in regular maritime traffic, Europe also faces a particular situation with the important flow of migrants crossing the Mediterranean sea, from Africa mainly, putting thousands of people at risk every month, on over-crowded and makeshift embarkations. In these conditions, S&R missions are particularly vital to avoid humanitarian disasters.

Search & rescue missions are mostly conducted by the Maritime Rescue Coordination Centres (MRCC) of MS, sometimes completed by NGOs, especially in the case of refugees. MRCCs can use satellite data for their operations, either by procuring it by themselves, or by using satellite products provided by EMSA. IT should be noted that as of today the support brought by EMSA to these operations is more based on information on maritime traffic management and assistance to ship casualty than EO images. When considering the wider potential applications for EO (beyond the CMS service, for instance used by MRCCs), satellite images can support 3 aspects of S&R missions:

- Location of vessels

The location of vessels in distress is the first phase of the rescue operation. The quick detection of vessels requiring assistance is vital in the S&R process as it triggers the commissioning of rescue ships on-site, either from MRCC, ONGs or other vessels near-by, depending on the closest one to the incident. In regions close to coast, radio systems are the most common means to launch warnings and ask for help. Systems such as the AIS ensure regular location of vessels, thus satellite images are not critical and are not used in typical missions. In regions far from coasts, the location of vessels relies more extensively on EO data. Radar images are well adapted to spot vessels on sea surface and offer the advantage of covering very large areas in remote locations. The use of HR and MR radar images is completed with VHR optical images to help identify the vessels.

- Support to S&R operations

Once a vessel has been located, a follow-up is required to conduct the rescue operation. This includes the identification of the boat, for instance in the case of small ships (less than 15m) to assess the required support before triggering the operation. Once the operation is launched, support can be required to provide situational awareness (traffic, near-by vessels, meteorology etc.). In some cases strong winds and currents can lead to the drift of vessels from the initial location, requiring additional research, which can be done “manually” (rescue ships start from the initial coordinates and follow an expanding spiral until spotting the vessel) or can be supported through drift modelling based on currents and winds. These support operations can benefit from similar satellite data as the vessels location, meaning MR/HR radar images, and HR/VHR optical images.

- Ship traffic information

Ship traffic information is obtained from a combination of various sources including AIS and satellite-AIS, Long Range Identification and Tracking (LRIT), Vessel Monitoring System (VMS), Vessel Detection System (VDS) etc. The picture obtained supports the implementation of MS responsibilities as flag States, port States and coastal States, such as inspections and accidents investigations. These missions reinforce the safety of ships and contribute to the reduction of maritime incidents, hence to the reduction of casualties.

Considering the numerous identification signals involved, only radar images contribute to this picture, which involves MR and HR radar data.

These activities are summarised in the following impact pathways, and the quantification of the 2 resulting impacts (S&R for regular vessels and for refugees' vessels) is detailed in the following sections.

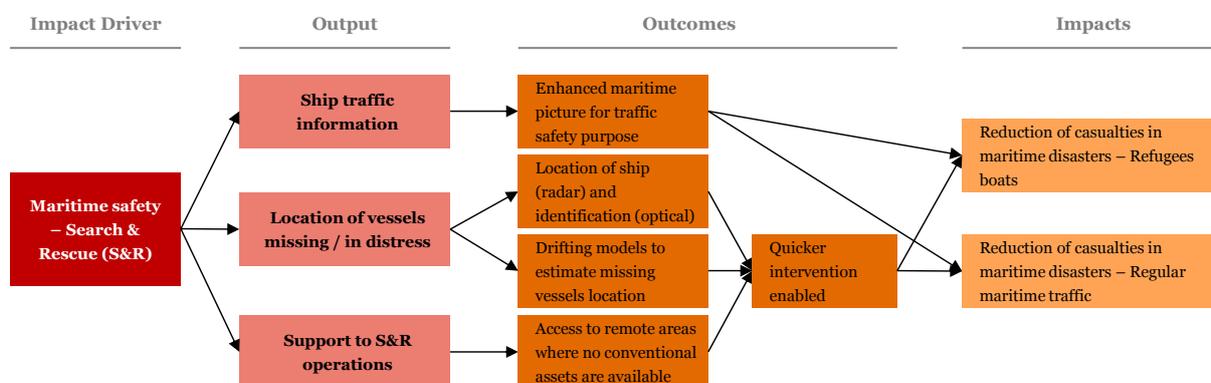


Figure 113 - Impact pathways for the impact driver "Maritime safety - Search & Rescue" (Source: PwC analysis)

Examples of use cases

The products delivered by the CMS for maritime safety served 2 operational tests. For the first one the Portuguese Navy requested images in support of a multi-purpose maritime surveillance exercise in Sao Tome and Principe on 14- 15 November 2016. For the second test, the French Polar Institute (L'Institut polaire français Paul-Émile Victor - IPEV) requested support to in the Antarctic via the European External Action Service (EEAS). The feasibility of using EO information for safety of navigation in ice conditions was assessed successfully, providing CMS EO data to assist the IPEV ship in finding safe navigation routes through the ice pack.

In Europe, the Ocean-SaR project is a service supporting MRCCs in their S&R missions by providing simulations of the currents and meteorological conditions at sea³²⁷. Though not provided through the CMS service but rather by the Copernicus Marine Environment Monitoring Service (CMEMS), it allows to forecast the possible trajectories of persons or objects drifting in the sea, based on data provided by the³²⁸. It produces maps of high-probability search areas, directly contributing to the planning of the rescue mission. The Ocean-SAR was used in concrete cases such as an accident between Italy and Albania in December 2014 on which Italian coast guards intervened based on 5 drifting scenarios (living person in water, deceased person in water, life-rafts of different classes etc.). Ocean-SAR was also used in July 2013 for the rescue of a passenger missing from a ferry ear Sardinia (whose body was found the next morning). Ocean-SAR project also supports interventions at global scale such as the search for the Malaysia Airlines aircraft (MH 370), which debris were discovered more than 2 years later. The Ocean-SAR project was also used to rescue migrants in 2013 and 2014, for a fishing trawler which drifted for 36 hours without

³²⁷ <http://www.ocean-sar.com/en/discover-sar>

³²⁸ EC workshop, Search and Rescue, Copernicus Environment Monitoring Service, Accessible at <http://workshop.copernicus.eu/sites/default/files/content/attachments/p.agostini.pdf>

engines in rough sea before being rescued, and for a coastal freighter on the Ionian Sea that drifted for 3 days (after being evacuated) before being towed³²⁹.

Expected uptake of EO and Copernicus (baseline)

In the future, the uptake of EO in general is expected to improve, in particular for the support to operations (potential foreseen as “very high”), and in lower extent for the location of vessels (potential foreseen as “high”). In both cases, the improvement of tasking time is a key criterion to increase attractiveness of satellite images to the users (with a target below 1 hour). The improvement of the resolution over large areas would also be valuable, especially for operations in high seas, to combine large swath and small vessels detection. Finally, a quicker revisit time would also contribute to improving responsiveness of satellites. Regarding ship traffic information, there is not much improvement expected (potential remaining as “medium”). The deployment of EO satellites in the coming years can be expected to progressively fulfil these expectations, thus increasing user uptake. In the current model, the contribution of EO grows from 0% to 5% in 2017 up to 10% to 15% in 2035.

Because the low uptake of EO is essentially linked to the existing alternative technologies and operating modes, Copernicus can hardly create a differentiation with the rest of EO sources as of today, but some ways to improvement exist. The gain in maturity of the CMS (still very young) and of the products from EMSA can be expected to support the uptake of Copernicus in the coming years, in particular as the characteristics of EO satellites improve in this direction, which would enable the CMS to upgrade its products similarly. Some specific products such as drifting models to estimate the location of targets at sea from a “last known position” will also contribute to the usefulness of Copernicus for S&R missions, though such impact remains limited today and challenging to quantify. In addition, this product could benefit from the Copernicus products developed in the frame of the CMEMS on currents forecasts. Another example of synergies with other Copernicus applications is the surveillance of areas of interest such as the Libyan coast (in the frame of pre-frontier surveillance for instance) to anticipate the flows of migrants, enabling MRCCs and ONGs to deploy the appropriate means at the right place at the right time. The current modelling assumes (for the baseline) a growth of the Copernicus uptake from 0%-5% up to 8% in 2025 for regular traffic, as only the cases where drift models can contribute would benefit from EO data. The growth can be expected to be up to 10% in 2025 for refugees rescue, which would benefit in addition from the pre-frontier analysis of departure countries (Libya mostly). Both values are then constant from 2025 up to 2035.

As mentioned above these figures represent the contribution of Copernicus data to S&R missions, not only through the CMS service but also through EO data procured by rescue organisations (MRCCs, ONGs etc.) for their operations.

³²⁹ EC workshop, Search and Rescue, Copernicus Environment Monitoring Service, Accessible at <http://workshop.copernicus.eu/sites/default/files/content/attachments/p.agostini.pdf>



Methodological approach to value the reduction of casualties in maritime disasters - regular maritime traffic

The use of satellite images contributes, even if it remains to a limited extent, to more efficient S&R operations, which implies the saving of additional lives. The contribution of EO materialises through situational picture and support to vessel location, with a differentiation made between the incidents occurring close to coasts (with very limited contribution of EO as many complementary means are available) and incidents occurring in high seas where the large coverage of satellites enable more direct benefits. The number of lives is then monetised by using the notion of statistical value for life (economic impact of an avoided fatality).

Reduction of casualties in maritime disasters – Regular maritime traffic Valuation approach



Description of the impact

A better response in case of a maritime incident can materialise in different manners, the most impactful one being the reactivity to commission rescue teams on-site, so the gain in efficiency enabled by satellite images can be reflected in additional lives saved. The lives saved thanks to Copernicus are then monetised through an approach based on the statistical value of life (economic impact of an avoided fatality). This approach attributes a monetary value to each life, which should not be seen as the value of the person of course, but as the economic footprint of each person in the society, in the sense of the economic value generated by all the day to day activities of this person (work, spending, taxes, social activities etc.).

Data for impact valuation

In the frame of the monitoring of maritime incidents (or regular traffic), EMSA runs the EMCIP database of accidents populated by the MS accident investigation bodies. As EMCIP grows, some 4,000 casualties and incidents are being recorded on average each year, and its future as a decision support tool is becoming clear. Since the creation of EMCIP in 2011, investigation bodies have launched 749 investigations and issued 1000 safety recommendations³³⁰.

The report of EMSA on marine casualties and incidents³³¹ reports that over 3,200 incidents are reported per year, involving different types of vessels (cargo ships, passengers' ships, service ships, fishing ships etc.). During these events, over 115 persons perished in 2015, above the yearly average on 2011 – 2015 (476 casualties in total). The contribution of Copernicus to the S&R missions is quantified through the number of lives saved (that can be attributed to the availability of Copernicus data), that is to say the total number of lives at risk minus the actual casualties. For the current exercise, only the incidents categorised as

³³⁰ EMSA, 2017, EMSA Outlook

³³¹ EMSA, 2016, Annual overview of marine casualties and incidents

“very serious” are considered, in accordance to the definition of EMSA: “A *very serious marine casualty* means a marine casualty involving the total loss of the ship or a fatality or severe damage to the environment.” These incidents represent 3% of the total incidents. In addition, it is estimated that the lives at risk are the total lives on-board vessels involved in the incidents categorised as “casualty with a ship”, which represent 68% of the incidents on average for the past 5 years. The remaining 32% of incidents, “occupational accidents”, potentially involve only one person, and are much less representative of the total. By estimating the average number of people on the ships (per category of ship), the total number of lives at risk can be assessed around 4,500 per year.

The statistical value of life (economic impact of an avoided fatality) used to attribute a monetary value to the lives saved is EUR 2.26 M per individual.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on S&R missions for regular vessel traffic relies on the following assumptions.

- The number of S&R missions to be conducted will increase at the same pace as the maritime traffic, suggesting that the denser the traffic the higher the risks of incidents. The yearly growth of maritime traffic is extrapolated from the 2002-2015 trend³³². It progressively decreases from 2.95% in 2017 down to 2% in 2035.
- The ratio of “very serious” incidents within the overall maritime incidents remains constant, equal to 3%.
- The ratio of incidents categorised as “casualty with a ship” remains constant, equal to 68%.
- The amount of casualties in the maritime incidents remains proportional the number of S&R missions (hence to the density of maritime traffic). It can be noted that this assumption is rather conservative as we may expect a progressive improvement of maritime safety (beyond S&R missions efficiency, the regulations, controls and equipment for regular vessels might lead to an improvement of the ratio of casualties over traffic).
- The statistical value of life (economic impact of an avoided fatality) is assumed constant, equal to EUR 2.26 M.

Results

Under the assumptions described above, the contribution of Copernicus to the reduction of casualties in S&R missions for regular traffic is the following. The first graph shows this impact in terms of number of lives and the second graph in monetary terms.

332 UNCTAD, 2016, Review of maritime transport 2016, accessible at: http://unctad.org/en/PublicationsLibrary/rmt2016_en.pdf

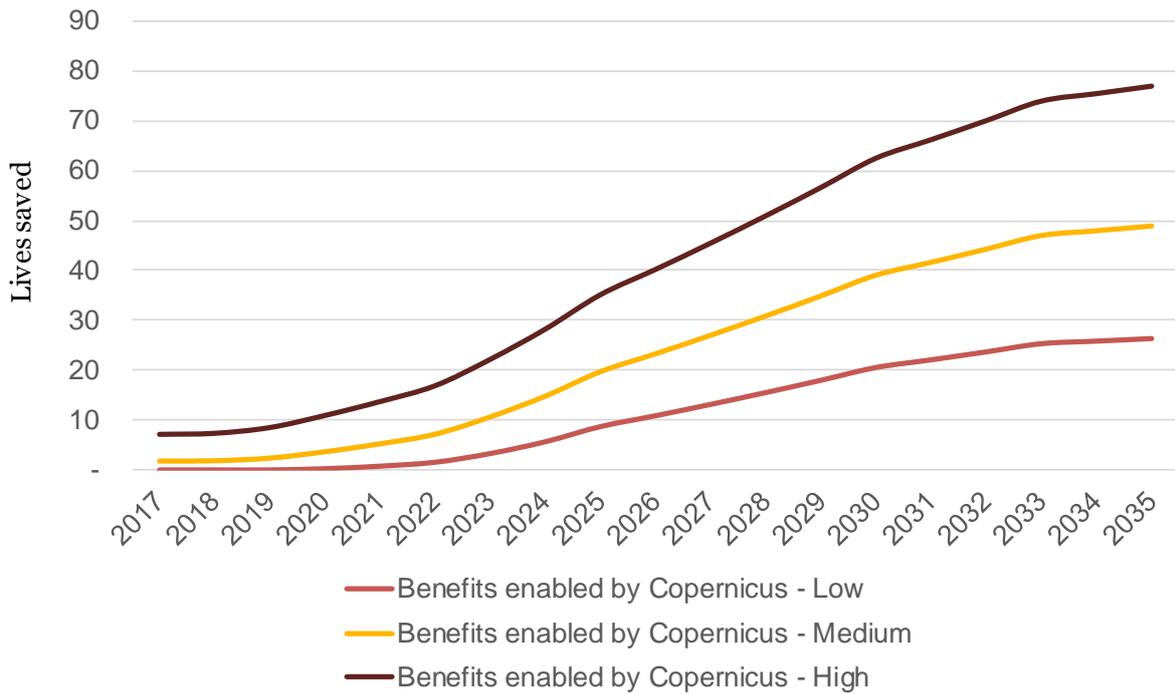


Figure 114 - Evolution of Copernicus benefits (lives saved) for the impact “Reduction of casualties in maritime disasters – regular maritime traffic” between 2017 and 2035 for Europe (Source: PwC analysis)

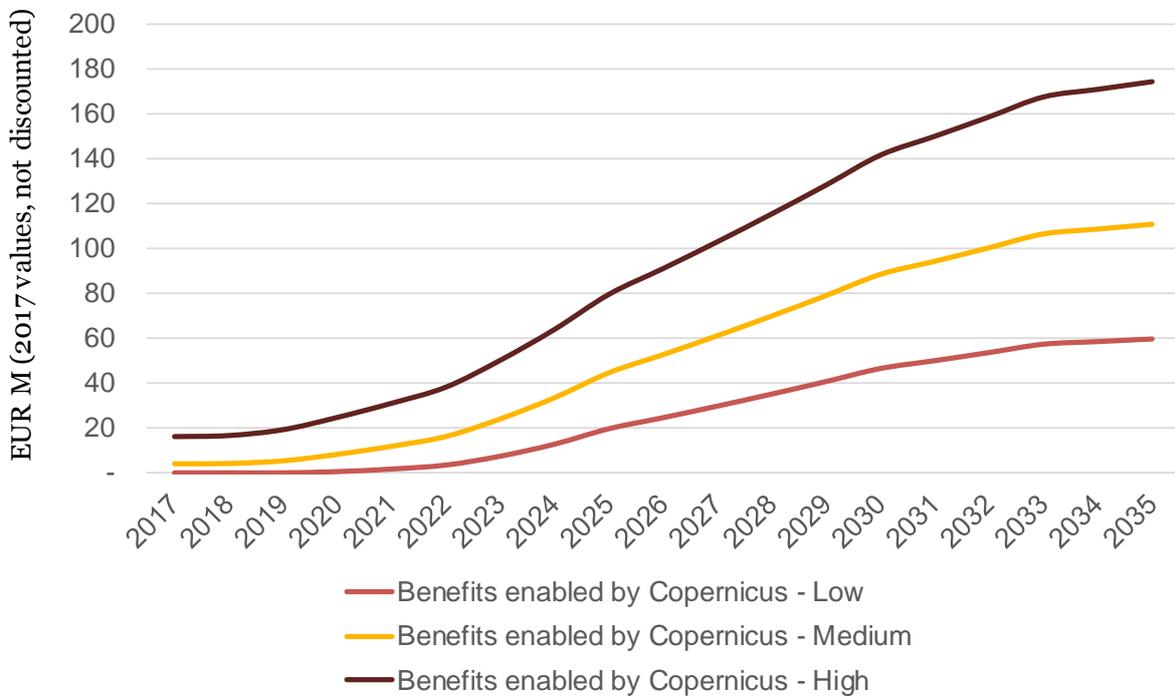


Figure 115 - Evolution of Copernicus benefits (EUR M) for the impact “Reduction of casualties in maritime disasters – regular maritime traffic” between 2017 and 2035 for Europe (Source: PwC analysis)

4.2.3.6.3.3 Reduction of casualties in maritime disasters – Refugees boats



Methodological approach to value the reduction in casualties in maritime disasters – refugees boats

The use of satellite images contributes, even if it remains to a limited extent, to more efficient S&R operations, which implies the saving of additional lives. The contribution of EO materialises through situational picture and support to vessel location. The contribution of Copernicus is evaluated through the extent of use of situational awareness data, drifting models and pre-frontier surveillance of North Africa countries in the S&R operations conducted by MRCCs, Frontex and ONGs.

The number of lives saved is then monetised by using the notion of statistical value for life (economic impact of a fatality).

Reduction of casualties in maritime disasters – Refugees boats *Valuation approach*



Description of the impact

The impact for refugees rescue missions, although measured on the same criterion (lives saved) is driven through slightly different levers than for regular traffic. The refugees crisis takes place in the Mediterranean sea, mainly between Libya and the Italian and Greek coasts. Similarly to regular traffic, several terrestrial means are commonly used to spot the vessels: satellite phones from refugees, patrols using radar or visual surveillance, aerial means such as drones (used by MRCCs and ONGs) etc. EO contributes to the efficiency of operations by helping on vessel identification (the appropriate rescue vessel varies as refugees boats can contain up to hundreds of people), by anticipating the migrant flows (surveillance of the Libyan coast, anticipation of peaks after long periods of hostile weather) and feeding drifting models to spot lost vessels (more efficient than spiral patrolling). If these levers are quite different from the regular vessels missions, the outcome remains the same, meaning an increase of lives saved. The lives saved thanks to Copernicus are then monetised through an approach based on the statistical value of life (economic impact of an avoided fatality).

Data for impact valuation

The estimation of the number of refugees lives saved is challenging because of the very variable nature of the refugees crisis, with figures potentially changing by a ratio of 3 or 5 from one year to another. Between 2015 and 2017, the number of refugees crossing the Mediterranean sea varies between 200,000 to over 1 million³³³. Although estimates vary considerably, it is estimated that about 30% of the refugees are rescued during the crossing³³⁴. It can be noted that rescued refugees are not necessarily people with their life at

333 UNHCR, 2017, Chiffres Clés Europe Jan-Juin 2017, accessible at <https://data2.unhcr.org/en/documents/download/58527> ; UNHCR operational portal, accessible at <http://data2.unhcr.org/en/situations/mediterranean>

334 Independent, 2017, Charities saving refugees in the Mediterranean are 'colluding' with smugglers, Italian prosecutor claims, Monday 24 April 2017

risk at the moment of the S&R mission, but people who are rescued considering the high risk of the crossing in such conditions. Based on database from UNHCR, the rate of casualties among refugees crossing the Mediterranean sea is about 1.1% (average on 2015 to 2017). Hence the estimate for the impact quantification considers that 1.1% of the refugees rescued would have perished without intervention.

The statistical value of life (economic impact of an avoided fatality) for the refugees is the same as for regular traffic, equal to EUR 2.26 million.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on S&R missions for refugees relies on the following assumptions.

- The main uncertainty related to the refugees crisis concerns its evolution in the coming years and decades. The variety of parameters influencing this phenomenon makes extremely difficult to assert what will be even its trend. The evolution of wars (in the Middle East and African regions, and at more global level) is foreseen by some experts to decrease in the future, potentially mitigating the displacements of population. In the meantime, other experts expect the progressive rise of the level of revenues in poor countries to enable more and more people to afford the journey, contributing to these flows. 3 scenarios have been built to cover the potential evolutions:
 - Scenario 1 (growth) foresees a linear increase of the number of refugees following the trend observed on the past 10 years (CAGR of 2.5%), starting from the 2016-2017 average.
 - Scenario 2 (stabilisation) foresees a constant number of refugees based on the monthly average number of arrivals of 20,000³³⁵.
 - Scenario 3 (decrease) foresees a linear decrease of the number of refugees, at the same reversed pace as the increase observed on the past 10 years (CAGR of - 2.5%), starting from the 2016-2017 average.

The figures used for the projection up to 2035 are based on scenario 2, meaning the impact of Copernicus could be scaled (up and down) to scenario 1 and 3 depending on the actual evolution of the situation.

- The ratio of casualties over attempts to cross the Mediterranean sea remains constant, equal to 1.1%.
- The statistical value of life (economic impact of an avoided fatality) is assumed to be constant, equal to EUR 2.26 million.

Results

Under the assumptions described above, the benefits of Copernicus to the reduction of casualties in S&R missions for refugees is the following.

335 UNHCR operational portal, <http://data2.unhcr.org/en/situations/mediterranean>

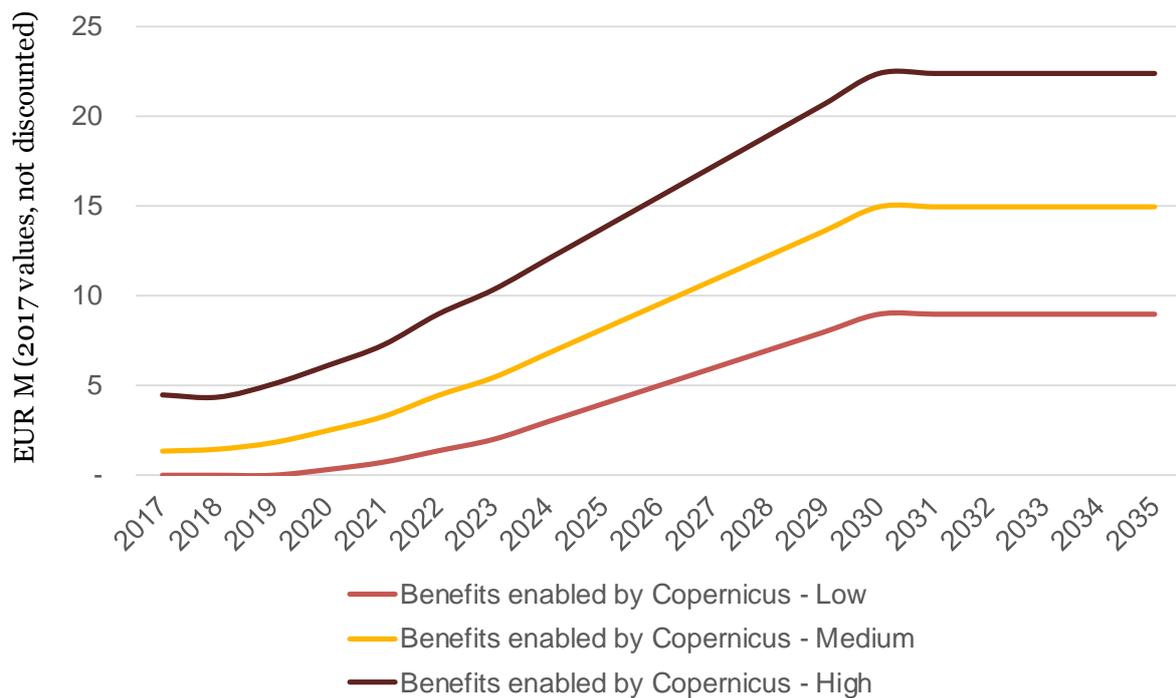


Figure 116 - Evolution of Copernicus benefits (EUR M) for the impact “Reduction of casualties in maritime disasters – refugees boats” between 2017 and 2035 for Europe (Source: PwC analysis)

To provide a comparison of the scenario of refugees crisis, the high value of Copernicus benefits in 2035 following scenario 1 (growth of the crisis) would be EUR 29 million. Following scenario 3, it would represent EUR 7 million.

Differentiation factor of EO and Copernicus D&I

Today the contribution of EO data to the location of vessels and to the support to S&R operations is estimated to be low to medium³³⁶. Different means exist to locate the vessels and to have a maritime picture of the situation, especially near the coasts where satellites play a marginal role. Yet, 80% of the accidents happen within territorial seas³³⁷ (extending at most 12 nautical miles from the coast) or internal waters. For the large majority of incidents occurring close to coasts, regular vessels are usually well equipped with communication means (beside AIS), and aerial means including drones are commonly used to monitor the areas. In the case of refugees embarkations, in more than half of the cases now MRCCs receive calls from satellite phones (as instructed by smugglers) to notify the situation and in addition the different authorities and ONGs in the Mediterranean sea conduct regular patrols near the Libyan coast or other areas of interest. In the remaining cases of incidents occurring in remote areas where radio links are not functional, regular vessels still can rely on satellite based links such LRIT and satellite-AIS. Satellite data comes to support the location and situation awareness but as a secondary mean, playing a limited role. The low interest for satellites in this type of mission is mainly linked to the low tasking time, as responsiveness after an event is critical, requiring detection within minutes to hours. Overall, the contribution of EO through these 3 outputs is assessed below 5%.

One channel through which satellite data contributes to the situational picture is the SafeSeaNet service provided by EMSA. This service contributes to increase maritime safety

³³⁶ Stakeholder consultation

³³⁷ EMSA, 2014, Annual overview of marine casualties and incidents

by sharing data among the users (national administrations, ports authorities, coastal stations, S&R teams, pollution response bodies etc.) on vessels locations and routes. SafeSeaNet works as a platform centralising various sources of information, providing vessels with a full picture of the situation, therefore avoiding any surprise leading to an incident.

Satellite data is involved marginally in the different roles presented above, and at the time of writing most of the data comes from other “traditional” sources and there is no particular dimension of the CMS oriented towards S&R missions. Though the CMS budget represents a consequent share of the overall EMSA budget for EO data procurement (a bit less than 50%), the products delivered aimed at safety purpose represented a fraction of the overall products delivered by the CMS in 2016 (14 products on 300, to serve feasibility tests)³³⁸. In addition, the S&R missions are achieved by national authorities (MRCCs) which can have their own procurement for satellite data. Yet the high responsiveness for tasking is a key criterion and direct contracts with commercial satellites are more valuable. Therefore, the share of products delivered by the CMS dedicated to safety (5%) can be seen as a higher boundary of the overall Copernicus contribution.

4.2.3.6.3.4 Summary of Copernicus contribution to Search & Rescue operations in Europe

The following graphs and table summarise the overall impact of Copernicus for the reduction of casualties in maritime incidents in Europe, under the assumptions described above (still using scenario 2 for the refugees crisis).

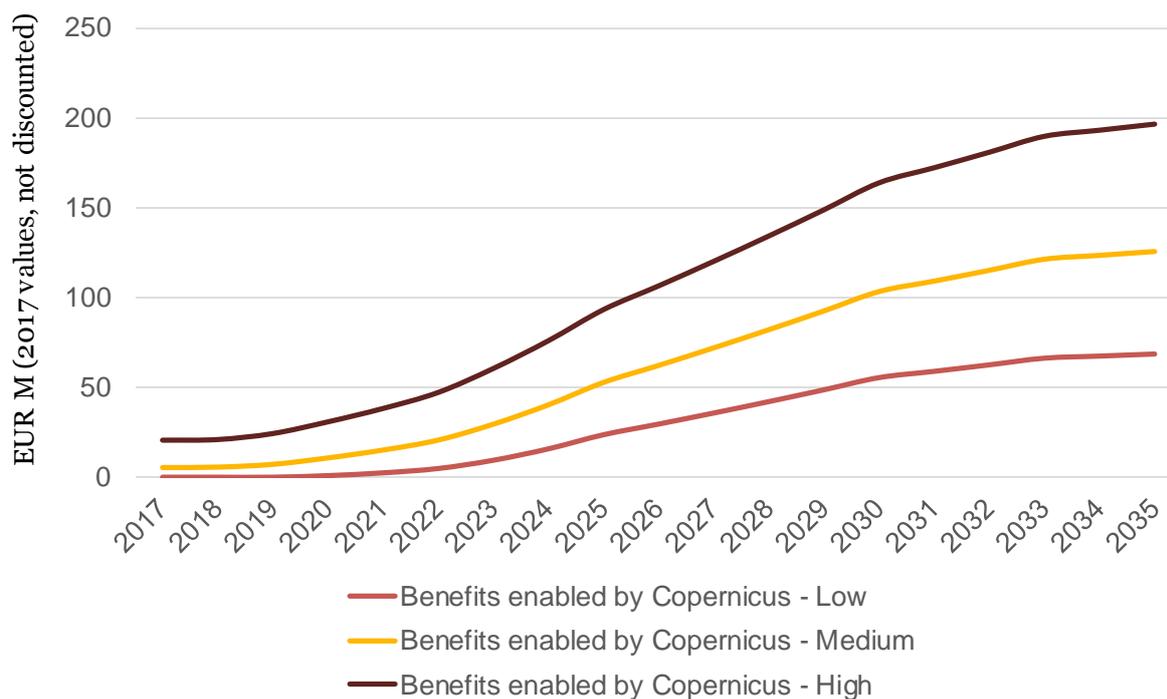


Figure 117 - Summary of Copernicus benefits (lives saved) for the impact driver “Maritime safety – Search & Rescue” between 2017 and 2035 for Europe (Source: PwC analysis)

338 EMSA, 2016, Maritime Surveillance Service – Annual implementation report

Copernicus benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	0	23.6	68.6	592.6
Medium estimate	5.4	52.8	125.8	1,195.1
High estimate	20.6	93.4	196.7	2,019.9

Table 32 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

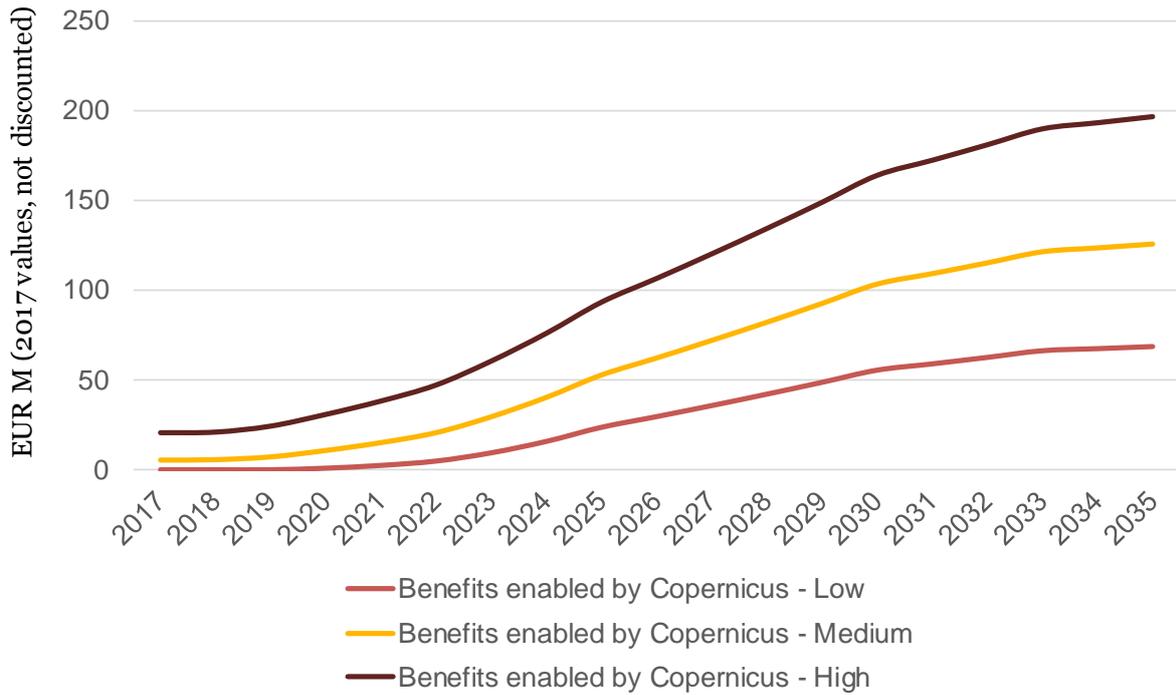


Figure 118 - Summary of Copernicus benefits (EUR M) for the impact driver “Maritime safety – Search & Rescue” between 2017 and 2035 for Europe (Source: PwC analysis)

4.2.3.6.4 Oil pollution monitoring

4.2.3.6.4.1 Context and role of EO

Among the core activities of the CMS service, the monitoring of marine pollution includes essentially the monitoring of oil pollution (which includes crude oil, related chemical products and other oils). The activities considered in this chapter include pollution from Oil & Gas (O&G) platforms (fixed structures) and from ships, typically oil tankers, which generate pollution either from accidents or from voluntary de-ballasting.

In the frame of CMS service, EMSA provides different types of pollution response services, which aim at completing the capacities owned by coastal MS. EMSA does not only provide support services such as spills detection and support to operations, but also operates spill response vessels which are on stand-by at all times (17 vessels including tankers, offshore supply vessels and dredgers). They are completed by the appropriate land-based equipment depending on the amount of dangerous cargo being transported, ship traffic density, as well as the coastal state's existing pollution response capacity. In addition, EMSA also provides support in the form of best practices dissemination and information exchange between MS, regional agreements and international maritime organisations. For instance, they can offer specialist information in the cases of chemical spills of hazardous and noxious substances. The CMS service contributes to pollution monitoring through 3 main outputs:

- Pollution detection

Pollution detection is the first step of the process of monitoring oil pollution. The detection service provided by EMSA existed prior to Copernicus through the CleanSeaNet pan-European component (operational since 2007). This satellite-based oil spill surveillance and vessel detection analyses, on a routine basis, MR SAR images to detect oil spills on the surface and correlates the findings to vessel traffic pictures to identify the potential sources of spills. The results are made available to the end users in NRT and they support the use of traditional aerial surveillance means. It should be noted that this component, although being provided by EMSA, existed prior to the Copernicus programme and is not part of the scope of the CMS service. However, as it relies extensively on Sentinel data, its impact is considered as part of the scope of the Copernicus programme.

- Specific tasking for operational support

The purpose of specific tasking is similar to pollution detection, except that it targets specific events. The aim to support operations such as aerial surveillance operations or refuelling at sea. Hence, this output requires a lower tasking time to address the area of interest quickly, or at least an acceptable revisit time to preserve the added value of EO. This output also relies on radar images, with HR completing MR.

- Support to pollution response

In the cases of very large spills or continuous releases, a monitoring of the spill is required to organise the response, and support the clean-up operations. This support includes for instance the mapping of oil extent, the rapid detection of the spill, tracing back to the polluters or information and coordination of the pollution response assets. In this phase, MR radar images are completed with HR radar and HR / VHR optical images.

As the support to oil pollution response also concurs to identifying the polluters, it contributes to triggering remediation payments (from the responsible O&G companies). However, the fines are sizeable in the cases of very large spills and disasters. The frequency of these events have significantly dropped over the past decades, and it is now too unrealistic to foresee such future catastrophe. Therefore, this impact is not quantified.

These 3 activities, supported through the CMS service, lead to the following pathways.

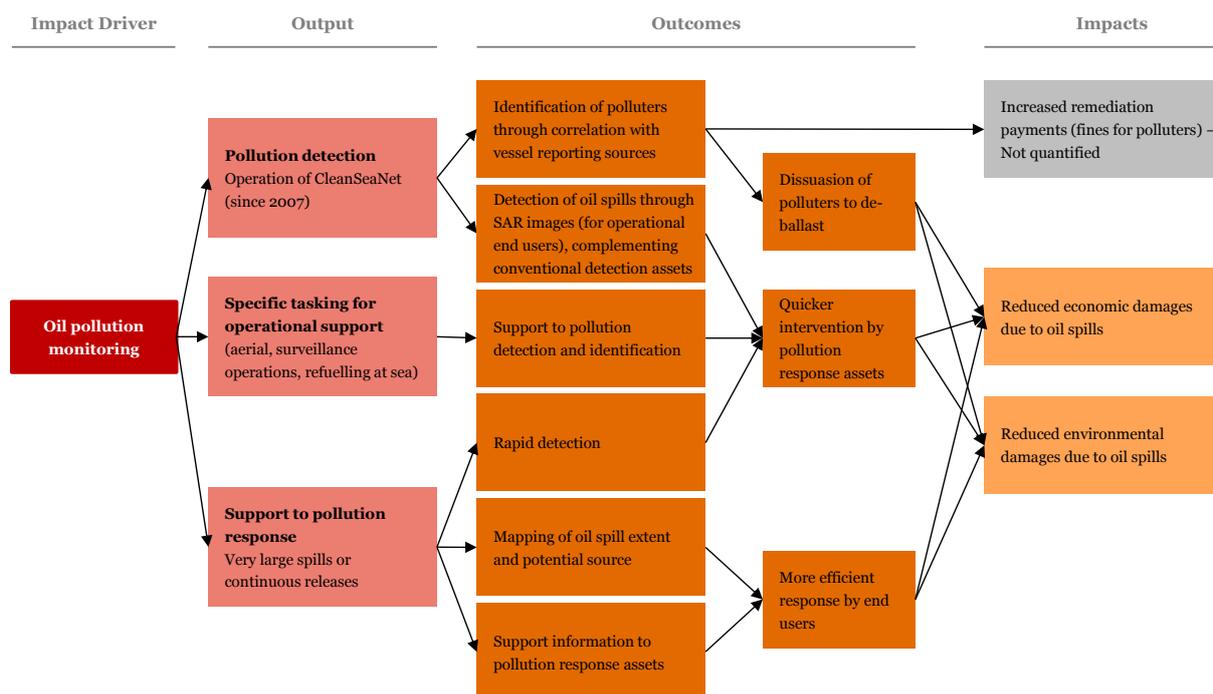


Figure 119 - Impact pathways for the impact driver “Marine pollution monitoring” (Source: PwC analysis)

Expected uptake of EO and Copernicus (baseline)

The improvement of satellite capabilities (higher number of satellites available, lower revisiting time, lower tasking time, higher resolution etc.) is expected to have a limited impact on the uptake of satellite data in general. In the case of routine monitoring for oil pollution, no particular increase is foreseen as the current capabilities are well adapted to the task. Some improvement is expected however for the operational support, mainly linked to the reduction of the tasking time. The contribution of EO is expected to grow from “medium” to “high” according to the stakeholders consulted, reaching between 10% and 15% in 10 years.

The contribution of Copernicus also depends on the application. For routine monitoring in the frame of CleanSeaNet, the suitability of Sentinel 1 satellites should keep increasing the share of Copernicus, from 80% currently up to 100% after one decade. The contribution of Copernicus to on-demand oil monitoring missions should not increase further, as the improvement of tasking performance should rather come from direct contract with commercial providers. Hence this contribution remains around 10% in the baseline modelling.

4.2.3.6.4.2 Reduced economic damages due to oil spills



Methodological approach to value the reduced economic damages due to oil spills

The oil spills in Europe from both ships (de-ballasting, accidents) and O&G platforms are associated to the average cost for each ton of oil for the local economy. The monitoring of oil spills (detection and response) by EO and Copernicus contributes to mitigating these damages.

Reduced economic damages due to oil spills Valuation approach



Description of the impact

Following an oil spill, the consequences include several types of damages on the near-by areas, with economic consequences on commercial activities. Among the activities most directly impacted, fisheries can lose a part of their production in addition to a negative impact on their image leading to a reduced selling price. The tourism sector suffers from the reduced volume of tourists on the coast, and the maritime transport undergoes financial consequences as the routes may be disturbed, imposing longer paths and delays. In addition, the clean-up operations and compensations linked to oil slicks imply substantial expenses by public authorities. The economic damages also include the value of the oil lost that cannot be exploited by O&G companies.

Based on the costs witnessed through past disasters, the economic damages are scaled to the size of the oil spills, leading to an estimate of the costs generated by the overall oil spills in Europe.

Data for impact valuation

Over the past 50 years, the amount of oil spills in the worldwide oceans and seas has drastically decreased, from over 3 million tons in the 1970s down to less than 200,000 tons in the 2000s and less than 40,000 tons since 2010³³⁹. A noticeable trend over this period is also the constant and consequent decrease of very large single oil spills in the total, from 53% in the 1970s down to 3% in the 2010s. Today the amount of oil spilled from vessels in the world varies greatly from one year to another, from 1,000 ton in 2012 up to 7,000 tons in 2015 for instance. Based on the average on 2010-2016, the oil spills per year can be estimated at 5,600 tons. When considering the main oil spills disasters since 1967, 60% occurred in Europe or in seas close to European coasts (such as Turkey or Morocco). This leads to estimates of oil spills from ships in Europe of 4,200 tons in 2015 and 3,600 tons in 2016.

In addition to leaks from ships, the large spills (> 1 m³) from O&G platforms in Europe represent close to 2,000 tons of oil and chemical products, most than half coming from Norwegian installations³⁴⁰.

The quantification of economic damages for each ton of oil spill is based on the costs assessed for the Prestige oil spill, which sank offshore of Galicia in Spain. During this

339 ITOPF, 2016, Oil tanker spill statistics

340 Petroleum Safety Authority Norway, 2015, RNNP-AU Acute spills report ; US Energy Information Administration, <https://www.eia.gov>

disaster, the tanker leaked about 60,000 tons of heavy oil. A study on the extent of the socio-economic consequences of this event shows that the total economic damages represented about EUR 2.5 billion for France and Spain³⁴¹, split across fisheries (22%), tourism (38%), maritime transport (1%) and costs for public administrations (39%). To these economic damages, the cost of oil lost in the disaster is added, based on the average price of the barrel of crude oil (155 litres) over the past decade, leading to EUR 510 per ton. This represents a total cost of about EUR 45,000 per ton of leaked oil as economic damages.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on economic damages due to oil spills relies on the following assumptions.

- The amount of oil spills from ships will keep decreasing at the same pace as on the past 50 years, to reach between 500 and 600 tons per year.
- The amount of oil and chemicals leaks from O&G platforms remains constant, following the situation over the past 15 years.
- The value of economic damages per ton of oil spilled is constant, equal to the current value of EUR 45,000 per ton.

Results

Under the assumptions described above, the contribution of Copernicus to the reduction of economic damages due to oil spills is the following.

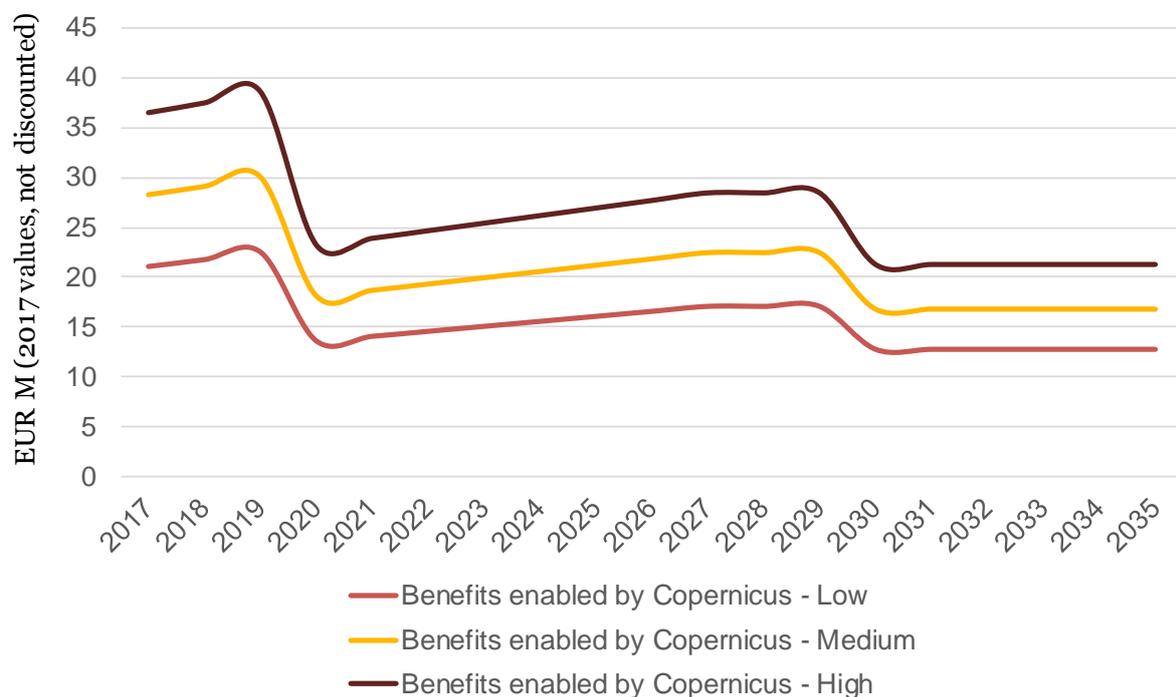


Figure 120 - Evolution of Copernicus benefits (EUR M) for the impact “Reduced economic damages due to oil spills” from 2017 to 2035 for Europe (Source: PwC analysis)

341 Maria L. Loureiro, 2009, Socioeconomic and environmental impacts of the Prestige oil spill in Spain



Methodological approach to value the reduced environmental damages due to oil spills

The oil spills in Europe from both ships (de-ballasting, accidents) and O&G platforms are associated to the average cost for each ton of oil on the environment. The monitoring of oil spills (detection and response) by EO and Copernicus contributes to mitigating these damages.

Reduced environmental damages due to oil spills Valuation approach

$$\text{Impact (EUR)} = \text{Contribution of Copernicus to oil pollution monitoring} \times \text{Environmental damage per ton of oil spill at sea} \times (\text{Oil spills from ships} + \text{Oil spills from platforms})$$

Description of the impact

Following an oil spill, the consequences include several types of damages on the near-by areas, with environmental consequences, mostly on the ecosystem of the polluted area.

The valuation of such impact is not straightforward, and is achieved by the Contingent Valuation method (used for the Prestige disaster as well as for the Exxon Valdez disaster). Based the costs witnessed through these past disasters, the environmental damages are scaled to the size of the oil spills, leading to an estimate of the costs generated by the overall oil spills in Europe.

Data for impact valuation

The quantification approach is the same as for the economic impact of oil spills (cf. previous impact), leading to estimates of oil spills from ships in Europe of 4,200 tons in 2015 and 3,600 tons in 2016 and close to 2,000 tons of oil and chemical products from O&G platforms³⁴².

The quantification of environmental damages for each ton of oil spill is based on the costs assessed for the Prestige oil spill, which sank offshore of Galicia in Spain. The study on the extent of the socio-economic consequences of this event shows that the total environmental damages represented about EUR 1.2 billion³⁴³. When scaled to the size of the oil spill (about 60,000 tons of heavy oil), this leads to an average cost about EUR 21,200 per ton. Another study on the consequences of the oil spill of Erika in 1999³⁴⁴ estimates the total environmental prejudice around EUR 371 million. When scaling it to the size of the spill, about 18,000 tons, this leads to an average cost of about EUR 21,200 as well.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on environmental damages due to oil spills relies on the following assumptions.

342 ITOPF, 2016, Oil tanker spill statistics ; Petroleum Safety Authority Norway, 2015, RNNP-AU Acute spills report ; US Energy Information Administration, <https://www.eia.gov>

343 Maria L. Loureiro, 2009, Socioeconomic and environmental impacts of the Prestige oil spill in Spain

344 François Bonnieux, INRA, 2006, Evaluation économique du préjudice écologique causé par l'Erika

- The amount of oil spills from ships will keep decreasing at the same pace as on the past 50 years, to reach between 500 and 600 tons per year.
- The amount of oil and chemicals leaks from O&G platforms remains constant, following the situation over the past 15 years.
- The value of economic damages per ton of oil spilled is constant, equal to the current value of EUR 21,200 per ton.

Results

Under the assumptions described above, the contribution of Copernicus to the reduction of environmental damages due to oil spills is the following.

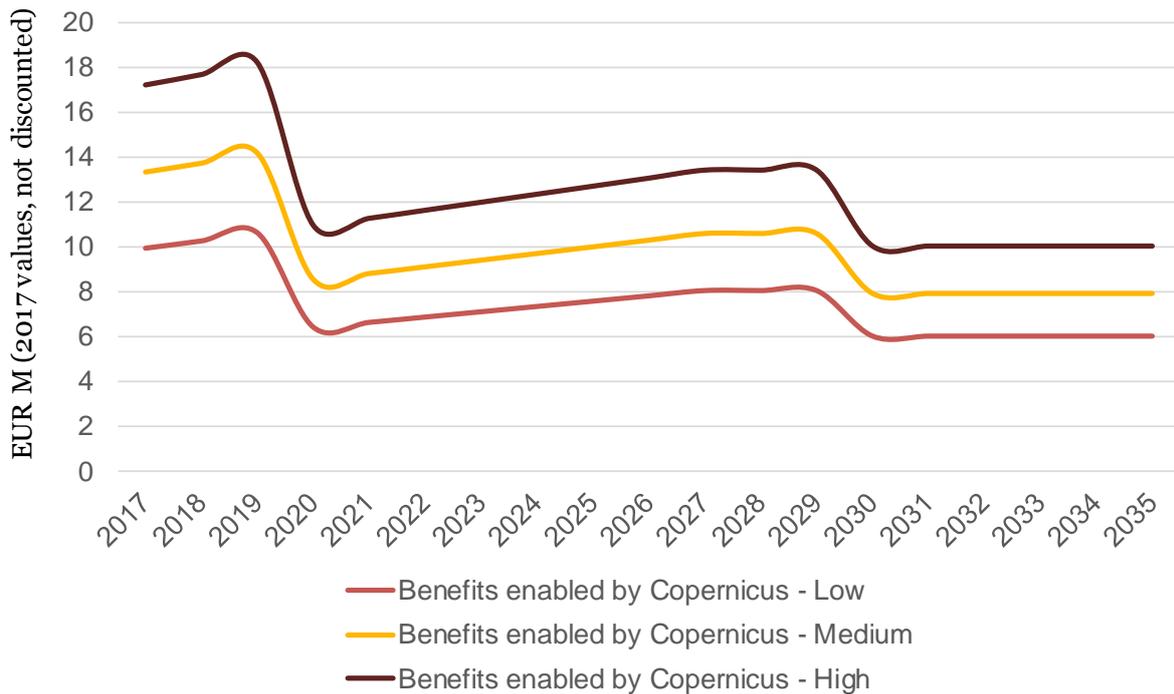


Figure 121 - Evolution of Copernicus benefits (EUR M) for the impact “Reduced environmental damages due to oil spills” from 2017 to 2035 for Europe (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

The contribution of EO to oil pollution monitoring is more pronounced on routine detection operations such as provided by CleanSeaNet. The routine dimension enables to acquire on a regular basis the satellite data without issues related to responsiveness and tasking capacity. Hence the impact of EO on pollution detection is evaluated as “high” already³⁴⁵, and is expected to remain so in the future. An increased revisit time would of course benefit the service but with limited added value. In quantified terms, the contribution of EO for the detection of oil spills is evaluated between 15% and 20%.

The contribution of EO is less important for on-demand needs such as response support and specific tasking, and is assessed as “medium”. For support to pollution response, for instance for continuous spills from O&G platforms, there is no particular improvement expected in the coming years. Regarding tasking for operational support, the specific requirements of operations related could benefit from an increased revisit time (through higher number of

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radar satellites available for instance) and a reduction of the tasking time. The contribution of EO to operational support and response support is estimated around 5%. Similarly to some previous drivers discussed, EO offers a clear advantage over other traditional assets (aerial and radio) when the theatre is located far from the coast. The advantage is less obvious when several concomitant means can answer users' needs, where the responsiveness of the satellites is often a drawback.

Copernicus contributes extensively to the oil detection routine operations, as Sentinel 1 data is the first source of data for CleanSeaNet, representing about 80% of the data³⁴⁶. CleanSeaNet constitutes all the pollution monitoring products provided at EMSA level as according to the annual implementation report of the CMS service, there was no product delivered for pollution monitoring in the frame of the CMS in 2016³⁴⁷. By assuming the vast majority of the oil detection based on EO is provided to users through CleanSeaNet (80% is a conservative assumption as there is no apparent reason not to resort to this service in the case of routine operations), this leads to a current share of Copernicus within EO data between 60% and 70% for oil detection.

Regarding the contribution of Copernicus for on-demand tasks, the high revisit time and low tasking time leads to a lower adoption. As no product is delivered through the CMS service, the only contribution of Copernicus materialises through the use of CleanSeaNet in the cases where the coverage and characteristics match the operational needs. There is not sufficient data to provide an estimate of the actual share of Copernicus, so an assumption is taken around 10%. It can be noted that a potential error in this estimate remains mitigated by the fact that oil pollution response and operational support are already moderately impacted by EO (around 5%).

4.2.3.6.4.4 Summary of Copernicus contribution to the driver “Oil pollution monitoring”

The following table and graph summarise the overall impact of Copernicus on oil pollution monitoring, under the assumptions described above.

<i>Copernicus benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	31.0	23.7	18.8	439.9
Medium estimate	41.6	31.2	24.7	582.0
High estimate	53.7	39.7	31.3	741.5

Table 33 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

³⁴⁶ Stakeholder consultation

³⁴⁷ EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

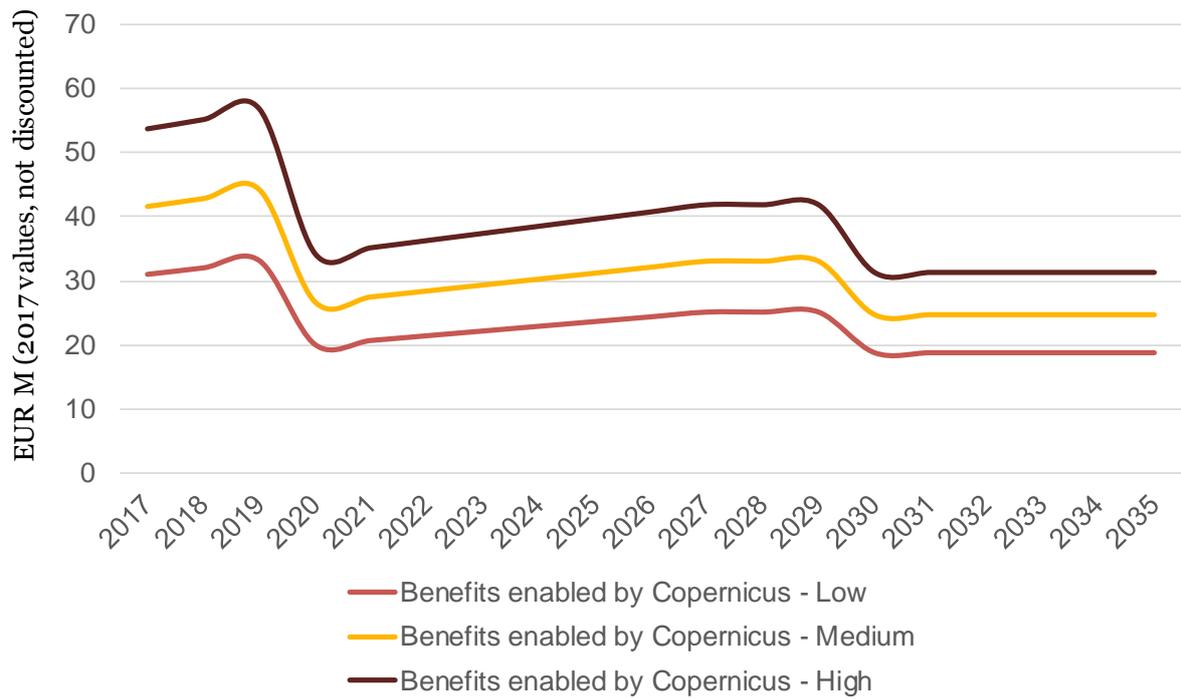


Figure 122 - Summary of Copernicus benefits (EUR M) for the impact driver “Oil pollution monitoring” from 2017 to 2035 for Europe (Source: PwC analysis)

4.2.3.6.5 Law enforcement and international crime

4.2.3.6.5.1 Context and role of EO

The role of the Security service is directly related to law enforcement, support to customs and fight against cross-border crime. These activities include both the repression of goods trafficking (counterfeit goods, drugs, weapons, stolen vehicles) and the fight against trafficking in Human Being (THB), a growing concern in Europe as the number of victims increases.

European borders, both at sea and on land, are a control limit where illegal goods and THB victims are smuggled into the EU. Traditional controls by customs are not sufficient alone, and they completed by surveillance means to enable anticipating these illegal activities and increase the efficiency of interceptions.

- At sea: detection and tracking of suspicious vessels

Law enforcement at sea relies on the detection and tracking of suspicious vessels, in particular of small non-reporting vessels on which there is no information available through AIS and VMS. These small vessels are commonly targeted by law enforcement authorities. Law enforcement at sea includes the detection of suspicious activities, such as abnormal behaviour of boats. These behaviours are spotted as soon as they suggest attempts to smuggle illegal goods (counterfeited, drugs etc.) or illegal migrants, with the risks of trafficking human beings. HR radar images are combined with HR and VHR optical data to identify the boats.

The use of EO for maritime surveillance can also lead to the identification of illegal oil exploration or surveying activities. Detecting these activities leads in some way to a better anticipation of the tensions it can generate with involved states, helping to address the problem as soon as possible, reducing the potential conflicts escalation. However this impact is not addressed here as, besides being challenging to be quantified, it mostly involves regions of the globe out of Europe.

- At land: monitoring of cross border crimes and unauthorised border crossings

The activity near land borders can also be monitored to increase the effectiveness of authorities against cross-border crimes. Suspicious activity can be detected and anticipated, by providing situational awareness, such as the 4,600 situational reports delivered by Frontex in 2016. Several operations are conducted by Frontex to enhance the situational awareness, both at sea (for the Italian forces in the Central Mediterranean area for instance via the Eurosur Fusion Services) and at land, for instance to support the Greek and other European partners in the ER Regional Task Forces (EURTF) in Piraeus. Pre-frontier monitoring in particular supports field interventions for higher efficiency, by foreseeing movements suggesting risks of persons smuggling. Satellite images are useful for this task requiring regular vision of remote areas and on large scales.

Either through sea or land borders, satellite images contribute to higher efficiency against cross-border crime, leading to the interception of more amounts of illegal goods one hand, and to the interception of a higher number of smuggled migrants on the other hand, who have high chances to be victims of THB.

These activities are summarised in the following impact pathways, and the quantification of the 2 resulting impacts is detailed in the following sections.

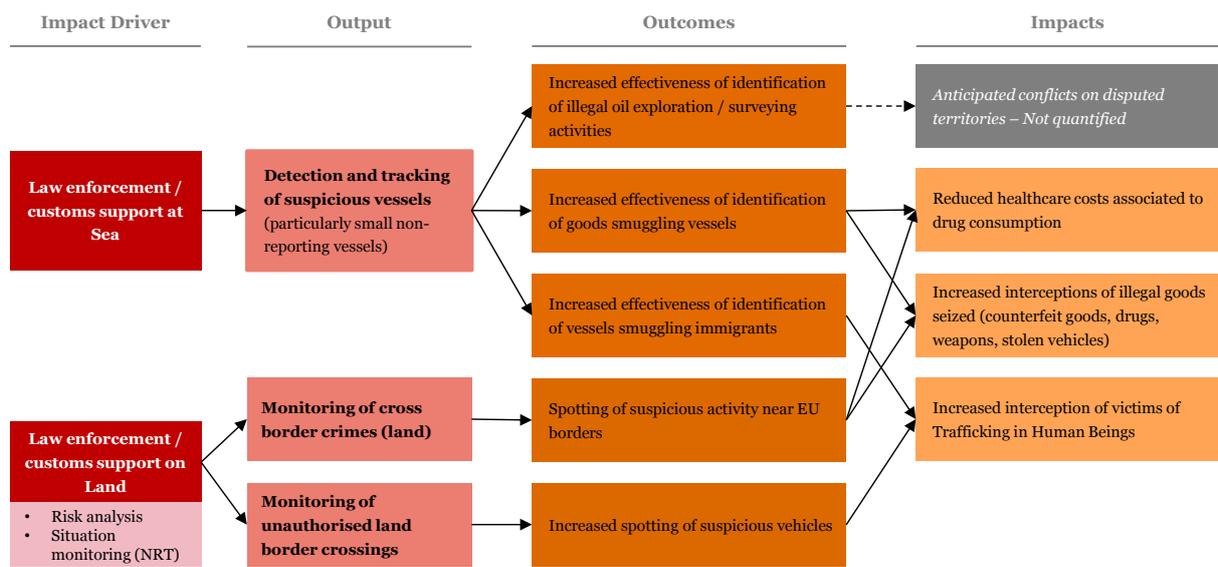


Figure 123 - Impact pathways for the impact driver “law enforcement and fight of international crime” (Source: PwC analysis)

Examples of use cases

In 2016, Frontex has been providing tailored services fused and delivered via the Eurosur Fusion Services (EFS). In this frame, Frontex handled more than 90 requests from Member States including Italy, Greece, Spain, France, Germany, Slovakia, and Malta and other partners³⁴⁸. The requests covered the Central and Eastern Mediterranean region. These requests included vessel detection services (over specific sea areas) and pre-frontier monitoring.

EMSA was also involved in requests from different MS. the branch of the Spanish Navy dedicated to cooperation with the civilian administration on maritime safety and security issues (‘Maritime Action Force’) contacted EMSA to request CMS services for law enforcement and maritime safety purposes³⁴⁹. The Spanish Navy was supported by EMSA to fill the user requirements questionnaire and is now preparing to receive initial services in 2017.

By the end of 2016, the creation of necessary account was initiated for the Icelandic Coastguard, which requested to have access to CMS service to support multi-purpose maritime surveillance operations in their coastal waters up to 50 nautical miles from the coast, for law enforcement and maritime safety purposes.

Expected uptake of EO and Copernicus (baseline)

A strong increase in the uptake of satellite images is foreseen for the detection and tracking of vessels and the detection of suspicious activities at sea, with a contribution estimated to be “very high” in the future³⁵⁰. To reflect this trend the contribution of EO increases to 20% (for sea activities) by 2035. The main reasons leading to this improvement should be the enhancement of the revisiting time for radar constellations with the increasing number of satellite available, boosting the ability to detect small vessels. Optical images would also benefit from lower revisiting time for the identification of vessels of interest. Although there

348 Frontex, 2017, Annual activity report 2016

349 EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

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was no similar evaluation of EO future contribution to fighting cross border crime activities on land, the lower suitability of satellite data for this use case (reflected in the current lower contribution) leads to a conservative approach of a much lower uptake of EO in the coming years. For land activities, the current model assumes a progressive growth of EO uptake up to 10% (highest value) in 2035.

In the baseline option the evolution of Copernicus contribution is foreseen constant equal to the values reached by 2019 (cf. above: up to 25% for sea activities and up to 100% for land activities). This assumes the satellite products provided by Frontex will keep being procured through Copernicus Security service (from EMSA and SatCen or other entities). This assumption is conservative as the quality and suitability of Copernicus products should keep increasing in the coming years, leading to even less EO data procured by MS on top of it, hence pushing Copernicus contribution. However, there is no sufficient information at this stage to quantify this increase.

4.2.3.6.5.2 Increased interceptions of illegal goods



Methodological approach to value the increased interception of illegal goods

The benefit of Copernicus is computed as its contribution to the seizures of different types of illegal goods at EU external borders: counterfeit goods (mainly cigarettes but includes all imported goods non-compliant with intellectual property rights), drugs (cannabis herb and resin, cocaine, heroin, and others) and stolen vehicles transiting through EU borders (usually out of EU).

The interception of illegal weapons is theoretically included in this contribution, but this type of seizure remains rare, as most of the illegal weapons circulating in the EU come from inside the EU.

Increased interceptions of illegal goods *Valuation approach*



Description of the impact

The amount of illegal goods intercepted at the border is an indicator of the law enforcement activities of MS. Illegal goods include:

- Counterfeit goods, that is to say the goods violating the rules on Intellectual Property Right. Today the most common good entering the EU in this situation are cigarettes (about 1/4 of the articles), followed by toys, labels ad stickers, food and body care items³⁵¹. The majority of counterfeit goods entering the EU come from China (41% of the articles, 58% of the value).

³⁵¹ European Commission, 2015, Report on EU customs enforcement of intellectual property rights, Results at the EU border 2015

- **Drugs:** cannabis (herbal and resin) is the most widespread drug in the EU in terms of users and intercepted volume³⁵², followed by cocaine and crack, amphetamines and heroin. The drugs are mostly transiting by sea (cannabis from North Africa), but a clear trend has seen an increasing amount of drugs is smuggled through Turkey in the past years. The impact of drugs is wider than law enforcement as it is now recognised as a contributor to the global burden of disease.
- **Stolen vehicles:** this type of activity has a lower extent, and has been decreasing steadily over the past decades, thanks to reinforced vehicles security systems. Stolen vehicles crossing the EU border are usually smuggled through eastern borders, towards Turkey and Byelorussia / Ukraine. However, a small share of the overall stolen vehicles in the EU are detected at external borders.

The impact from illegal weapons seizures remains very limited at EU borders. The majority of the weapons circulating in the EU come from former conflict zones such as the Western Balkans, and today very few weapons are intercepted at external borders, with hardly quantifiable impact from Copernicus (154 weapons reported by Frontex in 2016).

Consequently to less drugs being consumed in the EU, less addictions and acute health issues have to be treated by public healthcare structures in the MS. The effect on healthcare systems is not immediate however, as many health issues are triggered by recurrent consumption or long term exposure. The current approach assumes 5 years between the seizure of drugs at the borders and the materialisation of the effect on health systems.

Data for impact valuation

Since 2010, the value of counterfeit goods seized in the EU has decreased from over EUR 1.1 billion to stabilise between EUR 600 million and EUR 700 million per year since 2014³⁵³. Out of these illegal goods, 85% are intercepted at import, while the rest is detected in other phases (transit, warehouses control, export).

The total amount of drugs seized through the sea and land operations are assessed around at 215 tons in 2015 and 128 tons in 2016, representing EUR 3.46 billion in 2015 and EUR 1.83 billion in 2016³⁵⁴. Though cocaine represents a minor weight of the total (8% of the total weight), it represents a preponderant share of the total value, with about 34%. Hashish is much more common (more than 50% of the weight with about 93 tons per year) but represents about 33% of the total value, followed by herbal cannabis (about 61 tons representing about 23% of the overall value). The remaining 10% are distributed among the remaining substances (amphetamines, methamphetamines, MDMA and other opioids and psychoactive substances).

The number of stolen vehicles detected at EU external borders decreased from 519 in 2013 to 430 in 2014, down to 350 in 2015³⁵⁵. Taking an average value of EUR 6,400 per vehicle³⁵⁶, this leads to total of EUR 2.2 million in 2016.

The costs of treatments related to drugs is correlated to the level of consumption of drugs. According the EMCDDA, about 1.2 million people were treated in 2014 for drug issues³⁵⁷. In another report, the agency estimates the retail value of the drug market in the EU for the different drugs (EUR 9.3 B for cannabis products, EUR 6.8 B for heroin, EUR 5.7 B for

³⁵² EMCDDA, 2016, European Drug Report, Trends and Developments

³⁵³ European Commission, 2015, Report on EU customs enforcement of intellectual property rights, Results at the EU border 2015

³⁵⁴ EMCDDA, 2016, European Drug Report, Trends and Developments ; MAOC(N), Statistics, <http://maoc.eu/statistics/> ; Frontex, 2017, Annual activity report

³⁵⁵ Frontex, Annual Risk Analysis, 2015 & 2016

³⁵⁶ FBI, 2015, <https://ucr.fbi.gov/crime-in-the-u.s/2015/crime-in-the-u.s.-2015/offenses-known-to-law-enforcement/motor-vehicle-theft>

³⁵⁷ EMCDDA, Cost and financing of drug treatment services in Europe : an exploratory study

cocaine)³⁵⁸, enabling to estimate that between 1,400 and 1,500 tons of drugs are consumed in the EU each year. This leads to an estimate that the drugs seizures at EU borders enable to avoid about 180,000 treatments in the EU. The costs of treatments vary from one case to another due to the types of treatment required and the type of drug involved, but are estimated to range between EUR 500 and EUR 4,900 per person and per year³⁵⁹. An average of EUR 2,700 is used for the current model.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on the interception of illegal goods relies on the following assumptions.

- The volume of counterfeit goods intercepted at EU borders will continue to decrease following the trend observed since 2010, at an annual rate of - 4.3%.
- The evaluation of drugs seizures for 2017 relies, for each drug category, on:
 - The average amount of total drugs seized in the EU since 2009
 - The ratio of drugs seized at external borders for these drugs, based on the average since 2008
- The projection of the amount of drug seized evolves as the following
 - Herbal cannabis: increases from 2017 value, following the same trend observed since 2009 (from 66 tons in 2017 up to 90 tons in 2035);
 - Other drugs: constant, equal to 2017 value;
- The number of stolen vehicles intercepted at external border is constant, at 350 per year, with a constant average value for each stolen vehicle, at EUR 6,400.
- The reduced costs for healthcare systems follow the same growth as the seizures of drugs at EU borders.

Results

Under the assumptions described above, the benefits of Copernicus to the interception of illegal goods at EU borders is the following.

³⁵⁸ EMCDDA, 2016, European Drug Report, Trends and Developments

³⁵⁹ EMCDDA, Cost and financing of drug treatment services in Europe : an exploratory study

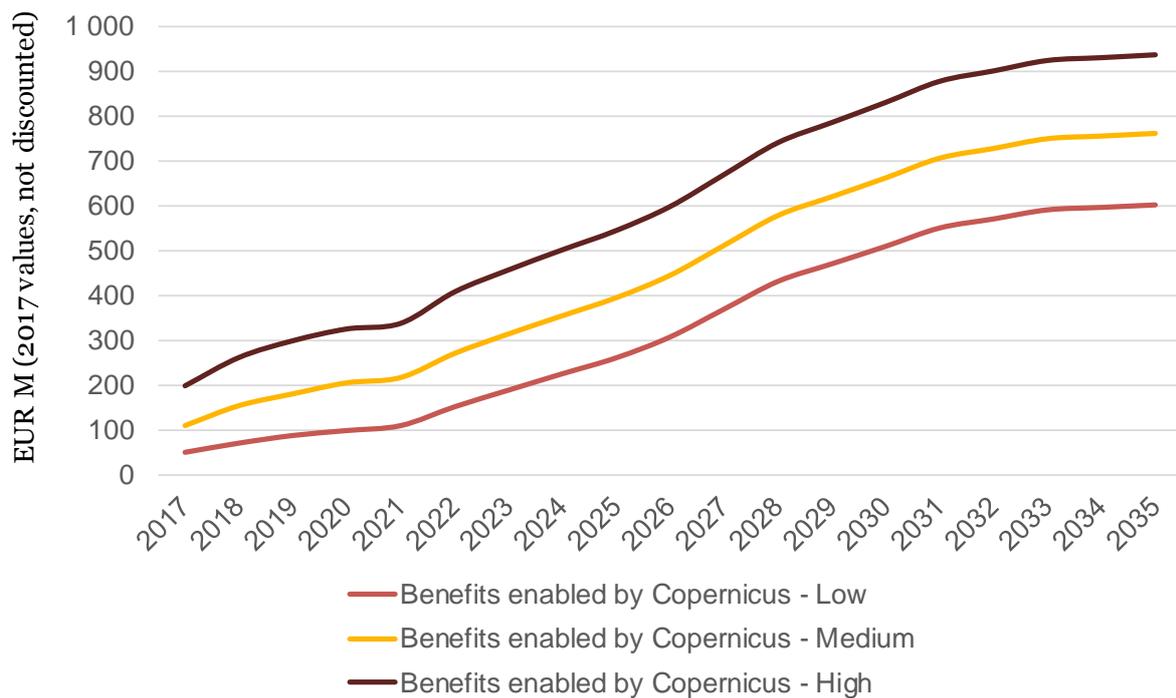


Figure 124 - Evolution of the Copernicus benefits (EUR M) for the impact “interception of illegal goods” from 2017 to 2035 for Europe (Source: PwC analysis)

4.2.3.6.5.3 Increased interceptions of victims of Trafficking in Human Beings



Methodological approach to value the increased interception of victims of THB

The valuation approach relies on the fact that victims of THB creates value on the clandestine network by enabling traffickers to make revenues out of illegal activities. Each victim intercepted is withdrawn from the clandestine network and contributes to decreasing the value associated with illegal activities. This reduced value of the illicit market is then weighted by the contribution of Copernicus to interception operations.

Increased interceptions of victims of THB Valuation approach



Description of the impact

Over the past decades, human mobility around the world have continuously developed, as illustrated by the increase in the number of international migrants, of +40% since 2000³⁶⁰ to reach 244 million in 2016. Although most of the migrants are not victims of trafficking of course, there is a correlation between the flows of migration and the amount of people victim of THB. The first category of exploitation for victims of THB is sexual exploitation, as it is the case for nearly 75% of women which represent about 70% of the victims (7% of men are also victim of sexual exploitation). The second main category of exploitation is forced labour, for 86% of men and 20% of women. The remaining categories include organ removal, child soldiers, forced marriage, forced begging or selling of children.

The illicit activities performed by the victims of traffickers generate revenues, mainly for sexual exploitation and forced labour. By extracting the victims out of the networks, authorities prevent traffickers from accessing these revenues.

Data for impact valuation

Out of the 63,000 victims identified over 2012 – 2014 by the United Nations Office on Drugs and Crime (UNODC), about 4,000 were identified in the EU³⁶¹. Out of these victims, investigations show that about 35% come from non-EU countries, representing around 1,400 persons potentially identifiable at EU external borders when entering the EU (every year).

Frontex estimates that people crossing the EU border at BCPs only represent a fraction of the overall border crossings (most of people crossing between BCPs). Over 2009 – 2016, assuming the victims of THB intercepted fall in the categories “refusal of entry”, “person using fraudulent documents” and “illegal border crossing at BCPs”, we can estimate that about 25% of them are actually intercepted by the authorities³⁶².

Past studies³⁶³ estimated the size of illicit markets linked to sexual exploitation and forced labour in the world. When scaling these revenues to the estimated number of victims, it can be estimated that each person exploited generates between EUR 15,000 and EUR 20,000 per year for the traffickers.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on the interception of victims of THB relies on the following assumptions.

- The number of victims of THB will keep increasing at the same pace as the global growth of migration over the past 15 years: about 2.5% per year.
- The ratio of victims intercepted at EU borders over the total number of victims reaching EU will remain constant, equal to 25%.
- The average revenues generated by each THB victim for the trafficker will remain constant, equal to EUR 18,000.

Results

Under the assumptions described above, the benefits of Copernicus to the interception of victims of THB at EU borders is the following.

360 UNODC, 2016, Global report on trafficking in persons 2016

361 UNODC, 2016, Global report on trafficking in persons 2016

362 Frontex, Annual Risk analysis, 2015 and 2017

363 UNODC, 2010, Report on trafficking in persons to Europe for sexual exploitation ; International Labour Organisation (ILO), 2005, A global alliance against forced labour

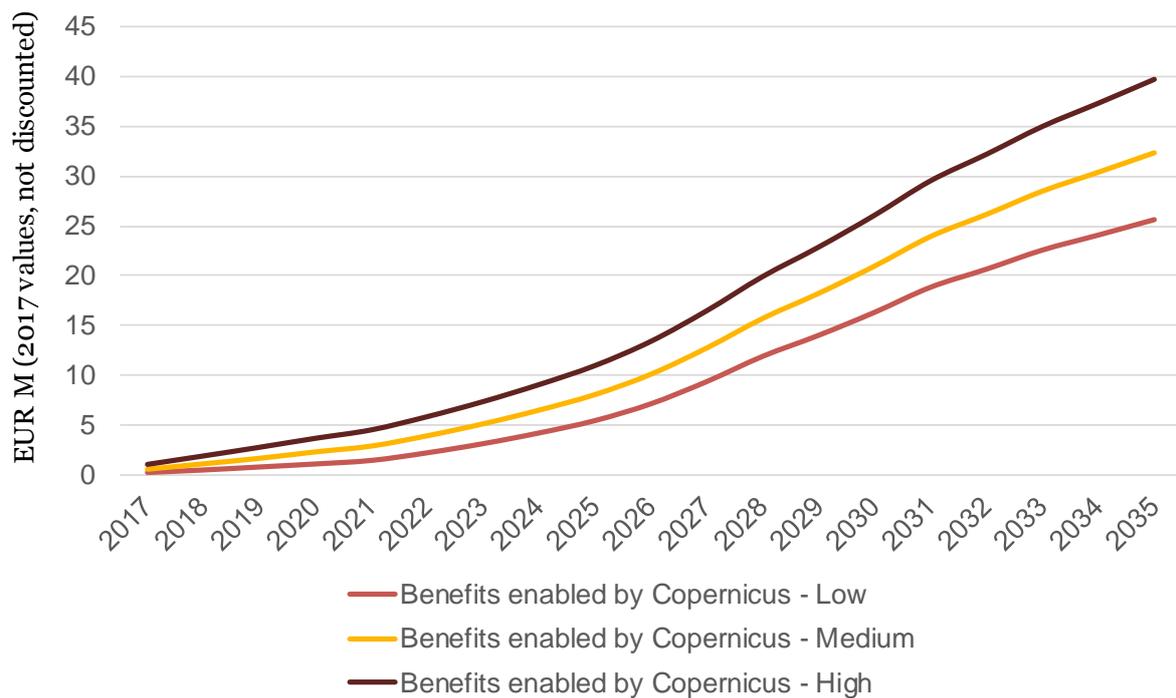


Figure 125 - Evolution of the Copernicus benefits (EUR M) for the impact “interception of victims of THB” from 2017 to 2035 for Europe (Source: PwC analysis)

Differentiation factor of EO and Copernicus D&I

For law enforcement at sea, the contribution of EO is estimated at “medium” currently³⁶⁴. The use of EO is rather helpful as the areas of interest are identified by previous intelligence services, easing the focus of VHR images on targets. While areas close to coasts benefit from alternative means such as aircraft and drones, these identified areas may be remote locations where other assets cannot be used. The extent of EO impact remains limited because some law enforcement activities target high volumes and traffic, such as cargo shipments. Customs controls remain the first source of detection of illegal activity, and they take place in many cases based on information unrelated to behaviour at sea (provenance of the ship, destination after transit, procedure irregularity, random controls etc.). The high volumes involved in large shipments are considerably larger than the capacity of small non-reporting vessels, leading to contribution of EO between 3% and 7%.

As the European coast guard agency, Frontex is supporting law enforcement operations at sea. The geospatial services used by Frontex are procured through SLAs with EMSA and SatCen (for a total of EUR 6.6 million payments in 2016, of which EUR 4.7 million from the EMSA SLA and EUR 1.9 million from the SatCen SLA³⁶⁵), and are funded through the Copernicus Security service. With about 96 tons of drugs seized in 2016 in the frame of Frontex joint operations³⁶⁶, they contributed to about 75% of the total drugs seizures. MS operations might be supported by satellite data as well, however the specific needs of these operations on NRT and high resolution prevent the use of Copernicus data and dissemination chain. Therefore, Frontex share is assumed to be the only source of contribution of Copernicus, as other initiatives at EU level are marginal. For instance, in 2016, EMSA also delivered 5 products in the frame of the CMS service, for general law

³⁶⁴ Stakeholder consultation

³⁶⁵ Frontex, 2017, Annual activity report 2016

³⁶⁶ Frontex, 2017, Annual Risk Analysis 2017

enforcement purposes, to the Maritime Analysis and Operation Centre –Narcotics (MAOC(N))³⁶⁷, over the 300 delivered in total (representing 2% of the total). They were VHR radar and optical data (Radarsat, Pleiades and Deimos), requested with a 2-day notice upfront the acquisition. The images were delivered successfully with EO information, less than 2 hours after the satellite acquisition. Beside the MAOC(N). Therefore, the contribution of Copernicus within EO data is assessed to be up to 75%. As the Security service has been set up very recently and is operational for only few months, a gradual uptake is applied to simulate the progressive switch from potential other EO sources used by MS towards EMSA and Frontex products. The ratio applied is 50%-60% in 2017, 60%-70% in 2018, and then 65%-75% from 2019.

Satellite images have a more limited impact on cross border crime reduction at land borders due to the nature of land borders activity. Illegal goods smuggling and hidden passengers in vehicles can hardly be detected through direct observation, as the criminal activities do not use specific paths or patterns. Risks analysis and situational intelligence exploit EO, but primarily for border surveillance (for control of migration flows typically), and controls achieved at Border Control Points (BCPs) remain the most effective action to intercept goods and people. By comparison with the sea borders applications, it can be estimated that the contribution of EO to the final seizures does not exceed 3%.

Similarly to the data used for law enforcement at sea, the geospatial services and services used by Frontex for land operations are procured through SLAs with EMSA and SatCen, financed by Copernicus budget (in addition it can be noted that most of the images used by SatCen for its services are procured through the Copernicus Data Warehouse). MS may procure satellite data on top of Frontex products and services, but it is expected to remain limited, if any. In order to remain conservative, it is assumed that 80% EO data used for law enforcement on land border is funded by Copernicus. Similarly to the sea activities, a gradual uptake is applied to simulate the progressive switch towards Frontex products. The ratio applied is 45%-55% in 2017, 60%-70% in 2018, and then 70%-80% from 2019.

4.2.3.6.5.4 Summary of Copernicus contribution to law enforcement and international crime

The following table and graph summarise the overall impact of Copernicus on oil pollution monitoring, under the assumptions described above.

<i>Copernicus benefits – EUR M</i>	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	51.4	267.2	628.2	6,446.7
Medium estimate	111.4	403.8	794.3	8,983.6
High estimate	200.4	556.5	976.8	11,859.1

Table 34 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

³⁶⁷ EMSA, 2016, Copernicus Maritime Surveillance Service, Annual implementation report 2016

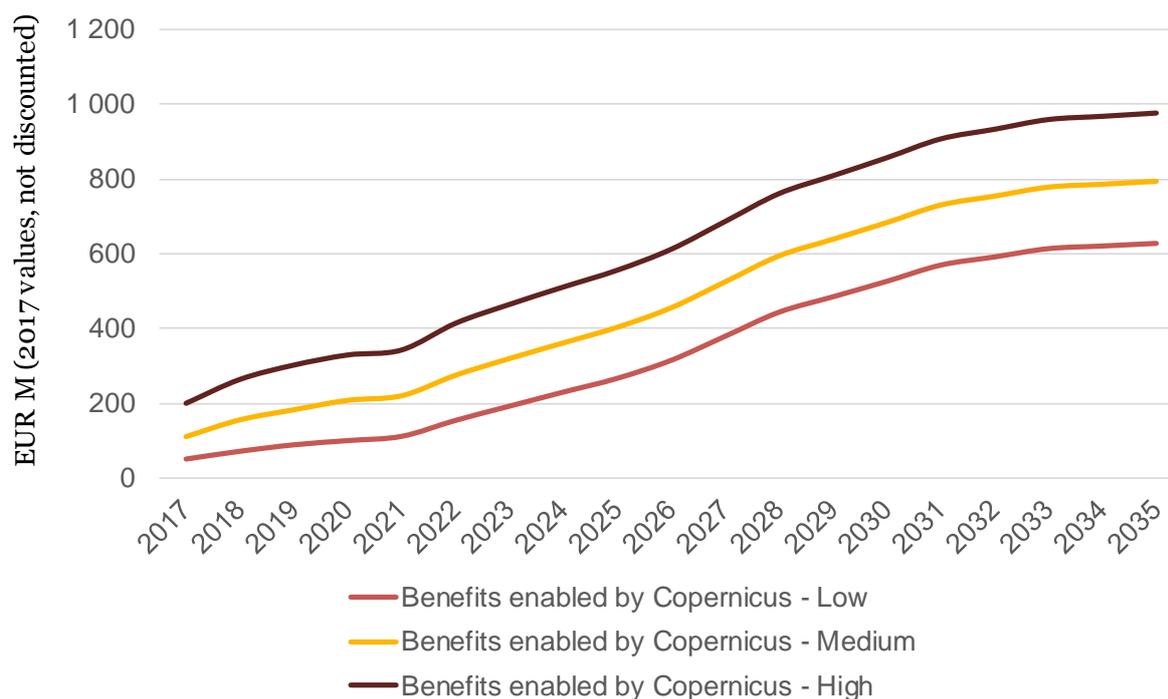


Figure 126 - Summary of Copernicus benefits (EUR M) for the impact driver “law enforcement and international crime” from 2017 to 2035 for Europe (Source: PwC analysis)

4.2.3.6.6 EU borders surveillance

4.2.3.6.6.1 Context and role of EO

Among its core missions of Frontex, as the EU borders agency, supports MS to achieve an efficient, high and uniform level of border control in accordance with the relevant EU Acquis in particular the Schengen Border Code. In particular, Frontex coordinates operational and EU measures to jointly respond to exceptional situations at the external borders. Operational activities differ between land and sea borders surveillance by the nature of the environment, but one of the main goals is the same, mainly oriented on the control of inbound immigration flows.

- Sea border surveillance involves 3 types of outputs:

The detection and tracking of migrants and suspicious vessels is a direct output of operational activities, ensured through situational monitoring. Situational pictures are based on an event layer (incidents from national and pre-frontier pictures), an operational layer (own Frontex assets, joint operations and pilot projects, environment information) and an analysis layer (key developments, analytical reports and briefing notes, analysed information and imagery and geo-data, reference imaging, background maps etc.).

The monitoring of points of departure focuses on 3rd states activity (mainly ports) to anticipate flows of activity and migration peaks by detecting departures of immigrants’ vessels. This However the role of EO in these operations remains very limited (assessed as “low”) as of today, as it requires NRT and VHR data to identify vessels of interest or to be able to analyse the local movements. The low revisit time of satellites and their small area of coverage in VHR optical prevent them from frequent analysis of the situation evolution.

Intelligence validation ensures reliable information for situation monitoring, regarding the events, operational and analysis layers of situational pictures.

- Land border surveillance involves 4 types of outputs:

Change detection and analysis, and monitoring of crisis situations are essential to anticipate threats from 3rd countries, including on migration flows (also on cross border crimes, support to customs etc.). Change detection and analysis exploits images of areas of interest to identify any evolution in time, on which satellite images can directly contribute, provided the revisit time is compatible with the need. Monitoring of crisis situation is less related to routine monitoring as it can be more intermittent, with frequent surveillance once a crisis has burst.

The provision of environment information and intelligence validation do not directly lead to the detection and identification of events requiring intervention, but they provide contextual information to support field operations related to immigration control. In particular, it ensures increased reaction capabilities from MS through a quicker decision process, allowing a better, tailored and cost effective mission planning with efficient use of assets. It is challenging to isolate this impact alone from the rest of the operations, and this impact is not quantified.

These activities are summarised in the following impact pathways, and the quantification of the resulting impacts is detailed in the following section.

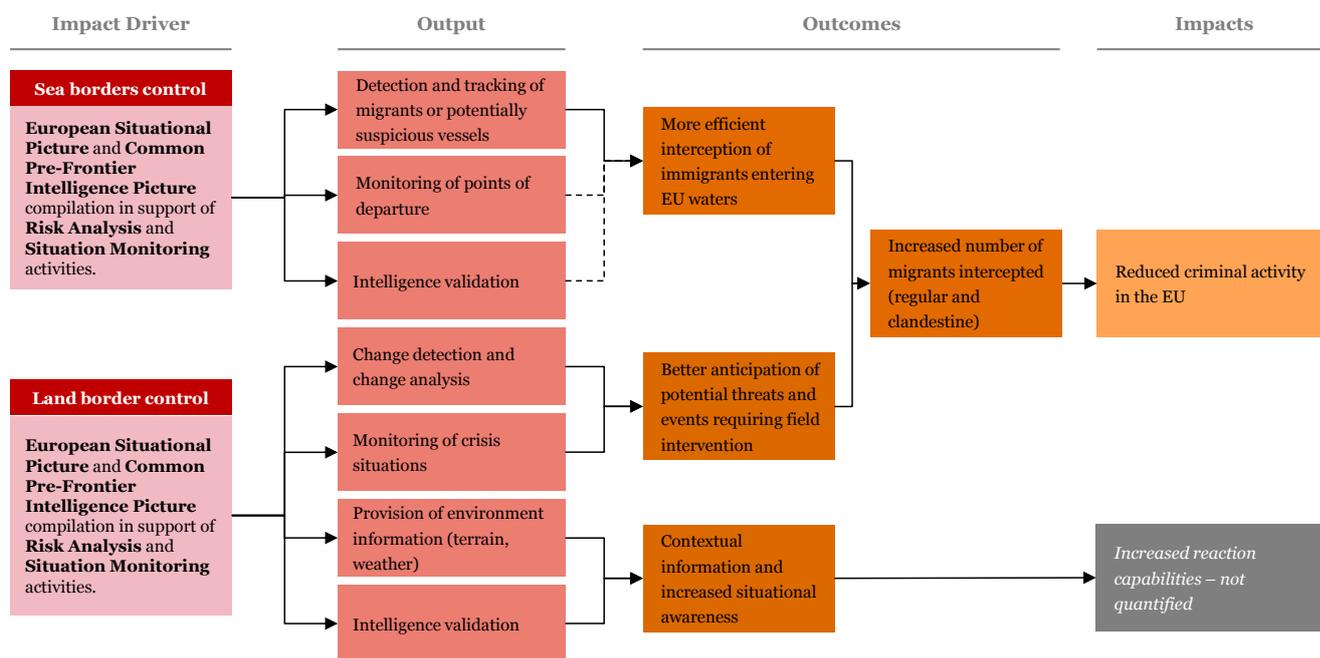


Figure 127 - Impact pathways for the impact driver “EU borders surveillance” (Source: PwC analysis)

Expected uptake of EO and Copernicus (baseline)

The contribution of EO is foreseen to grow significantly for some sea border applications, such as the detection of immigrant vessels (to “high”) and detection and tracking of vessels of interest in general (to “very high”). This increase is supported by the expected improvement of radar satellites characteristics, such as revisit time (as the number of satellites flying

increases). The possibility to monitor wide areas at high resolutions should also contribute to the progressive uptake of satellite images. The current model foresees a growth of EO contribution up to 20%.

In the baseline option the evolution of Copernicus contribution is foreseen constant equal to 70%-80% reached by 2019. This assumes the satellite products provided by Frontex will keep being procured through Copernicus Security service (from EMSA and SatCen or other entities). This assumption is conservative as the quality and suitability of Copernicus products should keep increasing in the coming years, leading to even less EO data procured by MS on top of it, hence pushing Copernicus contribution even higher than 80%. However there is no data to quantify this increase.

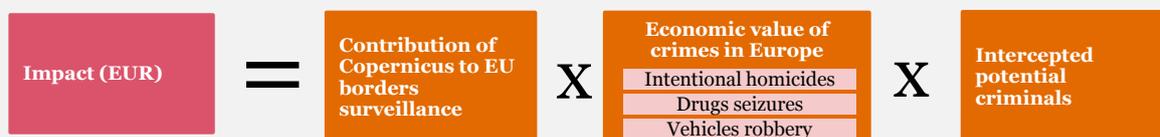
4.2.3.6.6.2 Security improvement through EU borders surveillance



Methodological approach to value security improvement through EU borders surveillance

The control of immigration flows at EU external borders allows to regulate the profiles entering the EU. Among the persons denied at BCPs, intercepted during clandestine entrance or through the apprehension of facilitators, the refusal of individuals lead to reduced dangerous profiles within the EU (in particular in the current context of terrorism risks). The impact on EU security is quantified through 3 types of crimes (homicides, drugs trafficking and vehicles robbery), by correlating the reduced number of suspicious immigrants to the reduced level of crime.

Increased interceptions of illegal goods Valuation approach



Description of the impact

If many immigrants at EU external borders are attempting to reach for EU for undisputable reasons (wars, political crisis, more favourable economic context etc.), many “non-compliant” profiles are intercepted by authorities during controls and are denied access to the EU. Among the reasons for denial, some are linked to regulatory and policy stances, while others are linked to the suspicions on the legitimacy of people, regarding their incentives for migration.

In the current context of security concerns in European MS and growth of terrorist activities, borders become a more and more strategic point to mitigate EU crime and avoid external threats to reach MS. The valuation of such control is achieved through the potential impact of suspicious profiles on EU criminality. Depending on the reason for denial, the profile can be estimated more or less risky with respect to the average crime rate. The valuation of crime rates is based on the same approach as previous drivers (statistical value of life (economic impact of an avoided fatality) and commercial value of drugs and vehicles).

The first category of interceptions are denial at BCPs with potential acceptance initially. The reasons for denials can be multiple, for instance use of invalid or absence of visa, or denial of

asylum application. In this case there is no mean to specify the profile of immigrants compared to the average EU inhabitants (in terms of risk for security), and the same criminality rate as the EU average can be expected. The second category of interceptions are either denials linked to fraudulent documents or interception of clandestine migrants. In this case, the *modi operandi* suggests an inclination for illicit activities, which can be expected to be reflected through a higher criminality rate than the average population.

Data for impact valuation

In Europe, average criminality rates vary considerably between crime categories (computed as the number of recorded acts over the total population). In the EU these rates vary from 0.0011% for intentional homicides (about 7,900 acts per year), to 0.06% for drugs unlawful acts (about 249,000 acts per year), to 0.16% for vehicles robbery (about 1,455,000 acts per year)³⁶⁸.

Of course, migrants intercepted with fraudulent documents or clandestinely (thus with higher inclination for illicit activities) cannot be all presumed to take part in criminal activities. Based on statistics on immigration within prison population and overall population³⁶⁹, an inflation ratio between 3 and 4 is adopted for the current model³⁷⁰ to inflate their crime rates compared to the overall EU population. This assumption is conservative as this figure takes into account the immigrants within EU MS, and does not take into account the fact that regular immigration has a criminality rate equal to 1, which lowers the average for all immigration.

The valuation of crimes is similar to the values used for previous drivers:

- The statistical value of life (economic impact of an avoided fatality) is estimated at EUR 2.26 M per person³⁷¹
- The average value of stolen vehicles is EUR 6,400³⁷²
- The drugs unlawful acts are considered to be drugs seizures, with an average value of EUR 26,300 per seizure³⁷³.

The number of immigrants intercepted with fraudulent documents is on average at 8,372 per year, and the number of clandestine immigrants intercepted is on average at 2,794 per year³⁷⁴. In addition, the apprehension of facilitator also contributes to reducing the number of illegal immigrants. On average, almost 1,100 facilitators are apprehended each year. The ratio between the total illegal crossing detected on facilitators detected suggests that facilitators smuggle about 21 person each per year, leading to about 23,000 illegal immigrants less every year. Considering the same ratio of 25% of immigrants intercepted at BCPs (cf. section 4.2.3.6.5 “Law enforcement”), interception of facilitators leads to a reduction of about 2,800 illegal immigrants entering the EU per year.

Evolution up to 2035

The projection up to 2035 of the impact of Copernicus on the EU borders surveillance relies on the following assumptions.

³⁶⁸ Eurostat, http://ec.europa.eu/eurostat/statistics-explained/index.php/Archive:Crime_statistics/fr. Averages computed over 2000 – 2007.

³⁶⁹ Open Immigration, February 2016, Prison and foreign detainees in Europe, accessible at <https://openmigration.org/en/op-ed/foreign-detainees-in-europe-and-in-italy/>; Eurostat, 2011, Communiqué de press 105/2011 – 14 Juillet 2011, Les ressortissants étrangers constituaient 6.5% de la population de l'UE en 2010

³⁷⁰ Immigration represents about 21% of prison population while constituting about 7% of the EU population in 2010.

³⁷¹ PwC valuation factors

³⁷² FBI, 2016, <https://ucr.fbi.gov/crime-in-the-u.s/2015/crime-in-the-u.s.-2015/offenses-known-to-law-enforcement/motor-vehicle-theft>

³⁷³ EMCDDA, 2016, EU drug report 2016

³⁷⁴ Frontex, Annual risk analysis, 2015 and 2017

- The number of entry refusal per year remains constant, equal to the average over 2009-2015
- The number of illegal immigrants intercepted at EU borders (fraudulent documents and clandestine crossings) and the number of facilitators intercepted remain constant, equal to the average over 2014-2016. This short period is justified as a net increase has been witnessed since the evolution of the geopolitical context in 2014.
- The inflation of the criminality rate for illegal immigration remains constant, equal to 3.23.
- The criminality rates considered follow the same trend as witnessed over 2000 – 2007:
 - Annual decrease of -3% for intentional homicides
 - Annual decrease of -5% for vehicle robbery
 - Annual increase of +1.5% for drugs unlawful acts

Differentiation factor of EO and Copernicus D&I

Regarding sea borders surveillance, the contribution of EO is assessed at “medium” for the detection and tracking of vessels of interest, as presented in the law enforcement driver. The contribution is the same for immigrant vessel detection, with the same limitation on revisit time. In this case, the small size of vessels requires VHR optical data, as typical migrants vessels are made of rubber, hindering the use of radar images. In accordance with this assessment, the contribution of EO to sea border surveillance is between 3% and 7% as of 2017.

Regarding land borders, satellite images have a more limited impact as they contribute to support and anticipation activities while the core of immigration control remains performed at BCPs, through traditional controls. Direct flows of immigration can hardly be detected through direct observation as migrants are often part of larger regular flows. Contribution of satellites materialises on risks analysis and situational intelligence, and it remains challenging to define the share of the overall immigration controls that are directly enabled by these activities, or even the gain in efficiency thanks to the use of satellite data. To remain consistent with the magnitude obtained for sea borders applications, it can be estimated that the contribution of EO to the final seizures does not exceed 3%.

Frontex supports MS in the border surveillance operations, both and sea and on land, in particular by providing products and services around risk analysis and situation monitoring. On one hand, the geospatial services used by Frontex are procured through SLAs with EMSA and SatCen (for a total of EUR 6.6 million payments in 2016, of which EUR 4.7 million from the EMSA SLA and EUR 1.9 million from the SatCen SLA³⁷⁵), and are funded through the Copernicus Security service. On the other hand, although MS involved in border surveillance operations with Frontex may procure satellite data on their own, on top of the products provided by Frontex, there is no quantification of such additional EO data, and it can be reasonably assumed that they constitute a minor share of the overall data used for border surveillance operations. Therefore, the modelling of border surveillance impacts assumes that most of the EO data used comes from Copernicus, with a maximum value at 80% to remain conservative. A gradual uptake is applied to simulate the progressive switch towards Frontex products. The ratio applied is 45%-55% in 2017, 60%-70% in 2018 and then 70%-80% from 2019.

4.2.3.6.6.3 Summary of Copernicus contribution to EU border surveillance

Under the assumptions described above, the benefits of Copernicus to the EU borders surveillance is the following.

³⁷⁵ Frontex, 2017, Annual activity report 2016

Copernicus benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	0.1	0.9	1.3	16.5
Medium estimate	0.3	1.1	1.6	21.6
High estimate	0.5	1.5	1.9	27.4

Table 35 - Copernicus total benefits for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

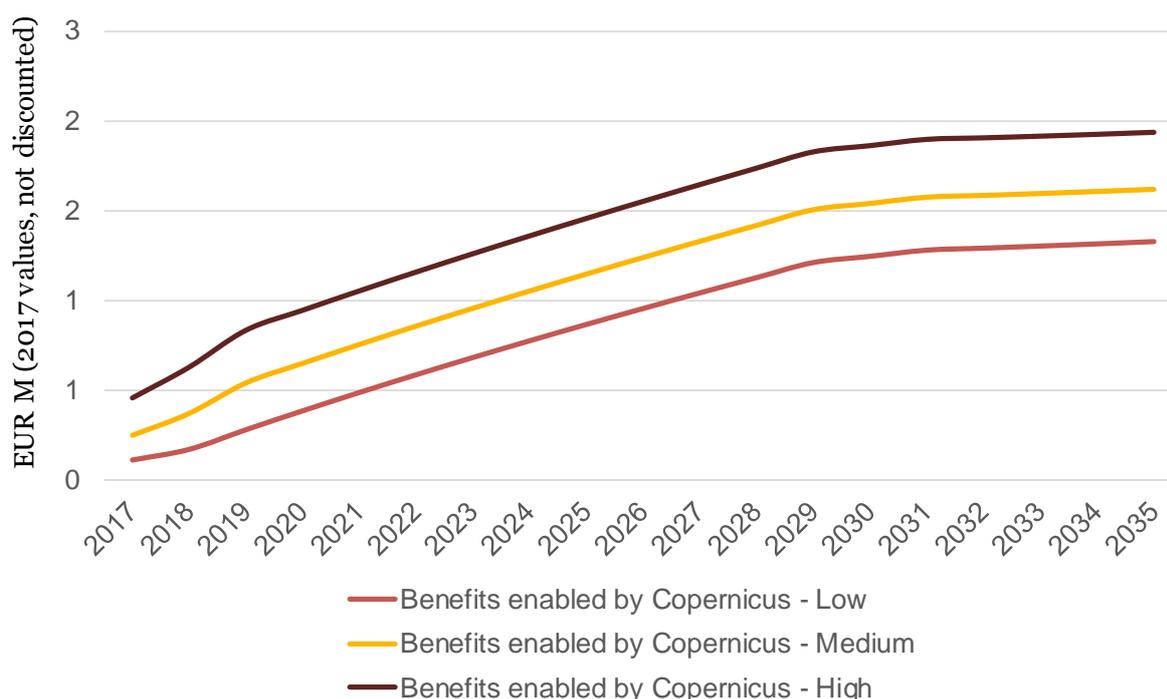


Figure 128 - Summary of Copernicus benefits (EUR M) for the impact driver "EU borders surveillance" from 2017 to 2035 for Europe (Source: PwC analysis)

4.2.3.6.7 Support to EU external actions

On the top of Copernicus services in response to Europe's internal security challenges, the Copernicus programme plays also a major role on security challenges outside of EU frontiers. The EU Satellite Centre (Sat Cen) is in charge of the Copernicus Security service in support to EU External Action (Copernicus SEA). Since May 2017, the service is fully operational and it provides security and defence authorised EU users' nine categories of EO-based products for³⁷⁶:

- **Reference map:** mutli-information layers cartographic products
- **Road network status assessment:** status of the road network to support logistic operation in the field
- **Conflict damage assessment:** change detection products to assess damage in a crisis area

³⁷⁶ SatCen and European Commission, 2017. Copernicus Service in support to EU External Actions. Product Portfolio.

- **Critical infrastructure analysis:** products assessing operational status, risks and potential damage to critical infrastructure
- **Support to evacuation plan:** provision of geo-spatial information to support evacuation of EU citizens from crisis areas
- **Non-EU border map:** provision of geo-spatial information to monitor specific non-EU borders, analysing people movement (military troops, refugees, etc.) and cross-border criminality
- **Camp analysis:** products to support decision-making regarding displaced populations
- **Crisis situation picture:** products assessing the dimension and the magnitude of overall impacts of a conflict/crisis
- **Activity report:** products analysing human activity. This type of product is very flexible and can be adapted to a wide range of situations.

All these product' categories can be provided (or will be provided in the future) to end users in two modes: one-shot analysis and monitoring³⁷⁷. The one-shot analysis refers to the case where user activates the service and requires one or several of these products of a given area at an instant t (it can be in the past, present or future). Second mode refers to the monitoring of a given area for a period of time to track and assess changes in infrastructure, people behaviours, etc. Both type of services are delivered after an activation from authorized users. Copernicus SEA can be freely activated by all authorized EU security and defence users: EU External Action Services (EEAS), EU MSs, European Commission (EC), and some international organizations (i.e. UN). The service is also foreseen to be opened to some third countries and other international organizations (i.e. Organization for Security and Co-operation in Europe (OSCE)) in the future.

These products can be requested as stand-alone (i.e. non EU-border map) or coupled products (putting together different products to respond to a complex situation in a remote area). Copernicus SEA aims to support EU External Actions in the following domains:

- Political and armed conflicts
- Situation awareness
- Humanitarian support
- Border survey (outside EU)
- Activity monitoring

4.2.3.6.7.1 Functioning of the Copernicus SEA: an introduction to SatCen's activities and role

Copernicus SEA is operated by SatCen who has developed over the last 25 years an extensive expertise in geo-spatial information products & services to support decision-making in the field of Common Foreign and Security Policy (CFSP), specifically focusing on Common Security and Defence Policy (CSDP) missions.

³⁷⁷ Four out of nine of these products do not currently provide "monitoring" mode: reference map, road network status assessment, conflict damage assessment and non EU-border map. Nevertheless, these products may/should be able to provide on-demand and monitoring modes in the future.

Service activation can be proceeded by any SatCen’s authorised users. The request for service is received by a SatCen point of contact who treats the demand and submits it to the tasking authority validation (EEAS). EEAS evaluates the content of the demand in order to assess the sensitivity and nature of the request. Depending of the nature and the sensitivity of the request (classified requests cannot be processed by SEA) it will be processed directly by SatCen or processed with Copernicus SEA managed by SatCen. In the latter case, authorised user’s requests will be acknowledged and processed with support of the Industry contracted through a Copernicus SEA procurement framework. For this purpose, an existing framework contract binds SatCen and an EU-commercial consortium for the provision of such services within the Copernicus SEA framework. The SatCen is responsible for the validation of the industrial production and for adding specific value if needed. The chart below illustrates the overall functioning of service activation for SatCen and Copernicus SEA.

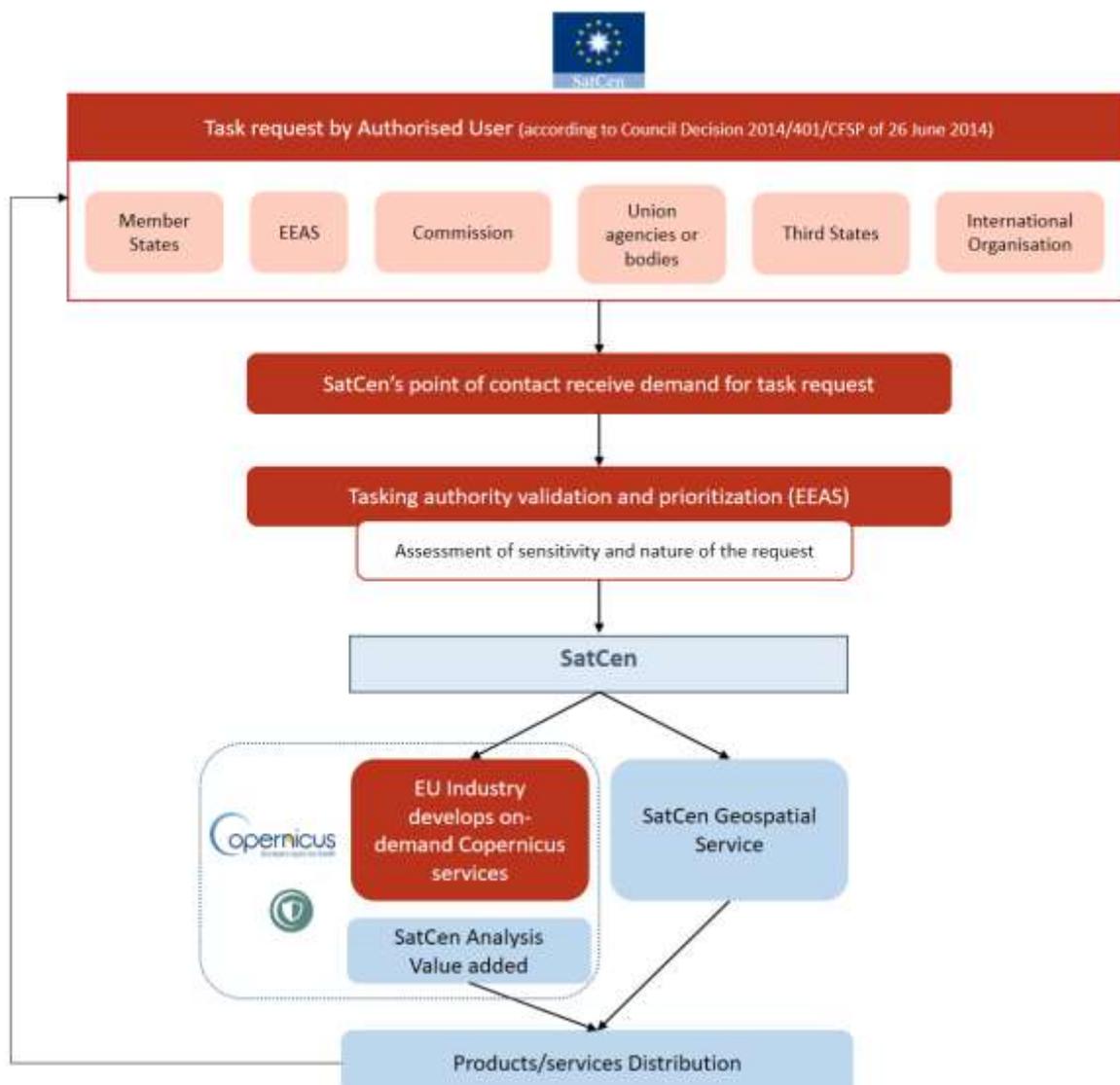


Figure 129 - High level illustration of SatCen and Copernicus SEA service activation (Source: PwC analysis)

4.2.3.6.7.2 Monetization of impacts attributed to the Copernicus programme

The impact of the Copernicus programme on EU External actions and CSDP missions was not able to be assessed and monetized in this study for several reasons listed above:

- Type of data required to perform this type of assessment is highly sensitive (and so not fully available);

- Service available on demand (activation mode), with no historical record (operational since May 2017);
- Complexity of EU external actions (not involved in all conflicts, different type of involvement (impacting the way geospatial information is used), not same contribution expected from SatCen);
- Some impact of this brand of the security service such as the EU international position and influence cannot be monetized;
- Complexity and inaccuracy of forecasts of future conflicts (number of conflicts, magnitude of conflicts, localisation of conflicts, etc.);
- No previous study exists on the impact of EU external actions and its monetary valuation;
- No previous study exists on the contribution of imagery and geospatial information to Defence and highly sensitive security missions (i.e. monitoring key infrastructure).

The contribution and value-added of Copernicus was then presented qualitatively to highlight the strategic impact of the Copernicus programme for European security and defence actors.

4.2.3.6.7.3 Value-added of the Copernicus programme

For more than 25 years, SatCen has been developing geospatial products for security and defence users before the development of Copernicus Security Service, and it still provides additional products not provided through Copernicus SEA including classified information.

Nevertheless, the Copernicus programme has enhanced the capability and efficiency of SatCen services to its users, especially to support EEAS decision making missions and other Defence and Security operations handled independently by EU MSs. Copernicus SEA is capitalizing on existing experience to enhance SatCen services by adding new capabilities and new budget to support European security and defence authorized users. The establishment of these new Copernicus services has also led to a mutualisation of efforts at European level by sharing the overall cost of the programme between all EU MSs – reducing the cost per EU MS – and by sharing all benefits derived from an investment. Positive impacts of efforts mutualisation are especially strong for smaller EU MSs that could not afford the development of such a service at national level. Major EU MSs also benefit from such service by enhancing their national capability – on the top of existing remote sensing assets – thanks to on-demand services available at a lower cost than what could have been done at national level.

4.3 Baseline option summary

This section brings together all the benefits enabled by the Copernicus D&I over the period 2017 – 2035 for the baseline option (option 1). The figure below summarises all the benefits (not discounted) for intermediate users and end-users over the period 2017 – 2035 for the three scenarios under scrutiny.

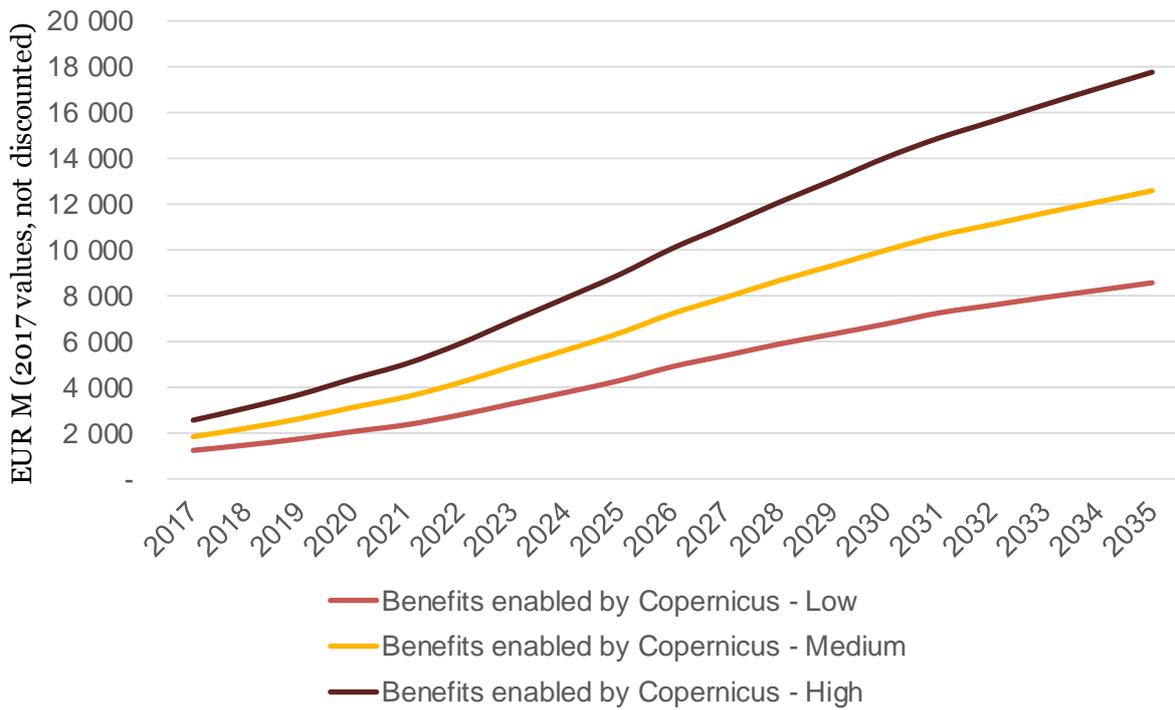


Figure 130 - Evolution of the overall baseline benefits enabled by Copernicus D&I for the three scenarios under scrutiny (Source: PwC analysis)

As a result, the total not discounted benefits linked to Copernicus are expected to amount to:

Copernicus EU benefits – EUR M	2017	2025	2035	Cumulative (2017 – 2035)
Low estimate	1,280.0	4,326.4	8,599.6	92,556
Medium estimate	1,875.6	6,400.0	12,618.6	136,320.7
High estimate	2,598.8	8,956.0	17,792.5	190,989.9

Table 36 - Copernicus total EU benefits of option 1 for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

When looking more in depth at the origin of the benefits enabled by Copernicus D&I, the first outcome is the fact most of the benefits are derived from end-users for the three scenario as illustrated in the diagram below, with the contribution of intermediate users ranging between 8% and 11% of overall benefits (cumulated not discounted benefits over the period 2017 – 2035).

5 Evolution options

These options represent different scenarios that are foreseen for the evolution of the Copernicus programme. The scope of these evolution options is not defined and finalised yet, which impact significantly option characterisation and impacts assessment. The options presented here are based on the information provided by the European Commission and interviews with experts from Copernicus core services and ESA. Nevertheless, impacts expected from these evolution options cannot be accurately fully monetized since most of the options foreseen are currently being defined. The benefits illustrated in this chapter have to be understood as order of magnitude of impacts.

5.1 Option 2 – Shutdown

The shutdown option represents the scenario where the Copernicus programme is stopped after 2030 without renewable of Sentinels spacecraft. Option 2 ends up in 2030 with:

- Transfer of ownership of flying satellites (Sentinels)
- Stop and disassemble existing Copernicus core services

The assessment of benefits is based on the baseline option's benefits assessed in the previous chapter, with a specific user uptake due to the peculiarity of the shutdown option. This element is detailed in the next sub-section.

5.1.1 Specific impact on Copernicus user uptake

Option 2 has a specific impact on the **Copernicus user uptake** presented in section 4.2.1. The S-shaped curve used to illustrate user uptake is **intrinsically linked to the continuity of the Copernicus programme**, ensure the availability of free and open data over the long-term. Announcement of the shutdown should be followed by a modification in users' behaviour that may start looking for another source of data. Indeed, in a recent EC survey about Copernicus data and information, 61% of the respondents consider that continuity – the survey talks about long-term predictability and availability of data – is the most important factor to support innovation derived from Copernicus data and information³⁷⁸. Sending a signal to users' communities that the Copernicus programme will be shutdown should then have a very negative impact on user uptake.

Projection of Copernicus D&I benefits follows the same S-shaped curve's user uptake, as detailed in section 4.2.1. Shutdown option is expected to result in a strong diminution of Copernicus user uptake after shutdown announcement. To illustrate this expected diminution of user uptake due to non-continuity, an inverse S-shaped curve has been used to decrease contribution of Copernicus in all impacts' model, starting from 2025 – expected date of shutdown announcement – leading to a complete disappearance of Copernicus D&I benefits in 2030 – date of the expected shutdown. Copernicus user uptake for the shutdown option is illustrated in the chart below.

³⁷⁸ European Commission, 2016. Boosting the growth of European EO companies. Survey analysis. Brussels, Belgium.

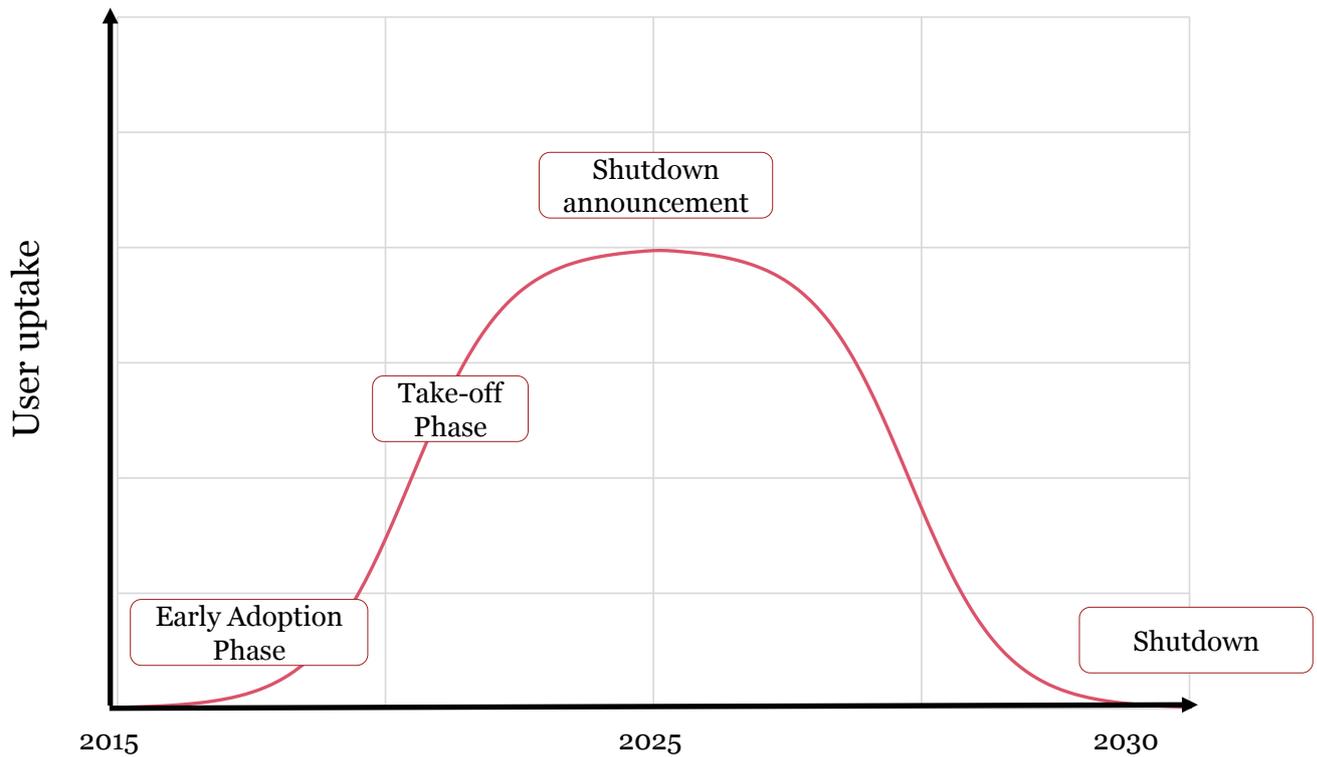


Figure 131 - Specific Copernicus user uptake for shutdown option (Source: PwC analysis)

Copernicus user uptake illustrated in the chart above aims to represent the phenomenon in a generic case rather than a precise user uptake for all impacts. User uptake in the initial phase – from Early adoption phase to Shutdown announcement – may vary from one impact to another, taken into account the fact that not all Sentinels are operational yet and the fact Copernicus core services will be introducing new products in the future, impacting specific users’ uptake.

5.1.2 Monetization of option 2 benefits

As highlighted in the previous section, the announcement of the shutdown of the Copernicus programme is expected to lead to a reduction of usage over the period 2025 – 2030, with a complete disappearance of all benefits enabled by Copernicus D&I by 2030. At this date, most satellites are expected to have reach end of their life without any renewable and flying satellites still operational will be transferred to the private; all Copernicus core services will also be stopped at this date.

The quantification of option 2 is based on all the benefits enabled by Copernicus D&I over the period 2017 – 2025, including both intermediate users and end-users benefits. After 2025, a reverse S curve, as already explained previously, reduces Copernicus D&I benefits to reach EUR 0 by 2030 (end of the programme).

The total not discounted benefits linked to Copernicus D&I for option 2 are expected to amount to:

Copernicus benefits – EUR M	2017	2025	2030	Cumulative (2017 – 2030)
Low estimate	1,279.0	4,110.0	0	30,034.7

Medium estimate	1,875.6	6,089.1	44,671.7
High estimate	2,598.8	8,512.0	62,362.0

*Table 37 - Copernicus total benefits of option 2 for the three scenarios (EUR 2017, not discounted values)
(Source: PwC analysis)*

The global trend over the period is illustrated in the chart below (not discounted).

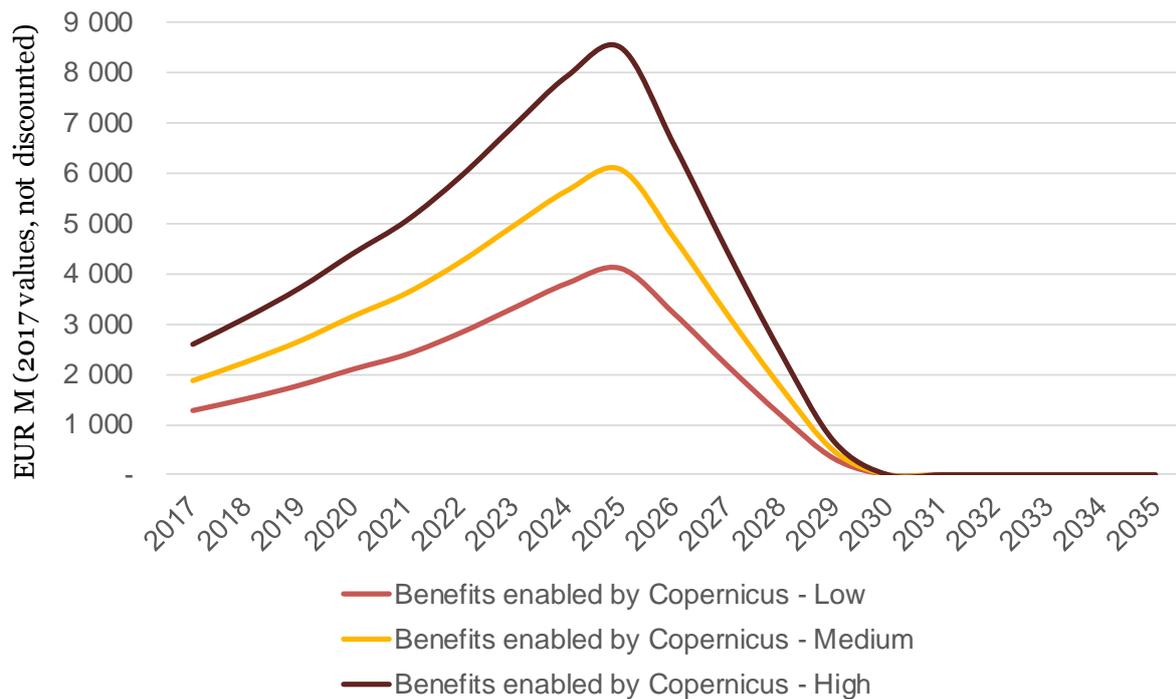


Figure 132 - Benefits enabled by Copernicus data and information for evolution option 2 (EUR M; EUR2017; undiscounted values) (Source: PwC analysis)

5.1.3 Comparison of Shutdown option (option 2) with the baseline option (option 1)

Option 1 and 2 have common benefits until 2024 for the three scenarios. Starting from 2025 up to 2030, benefits derived from Copernicus D&I for option 2 go down to EUR 0. This section aims at comparing the shutdown option with the baseline, in order to assess the delta between the options.

Several limitations need to be considered before analysing the results:

- Baseline option and shutdown option have very different cost (cost of renewable of assets for option 1; no cost for option 2), which are not considered in this assessment;
- The assessment focuses on the benefits derived from Copernicus D&I but counterfactuals and alternatives solutions can potentially be found by intermediate

and end-users to limit the loss of benefits. Our assessment does not take into account such possibility of adaptation;

- Access and utilisation of free and open data sources for a long period of time, like in the case of Copernicus programme, may create dependencies on users' side; this statement is particularly strong for intermediate users. Such dependencies would be materialised into negative externalities if the programme was stopped, leading to potential additional costs (on the top of the loss of benefits). Nevertheless, the assessment of these negative externalities is not in the scope of this study.

The next sub-sections introduce the comparison of the Shutdown option (option 2) and the baseline option (option 1) over the period 2017 – 2035 for three scenarios: pessimistic (low estimate), average (medium estimate) and optimistic (high estimate).

5.1.3.1 Low estimate

The sum of all the benefits derived from Copernicus D&I for intermediate and end-users have been presented over the period 2017 – 2035 for the pessimistic scenario, as illustrated in the chart below.

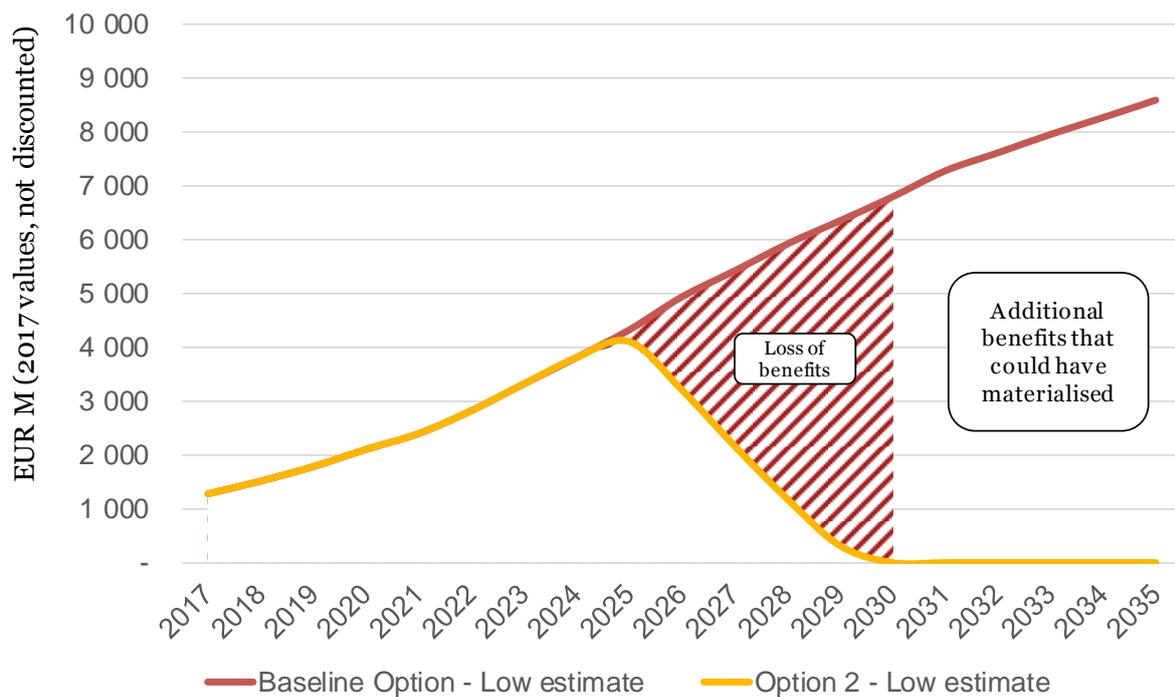


Figure 133 - Comparison of the evolution of Copernicus D&I benefits for Baseline option (option 1) and Shutdown option (option 2) over the period 2017–2035 – Low estimate (Source: PwC analysis)

Hatched area represents the amount of benefits loss from the Copernicus programme without impacting Copernicus scope & budget, so the benefits loss over the period 2025 – 2030. After this period (2031 – 2035), the chart illustrates additional benefits that could have materialised in the case assets would have been renewed. However, these additional benefits come with a cost that would have been borne by the European society so they should not be fully included into the comparison between shutdown and baseline option.

The difference between shutdown and baseline option is analysed in the table below, in non-discounted values.

Low estimate – EUR M	Loss of benefits for the society (2025 – 2030)	Additional benefits that could have materialised (2031 – 2035)
Net loss between option 1 & 2	22,780.1	39,741.2

Table 38 - Comparison of option 1 and 2 for the pessimistic scenario (EUR 2017; not discounted values) (Source: PwC analysis)

5.1.3.2 Medium estimate

The sum of all the benefits derived from Copernicus D&I for intermediate and end-users have been presented over the period 2017 – 2035 for the average scenario, as illustrated in the chart below.

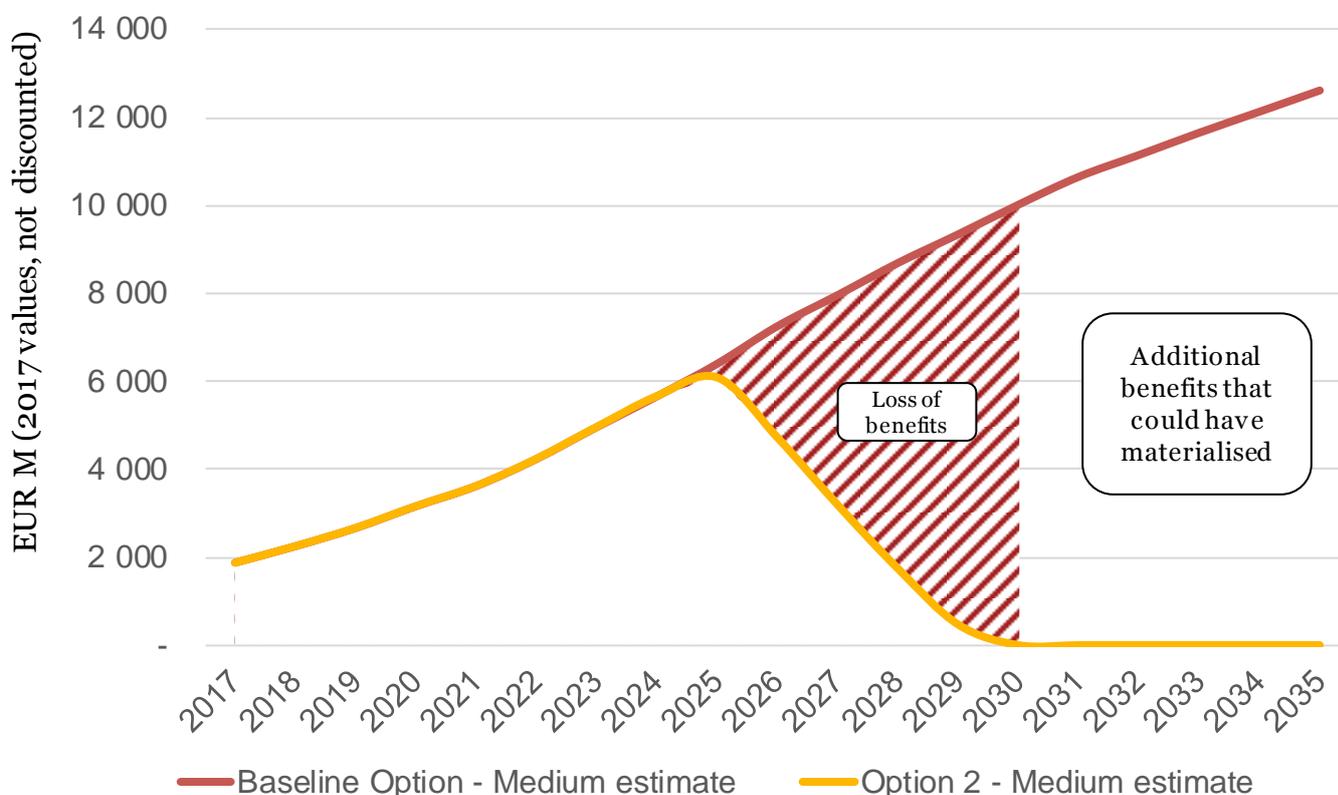


Figure 134 - Comparison of the evolution of Copernicus D&I benefits for Baseline option (option 1) and Shutdown option (option 2) over the period 2017–2035 – Medium estimate (Source: PwC analysis)

Hatched area represents the amount of benefits loss from the Copernicus programme without impacting Copernicus scope & budget, so the benefits loss over the period 2025 – 2030. After this period (2031 – 2035), the chart illustrates additional benefits that could have materialised in the case assets would have been renewed. However, these additional benefits come with a cost that would have been borne by the European society so they should not be fully included into the comparison between shutdown and baseline option.

The difference between shutdown and baseline option is analysed in the table below, in non-discounted values.

Medium estimate – EUR M	Loss of benefits for the society (2025 – 2030)	Additional benefits that could have materialised (2031 – 2035)
Different of benefits between option 1 & 2	33,492.6	58,215.7

Table 39 - Comparison of option 1 and 2 for the medium scenario (EUR 2017; not discounted values) (Source: PwC analysis)

5.1.3.3 High estimate

The sum of all the benefits derived from Copernicus D&I for intermediate and end-users have been presented over the period 2017 – 2035 for the optimistic scenario, as illustrated in the chart below.

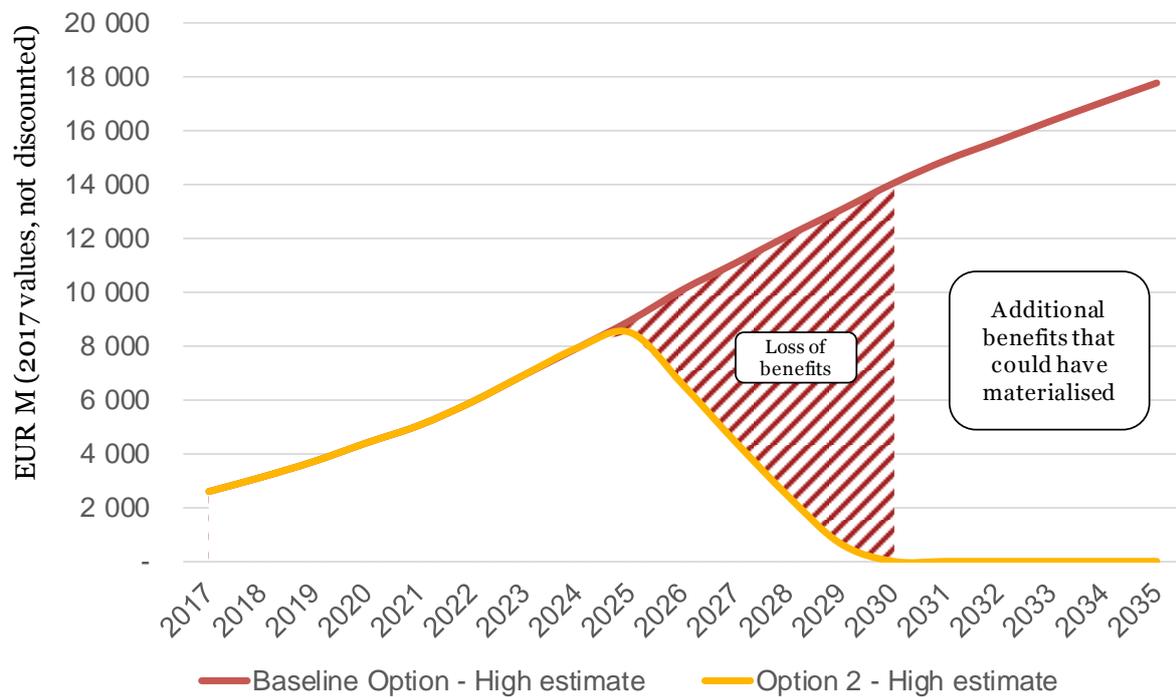


Figure 135 - Comparison of the evolution of Copernicus D&I benefits for Baseline option (option 1) and Shutdown option (option 2) over the period 2017–2035 – High estimate (Source: PwC analysis)

Hatched area represents the amount of benefits loss from the Copernicus programme without impacting Copernicus scope & budget, so the benefits loss over the period 2025 – 2030. After this period (2031 – 2035), the chart illustrates additional benefits that could have materialised in the case assets would have been renewed. However, these additional benefits come with a cost that would have been borne by the European society so they should not be fully included into the comparison between shutdown and baseline option.

The difference between shutdown and baseline option is analysed in the table below, in non-discounted values.

High estimate – EUR M	Loss of benefits for the society (2025 – 2030)	Additional benefits that could have materialised (2031 – 2035)
Different of benefits between option 1 & 2	46,815.2	81,839.9

5.2 Option 3 – Enhanced environmental services

Option 3 illustrates the scenario where current scope of environmental services is extended by adding new capabilities to the Sentinel fleet and potential new in-situ data. Option 3 is modular, with four different modules targeting different areas, and gathers:

1. Anthropogenic CO₂ emissions monitoring;
2. Arctic Environment and snow evolution Monitoring;
3. Thermal InfraRed (TIR) capability to monitor water and agriculture;
4. Hyper spectral capability to monitor biodiversity, forestry, land, agriculture and mining.

At the time of writing this report, these four modules are being analysed and no concrete decisions have been taken on the exact scope of each of these options (spatial resolution, temporal resolution, and geographical coverage). Note that some options analysis are more advanced (i.e. Anthropogenic CO₂ emission monitoring) than others (i.e. thermal infrared capability). The benefit assessment of these options needs to be taken as the **assessment of a potential order of magnitude rather than a precise assessment, due to scarcity of information on these potential evolution options and so on their potential benefits**. Moreover, with all these benefits to be assessed up to 2035, many factors (i.e. development of third countries programme (public or private) providing the same type of capability or coverage) can interfere and completely disrupt user uptake and benefits derived from the Copernicus programme.

5.2.1 Monetization of option 3 benefits

Two different types of methodologies have been used to monetize the benefits brought by Option 3: if the new capability brought by Copernicus enables benefits for new applications that Copernicus did not contribute to before, the methodology is explained per benefit; if the new capability enables to improve the benefits of an application that Copernicus already contributed to, the methodology used is the one presented below.

The approach used is based on the re-evaluation of Copernicus' contribution for each impact to which an enhanced capability would be relevant. The monetization of these benefits is built upon the following steps:

1. Identify the impact drivers and derived benefits that are affected by an enhanced capacity, whether snow monitoring, thermal infrared or hyperspectral.
2. Identify new variables or new parameters that can be measured with enhanced space borne instruments. These parameters were measured with less accuracy or were not measurable in the baseline scenario.
3. Adjust the Copernicus contribution in consequence (and other parameters if necessary) in the models developed for the baseline scenario.
4. Extract the results obtained from the difference between values reached in the baseline scenario and those reached in Option 3 to obtain the additional gain.

The point 3 of this methodology is based on the analysis of each impact to understand how Copernicus currently contributes to the benefit and what hinders or limits its uptake. Then we assess to what extent the new capacity can remove these limitations, reinforce the service by meeting additional users' requirements, and overall enhance the contribution of Copernicus to the benefit. This qualitative assessment is calibrated with desk research and stakeholder consultation.

Criteria used to assess to what extent benefits defined above, are affected by enhanced capabilities introduction, are exposed below:

- Very High is when the enhancement remove limitations that previously exist (e.g. qualitative forests inventory in the case of hyperspectral) or provide access to new application that are unavailable in the current Copernicus products portfolio.
- High is for applications that already exists but will be strongly enhanced with the introduction of the new technology.
- Medium is when users of the application would really appreciate the improvement of the service but the new capabilities does not seem to be a priority for them.
- Low is for applications where Copernicus contribution is already low, and even with the improvement enabled by the new capabilities, a lot of limitations will remain and will hinder the adoption of Copernicus by the users.

Option 3 is **built on the top of the baseline option (option 1)**, enhancing Environmental services by potentially one (or all) of the following module. **All the benefits assessed in the next sections have to be summed with all benefits derived from baseline option over the period 2017 – 2035.** The next sub-sections introduce in more details the expected impacts derived from these four modules.

5.2.2 Option 3A – Anthropogenic CO₂ emissions monitoring

5.2.2.1 Description

The anthropogenic CO₂ emissions monitoring option under a dedicated Sentinel mission will contribute to elaborating an operational capacity to monitor and to verify anthropogenic CO₂ emissions. The associated space component intends to fill up an existing gap within the fleet of current the Copernicus satellites and the Copernicus programme offers the appropriate frame to develop such a CO₂ service. The space component is actually envisaged and evaluated on the basis of a constellation of a minimum set of 3 satellites to ensure the relevant space-time coverage while maintaining a sufficiently high spatial resolution and accuracy in these observations. The operational capacity requires designing a ground based infrastructure to ingest and to interpret with state of the art inverse modelling techniques this ensemble of space –based observations. The latter will be complemented by any useful and relevant in-situ datasets and ancillary information as well. The ultimate objective is thus to propose an information system dedicated to policy makers regarding the impact and evolutions of the international agreements about CO₂ concentrations and trends and the national actions that have been agreed upon by all parties having signed the Paris agreement.

Such a capacity to monitor at high resolution the CO₂ emissions will have multiple applications in the mitigation and mitigation policies, at the mega city, regional and national scales. It will be accompanied by systematic observations of atmospheric methane CH₄.

The expected benefits from extending the functionality of Copernicus in this domain are illustrated below.

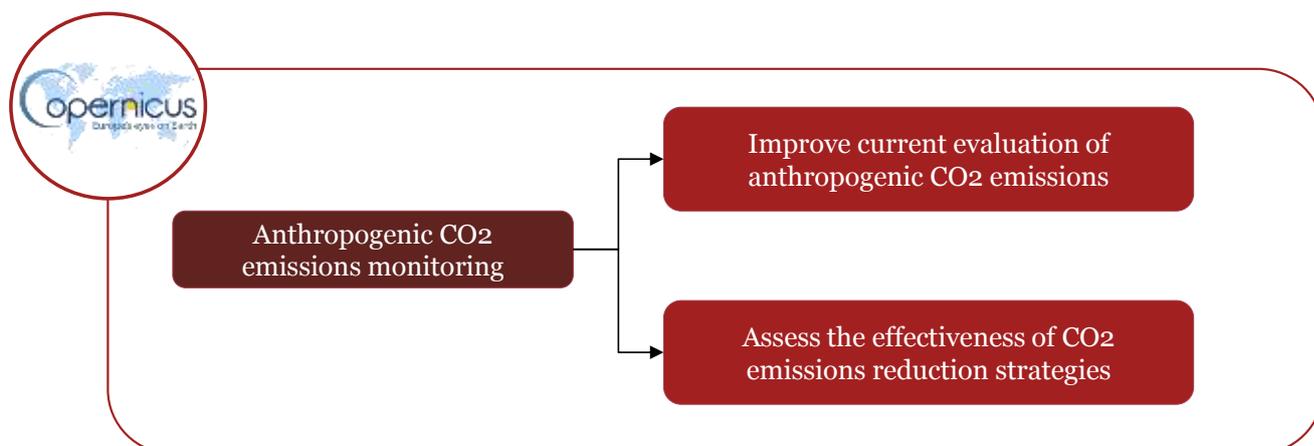


Figure 136 - High level illustration of the impacts expected from evolution option 3 – Anthropogenic CO2 emissions (Source: EC)

5.2.2.2 Monetization of option 3A benefits

Benefits of the planned Copernicus CO2 monitoring service from 2025

Greenhouse gas emissions are currently measured using a bottom up approach based on self-reported energy-use statistics for different sectors by country. There are critical uncertainties in these inventories (estimated to be better than 3% in OECD countries to worse than 10% in non-OECD countries)³⁷⁹. Moreover, it remains challenging to verify the statistics and procedure adopted for the inventories, thereby posing a limitation to global climate mitigation policies (the current uncertainties about emissions in China has the same order of magnitude as the emissions from Germany, equivalent to a large fraction of the estimated land sink).³⁸⁰ Furthermore, there is at least a two year time lag between the emissions and those being captured in inventories³⁸¹. Emission reduction targets, policies and carbon taxes are often implemented based on these inventories without independent monitoring and verification of these emissions. The uncertainty in global emissions has increased, which is a limitation to mitigation policy and carbon emission reductions³⁸².

The current Copernicus C3S and CAMS services will join forces to monitor anthropogenic CO2 from space from 2025. The intention is to separate the anthropogenic contribution from natural fluxes in order to verify and validate emission trends from national emission inventories to test and improve information on the effectiveness of emission reduction strategies³⁸³. This could also identify GHG emission hot spots and support national and local emission reduction strategies. This monitoring system has been requested in a resolution of the European Parliament and is a direct response to the Paris Agreement³⁸⁴. The service is expected to be operational from 2025 and will provide free data. One may expect that the monitoring system and the associated ground based capacity may become an essential service to the UNFCCC and strengthen the position and leadership of Europe in support of the international climate agreements.³⁸⁵

³⁷⁹ Gregg et al, 2008. Tu, 2011. Olivier, 2002.

³⁸⁰ European Commission, 2015. Towards a European Operational Observing System to Monitor Fossil CO2 emissions.

³⁸¹ EC documentation on CO2 option.

³⁸² Cooke et al., 2016. Using the social cost of carbon to value earth observing systems.

³⁸³ Interview with Hugo Zunker (EC) 22nd June 2017.

³⁸⁴ European Commission, 2015. Towards a European Operational Observing System to Monitor Fossil CO2 emissions.

³⁸⁵ EC documentation.

It is thus expected that the availability of atmospheric data on anthropogenic emissions will assist parties in evaluating and enhancing the effectiveness of their GHG emission reduction strategies, in line with commitments made under the UNFCCC Paris Agreement.

The planned C3S/CAMS service would not in itself lead to improved carbon reduction strategies, but would support these by providing policymakers with actionable information at various stages of the policy cycle³⁸⁶. Our approach assumes that CO2 service will provide improved information on greenhouse gas inventories, which reduces errors and uncertainties and improves policy decision making, which creates economic value through more effective climate mitigation policy³⁸⁷. In theory, this service could reduce mitigation costs rather than increase effectiveness, but for practical reasons of data availability we have focused on the mitigation benefits only.

The impact pathway below outlines the intended effects of the service, showing how it could lead to benefits for society through reduced greenhouse gas emissions.

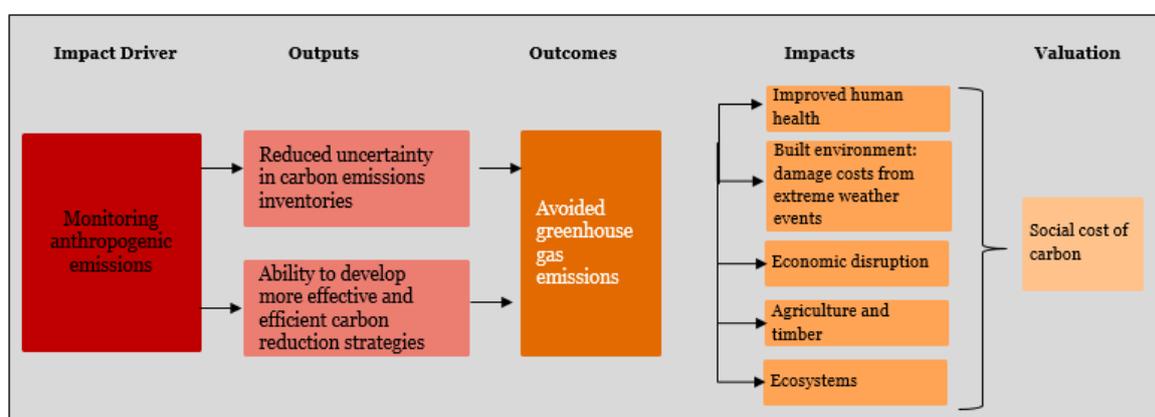


Figure 137 - Impact pathway for monitoring anthropogenic carbon emissions (Source: PwC analysis)

Approach to quantifying benefits

Under the UNFCCC Paris Agreement, 196 countries announced pledges to limit their greenhouse gas emissions, known as Nationally Determined Contributions (NDCs). In its NDC, the EU has committed to reducing its greenhouse gas emissions by 40% in 2030 compared to 1990 levels³⁸⁸. Our approach seeks to quantify the value of C3S/CAMS's information to meeting the NDCs in Europe and the rest of the world.

We estimated the value to society from meeting the NDCs by multiplying the reduction of GHG emissions by the social cost of carbon, which represents the net present value of impacts from climate change, expressed per tonne of CO₂ emitted. We multiplied this by an assessment of the contribution that the service's information could make to achieve this goal. This is broadly equivalent to the value of CO₂ emissions that could be avoided as a result of the services.

³⁸⁶ European Commission, 2015. Towards a European Operational Observing System to Monitor Fossil CO₂ emissions.

³⁸⁷ Cooke et al., 2016. Using the social cost of carbon to value earth observing systems.

³⁸⁸ EU INDC submission. Available at: < <http://www4.unfccc.int/submissions/INDC/Published%20Documents/Latvia/1/LV-03-06-EU%20INDC.pdf>>



Methodological approach to monitoring anthropogenic carbon emissions

Our approach is based on a study by Cooke et al 2016³⁸⁹, using the social cost of carbon to value CO₂ monitoring in Earth Observation Systems through the increased ability to meet carbon reduction targets. The steps to valuation are:

1. Determine the reduction in GHG emissions from meeting the NDC targets by comparing business-as-usual (BAU) and NDC emissions
2. Value this reduction using the social cost of carbon
3. Find the contribution of Copernicus in improving CO₂ monitoring and ability to meet NDC targets

Benefits from monitoring anthropogenic carbon emissions **Valuation approach**



Each component of this analysis is explained in the sections below.

Avoided GHG emissions from meeting NDCs

We have based our valuation approach on Cooke et al 2016, using the social cost of carbon and the latest research on applying this to EO systems³⁹⁰. To estimate emissions reductions due to the NDCs, we compared GHG emissions under NDC and business-as-usual scenarios using data from the United Nations Environment Programme (UNEP). Only CO₂ and CH₄ (methane) are included in the CO₂ service plans³⁹¹ so other greenhouse gas emissions were excluded from the analysis. For the rest of the world, we included all emissions. This assumes that service would provide data at a global level with the same quality as for Europe, and that this would be used by policymakers in all Paris Agreement signatories to equivalent effect.

Social cost of carbon

Climate change has a wide variety of impacts for different regions and stakeholders over different timescales. The overall net cost to society of all the current and future impacts is referred to as the social (or societal) cost of carbon (SCC). The social cost of carbon takes into account the impacts of climate change on human health, built environment, economic disruption, agriculture, desertification and ecosystem.

Estimates of the SCC are typically calculated in five steps³⁹²:

³⁸⁹ Cooke et al., 2016. Using the social cost of carbon to value earth observing systems.

³⁹⁰ Cooke et al., 2016. Using the social cost of carbon to value earth observing systems.

³⁹¹ Specification document from the EC. AI5 - TFO7 CO₂ - MRD - vo.2.pdf

³⁹² Integrated assessment models (IAMs) are widely used for estimating the SCC, and represent a simplified version of the five steps in a single model.

- **Define emissions scenarios:** GHG emissions are projected into the future, on the basis of scenarios of economic, social, and technological development.
- **Project climate change:** Climate models³⁹³ are used to translate emissions scenarios into changes in climate-related variables, such as temperature and precipitation, for each position in space and time.
- **Project environmental impacts:** Impact assessment models use climate model outputs to predict the subsequent impact on environmental systems not covered by climate models. Examples include storm and tropical cyclone models for extreme weather, and inundation models for sea-level rise.
- **Quantify impacts on society:** Economic models are used to assign monetary values to environmental impacts, based on the economic and social disruption that will be caused.
- **Aggregate impacts:** Social costs and benefits accrue in different times and places. To estimate a single figure for the SCC, these are aggregated globally and discounted to their present value. The chosen social discount rate indicates the rate at which society values present consumption relative to future consumption, and strongly affects the resulting SCC estimate.

There are over 300 published estimates of the SCC. It is therefore advisable to draw on this existing body of knowledge. PwC has published a meta-analysis of existing SCC estimates, which provides mean and median SCC estimates³⁹⁴. Based on this analysis, we have used a value of EUR 74.8/tCO₂e (2017 prices). The PwC analysis is part of PwC's natural capital valuation methodologies. An Independent Methodology Review Panel set up by the Natural Capital Coalition recommended PwC's approaches along with three others to inform the development of the Natural Capital Protocol. Full details of the PwC greenhouse gas valuation methodology and meta-analysis are published online at <http://www.pwc.co.uk/naturalcapital>.

Contribution of CO₂ Service to meeting the NDCs

In practice, it is challenging to estimate the potential value of CO₂ service's information for carbon emissions reductions. At present no satellite monitoring capability is mature enough to satisfy the requirement and no previous CO₂ emission monitoring and verification system of this nature exists. In addition, the contribution of Copernicus depends on the actions taken by policymakers based on this data and whether it influences international policymaking. As a result, there are no existing estimates in the literature that can be used, as far as we are aware, and it is difficult to precisely estimate the future impact of this service. Copernicus makes a contribution to climate targets by providing better information for policymakers to inform their decisions.

However, this is only a small part of what is needed; Copernicus itself does not lead the EU to meet its climate objectives. For example, significant investment will be required and data beyond Copernicus is also needed. The calculated benefits in this study indicate the value of the improved information from Copernicus to meeting the EU's climate goals. It is beyond the scope of this study to estimate the cost of meeting climate targets without the benefit of Copernicus data.

In the absence of existing data, there is a high level of uncertainty around the contribution for Copernicus. We have assumed a small percentage contribution of Copernicus between 0.1 and 0.5% to meeting the NDC targets. This is because numerous other factors affect whether countries will meet the NDC targets, including the existence of other monitoring and measurement systems, policies enacted, exogenous weather shocks (e.g. forest fires), economic output, population growth, technological changes and energy improvements. Our

³⁹³ These are typically general circulation models (GCMs).

³⁹⁴ PwC social cost of carbon methodology. Available at: < <http://pdf.pwc.co.uk/pwc-environmental-valuation-methodologies.pdf>>

assumption is consistent with previous studies and stakeholder consultations³⁹⁵. It is important to note that the benefits monetised here are contingent on policymakers acting on the Copernicus data to enable more rapid or effective policy change. Furthermore, this is a high level estimate and does not distinguish between different sectors and policies, which could be explored in future studies.

The service is expected to be fully operational from 2025, therefore, additional cumulated benefits over the period in the EU are expected to range between EUR 1,953.6 M (low) and EUR 9,505.9 M (high) in undiscounted 2017 values, and their evolution are illustrated in the chart below.

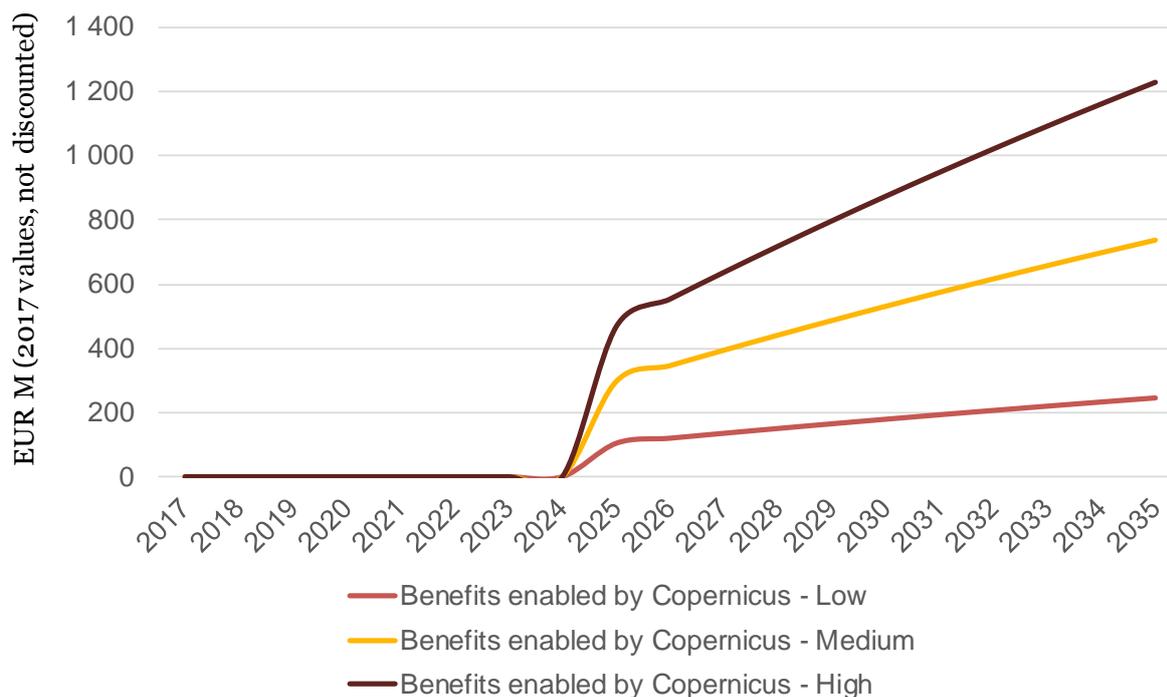


Figure 138 - Benefits enabled by Copernicus data and information to increased progress towards meeting Paris agreement targets in EU (EUR million in nominal values) (Source: PwC analysis)

³⁹⁵ For example: PwC 2006 and Booz 2011

The expected additional cumulated benefits in the rest of the world are between EUR 17,478.4 B (low) and EUR 42,827.7 B (high) in 2035 in 2017 undiscounted values, as illustrated below.

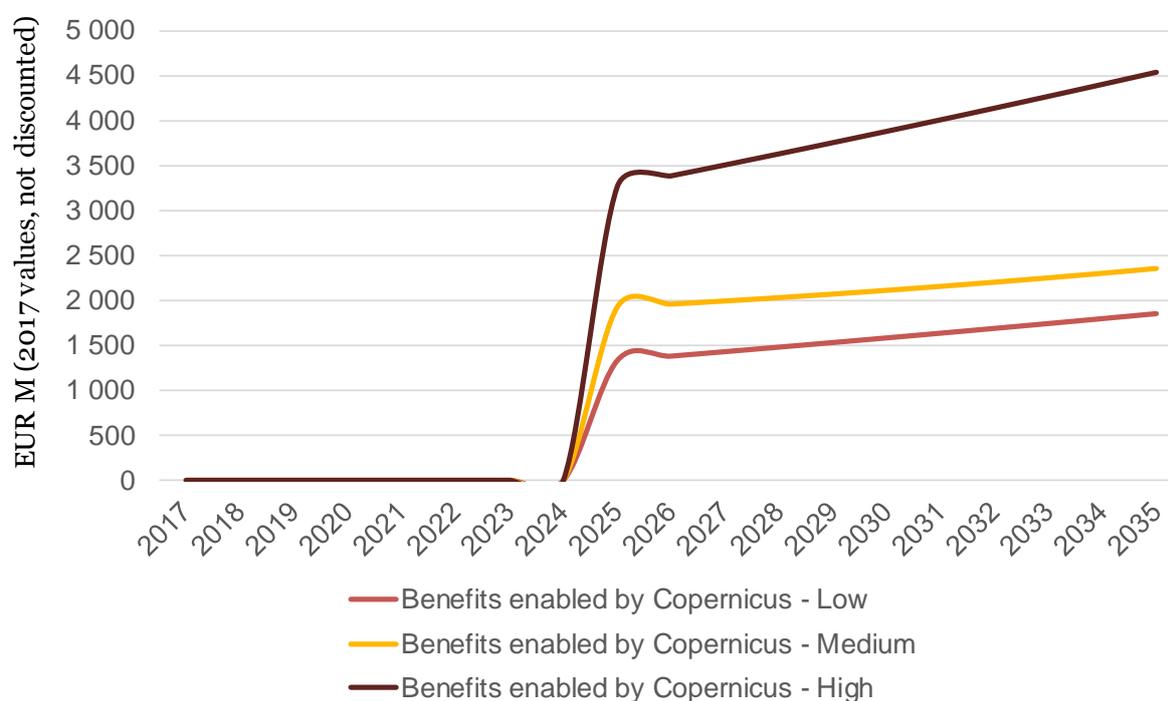


Figure 139 - Benefits enabled by Copernicus data and information to increased progress towards meeting Paris agreement targets in the rest of the world (without EU) (EUR million in nominal values) (Source: PwC analysis)

5.2.2.2.1 Total benefits under option 3A

Impact driver	Zone	Scenario	Gain
Monitoring anthropogenic carbon emissions	EU	Low	EUR 1,953.6 M
		Medium	EUR 5,783.1 M
		High	EUR 9,505.9 M
	Rest of the World	Low	EUR 17,478.4 M
		Medium	EUR 23,388.2 M
		High	EUR 42,827.7 M

Table 41 - Copernicus total benefits of option 3A for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

5.2.3 Option 3B – Arctic environment and snow evolution monitoring

5.2.3.1 Description

Option 3B is composed of two main enhancements of the services currently offered by the Copernicus programme: first the improvement of Arctic environment monitoring; second the improvement of snow monitoring activity over European mountain areas. Indeed, conservation and management of the Arctic region is becoming a key priority area for

Europe, and is part of the strategic goals of the European Union over the next decade³⁹⁶. Besides, the measurement of snow parameters such as snow extent, snow water equivalent (SWE) and snow melt are essential for several sectors such as hydrology (e.g. preparedness to flood), climatology (e.g. the evolution of climate systems on which evolution of snow extent have a major influence), meteorology (fog development) or water resources management (e.g. hydropower activities or water supply for agriculture).

Such an option would rely on an expansion mission including one or more satellites to fly in parallel with the current constellation (the first satellite should then be launched between 2025 and 2030). Some activities can already been done with the Sentinel satellites currently launched (Sentinel-1, 2 and 3) but this mission could be providing additional information related to floating ice parameters, glaciers, caps and ice sheets parameters, sea level, sea surface temperature (SST), permafrost, surface fresh water, surface Albedo or even snow (on a seasonal basis). By improving current observation and potentially offering additional ones, the aim would be to improve for example sea ice and iceberg monitoring capacities, including observation and/or models, as well as snow extent and corresponding water equivalent.

This option would potentially yield benefits across four domains namely, the first three being directly related to Arctic environment, the fourth one being linked to the snow monitoring capability:

- Support shipping and safe navigation in the Arctic region and adjacent seas;
- Support search and rescue in northern European countries and Arctic region;
- Support off-shore operations in the Arctic region and adjacent seas;
- Support water resources management through the improvement of hydropower water monitoring.

The expected benefits derived from this module are illustrated in the chart below.

³⁹⁶ European Commission, 2016. An integrated European Union policy for the Arctic. Joint communication to the European Parliament and the Council. Brussels, Belgium.

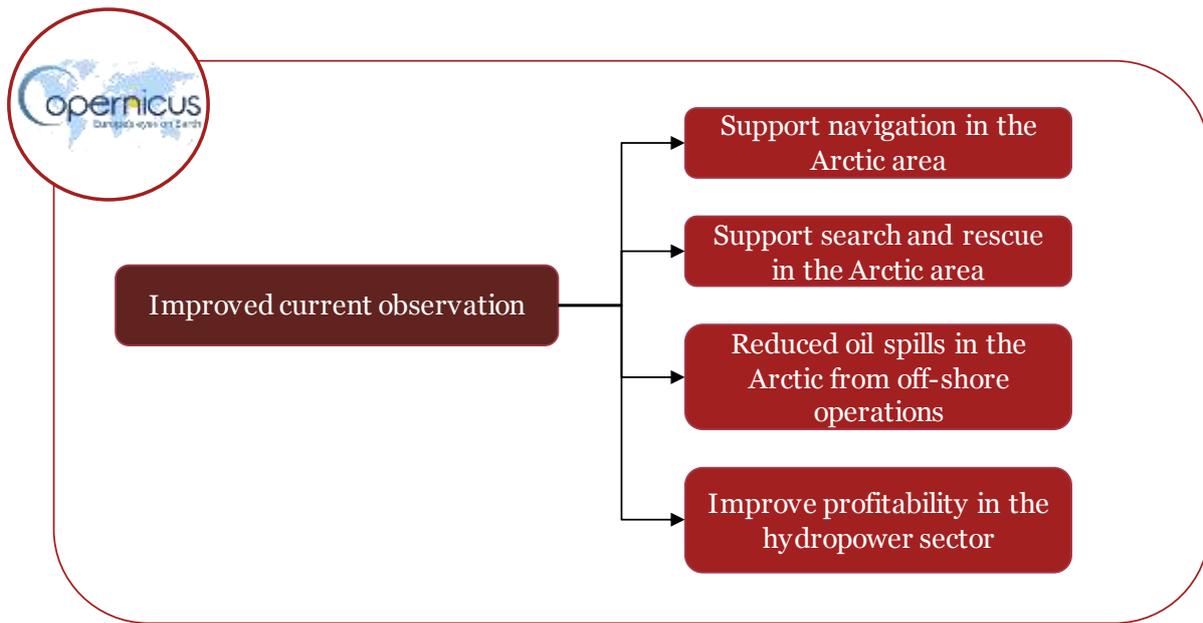


Figure 140 - High level illustration of the impacts expected from evolution option 3 – Arctic environment monitoring (Source: EC)

5.2.3.2 Monetization of option 3B benefits

The exact specifications of the Arctic environment and snow monitoring evolution option are still to be determined. As such, it has not been possible to monetise economically all the benefits of snow monitoring, notably those related to climate modelling, as there is not enough data and information on the specifications of the service and its potential impacts. The benefits of supporting climate change mitigation have been valued in the climate modelling application which, among others, includes data and re-analysis of the Arctic climatic conditions to improve climate models and projections.

Some benefits of this Arctic environment and snow monitoring service in the key EU policy areas can be monetised by scaling some applications from the baseline scenario, in the areas of maritime transport and security, to improve current observation in the Arctic. With the melting of the Arctic sea ice, shipping and off-shore operations are expected to increase in this region. Three key impact areas have been monetised:

- Maritime transport: Ice monitoring to support shipping navigation in the Arctic
- Security: Support search and rescue in the Arctic
- Pollution: Reduce oil spills in the Arctic from off-shore operations

It is important to note that there are also societal costs from increased traffic and resource extraction in the Arctic, which have not been valued here. Additionally, some of the benefits monetised below are likely to accrue to non-EU businesses and individuals, however as the study has taken a high level analysis, it is not possible to distinguish these due to boundary disputes, uncertain oil exploration and vessels and individuals from multiple countries active in the Arctic. In a future more detailed study, these assumptions should be refined.

The other benefit that can be monetised is the one related to the improved profitability of the hydropower sector. This benefit is enabled by the improvement of snow monitoring, as snow that is melt can be used for filling the hydropower facilities' reservoirs. Thanks to the

capability of monitoring Snow Water Equivalent, the impact of option 3B is deemed very high.

5.2.3.2.1 Arctic monitoring

5.2.3.2.1.1 Ice navigation in the Arctic

On the basis of a study by EARSC³⁹⁷ on the quantified benefits of ice navigation in the Baltic (Section 4.2.3.4.4), these impacts have been scaled to the Arctic, assuming that equivalent data to that provided by Sentinel-1 in the Baltic can be provided in the Arctic. The benefits have been scaled using the number of cargo vessel trips in the Arctic compared to the Baltic. All other assumptions from the Baltic model have been adapted, including user uptake. The benefits of ice navigation include the reduced cost of navigation, decreased pollution due to shortened journeys, increased commercial traffic and tourism. Benefits are quantified from 2025 to 2035.

Currently, the Arctic has 39% of the cargo shipping volumes of the Baltic³⁹⁸. As sea ice melts with climate change, it is projected that an additional 1% of global shipping will be diverted to the Arctic per year between 2020 and 2030 and 2% of global shipping per year between 2030-2035³⁹⁹. This growth in Arctic shipping has been included in the estimation of benefits. This gives a total indicative economic value of supporting ice navigation in the Arctic between EUR 371.2 million to EUR 669.0 million in 2035, in 2017 nominal prices.



Methodological approach for ice navigation in the Arctic

Our approach is based on section 4.2.3.4.4.1 which values the benefit of Copernicus from improved navigation routes in the Baltic region due to the ice navigation service. All assumptions have been adapted including user uptake. The steps of valuation are as follows:

1. Benefits of ice navigation in the Baltic region have been taken.
2. Scale by using number of cargo vessel trips in the Arctic compare to the Baltic.
3. Find growth in Arctic shipping as sea ice melts and apply this.

Benefits from ice monitoring in the Arctic Valuation approach



397 EARSC case study. (Online) Available at : <http://earsc.org/news/copernicus-sentinels-products-economic-value-study> (Accessed: July 19th 2017)

398 Calculated using: Eguluz et al, 2016. A quantitative assessment of Arctic shipping in 2010-2014. Available at: <https://www.nature.com/articles/srep30682>

399 Corbett et al., 2010. Arctic shipping emissions inventories and future scenarios. Available at: <https://www.atmos-chem-phys.net/10/9689/2010/acp-10-9689-2010.pdf>

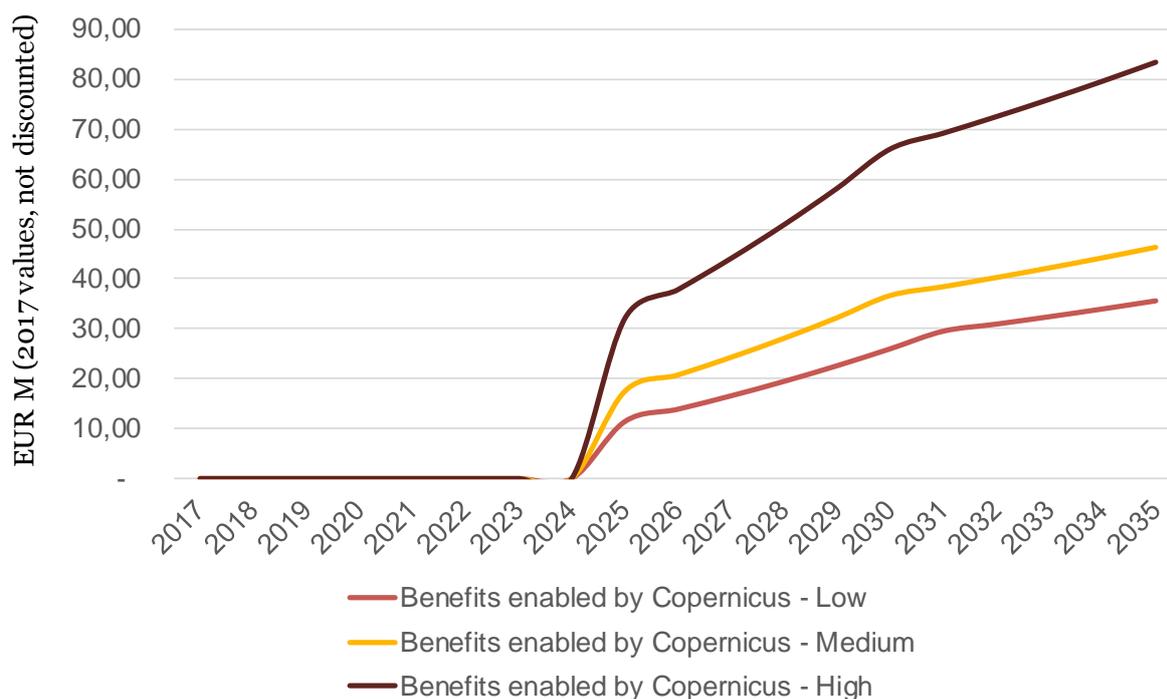


Figure 141 - Benefits enabled by Copernicus data and information to ice navigation in the Arctic (EUR million in nominal values) (Source: PwC analysis)

5.2.3.2.1.2 Search and rescue in the Arctic

The quantified benefits of the EMSA Search & Rescue (S&R) missions to vessels in emergency in Section 4.2.3.6.1 have been scaled to the Arctic by the number of vessels in the Arctic compared to the EU. It is assumed that this type of observation of vessels can be expanded to the Arctic as shipping traffic increases due to reduction in sea ice. All other assumptions have been maintained from the original model. Benefits include the statistical value of lives (economic impact of an avoided fatality) saved and are quantified from 2025 to 2035.

Currently, the Arctic has 10% of the cargo shipping volumes of the EU⁴⁰⁰. As sea ice melts with climate change, it is projected that 1% of global shipping will be diverted to the Arctic per year between 2020 and 2030 and 2% of global shipping per year between 2030-2035. This growth in Arctic shipping has been included in the valuation.

⁴⁰⁰ Calculated using World Bank data on container port traffic. Available at: https://data.worldbank.org/indicator/IS.SHP.GOOD.TU?locations=EU&year_high_desc=false



Methodological approach for search and rescue in the Arctic

Our approach is based on section 4.2.3.6.3.2 which values the benefit of a reduction in lives lost in maritime disasters. The use of satellite images contributes to more efficient S&R operations, which implies the saving of additional lives. The number of lives is then monetised by using the notion of statistical value for life (economic impact of an avoided fatality). All assumptions have been adapted including user uptake. The steps of valuation are as follows:

1. Benefits of search and rescue through EMSA have been taken.
2. Scale by using number of vessel trips (cargo, passenger and fishing) in the Arctic compare to the Baltic.
3. Find growth in Arctic shipping as sea ice melts and apply this.

Benefits from search and rescue in the Arctic *Valuation approach*



This yields a benefit of EUR 9.0 million to EUR 21.7 million in the statistical value of lives (economic impact of an avoided fatality) saved in the Arctic per year by 2035, in 2017 nominal prices. This generates a cumulated benefit of EUR 76.2M to EUR 192.5M in the statistical value of lives (economic impact of an avoided fatality) saved in the Arctic by 2035, in 2017 nominal prices.

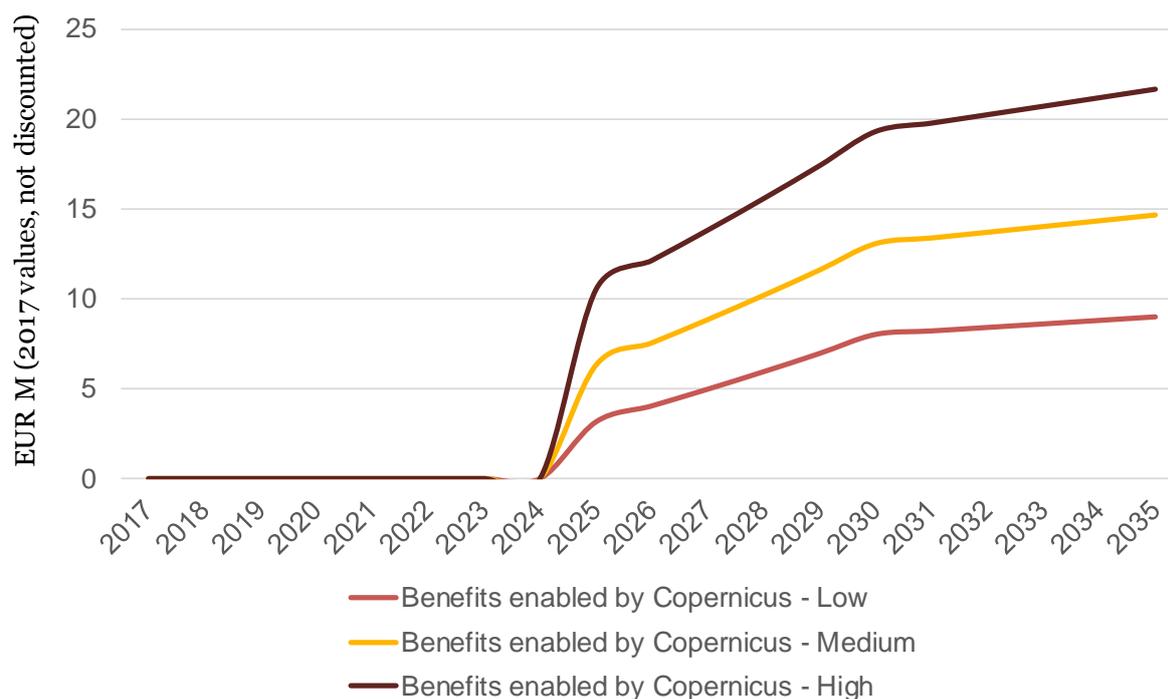


Figure 142 - Benefits enabled by Copernicus data and information for search & rescue of vessels in the Arctic (EUR million in nominal values) (Source: PwC analysis)

5.2.3.2.1.3 Reduced oil spills in the Arctic from off-shore operations

The quantified benefits of reducing oil pollution in Europe have been scaled to the Arctic using the projected oil extraction in the Arctic. Oil exploration in the Arctic has just begun, so it is expected that extraction in the Arctic reaches commercial volumes in 2030.⁴⁰¹ It is estimated that the Arctic region holds 13% of global oil reserves⁴⁰². It is assumed here that the Arctic will produce 13% of global current oil production, thereby producing 10 million barrels of oil a day at full capacity in 2030. This means it would have oil production at a factor 3.61 greater than Europe. The benefits quantified include the reduction in oil spills from oil platforms as well as oil spills from ships. The benefits of the reduced oil pollution in Europe is scaled using this factor, assuming the same frequency of oil spills as in Europe. It is assumed that in 2025 oil production is at 10% of total capacity, scaling up to 70% in 2035.

⁴⁰¹ <http://www.bbc.co.uk/news/business-33379982>

⁴⁰² Geopolitics of Arctic oil and gas: the dwindling relevance of territorial claims, E. Wong (Journal of George Mason University, 2013)



Methodological approach for reduced oil spills in the Arctic

Our approach is based on section 4.2.3.6.4 which values the economic and environmental benefit of Copernicus in monitoring oil pollution during oil spills. This values the reduction in economic and environmental costs from oil spills from ships and O&G platforms. All assumptions have been adapted including user uptake.

The steps of valuation are as follows:

1. Benefits of Copernicus oil spill monitoring in Europe have been taken.
2. Find projected oil reserve volumes in the Arctic in 2030.
3. Scale European benefits by project oil production volumes in the Arctic.

Benefits from reduced oil spills in the Arctic Valuation approach



This yields a benefit of EUR 47.6 million to EUR 79.2 million in reduced impacts from oil pollution in the Arctic per year by 2035. This generates cumulated benefits ranging between EUR 324.3 M to EUR 540.5 M in reduced impacts from oil pollution in the Arctic per year by 2035.

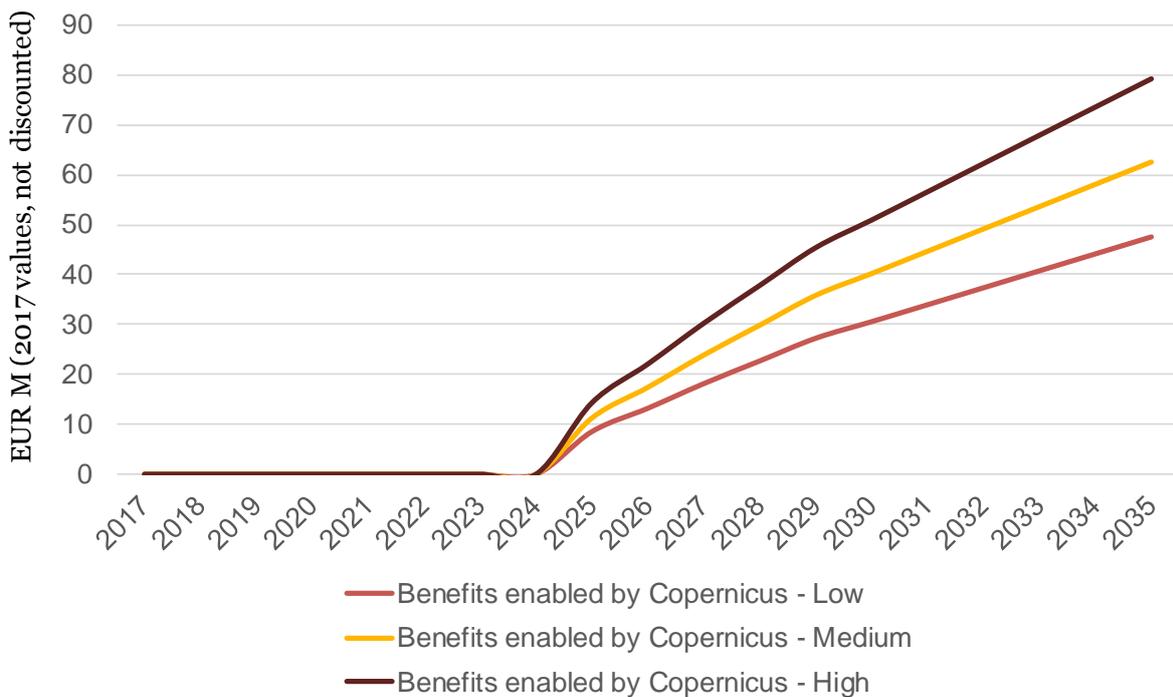


Figure 143 - Benefits enabled by Copernicus data and information for reduced oil spills from offshore operations in the Arctic (EUR million in nominal values) (Source: PwC analysis)

5.2.3.2.2 Water resources management

5.2.3.2.2.1 Improve profitability in the hydropower sector

In order to accurately measure how a basin will fill thanks to snow melting, the capacity to determine snow water equivalent (SWE) can be particularly useful. SWE corresponds to the amount of water contained within a snowpack. There is currently no satellite enabling to measure SWE in high resolution (with a spatial resolution of 100-500m), though some are under investigation. Moreover, given current non-satellite-based technologies, it is impossible to measure SWE in complex terrains (e.g. in mountains): it is only feasible in forests and in plains.

Today, predictive models exist to calculate the amount of water expected from snow melt, notably based on microwaves, which have a lower spatial resolution. As mentioned in section 4.2.3.2.3.1 – Improve profitability in the hydropower sector, hydropower dam managers currently use statistics of historical data on climate to forecast forthcoming water level. These statistics prove less and less relevant given the global warming context which has led to drastic change in climatic conditions over the years. As such, option 3B could prove essential to the hydropower industry, which is already using Copernicus data for hydroelectric plant management, through the improvement in the measurement of one of the water sources that feeds the reservoirs.



Methodological approach to value the improved profitability in the hydropower sector

Our model is based on the fact that improved accuracy in water flow knowledge results in higher benefits for hydropower plants through better reservoir optimization. The steps are:

1. Assess the percentage of hydroelectricity generated by dams using satellite –based forecast (for large dams and small dams)
2. Isolate the share of hydroelectricity due to snow melt and glacier runoff
3. Apply Copernicus option 3B contribution to this share of produced hydroelectricity, i.e. the gain in accuracy resulting from the development of SWE

Improve profitability of the hydropower sector

Valuation approach



There are several mountain regions in Europe, including the Alps, the so-called Europe’s water towers, which are considered to largely provide for four main rivers, the Rhine, the Po,

the Rhône and the Danube⁴⁰³. In Europe, the largest hydropower producing countries are Norway, Sweden, France, Italy, Austria, Switzerland: they account for about 70% of the European hydropower production⁴⁰⁴. From these countries, the share of water coming from glacier runoff and snow melt is extrapolated and estimated to represent about 23% of water supplies in European hydropower plants. Indeed, 15% of the hydroelectricity comes from glacier and snow melt in Norway (the biggest hydropower producer in Europe), 50% in Switzerland, the biggest hydropower plant in Austria is fed at 60% by glacial runoff, and more than a fourth of France' hydropower plants are fed by Alps glaciers⁴⁰⁵.

The same methodology is used as in section 4.2.3.2.3.1 – Improve profitability in the hydropower sector, with the major difference that the long term forecasts based on satellite data to predict the water flow coming from snow melt in reservoirs is now replaced by an accurate technique to calculate SWE and anticipate how the reservoir will fill. The forecast of other water sources such as precipitation remain unchanged through option 3B. As such, only a share of the additional revenues for the hydropower sector thanks to the use satellite data is concerned.

Option 3B is expected to be operational by 2025. As there is currently no other satellite able to provide SWE techniques, Copernicus would be the only programme able to provide this. However, it does not imply that the contribution of Copernicus option 3B is 100%: knowing only SWE is not useful for hydropower dams' managers, there is a need to combine with other type of data such as climatic data to know when glaciers and snow are expected to melt for instance. Therefore, option 3B provides additional sources of information compared to what already exists. In 2025, the contribution is expected to be of 0.1% to 0.5% as forecast providers will slowly start to integrate SWE to their analysis, growing to between 3% and 5% in 2028, reaching between 20% and 40% in 2035.

The expected total benefits of the Copernicus option 3B for improved profitability in the hydropower sector are to amount to between EUR 18 K and EUR 205 K in 2025, rising to between EUR 6.8 M and EUR 31.1 M in 2035.

The evolution option 3B for improved profitability in the hydropower sector therefore represents an increase of between EUR 29.8 M and EUR 132.3 M compared to option 1, the baseline option (not discounted values).

403 Euromontana, 2010, Energy in Mountain Areas (Online). Available at: https://www.euromontana.org/wp-content/uploads/2014/08/2010-04-01_PositionPaperEnergy_EN.pdf

404 World Energy Council Website. Available at: <https://www.worldenergy.org/data/resources/resource/hydropower/>

405 Singh, V. P., Singh, P. & Haritashya, U. K., 2011, Encyclopaedia of Snow, Ice and Glaciers

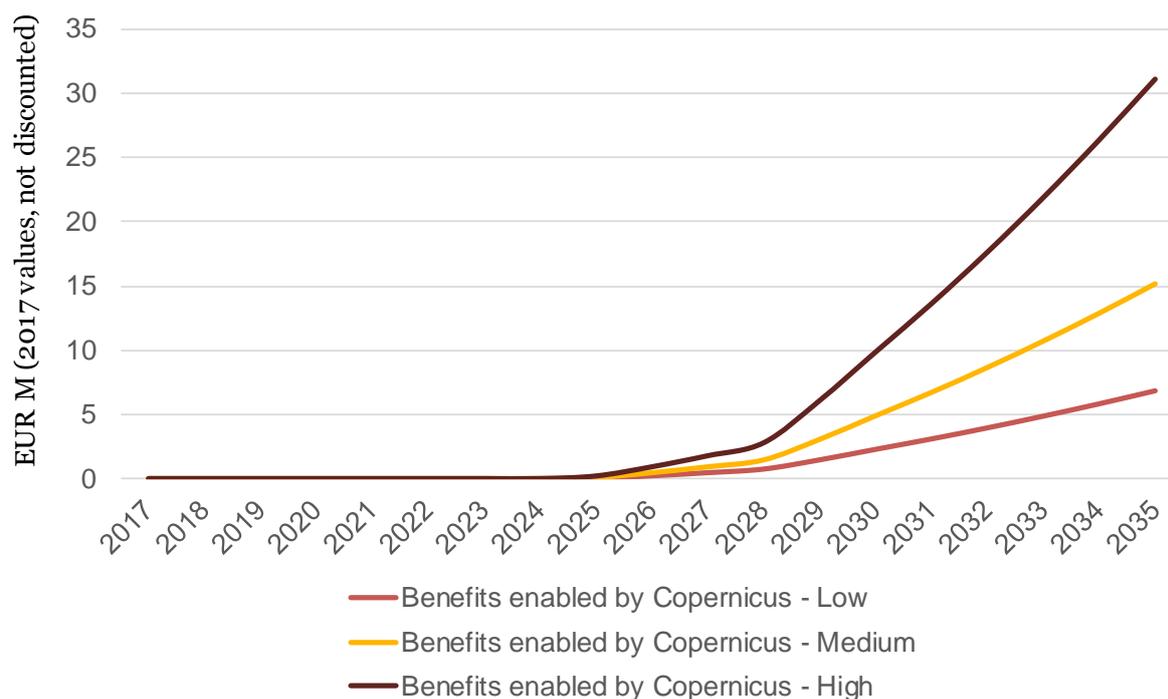


Figure 144 - Evolution of the Copernicus benefits attributed to option 3B for the impact “Improve profitability in the hydropower sector” from 2017 to 2035 (Source: PwC analysis)

5.2.3.2.3 Additional impacts not monetized for snow monitoring

As previously mentioned, besides on the hydropower sector, snow monitoring can have several impacts.

First, the snow monitoring service could support preparedness to flood. Currently, there are snow monitoring services that operate at a global scale but do not provide the right accuracy to be used at regional level. Public authorities, part of civil protection, would be the first concerned by such an application. If, snow is not often involved in flooding, when it is, it can be devastating: for instance, in May 1999 in the Bavarian region as well as in Austria, the combination of the relatively high temperatures compared to the seasonal norms and the following three days of heavy rain led to dramatic flooding. As such, hydrographic services deeply need information on snow melt to propose adapted responses to floods and to anticipate them through predictive models. Snow melt products are of important use in this case (it is already possible to develop such products with current Sentinel satellites) but also snow water equivalent products which give the exact amount of water contained in a snowpack.

Second, the ability to monitor snow evolution plays a key role in weather and climate monitoring. This service would prove useful in the development of weather prediction models and in the running of climate models. Public authorities would once again be the main users. Indeed, snow can have severe consequences if not predicted in advance on infrastructure such as road blocked or railways perturbed: it will be used to optimize operation and maintenance of infrastructure.

Third, an indirect impact on tourism can be noted. The snow monitoring service can be used by ski resort managers to predict snow levels and adapt in case of lower snow levels during very touristic seasons. This does not imply that more tourists will be attracted but that ski resort managers will be able to optimize the management of their facilities. Currently, ski resort managers already have systems to monitor snow levels but not through satellite data. The snow extent, already enabled by Sentinel-2 and 3, would be key for such an application.

5.2.3.2.4 Total benefits under option 3B

Impact driver	Impact/benefit	Scenario	Gain
Arctic monitoring	Ice navigation in the Arctic	Low	EUR 272.6 M
		Medium	EUR 371.2 M
		High	EUR 670.0 M
	Search & rescue in the Arctic	Low	EUR 76.2 M
		Medium	EUR 127.8 M
		High	EUR 192.5 M
	Oil pollution in the Arctic	Low	EUR 324.3 M
		Medium	EUR 426.7 M
		High	EUR 540.5 M
Snow Monitoring	Improve profitability of hydropower sector	Low	EUR 29.8 M
		Medium	EUR 65.0 M
		High	EUR 132.3 M

Table 42 - Copernicus total benefits of option 3B for the three scenarios (EUR 2017, not discounted values)
(Source: PwC analysis)

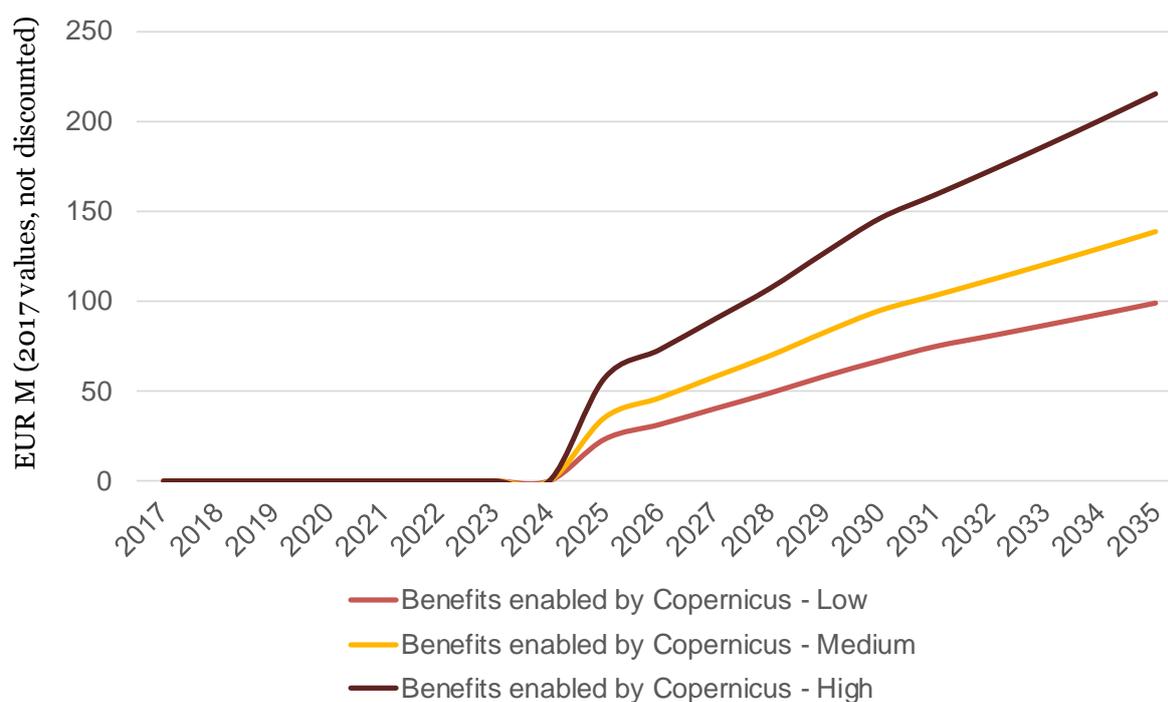


Figure 145 - Benefits enabled by Copernicus data and information for evolution option 3B (EUR million in undiscounted values) (Source: PwC analysis)

5.2.4 Option 3C – Thermal infrared capability to monitor water and agriculture

5.2.4.1 Description

Option 3C aims to complement Sentinel observation capabilities with enhance Thermal InfraRed (TIR) capability over land and coastal areas to notably support agriculture management services as well as additional applications. This new capability is expected to be launched in 2026 and operational by 2027.

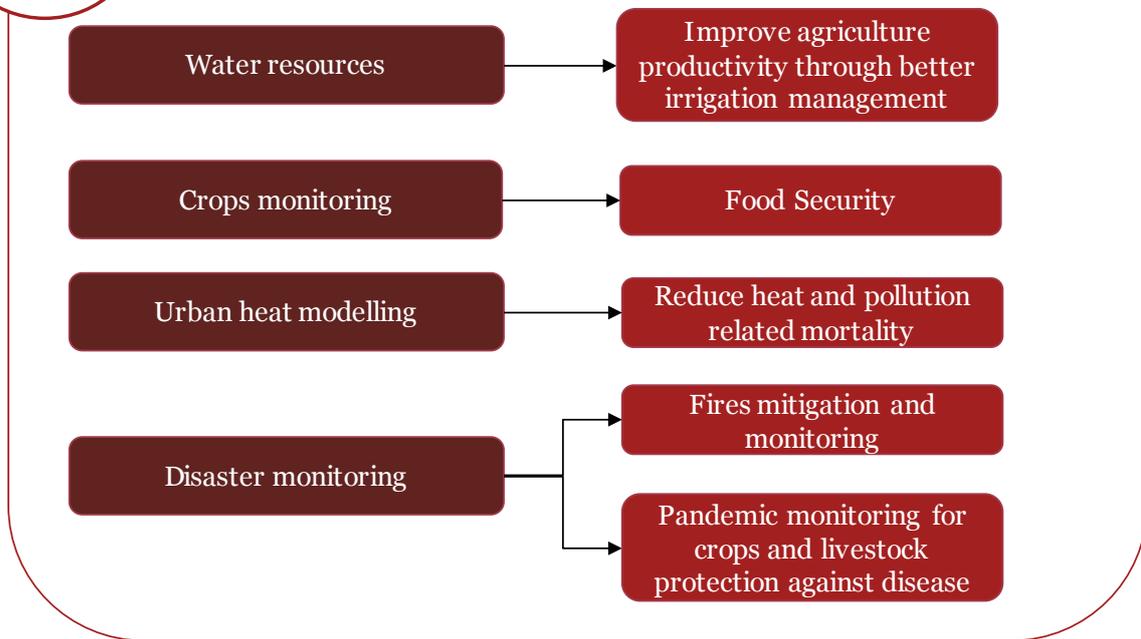
The Copernicus programme already provides thermal information over land and water through contributing missions such as Landsat 8 and Sentinel missions such as Sentinel-3A and 3B. However, these existing thermal infrared capabilities will not be sufficient enough to answer growing needs for surface temperature data in critical domains and applications such as agriculture, water management, urban management, fire monitoring and pandemic monitoring. The current Sentinel 3 mission sensors cannot provide measurement with a greater resolution than 1km. Therefore, a dedicated mission providing high spatio-temporal resolution thermal infrared data is envisaged as an evolution option.

The key target of the Option 3C mission is to monitor evapotranspiration at European level, analysing the variability of Land Surface Temperature (LST) to support agriculture. Enhanced Thermal InfraRed capability could also support mapping and monitoring of soil composition (mineralogy and organic matter).

Therefore, introduction of new enhanced TIR capabilities within Copernicus products portfolio, could affect the following impact drivers and certain of their derived benefits:

- Water resources management as far as the irrigation management for agriculture is concerned.
- Crops monitoring concerning the Food security issue (water stress detection)
- Urban Monitoring when it comes to Urban Heat Islands mitigation
- Fire detection and monitoring, concerning both environmental consequences and economic ones;
- Pandemic monitoring for the protection of crops and livestock against disease.

The expected benefits derived from this module are illustrated in the chart below.



5.2.4.2 Monetization of option 3C benefits

The results of the qualitative assessment of the impact of Copernicus option 3C, as mentioned in the introductory part of option 3, are presented in the following table:

Evolution option	Extent of the impact on use cases				
	Improve agriculture through better irrigation management	Improve food security	Reduce Urban Heat Islands	Fire detection and monitoring	Improve crops protection against disease (Pandemics)
Thermal Infrared sensor : assess the Land Surface Temperature and the Evapotranspiration of plants	High	High	Medium	Low	Very High

Table 43 - Qualitative assessment of the impact of Copernicus option 3C on the different benefits (Source: PwC analysis)

5.2.4.2.1 Crop monitoring – support to agriculture

5.2.4.2.1.1 Improve food security through better assessment of crops stress

Drought and floods can cause great social, environmental and economic impact, especially when it causes food security issues. To monitor the severity of these natural events as well as to support decision makers in mitigating drought impacts, institutions and NGOs need dynamics approach with a better coverage than the currently used rain gauge network. To face this need for accurate data on crops status and level of precipitation, operational satellite-based hydrologic monitoring is one of the best option.

To monitor anomalies in agricultural water use and ecosystem health, assessment of the evapotranspiration (ET) of crops and maps of land surface temperature (LST), are crucial data to mitigate food security issues. Indeed TIR sensor can detect high resolution thermal signatures and so assess the crops water status and overall stress. With access to evapotranspiration data, crops stress can be detected before crops start to show visual signs of bad health. This is crucial for early warning as the fatal consequences of droughts and harvest failures (famine) can be tackled before they evolve. Hence the introduction of TIR capability could really enhance the contribution of Copernicus to early warning services for food security matters.



Option 3C - Methodological approach to value the impact on food security

We measured the impact of Copernicus on food security by assessing the decrease in the amount of money disbursed for food assistance (by the EU). This decrease is enabled by early warning system like the ones used for small holder insurance. We took crops insurance as a proxy to assess the benefit of early warning. The steps are:

1. Assess the total pay-out from small holder insurance in case of harvest failure (risk modelling).
2. Calculate the equivalent in emergency aid that should have been disbursed if the crisis has evolved (ratio of 4.4)
3. Make the difference between the two to have the saving realised thanks to Early intervention
4. Assess improved Copernicus contribution to early warning system and to index based insurance, thanks TIR capability.

Improved food security

Valuation approach



The methodological approach is the same as in the baseline scenario (see section 4.2.3.2.1.3), but with TIR capabilities, the Copernicus contribution to early warning is expected to increase. Indeed with TIR technology, Copernicus services for food security will be enhanced and meet perfectly the requirement to develop a robust early warning systems.

As TIR capability is expected to be operational in 2027, the uptake of Copernicus data will increase from this date onwards. The expected additional benefits of Copernicus with option 3C, are to amount EUR 5.2 M in 2027, rising to between EUR 90.2 M and EUR 116.0 M in 2035 for a total cumulative value over the 2027-2035 period of between EUR 353.2 M and EUR 471.8 M.

Compared to baseline scenario, the evolution of the additional gain resulting from option 3C is represented in the chart below:

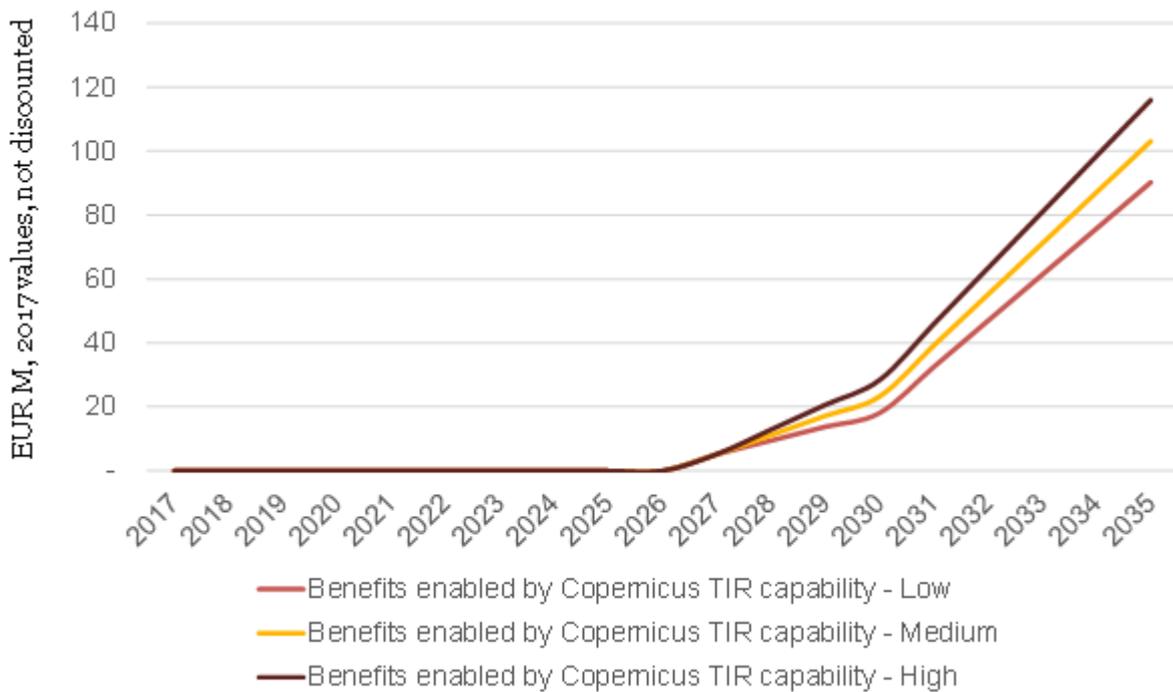


Figure 146 - Evolution of the additional gain enabled by TIR for “Improve Food security” from 2017 to 2035 (Source: PwC analysis)

5.2.4.2.2 Water resources management

5.2.4.2.2.1 Improve agriculture productivity through better irrigation management

High resolution thermal data enables improved monitoring of crop water and supports better irrigation management. Improved evapotranspiration measures give particularly relevant information on the crops need for water. Therefore irrigation systems can be calibrated to give the crops exactly the amount of water they need at the right moment. It would give greater support to farmers by leading them to better decision making. Furthermore, increasing the frequency of the provision of evapotranspiration measures would logically have a significant impact on crop water productivity.

Monitoring of high resolution thermal signatures (assessing the crop water status) allows to derive essential soil parameters that cannot be retrieved with the VNIR/SWIR spectral range. This would support the implementation of resilient agricultural practices, maintaining ecosystems and progressively improving land and soil quality, and thus leading to sustainable agriculture. Finally higher thermal image resolution would also impact smaller agricultural water users with small and/or scattered crop fields with a size below 1 hectare as their modest in size crops would be covered and they could use thermal information to optimise their water productivity.

Hence Copernicus TIR capability would really optimise irrigation management for agriculture. This kind of precision farming techniques (irrigation precision) are already proposed by Copernicus services through other measurement (soil moisture for example), but the introduction of Thermal infrared technology will clearly improve the benefits for the agriculture sector. Indeed Surface temperature is already being observed from space with TIR sensors, however at spatio-temporal resolutions insufficient for agriculture. A TIR

satellite mission which would be able to complement the high resolution visible (VIS) and near-infrared (NIR) observation acquired by Sentinel-2 and Landsat satellites would be a real asset for irrigation management and food security.



Option 3C - Methodological approach to value the improved Productivity for Agriculture (irrigation)

Our model is based on the volume of water saved thanks to better irrigation management enabled by EO information. The steps are:

1. Assess the volume of irrigation water used on crops monitored by PF/satellite data based tools
2. Assess the percentage of water saved thanks to better irrigation management enabled by EO information including TIR capabilities, and multiply it by the price of 1 m³ of irrigation water
3. Multiply by an improved Copernicus contribution thanks to TIR capability

Improve agriculture productivity through better irrigation management

Valuation approach



The methodological approach is the same as in the baseline scenario (see section 4.2.3.2.3.3), but the Copernicus contribution is increased. Indeed considering that TIR capability is expected to be operational starting from 2027, the uptake of Copernicus data by farmers will increase from this date onwards.

The expected additional benefits of Copernicus with option 3C for irrigation management, are to amount between EUR 0.6 M and EUR 0.8 M in 2027, rising to between EUR 12.7 M and EUR 25.9 M in 2035 for a total cumulative value over the 2027-2035 period of between EUR 48.3 M and EUR 98.8 M.

Compared to baseline scenario, the evolution of the additional gain resulting from option 3C is represented in the chart below:

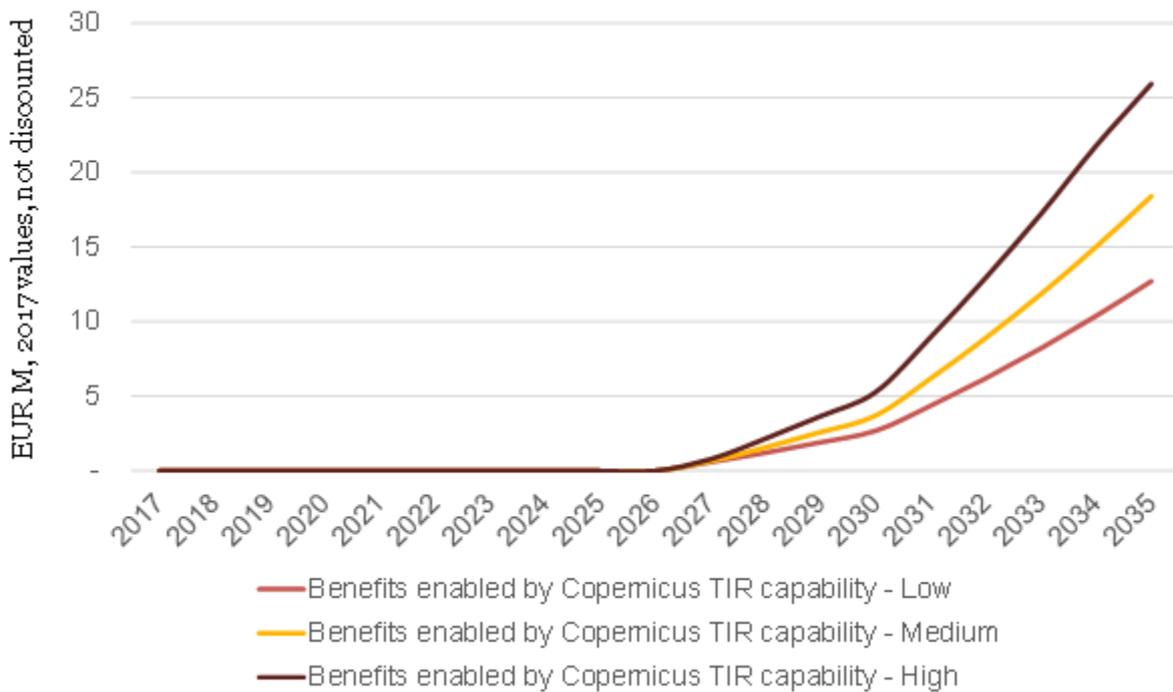


Figure 147 - Evolution of the additional gain enabled by TIR for “Improve Agriculture productivity through better irrigation management” from 2017 to 2035 (Source: PwC analysis)

5.2.4.2.3 Urban area monitoring

5.2.4.2.3.1 Reduced mortality rate caused by Urban Heat Islands

Improved thermal observation means would be fully relevant within the strategy to be introduced with the objective to limit global temperature increase below 2 degrees Celsius expressed through the COP 21 Paris agreement in December 2015. An enhanced Thermal InfraRed capability provided by the implementation of Option 3C would enable a more precise identification of Urban Heat Islands. Indeed, with an increased spatial resolution comprised between 20 and 50 meters, urban heat spots would be detected more efficiently allowing an improved reduction of fatalities caused by excess heat. Thermal landscape data with better spatial resolution would empower city planners with greater flexibility when conceiving smarter and cooler cities.



Methodological approach to value the contribution of Copernicus to the reduction of the mortality rate caused by Urban High Islands effects

The model is based on the economic impact of the number of fatalities caused by Urban Heat Islands.

The steps are:

1. Assessment of the potential number of fatalities caused by the effects of Urban Heat Islands in baseline scenario
2. Assessment of the potential number of fatalities caused by the effects of Urban Heat Islands in mitigation scenario
3. Assessment of the potential number of fatalities saved in mitigation scenario when

- comparing it to the baseline scenario
- Assessment and application of the contribution of Copernicus to mitigate the effects of Urban Heat Islands and to support the reduction of the number of casualties caused by Urban heat Island upgraded by additional TIR capability comprised by the potential implementation of Option 3C.

Reduced Traffic accidents

Valuation approach

$$\text{Impact (EUR)} = \text{Contribution of Copernicus TIR to the improvement of road security} \times \left(\text{Number of road accidents fatalities avoided in urban area} \times \text{Average economic impact of EU fatality} + \text{Number of road accidents fatalities avoided in urban area} \times \text{Average economic impact of EU fatality} \right)$$

As mentioned in the steps followed to monetise the benefits of option 3C, the contribution of Copernicus was adjusted according to the greater resolution that would be achieved through enhanced Thermal InfraRed capability. Therefore, the values obtained in the baseline were increased from 2027 to 2035. By 2027, when sentinel mission carrying improved TIR sensors would be hypothetically launched, the expected additional benefits of Copernicus with option 3C, would amount between EUR 402K and EUR 1.491M in 2027, rising to between EUR 25.7M and EUR 147.9M in 2035 for a total cumulative value over the 2017-2035 period comprised between EUR 73.2M and EUR 395.3M.

Compared to baseline scenario, the evolution of the additional gain resulting from option 3D is represented in the chart below:

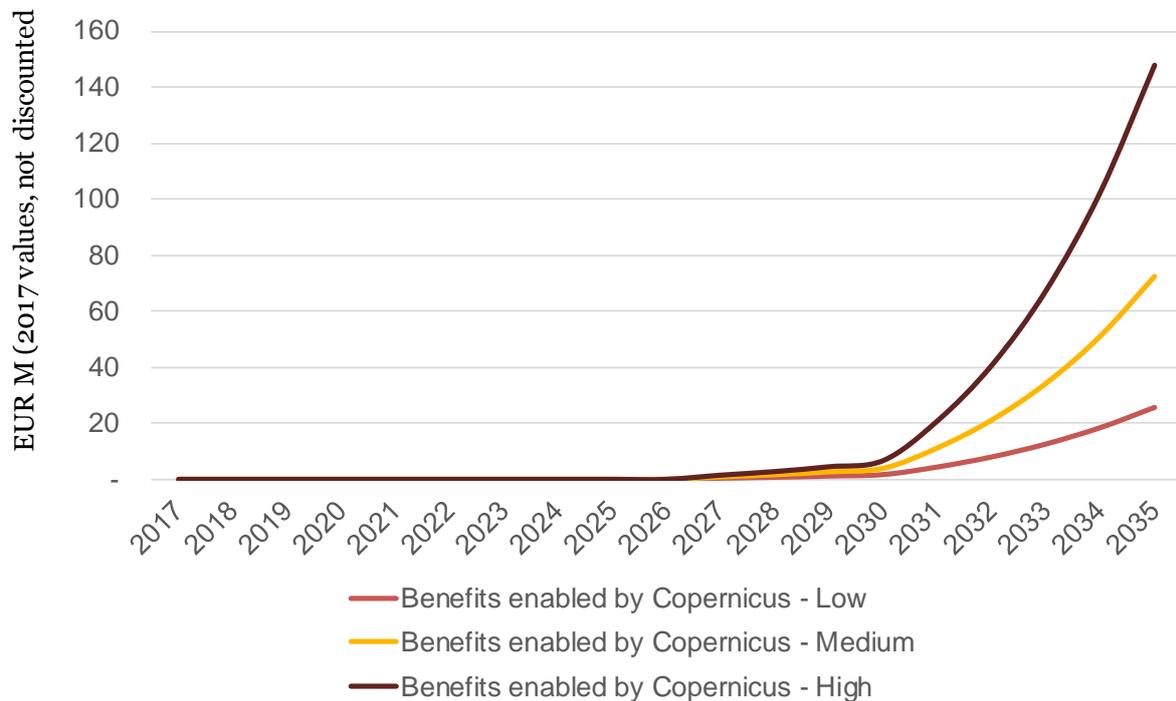


Figure 148 - Evolution of the additional gain enabled by TIR for the impact "Reduced mortality rate caused by urban heat islands" from 2017 to 2035 (Source: PwC analysis)

5.2.4.2.4 Fire detection and monitoring

The introduction of a Thermal Infrared capability is expected to have an impact on fire detection, hence on prevention, preparedness and response but not on the next phase which

consists in risk and recovery mapping. As such, the EFFIS service, presented in section 4.2.3.5.1 – Fire detection and monitoring, is going to be impacted by this new capability. The advantage of thermal is that it detects the energy that is emitted rather than the energy that is reflected⁴⁰⁶: this can prove useful to anticipate wildfires.

5.2.4.2.4.1 Reduced environmental damages



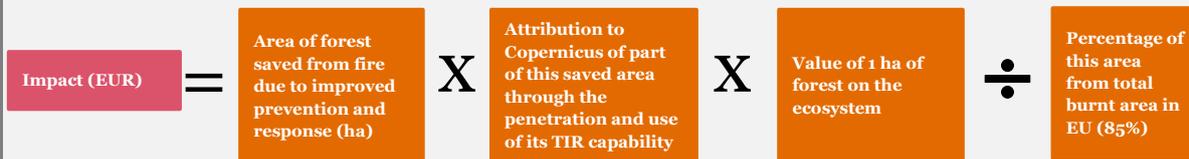
Methodological approach to value to socio-environmental benefits of reduced forest fire area

The assessment consists in looking at the areas saved from burning thanks to EFFIS and the Copernicus EMS mapping service and to analyse the environmental value that was prevented from being lost. The steps are:

1. Determine the size of the areas that could theoretically be saved from fire burning thanks to fire prevention strategies and preparedness in five countries (Portugal, Spain, Italy, Greece and France⁴⁰⁷).
2. Expand the size of the areas saved to the whole of Europe by doing a ratio between burnt areas in Europe and in these five countries.
3. Take into account the 10-year recovery rate of burnt areas.
4. Apply a valuation coefficient to each type of areas that was not burnt and that has not recovered yet, which corresponds to the value that each type of land provides to the ecosystem.
5. Apply the contribution of Copernicus enhanced TIR capability to the EMS mapping service and EFFIS.

Social and Environmental benefits due to reduced forest fire area

Valuation approach



A similar methodology is applied as in section 4.2.3.5.1.1 – Reduced environmental damages. The major difference lies in the contribution of Copernicus, and here, more precisely, of the thermal infrared capability. TIR is expected to add between 0.1% and 0.5% added value to the current contribution of Copernicus through EFFIS to burnt areas saved, rising to 2% to 5% in 2035.

The expected total benefits of Copernicus are to amount to between EUR 113.8 K and EUR 569.0 K in 2027, rising to between EUR 614.5 K and EUR 3.07 M in 2035. The evolution option 3C therefore represents an increase of between EUR 3.8 M and EUR 18.9 M compared to option 1, the baseline option (not discounted values).

406 Allison, R. S., Johnston, J.M., Craig, G. & Jennings, S., 2016, "Airborne Optical and Thermal Remote Sensing for Wildfire Detection and Monitoring", Sensors

407 San-Miguel-Ayanz and EFFIS Team, 2015. The European Forest Fire Information System

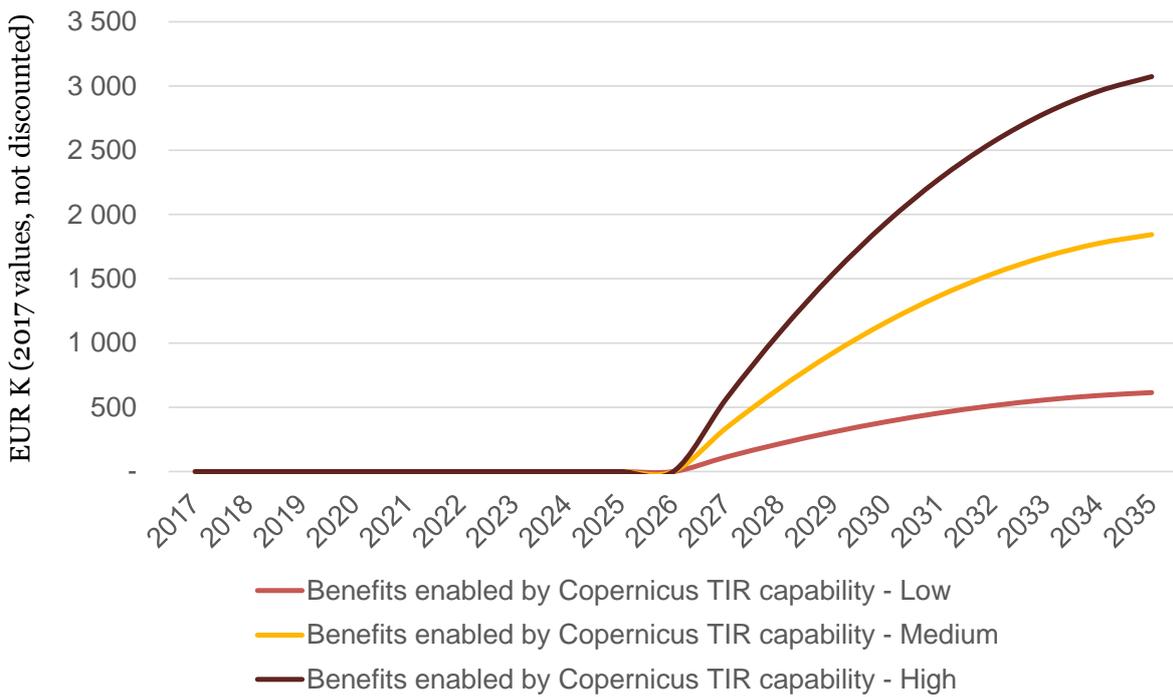


Figure 149 - Evolution of the Copernicus benefits attributed to option 3C for the impact “Reduced environmental changes” from 2017 to 2035 (Source: PwC analysis)



Methodological approach to value the benefits of reduced toxic emissions due to reduced burnt area

The assessment consists in looking at the areas saved from burning thanks to EFFIS and the Copernicus EMS mapping service and to analyse the environmental value that was prevented from being lost. The steps are:

1. Determine the size of the areas that could theoretically be saved from fire burning thanks to fire prevention strategies and preparedness in five countries (Portugal, Spain, Italy, Greece and France⁴⁰⁸).
2. Expand the size of the areas saved to the whole of Europe by doing a ratio between burnt areas in Europe and in these five countries.
3. Apply a CO₂ valuation coefficient based on the CO₂ mass that is emitted per ha of forest.
4. Apply the contribution of Copernicus enhanced TIR capability to the EMS mapping service and EFFIS.

Environmental benefits due to reduced forest fire area

Valuation approach



A similar methodology is applied as in section 4.2.3.5.1.2 – Reduced toxic emissions. The major difference lies in the contribution of Copernicus, and here, more precisely, of the thermal infrared capability. TIR is expected to add between 0.1% and 0.5% added value to the current contribution of Copernicus through EFFIS to burnt areas saved, rising to 2% to 5% in 2035. This is similar as the results of the previous benefits as the effects are all intertwined.

The expected total benefits of Copernicus are to amount to between EUR 666 K and EUR 3.3 M in 2027, rising to between EUR 13.3 M and EUR 33.3 M in 2035. The evolution option 3C therefore represents an increase of between EUR 54.6 M and EUR 133.2 M compared to option 1, the baseline option (not discounted values).

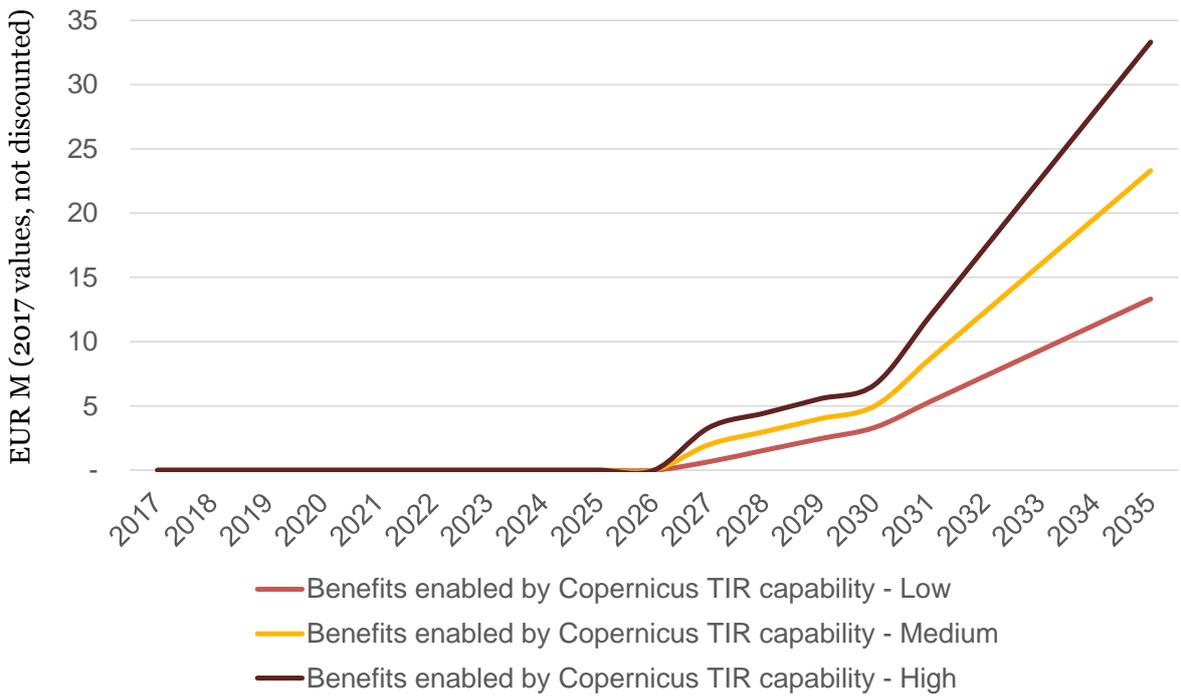


Figure 150 - Evolution of the Copernicus benefits attributed to option 3C for the impact “Reduced toxic emissions” from 2017 to 2035 (Source: PwC analysis)



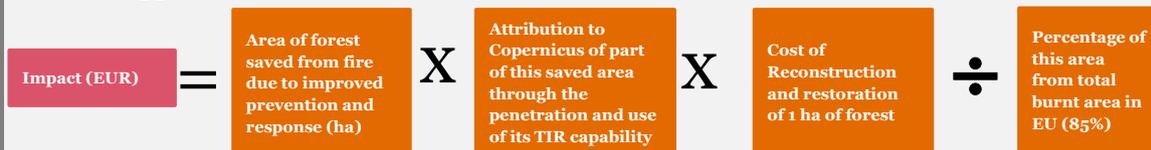
Methodological approach to value economic benefits due to reduced forest fire area

The assessment consists in looking at the areas saved from burning thanks to EFFIS and the Copernicus EMS mapping service and to analyse the environmental value that was prevented from being lost. The steps are:

1. Determine the size of the areas that could theoretically be saved from fire burning thanks to fire prevention strategies and preparedness in five countries (Portugal, Spain, Italy, Greece and France⁴⁰⁹).
2. Expand the size of the areas saved to the whole of Europe by doing a ratio between burnt areas in Europe and in these five countries.
3. Apply the economic cost of a hectare of forest lost.
4. Apply the contribution of Copernicus enhanced TIR capability to the EMS mapping service and EFFIS.

Economic benefits due to reduced forest fire area

Valuation approach



A similar methodology is applied as in section 4.2.3.5.1.3 – Reduced economic losses. The major difference lies in the contribution of Copernicus, and here, more precisely, of the thermal infrared capability. TIR is expected to add between 0.1% and 0.5% added value to the current contribution of Copernicus through EFFIS to burnt areas saved, rising to 2% to 5% in 2035. This is similar as the results of the previous benefits as the effects are all intertwined.

The expected total benefits of Copernicus are to amount to between EUR 2.8 M and EUR 13.8 M in 2027, rising to between EUR 55.4 M and EUR 138.4 M in 2035. The evolution option 3C therefore represents an increase of between EUR 226.9 M and EUR 553.5 M compared to option 1, the baseline option (not discounted values).

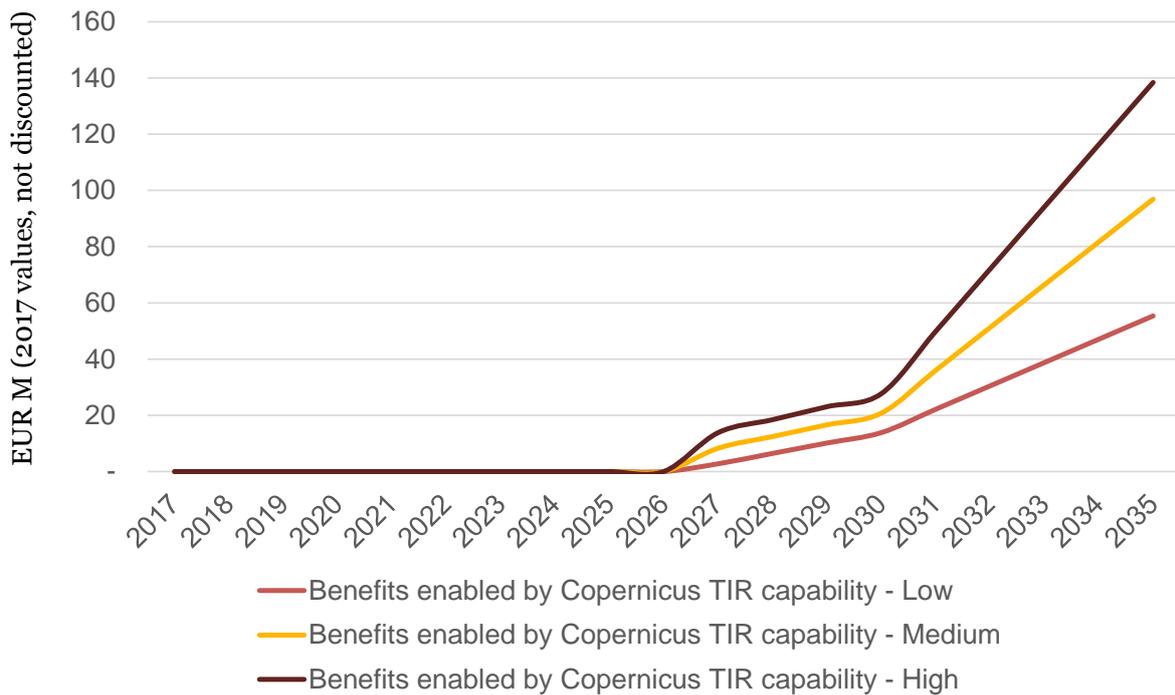


Figure 151 - Evolution of the Copernicus benefits attributed to option 3C for the impact “Reduced economic losses” from 2017 to 2035 (Source: PwC analysis)

5.2.4.2.5 Pandemic monitoring

5.2.4.2.5.1 Crop areas protected/livestock saved from the development of disease resulting in increase in revenue for farmers

Existing Sentinel satellites do not enable to have precise information on disease affecting crops and plants. For some diseases, the symptoms are not visible to the human eyes before long and only remote sensing technology could enable an upstream detection of the disease through the analysis of the plant physiology. As such, having access to Thermal Infrared capabilities could facilitate the tackling of some crop and plant diseases, moreover that the same disease may affect several types of crops and plants.



Methodological approach to value the crop areas protected from the development of diseases and resulting in an increase in revenue for farmers

Our model is based the volume of cereals that could have been harvested every year but that was lost to diseases. The steps are:

1. Calculate the volume of cereals that could have been harvested if there was no disease affecting the plantations
2. Determine the average size of the plantations corresponding to the volume of cereals not harvested
3. Based on the gross margin of European cereal producers, determine the revenues that was lost
4. Assess how the Copernicus TIR capability could contribute to diminishing these losses

Crop areas protected from the development of diseases and resulting in an increase in revenue for farmers

Valuation approach



The model is based on the volume of cereals harvested every year. This volume is expected to grow by 0.99% per year based on the trend of the 10 previous years⁴¹⁰. To this volume of cereals harvested is associated a size of plantations in hectare. Though the volume of cereals harvested is supposed to increase, the size of plantations is set to diminish by an average of 0.51% per year, based on the trend of the previous 10 years⁴¹¹: this means that productivity over a hectare of land is increasing over the years. Moreover, actual cereal losses due to weeds, animal pests and diseases ranges from 14% to 28.2% and are expected to diminish over the period thanks to improvement of chemical solutions (such as pesticides). Thanks to this value of actual losses, it is possible to calculate the size of cereal plantations that could have been harvested if no disease had occurred. Once this value is known, it can be compared to the gross margin of farmers or cereals per hectare in order to calculate the value that was lost.

Considering that TIR capability is expected to be operational in 2027, the uptake of Copernicus data by farmers or policy makers in charge of crops and plants disease surveillance will increase from this date onwards, ranging from 0.1% in 2027 to 1.3% in 2035. The expected total benefits of Copernicus are to amount to between EUR 1.5 M and EUR 3.7 M in 2027, rising to between EUR 12.9 M and EUR 39.4 M in 2035.

The evolution option 3C therefore represents an increase of between EUR 60.4 M and EUR 176.9 M compared to option 1, the baseline option (not discounted values).

410 Eurostat data. Available at: <http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do>

411 Eurostat data. Available at: <http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do>

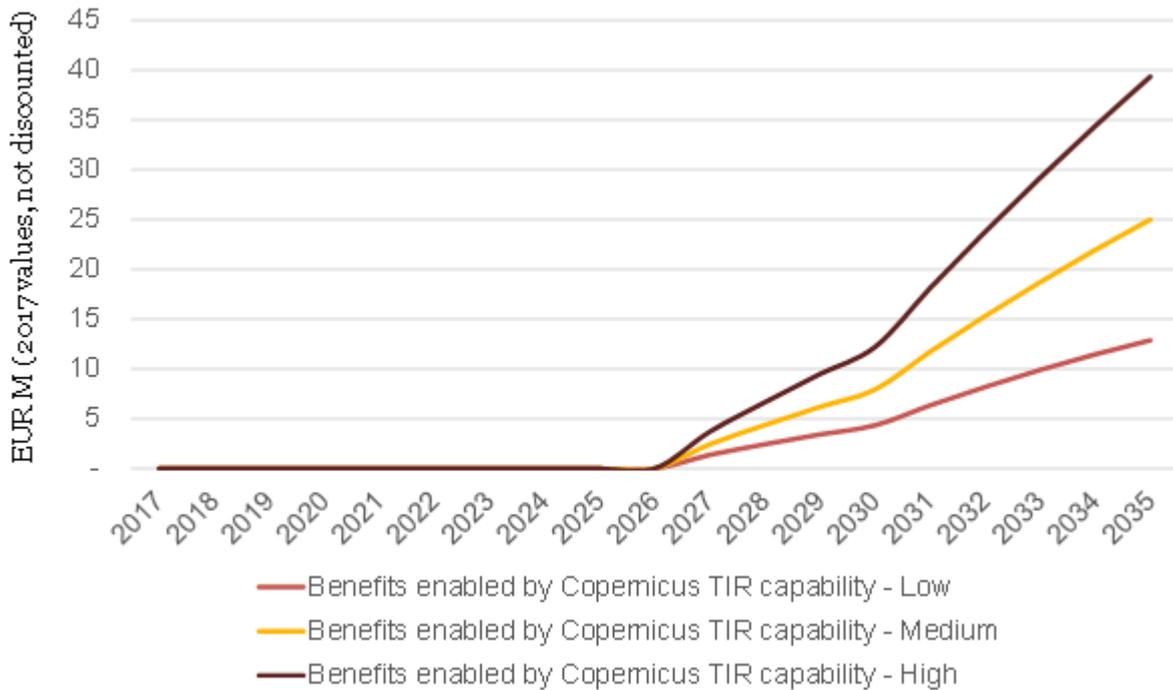


Figure 152 - Evolution of the Copernicus benefits attributed to option 3C for the impact “Crop areas protected/livestock saved from the development of disease resulting in increase in revenue for farmers” from 2017 to 2035 (Source: PwC analysis)

5.2.4.2.6 Total benefits under option 3C

Impact driver	Impact/benefit	Scenario	Gain
Water resources management	Improve agriculture productivity through better irrigation management	Low	EUR 48.3 M
		Medium	EUR 68.9 M
		High	EUR 98.8 M
Crop monitoring	Improve food security	Low	EUR 353.2 M
		Medium	EUR 412.5 M
		High	EUR 471.8 M
Urban area monitoring	Reduced mortality rate caused by Urban Heat Islands	Low	EUR 60.4 M
		Medium	EUR 113.7 M
		High	EUR 176.9 M
Fire detection and monitoring	Reduced environmental damages	Low	EUR 3.8 M
		Medium	EUR 11.3 M
		High	EUR 18.8 M
	Reduced toxic emissions	Low	EUR 54.6 M
		Medium	EUR 93.9 M
		High	EUR 133.2 M
	Reduced economic losses	Low	EUR 226.9 M
		Medium	EUR 390.2 M
		High	EUR 553.5 M
Pandemic monitoring	Crop areas protected/livestock saved from the development of disease	Low	EUR 60.4 M
		Medium	EUR 113.7 M
		High	EUR 176.9 M

Table 44 - Copernicus total benefits of option 3C for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period for Option 3C, Thermal Infrared capacity, is illustrated in the chart below:

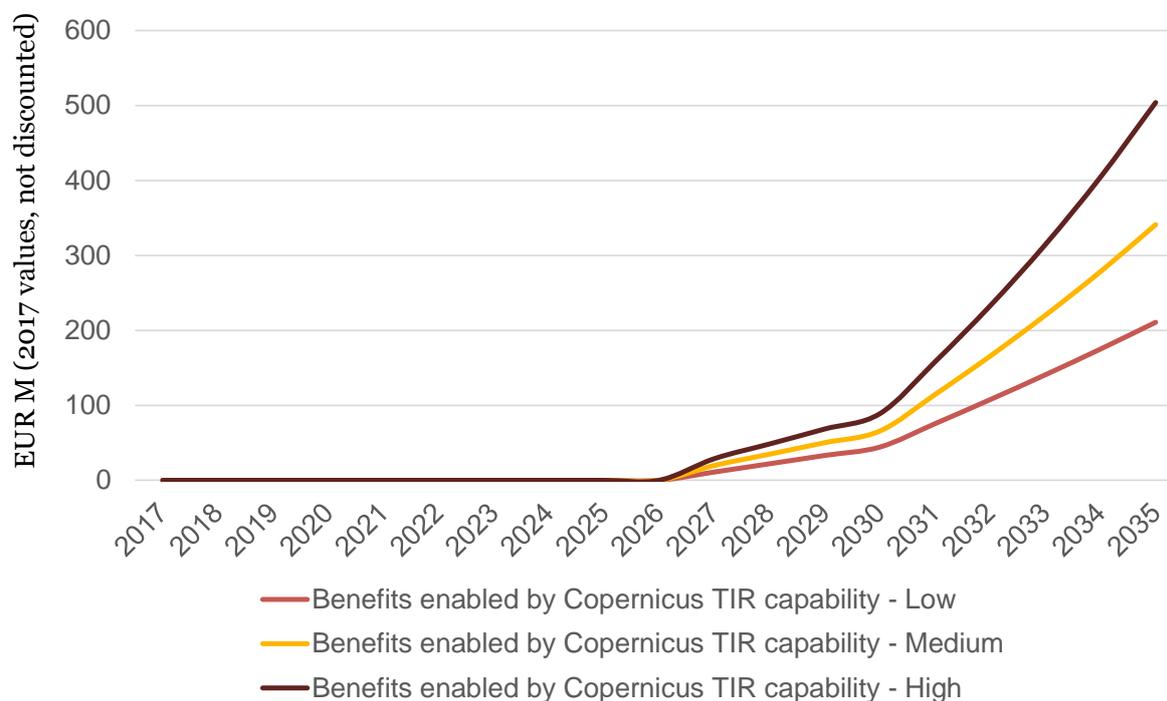


Figure 153 - Global Evolution of the additional gain enabled by TIR from 2017 to 2035 (Source: PwC analysis)

5.2.5 Option 3D – Hyper spectral capability to monitor biodiversity, forestry, land, agriculture and mining

5.2.5.1 Description

The aim of option 3D would be to provide hyper spectral resolution over land and coastal areas in support of natural resources management. The hyperspectral mission would more specifically enable to add several new spectral bands compared to what's already available on the Sentinel-2 multispectral mission.

Hyperspectral imagery is composed of a large number of narrower bands obtained by the use of an imaging spectrometer instrument. Hyperspectral sensors equipped on board of a potential Sentinel mission would be capable of providing 20-30 resolution imagers in several hundreds of narrow bands. Such feature should enable the direct and indirect distinction of surface quantities.

Hence, these new hyperspectral bands could support the identification and characteristics of soil composition, of wetlands properties and of coastal regions constituents. ESA's PROBA1/CHRIS has stressed the utility of hyper spectral imaging through a seventeen-year operation (launch in 2001, still operational), demonstrating potential value for mining, geology, forestry, agriculture; civil engineering; water quality and environmental management. Nowadays, this type of sensor is experiencing a strong growth in commercial applications based on airborne, UAV and hand-held platforms.

Therefore the primary targeted actors for this option are the environmental authorities for biodiversity assessment (forestry, wetlands...) and raw materials communities.

Hence the Impact drivers and derived benefits affected by the entry into operation of Option 3D are:

- Forestry Management and protection, for the benefit “Improve and preserve forest ecosystems and green infrastructures
- Crop Monitoring – support to agriculture, for the benefit “Improved agriculture profitability and cost efficiency”
- Wetlands monitoring, as Hyperspectral enhances the benefit of EO linked to Wetlands ecosystems restoration
- Mining and quarrying: minerals and raw materials extraction, for the support of the exploration and extraction of mines as well as the pollution resulting from mining activities.

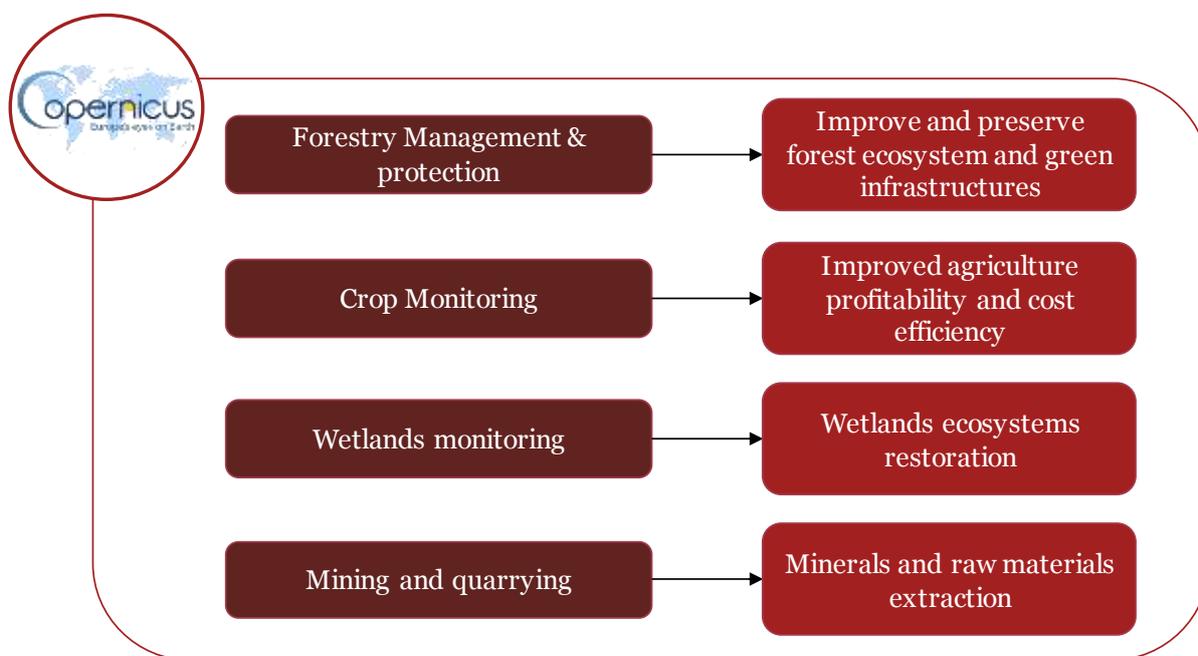


Figure 154 - High level illustration of the impacts expected from evolution option 3 – Hyper spectral capability

5.2.5.2 Monetization of option 3D benefits

The results of the qualitative assessment of the impact of Copernicus option 3D, as mentioned in the introductory part of option 3, are presented in the following table:

Evolution option	Extent of the impact on use cases			
	Improve forests ecosystems	Improved agriculture profitability and cost efficiency”	Improve monitoring of wetlands monitoring	Improve mine site surveying, resource reserves exploration, drilling and blasting

Hyperspectral sensor: higher level of spectral detail	Very High	High	Very High	Low
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Table 45 - Qualitative assessment of the impact of Copernicus option 3D on the different benefits (Source: PwC analysis)

Nevertheless, if hyperspectral is expected to bring significant benefits in various sectors, some of the experts met from the Copernicus core services were not convinced by the feasibility of this option. Indeed the technology is hard to use with space born system as the spectral “fingerprint” of observed object (chemical composition) is often blurred by interference of the atmospheric composition. Hence it is not always possible to exploit the data gathered by the sensor. It seems clear that hyperspectral instrument will play an important role for the next generation of optical satellite sensors, but the cost and complexity of the instruments, computers processing and algorithms required to analyse hyperspectral data, can hinder the adoption of the technology. Three main limitations will have to be overcome: processing power (large volume of data), communication bandwidth and power supply (the heat produced by the electronics can distort the information the sensor collects)⁴¹².

This risk of lack in accuracy undermines the capacity to estimate precisely the benefits hyperspectral could generate. As such, the results presented below takes into account the lack of current knowledge on the efficiency of a hyperspectral capability, as it does not exist yet.

5.2.5.2.1 Forestry management

5.2.5.2.1.1 Improve Forest ecosystem and green infrastructure

The introduction of a Hyperspectral mission would be a major asset for forest management. Indeed, as exposed in the baseline, EO data are used for monitoring Natura 2000 and other EU directives related to biodiversity. However currently, there is still a gap between data providing by remote sensors and those required for ecological assessment. In general, EO data can instead provide information on quantity, such as elucidating how much area is under forest canopy, rather than providing information on quality (what trees species are present, what is the health status...). Hence Hyperspectral capacity enables applications such as:

- Monitoring of forest health,
- Monitoring and tracking of invasive species,
- Creation of accurate forest inventory (detect type of wood).
- Early warning for forest fires: assess moistures properties, burn scares...

Improving general forest classifications and being able to differentiate between actual deforestation and forest damages caused by other factors (fires or invasive species), is required for international reporting on forests⁴¹³. Moreover better identify forest stress (invasive species for example) and being able to map which species, and which forest areas are under the most stress, allow the authorities to set up the right mitigating measures in order to reduce forest losses and to monitor forest regeneration.

These information are crucial for the implementation of EU directives on biodiversity, and they are not provided by the actual Copernicus instrument or at a much coarser resolution or limited coverage.

⁴¹² Hyperspectral analysis set to expand incoming decade, IHS Jane's Military & Security Assessments Intelligence Centre, 2017

⁴¹³ Concept study for Canadian hyperspectral mission, Euroconsult for CSA - 2015

In terms of technology, for forestry application, a 10 m resolution is enough⁴¹⁴ with a large spatial extent) and a frequent revisit time (depending on the process actually monitored).



Option 3D - Methodological approach to value the improved forest ecosystems

Our model is based on Copernicus contribution to the implementation of the Habitats Directive through the monitoring of Natura 2000 areas. Thanks to these initiatives Forests in favourable conservation status are restored every year. The steps are:

1. Assess the additional forest area restored each year thanks to Nature 2000 i.e. the surface of forest which goes from “unfavourable” to “favourable” status
2. Multiply it by the valuation coefficient of 1ha of forest in good health. It corresponds to the economic value of lost ecosystem services associated with the conversion and/or degradation of forest areas (erosion control, water filtration...)
3. Assess the contribution of Copernicus to the Habitats Directive: [Natura 2000 areas covered by Copernicus products x effective use of Copernicus by authorities x quality requirements fulfilled by Copernicus]. Then multiply the rest by it.

Improve and restore forest ecosystems and green infrastructures

Valuation approach



The methodological approach is the same as in the baseline scenario (see section 4.2.3.2.2.3), but the Copernicus contribution is increased. Considering that Hyperspectral capability is expected to be operational starting from 2030, the uptake of Copernicus data by end-users will increase from this date onwards.

Thanks to the enhanced capabilities of Copernicus due to HIS, the expected additional benefits of Copernicus with option 3D, are to amount to EUR 6.1 M in 2030, rising to between EUR 128.2 M and EUR 213.7 M in 2035 for a total cumulative value over the 2030-2035 period of between EUR 328.3 M and EUR 528.8 M.

Compared to baseline scenario, the evolution of the additional gain resulting from option 3D is represented in the chart below:

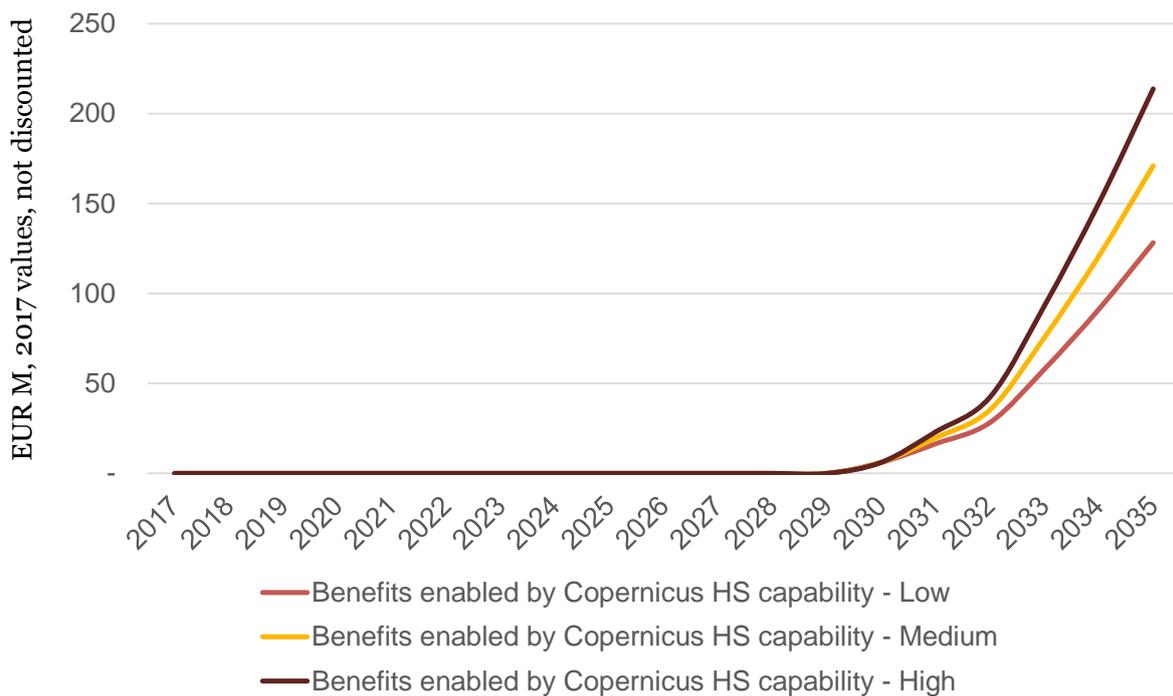


Figure 155 - Evolution of the additional gain enabled by Hyperspectral for “Improve forests ecosystems and green infrastructures” from 2017 to 2035 (Source: PwC analysis)

5.2.5.2.2 Crop monitoring – support to agriculture

5.2.5.2.2.1 Improve agriculture profitability and cost efficiency

Hyperspectral capability will lead to enhancement of current services for agriculture and development of new solution. Today Copernicus services are already used for agriculture purposes and Copernicus raw data are even included in commercial solution for precision farming (see Farmstar for example). Agriculture stakeholders are expected to be key beneficiaries of the emergence of an operational hyperspectral solution with spectral requirements along the visible to near-infrared (red-edge) to better delineate crop health and speciation. Added hyperspectral data would be expected to increase accuracy of services offered to end-users who seek to identify agriculture sensitive area (crop health/stress) and to forecast/assess seasonal variations in crop yield. More accurate crop identification and classification is also useful for land use and agricultural policies. Other direct benefits result mostly from cost avoidance thanks to better preventive measures, especially concerning assessment of crops health and of soil properties and degradation. Collecting data on soil nutrient loading is crucial for farmers to adapt their agricultural practises (fertilizer and planting trees or special crops to reduce surface run-off). Data would be used to provide better information on risk areas and earlier warning.

For the agriculture sector, hyperspectral capability enables applications such as:

- Assessing soil properties and land degradation
- Assessing crop health (Crop biochemical/physical monitoring)
- Crop identification and classification (Land cover mapping)

Hyperspectral data are clearly an asset for the Copernicus services dedicated to agriculture. They could improve the quality and the accuracy of the information provided, enabling more reactive mitigating measures in cases of crops stress or soil degradation, and so cost savings for farmers (and authorities).



Option 3D - Methodological approach to value the profitability increase in Agriculture

Our model is based on the amount of savings per hectare a farmer can achieve using Earth Observation data for precision farming application (variable rate technologies for fertilizer spreading, in this case). The steps are:

1. Assess the surface of crops monitored/exploited with precision farming techniques like VRT (Cereals and Canola represent the vast majority of crops monitored with PF techniques)
2. Assess the gain per hectare enabled by this technology
3. Assess the improved Copernicus contribution to precision farming thanks to HSI capability, i.e. to what extent intermediate users develop PF applications based on Copernicus data. And multiply the three.

Improved agriculture profitability and cost efficiency

Valuation approach



The methodological approach is the same as in the baseline scenario (see section 4.2.3.2.4.1), but the Copernicus contribution is increased. Considering that Hyperspectral capability is expected to be operational starting from 2030, the uptake of Copernicus data by end-users will increase from this date onwards.

For Crop monitoring (Improve profitability) application, the expected additional benefits of Copernicus with option 3D, are to amount between EUR 1.5 M and EUR 3.2 M in 2030, rising to between EUR 32.4M and EUR 100.1 M in 2035 for a total cumulative value over the 2030-2035 period of between EUR 84.7 M and EUR 255.8 M.

Compared to baseline scenario, the evolution of the additional gain resulting from option 3D is represented in the chart below:

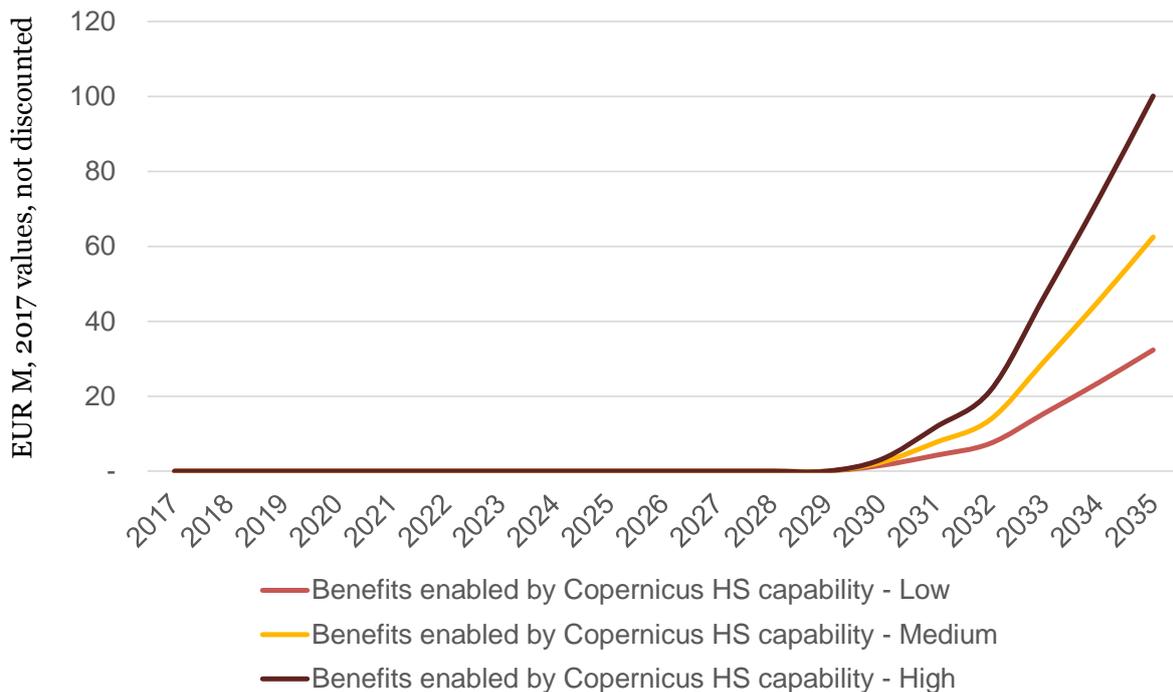


Figure 156 - Evolution of the additional gain enabled by Hyperspectral for “Improve agriculture profitability and cost efficiency” from 2017 to 2035 (Source: PwC analysis)

5.2.5.2.3 Wetlands monitoring

5.2.5.2.3.1 Improve wetlands ecosystems

Similar to the previous impact, EO data is used for monitoring the implementation of directive on biodiversity and by doing so, it has a positive impact on the restoration of wetlands habitats. Wetlands are particularly rich ecosystems which hosts key dynamic environmental process (carbon storage, water filtering...) and a very large variety of species (vegetation, insects, birds...). If current use of EO is a great support to monitor wetlands area, it cannot captures and assess all the richness and diversity of this habitat. Therefore Hyperspectral technology and its capability to distinguish the different vegetation types and status, and measuring accurately several biochemical variables (soil moisture, soil/water contamination), is really a key instrument to monitor wetlands.

Hyperspectral capacity enables applications such as:

- Tracking invasive species, monitoring spread and persistence
- Mapping contamination in case of pollution
- Monitoring stress and recovery in wetland plant communities

Being able to differentiate each kind of plant species has a real value added for the monitoring of wetlands habitats, which can be threatened by invasive species and have to be protected. Moreover Hyperspectral sensors can detect soil and water chemical properties like moisture, salinity, oxidation... which are precious information to prevent the spreading of pollution.

Clearly Hyperspectral capacity would be a real asset to monitor wetlands and biodiversity in general. The technology requirements are the same as for forestry (10 m resolution, large spatial extent and frequent revisit time).



Option 3D - Methodological approach to value the improved wetlands ecosystems

Our model is based on Copernicus contribution to the implementation of the Habitats and Birds Directive through the monitoring of Natura 2000 areas. Thanks to these initiatives Wetlands in favourable conservation status are restored every year. The steps are:

1. Assess the additional Wetlands area restored each year thanks to Natura 2000 i.e. the surface of Wetlands which goes from “unfavourable” to “favourable” status
2. Multiply it by the valuation coefficient associated with 1ha of Wetland in good health. It corresponds to the economic value of lost ecosystem services associate with the conversion and/or degradation of wetlands areas (water filtration, climate regulation...)
3. Assess the contribution of Copernicus to the Habitats Directive: [Natura 2000 areas covered by Copernicus products⁴¹⁵ x effective use of Copernicus by authorities x quality requirements fulfilled by Copernicus]. Then multiply the rest by it.

Improve restoration of wetlands ecosystems

Valuation approach



The methodological approach is the same as in the baseline scenario (see section 4.2.3.2.4.1), but the Copernicus contribution is increased. Considering that Hyperspectral capability is expected to be operational starting from 2030, the uptake of Copernicus data by end-users will increase from this date onwards.

For wetlands monitoring application, the expected additional benefits of Copernicus with option 3D, are to amount between EUR 14.8 M and EUR 51.8 M in 2025, rising to between EUR 434.5 M and EUR 724.2 M in 2035 for a total cumulative value over the 2017-2035 period of between EUR 3,226 M and EUR 5,479 M.

Compared to baseline scenario, the evolution of the additional gain resulting from option 3D is represented in the chart below:

415 Contribution of Copernicus in support to monitoring of habitats, species and the Natura 2000 network, EEA, 2016

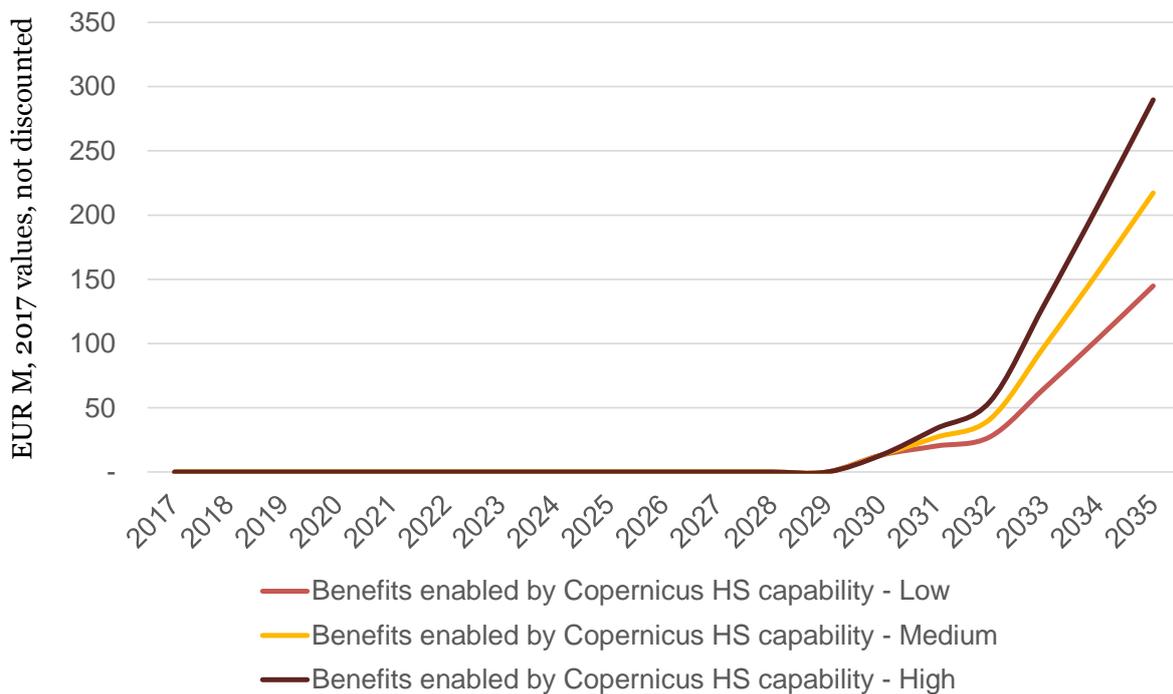


Figure 157 - Evolution of the additional gain enabled by Hyperspectral for “Improve restoration of wetlands ecosystems” from 2017 to 2035 (Source: PwC analysis)

5.2.5.2.4 Mining and quarrying: minerals and raw materials extraction

Compared to what is enabled by currently existing Sentinel satellites, the introduction of a hyperspectral capability would be a major asset for the mining and quarrying sector. Hyperspectral images enable to detect the different mineral types composing a mining area and to delineate them. Combined with other types of data such as GIS, hyperspectral can prove useful for both the monitoring of mine sites and the exploration and extraction of raw materials. For instance, it enables to improve mining waste mapping or to develop soil pH maps⁴¹⁶. On an environmental point of view, hyperspectral images can be key to perform ecological impact assessment of current or former mining areas, such as aerosols and chemical pollution monitoring. Only the first aspect is monetized below.

Both the exploration and extraction mining phase are facilitated by a hyperspectral capability that will possess a higher ground resolution. For the exploration part, hyperspectral data are mostly combined with GIS data to develop prospecting tools and facilitate the sites to explore. For the extraction part, hyperspectral data are used for monitoring on-site activities and extending the mining area. For this second part, currently available data are either too costly or based on aerial vehicles.

Currently, no hyperspectral capability is fully available (mostly in pre-operational phase). Moreover, only two commercial missions are planned in Europe, EnMAP and PRISMA. Mine sites operators are forced to buy expensive commercial imagery to do their activities: indeed, current solutions providing similar data as hyperspectral missions are either aerial As such, option 3D would enable a major cost avoidance. Besides, the interoperability of the new

⁴¹⁶ EuroGeoSurveys, 2016, Earth Observation for Raw Materials (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/form-ZpdWWke1Pspaj6_KXzsXFbLNWJoJ_DnBIyREBgIXAsY/herrera_-_egs.pdf

hyperspectral capability with currently used Sentinel-2 will be a major asset for mine sites operators.



Methodological approach to value the improvement of exploration and extraction

Our model is based on the Gross Value Added (GVA) of the mining and quarrying sector that is attributable to space activities and in particular to Copernicus. The steps are:

1. Assess the GVA of the mining and quarrying sector
2. Determine the share of the GVA that is generated thanks to space activities
3. Isolate, among space activities, the share that is due to Earth Observation
4. Assess the contribution of the new Copernicus hyperspectral capability to Earth Observation imagery used for extraction and exploration activities

Improved exploration and extraction Valuation approach



The methodology is similar to the one previously mentioned in section 4.2.3.3.4.1 - Improved mine site surveying, resource reserves exploration and drilling and blasting leading to an increased output. For the GVA of the mining and quarrying sector and the contribution of space-related applications to this GVA, similar assumptions are taken. However, with the introduction of hyperspectral capabilities, the reliance on Earth Observation is set to increase from 0.1%-0.2% to 1%-2%. Indeed, the hyperspectral capabilities is expected to fill several gaps currently existing in the mining life cycle⁴¹⁷.

Considering that the hyperspectral capability is expected to be operational in 2030, the uptake of Copernicus data by mine site operators will increase from this date onwards, with a contribution of 0.1% in 2030, increasing to 1% in 2032, up to 3% in 2035. The expected total benefits of Copernicus are to amount to between EUR 0.7 M and EUR 1.4 M in 2025, rising to between EUR 22.2 M and EUR 42.5 M in 2035.

The evolution option 3D therefore represents an increase of between EUR 64.1 M and EUR 128.2 M compared to option 1, the baseline option (not discounted values).

⁴¹⁷ European Commission, 2016, Report : Copernicus for Raw Materials workshop (Online). Available at: http://workshop.copernicus.eu/sites/default/files/content/attachments/ajax/raw_materials_ws_report.pdf

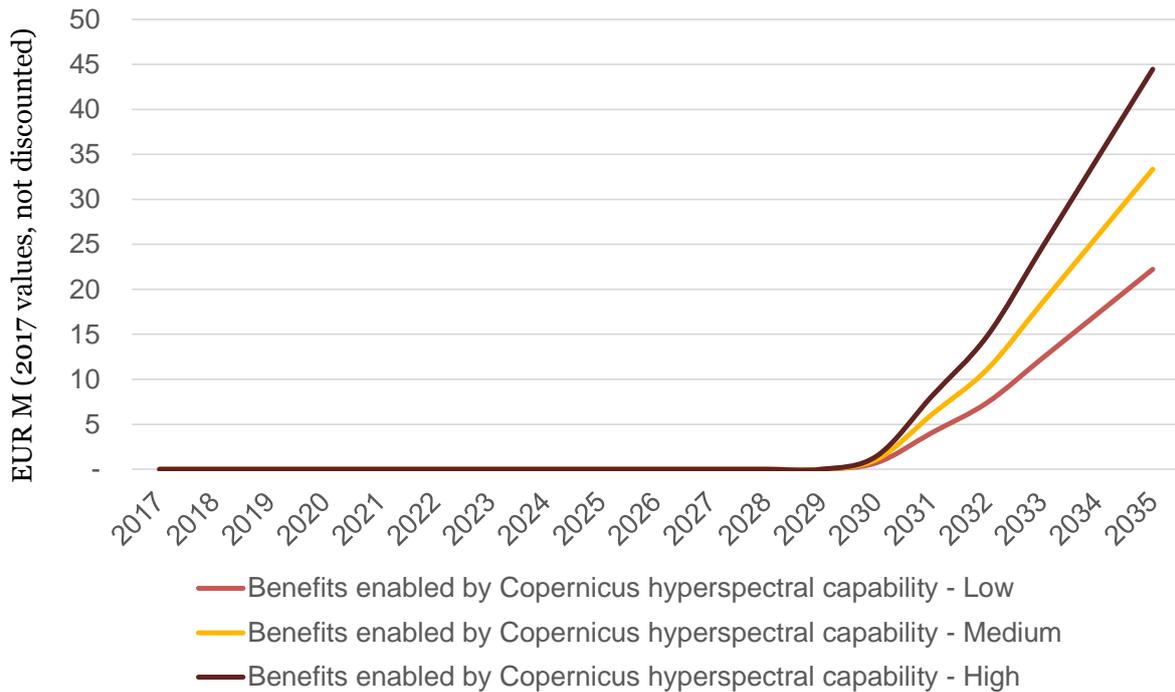


Figure 158 - Evolution of the Copernicus benefits attributed to option 3D for the impact “Improved mine site surveying, resource reserves exploration and drilling and blasting leading to an increased output” from 2017 to 2035 (Source: PwC analysis)

5.2.5.2.5 Total benefits under option 3D

Impact driver	Impact/benefit	Scenario	Gain
Forestry management & protection	Improve restoration of wetlands ecosystems	Low	EUR 328.3 M
		Medium	EUR 428.5 M
		High	EUR 528.8 M
Crops Monitoring	Improved agriculture profitability and cost efficiency	Low	EUR 84.7 M
		Medium	EUR 161.1 M
		High	EUR 255.8 M
Wetlands monitoring	Improve and preserve forest ecosystems	Low	EUR 375.3 M
		Medium	EUR 552.0 M
		High	EUR 730.7 M
Mining and quarrying	Minerals and raw materials extraction	Low	EUR 64.1 M
		Medium	EUR 96.2 M
		High	EUR 128.2M

Table 46 - Copernicus total benefits of option 3D for the three scenarios (EUR 2017, not discounted values) (Source: PwC analysis)

The global trend over the period for the Option 3D Hyperspectral Capacity, is illustrated in the chart below

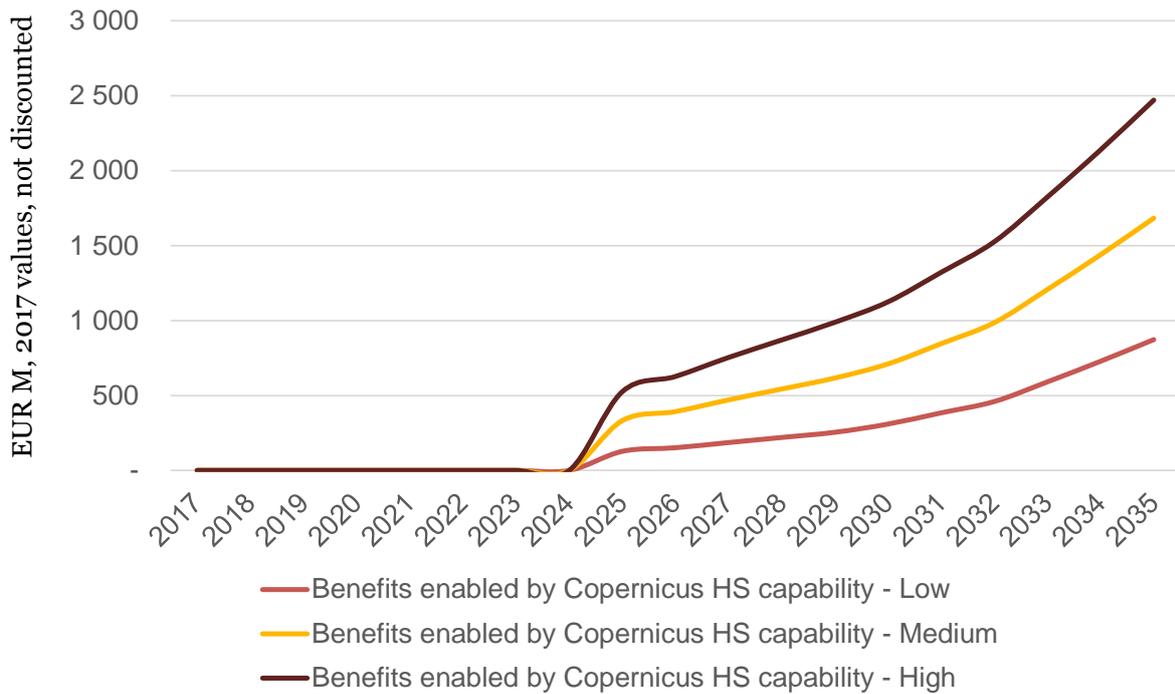


Figure 159 - Global Evolution of the additional gain enabled by Hyperspectral from 2017 to 2035 (Source: PwC analysis)

5.2.6 Evolution option 3 summary

This section brings together all the benefits enabled by the Copernicus D&I over the period 2025 – 2035 for the Enhanced Environmental Services evolution option (option 3). The results (2017 values, not discounted) are presented in the table below for EU only.

Copernicus cumulated benefits – EUR M	Option 3A	Option 3B	Option 3C	Option 3D
Low estimate	1,953.6	702.8	820.4	852.2
Medium estimate	5,783.1	990.6	1,290.2	1,238.7
High estimate	9,505.9	1,535.3	1,848.2	1,387.6

Table 47 - Cumulated Copernicus D&I benefits of option 3 for the three scenarios (Source: PwC analysis)

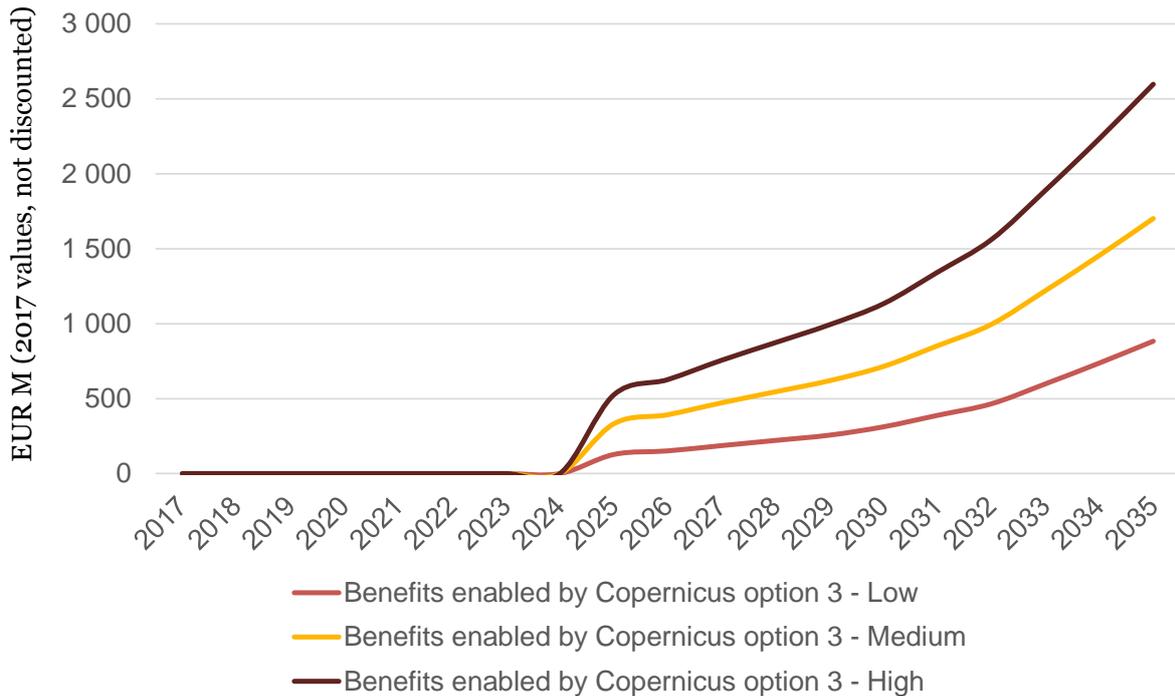


Figure 160 - Benefits enabled by Copernicus data and information for evolution option 3 (EUR M; EUR 2017; undiscounted values) (Source: PwC analysis)

5.3 Option 4 – Enhanced security service

5.3.1 Description

In the current context, security stakes for Europe, both internally and with regards to the world, are increasingly important and complex. Among the priorities of Europe External Action presented in the Global Strategy for the EU’s Foreign and Security Policy, the security of the Union is more and more challenging to ensure, with still higher needs to remain resilient to the Middle East and North Africa regions. The management of conflicts demands a deeper cooperation both between MS and with 3rd countries, requiring integrated approaches to solve conflicts. The development of the security component of Copernicus is a lever to bring an answer to these types of challenges.

At this stage, the exact features to be developed under option 4 could not have been precisely characterised, and this scenario is based on the improvement of existing features rather than the development and implementation of new satellite capabilities (as for option 3).

The characterisation of option 4 revolves around the following features that must be made accessible to EU security actors:

- **Higher spatial resolution** over wide areas: many security applications would benefit from higher resolution (both radar and optical), in particular if combined with the monitoring of wide areas, to exploit the full potential of satellites. This feature is useful for instance to detect small vessels, or to identify vessels once they have been detected.
- **Guaranteed access to tasking** (i.e. crisis management): the need to rely on other sources of data than the ones produced by EO is often related to the uncertainty of being granted the access to satellite payload when an urgent need occurs. A

guaranteed access would strongly mitigate this risk and would ensure the delays to receive the image to be only imposed by data dissemination processes. The procurement contracts with commercial providers used currently by EMSA and SatCen raise limitations on this aspect as they may have a low priority during tasking bottlenecks, with no option to obtain guarantee of access from private providers. An alternative procurement scheme would be required for such feature (anchor customer, dedicated infrastructure etc.).

- **Near-real time data:** the delay between the need for data and the reception of the images has a strong influence on the relevance of EO data. Many security applications require to receive the data less than 30 minutes after the request, with increasing interest in even shorter delays.

The assumption is made that these criteria can be influenced through investments in the Copernicus programme, without investigating the feasibility and levers to do so. Hence, the costs associated are not considered in the current analysis.

In addition to these criteria, collaborations within the Copernicus programme and horizontal integration of Copernicus data with other initiatives could also play an important role in the improvement of the Security service⁴¹⁸:

- In the frame of the Common Information Sharing Environment (CISE), the European Commission and EEA MS are developing mechanisms integrating various surveillance data streams, of which EO data, and delivering it to authorised users for maritime related missions: maritime safety, fisheries control, maritime pollution preparedness, customs, border control, general law enforcement and defence. A more integrated approach leads to higher operational efficiency as the information is available quickly to the authorised users.
- Closer support to EEAS would enable to exploit EO data in different use cases such as piracy and armed robbery in the Indian Ocean and the Gulf of Guinea, in particular since national authorities have limited resources for situational awareness.
- Similarly to the current collaboration between EMSA and EFCA, stronger collaboration with the European Anti-Fraud Office (OLAF) could bring substantial value to customs related activities, through the monitoring of compliance with customs regulations and early warning / identification of goods trafficking. For instance this cooperation could enable information exchanges between customs and transports logistics and fisheries.

The improvement of all these criteria is translated into an increased contribution of Copernicus to the different impact drivers as it increases its relevance with operational needs. Although the extent of improvement is not defined yet (thus the valuation of the benefits is theoretical), the aim is to provide a comparative assessment of the incremental benefits generated for each security driver (EU borders surveillance, law enforcement and international crime, Search & Rescue, control of IUU fishing and oil pollution monitoring).

Option 4 is built on the top of the baseline option (option 1), enhancing Security services. All the benefits assessed in the next section have to be summed with all benefits derived from baseline option over the period 2017 – 2035.

⁴¹⁸ Stakeholder consultation

5.3.2 Major points relevant to option 4 (enhanced security service)

The nature of security benefits can sometimes be hard to monetize, such as geopolitical and strategic impact. As for the Global EU strategy, EU Space Strategy and European Defence Action Plan, the scope of the study – assessing economic, societal and environmental spillovers derived from Copernicus D&I – cannot take those documents directly into account since their impacts cannot be turned into monetary terms. For instance, the notion of autonomy is key for the strategic objectives of the EU, as stated in the three past mentioned document, but cannot be valued in monetary terms. Moreover, the notion of creating more synergies between civilian and military is not in the scope of this particular study.

It is important to note again that this study is **only an input of the future EC impact assessment** on the evolution of the Copernicus programme with a particular **scope focusing only on benefits that can be monetized**. In the context of option 4, this means that **additional strategic impacts related to autonomy and geopolitics would need to be taken into account in the future EC impact assessment**.

5.3.3 Monetization of option 4 benefits

The valuation of the impact drivers assessed in the baseline rely on the relative increase in Copernicus uptake. In the cases where Copernicus represents a large share of the EO data used (close to 100%) and is expected to become more attractive for users, the increase in uptake is deferred on the share of EO data in the operational value chain.

The quantification of the increase in Copernicus uptake is based on:

- The qualitative assessment of the contribution of the different criteria to the use cases, i.e. to each impact. This assessment is based on the analysis of each use case, how Copernicus currently contributes to the operations and moreover what currently hinders its uptake and further adoption, as discussed with stakeholders. To the 3 main criteria considered in option 4 (guaranteed access to tasking, higher resolution and NRT data), 2 additional criteria are added, to take into account the improvement of integrated services and the collaboration with other entities involved in the operations (MS authorities, EFCA, OLAF, MAOC(N) etc.).

The assessment is presented in the following table:

Evolution option criteria	Extent of the impact on use cases						
	Search & Rescue	Control of IUU fishing	Oil pollution monitoring	Law enforcement at sea	Law enforcement on land	Sea borders surveillance	Land borders surveillance
Guaranteed access to tasking	Very high	Low	Medium	High	High	Medium	High
Higher resolution over wide areas	Very high	High	Medium	Very high	Medium	High	Medium
Better timeliness (NRT)	Very high	Very high	High	High	High	High	High
More integrated services	Medium	Very high	Medium	Medium	High	Medium	High
Increased collaboration with	Low	Low	Medium	High	Low	Low	Low

Figure 161 - Qualitative assessment of the impact of Copernicus option 4 on the different benefits (Source: PwC analysis)

The considerations for the evolution of each driver are detailed in the following sub-sections.

- Assumptions on the distribution of these service evolutions and their respective extent on the attractiveness of Copernicus and EO data. The aim is to link the qualitative assessment above to new contributions of Copernicus to the operations results. The values defined for the current model are the following:

	Influence on the future security service	Extent of evolution of a criteria	Ratio of increase for Copernicus uptake
Guaranteed access to tasking	25%	Very high	4
Higher resolution over wide areas	25%	High	3
Better timeliness (NRT)	25%	Medium	2
More integrated services	15%	Low	1.5
Increased collaboration with 3rd parties	10%		

Figure 162 - Assumptions for the evolution of the Security service in terms of Copernicus uptake (Source: PwC analysis)

The modelling of option 4 relies on the assumption that the evolutions will materialise from 2021. To simulate the reality of data adoption by end users, a progressive linear uptake is applied from 2021 to the final value, spread over 14 years.

Applying these criteria, the benefits generated by Copernicus are re-assessed and compared to the benefits generated in the baseline scenario. For instance, for the Search & Rescue benefit, the impact of tasking, higher resolution and improved timeliness is deemed very high, whereas the impact of more integrated services is considered medium and the impact of the increased collaboration with different entities is low. Based on the table of the assumptions for the security evolution option, this implies that the ratio of increase for the Copernicus uptake of this benefit is 3.45 ($4 \times 25\% + 4 \times 25\% + 4 \times 25\% + 2 \times 15\% + 1.5 \times 10\%$).

It should be noted that the results presented below are the delta between the benefits of Option 4 and the baseline (additional benefits) rather the overall benefits of option 4 (absolute benefits).

5.3.3.1 Control of IUU fishing

Monitoring of IUU fishing boats would seize the full potential of satellites if the revisiting time was lower, by improving the control of vessels during non-reporting intervals. A higher resolution would also extend the scope of vessels that can be identified through satellite

images, for which a higher integration of the service with other data sources would be highly beneficial.



Methodological approach to value the impact on IUU fishing monitoring

The approach to value each impact sub-driver of IUU fishing monitoring remains the same (cf. baseline).

Option 4 relies on the improvement of current EO data characteristics (resolution, timeliness, guarantee of access) rather than the development of complementary products or instruments. Thus, the gap with the baseline materialises through an increase in the uptake of current products (higher contribution of Copernicus).

Under the assumptions described above, the additional benefits of Copernicus to the control of IUU fishing with the evolution option 4 are the following.

<i>Copernicus benefits – EUR M</i>	2025	2035	Cumulative (2025 – 2035)
Low estimate	0.73	2.7	21.6
Medium estimate	0.96	3.1	25.8
High estimate	1.2	3.6	30.4

Table 48 - Copernicus “Control of IUU fishing” additional benefits of option 4 for the three scenarios (Source: PwC analysis)

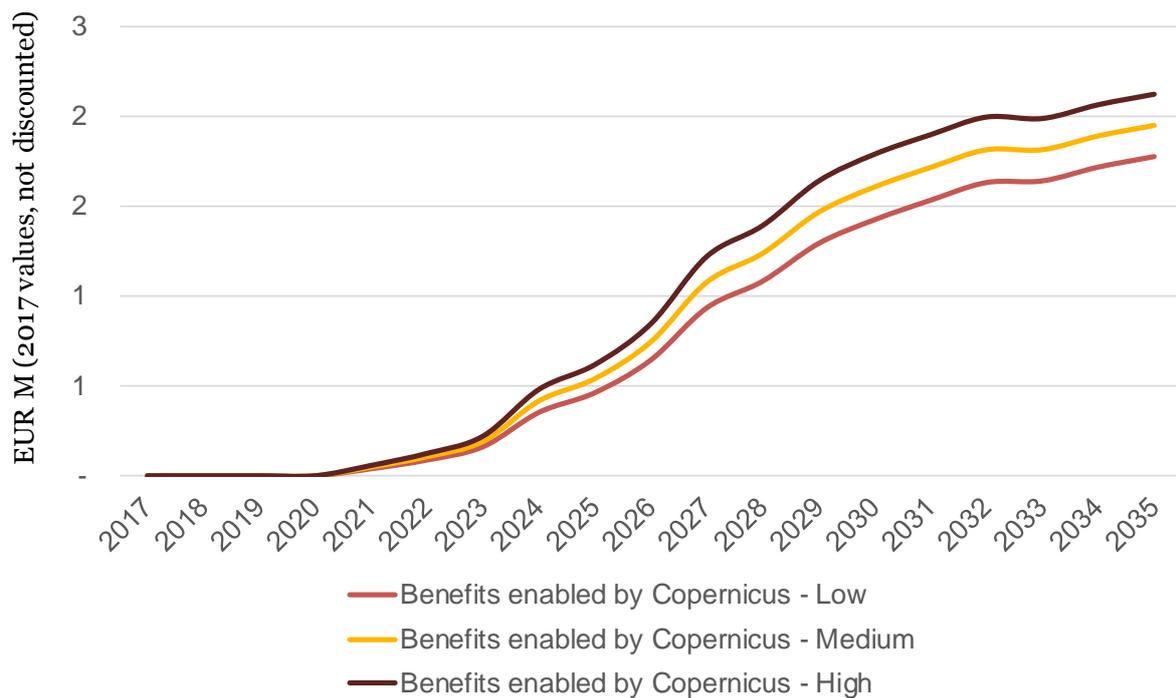


Figure 163 - Summary of Copernicus additional benefits (EUR) to the impact driver “Control of IUU fishing activities” under evolution option 4, between 2017 and 2035 for Europe (Source: PwC analysis)

5.3.3.2 Maritime Safety – Search and Rescue

S&R missions demand high reactivity and responsiveness as lives are at threat. Low interest for operational use of satellite data during rescue mission is linked to the low tasking time and lack of guarantee for NRT access. In the case of small boats such as refugees’ embarkations, higher resolution would facilitate the detection and location of the vessels. A higher integration of services would have moderate benefits as most of the missions are delivered by dedicated vessels (MRCCs, ONGs, Frontex), and for instance the coordination with 3rd party vessels (commercial typically) have a limited contribution.

A key evolution within option 4 is the deeper involvement of EMSA in the provision of the EO products suited for S&R, to gain a more central position in the procurement chain of the S&R organisations such as MRCCs. Hence, in addition to the increase of Copernicus contribution to S&R missions, the CMS service would also hold a more central role as a source of these products.



Methodological approach to value the impact on Search & Rescue missions

The approach to value each impact sub-driver of Search & Rescue missions remains the same (cf. baseline).

Option 4 relies on the improvement of current EO data characteristics (resolution, timeliness, guarantee of access) rather than the development of complementary products or instruments. Thus, the gap with the baseline materialises through an increase in the uptake of current products (higher contribution of Copernicus).

Under the assumptions described above, the additional benefits of Copernicus to Search & Rescue missions with the evolution option 4 are the following.

Copernicus benefits – EUR M	2025	2035	Cumulative (2025 – 2035)
Low estimate	89.6	246.6	2,229.6
Medium estimate	160.1	358.6	3,443.2
High estimate	247.8	491.3	4,930.4

Table 49 - Copernicus “Maritime safety – Search and Rescue” additional benefits of option 4 for the three scenarios (Source: PwC analysis)

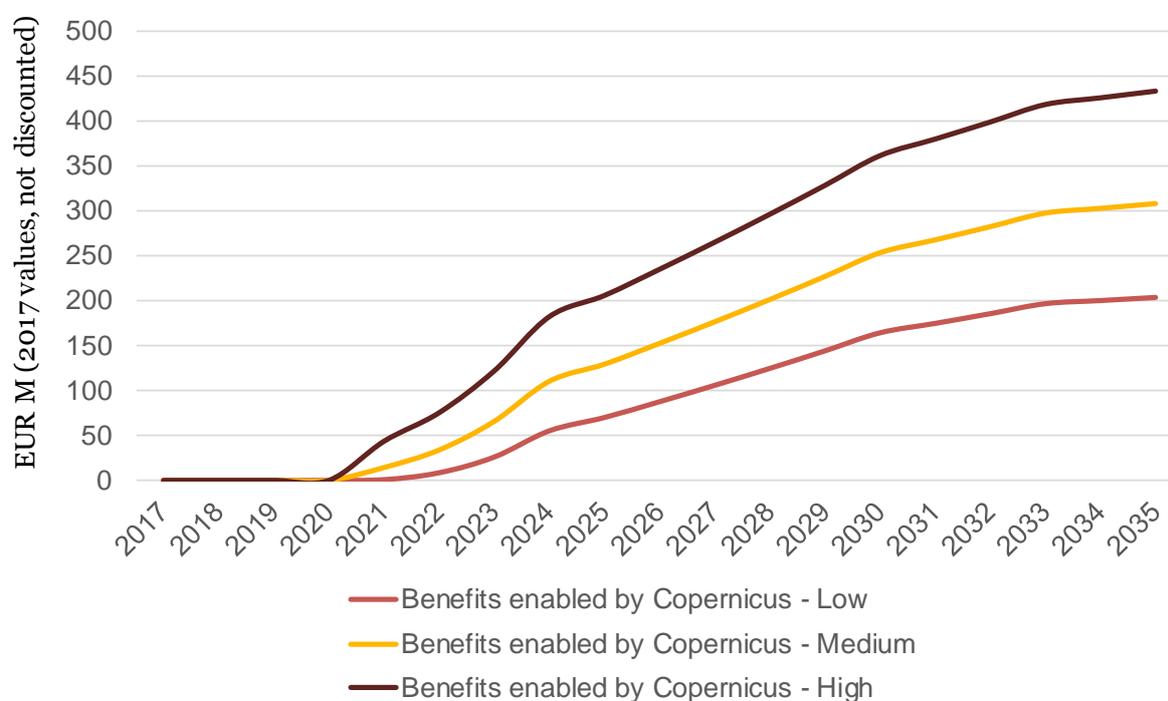


Figure 164 - Summary of Copernicus additional benefits (EUR) to the impact driver “Maritime safety - Search & Rescue” under evolution option 4, between 2017 and 2035 for Europe (Source: PwC analysis)

5.3.3.3 Oil pollution monitoring

As the stronger contribution of EO to oil pollution monitoring is the routine monitoring and detection of spills, an improvement of the timeliness of satellites images would increase again their usefulness and their uptake by national authorities. In a more limited extent, a quick situational picture would also be valuable in the rare events of large disasters requiring rapid field intervention.

As large pollution catastrophes become more and more exceptional, the margin for improvement in pollution monitoring should target rather the intentional discharges, in particular from small vessels along the coast. The improvement of images resolution would support this purpose.



Methodological approach to value the impact of oil pollution monitoring

The approach to value each impact sub-driver of oil pollution monitoring remains the same (cf. baseline).

Option 4 relies on the improvement of current EO data characteristics (resolution, timeliness, guarantee of access) rather than the development of complementary products or instruments. Thus, the gap with the baseline materialises through an increase in the uptake of current products (higher contribution of Copernicus).

Under the assumptions described above, the additional benefits of Copernicus to oil pollution monitoring with the evolution option 4 are the following.

Copernicus benefits – EUR M	2025	2035	Cumulative (2025 – 2035)
Low estimate	36.1	25.9	423.2
Medium estimate	39.1	27.8	455.9
High estimate	41.2	29.1	476.7

Table 50 - Copernicus “Oil pollution monitoring” additional benefits of option 4 for the three scenarios (Source: PwC analysis)

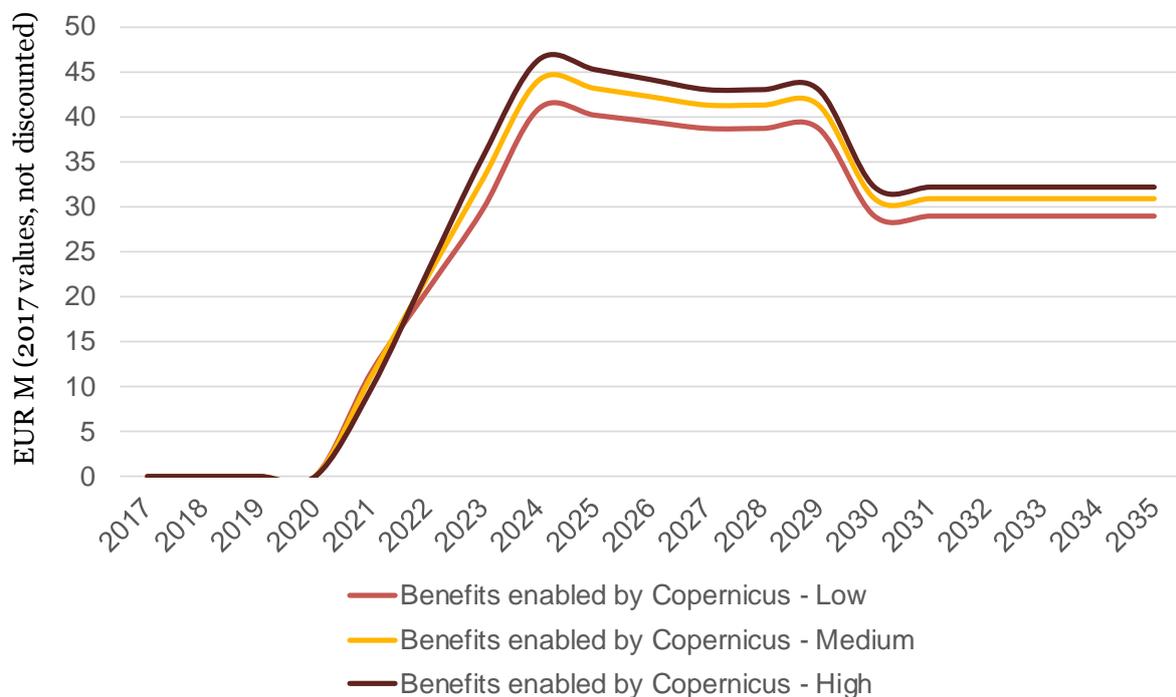


Figure 165 - Summary of Copernicus additional benefits (EUR) to the impact driver “Oil pollution monitoring” under evolution option 4, between 2017 and 2035 for Europe (Source: PwC analysis)

5.3.3.4 Law enforcement and international crime

Law enforcement at sea relies on the detection and tracking of suspicious vessels, in particular of small non-reporting vessels on which there is no information available through AIS and VMS. In this case the availability of higher resolution data would strongly serve the use of satellite images. The initial detection of these vessels and other activities (illegal surveying for instance), relies on routine monitoring and the improvement of data timeliness would increase the probability of detection. Many other entities also intervene at sea and can contribute to law enforcement operations conducted by MS (EFCA, OLAF, MAOC(N), Frontex etc.), and an improvement of data provision and coordination between these entities would support the uptake of Copernicus data.

For law enforcement on land, satellite images are mostly used for situational awareness. A better timeliness would improve the detection of events and in the case of specific operations requiring support information, a guarantee of access to the data would also be valuable to Frontex and MS authorities. The integration of services is also a strong contributor as Frontex exploits information on adjacent countries (infrastructure, operations etc.) to conduct the joint operations.



Methodological approach to value the impact of law enforcement

The approach to value each impact sub-driver of law enforcement and cross-border crimes remains the same (cf. baseline).

Option 4 relies on the improvement of current EO data characteristics (resolution, timeliness, guarantee of access) rather than the development of complementary products or instruments. Thus, the gap with the baseline materialises through an increase in the uptake of current products (higher contribution of Copernicus).

Under the assumptions described above, the additional benefits of Copernicus to law enforcement at EU borders with the evolution option 4 are the following.

<i>Copernicus benefits – EUR M</i>	2025	2035	Cumulative (2025 – 2035)
Low estimate	1,409	1,333	15,267
Medium estimate	1,636	1,576	17,949
High estimate	1,849	1,803	20,456

Table 51 - Copernicus “Law enforcement and international crime” additional benefits of option 4 for the three scenarios (Source: PwC analysis)

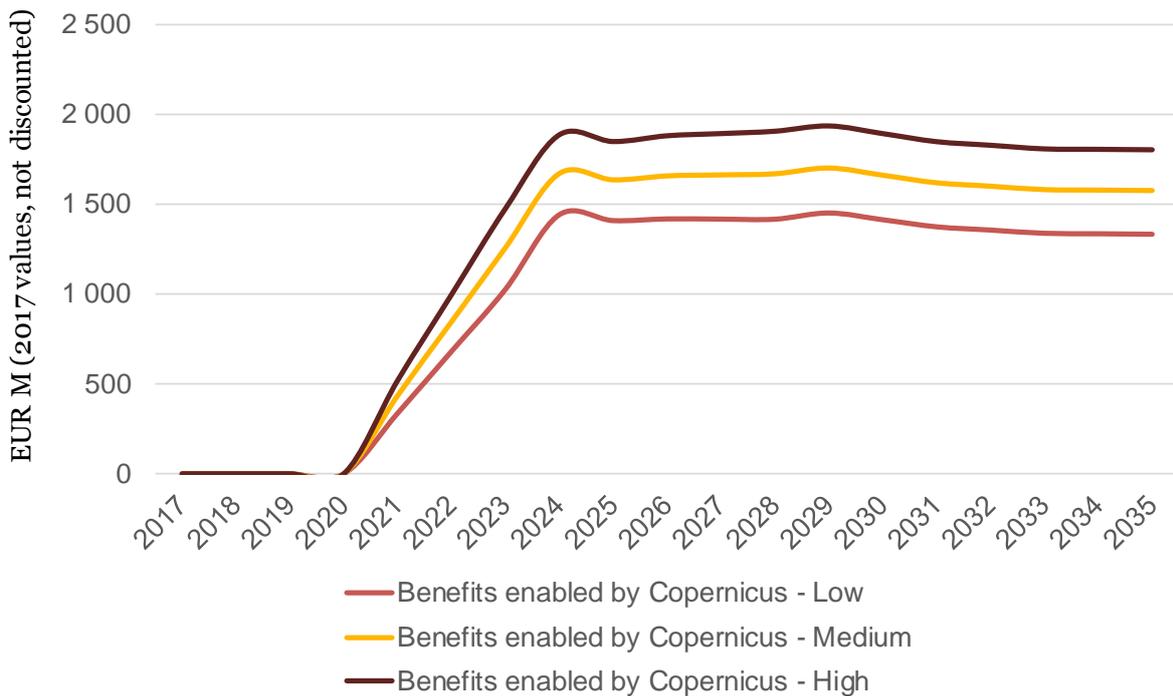


Figure 166 - Summary of Copernicus additional benefits (EUR) to the impact driver “Law enforcement and international crime” under evolution option 4, between 2017 and 2035 for Europe (Source: PwC analysis)

5.3.3.5 EU borders surveillance

The incremental benefits for border surveillance are expected to remain moderate, due to the nature of operations of controlling of people entering the EU.

Sea borders surveillance would mostly benefit from improved resolution and timeliness for data access, to contribute more efficiently to the detection of small vessels and the identification of suspicious behaviours.

On land border, EO contributes to the situational picture, through change detection, which will be improved with a better timeliness and access to NRT data. The monitoring of crisis situations is more of a one shot activity, and would benefit directly from a guaranteed access to EO images. In both cases the images deliver their full potential when combined with other sources of information on the country, the infrastructures, the operations etc., and thus the development of integrated services are a key aspect for these missions.



Methodological approach to value the impact of border surveillance

The approach to value each impact sub-driver of border surveillance remains the same (cf. baseline).

Option 4 relies on the improvement of current EO data characteristics (resolution, timeliness, guarantee of access) rather than the development of complementary products or instruments. Thus, the gap with the baseline materialises through an increase in the uptake of current products (higher contribution of Copernicus).

Under the assumptions described above, the additional benefits of Copernicus to EU borders surveillance with the evolution option 4 are the following.

<i>Copernicus benefits – EUR M</i>	2025	2035	Cumulative (2025 – 2035)
Low estimate	3.46	2.33	38.9
Medium estimate	3.92	2.68	45.3
High estimate	4.34	3.01	51.1

Table 52 - Copernicus “EU borders surveillance” additional benefits of option 4 for the three scenarios (Source: PwC analysis)

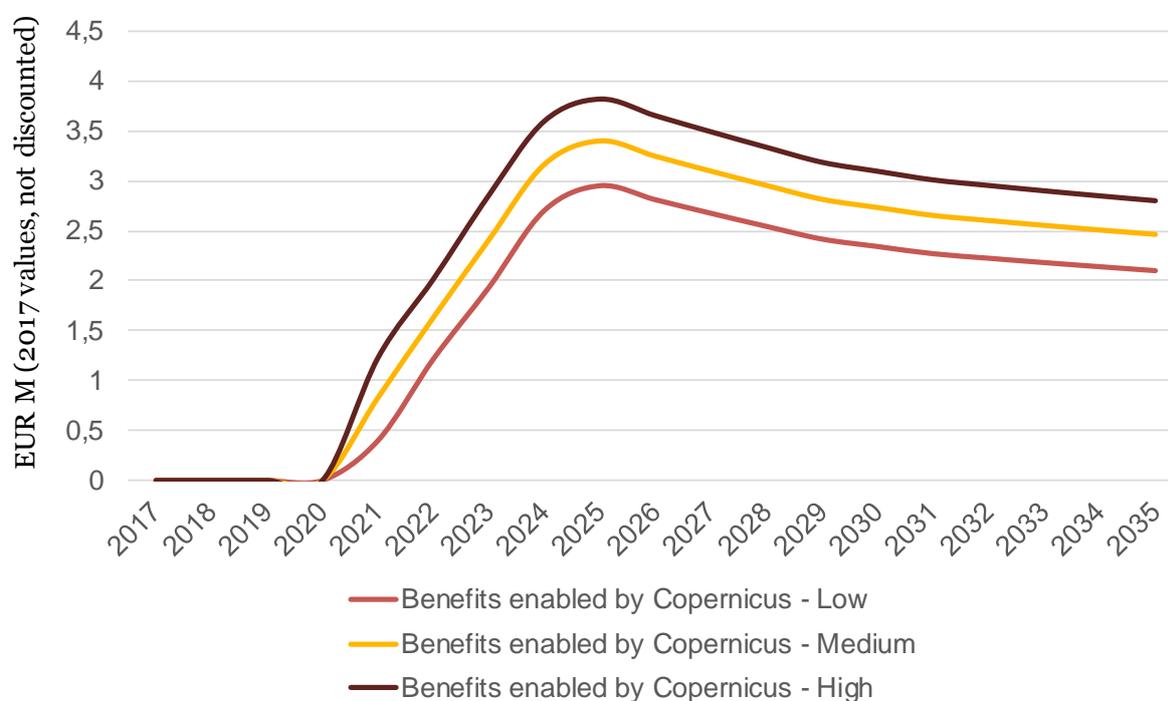


Figure 167 - Summary of Copernicus additional benefits (EUR) to the impact driver “EU borders surveillance” under evolution option 4, between 2017 and 2035 for Europe (Source: PwC analysis)

5.3.3.6 Evolution option 4 summary

This section brings together all the benefits enabled by the Copernicus D&I over the period 2025 – 2035 for the Enhanced Security Service evolution option (option 4). The results (2017 values, not discounted) are presented in the table below for EU only.

<i>Copernicus benefits – EUR M</i>	2025	2035	Cumulative (2021 – 2035)
Low estimate	1,522.7	1,569.9	21,021.9
Medium estimate	1,812.6	1,920.1	25,544.0

High estimate

2,104.8

2,274.0

30,096.0

Table 53 - Cumulated Copernicus D&I benefits of option 4 for the three scenarios (Source: PwC analysis)

The expected benefits of option 4 projected over the period 2017 – 2035 are displayed in the chart below.

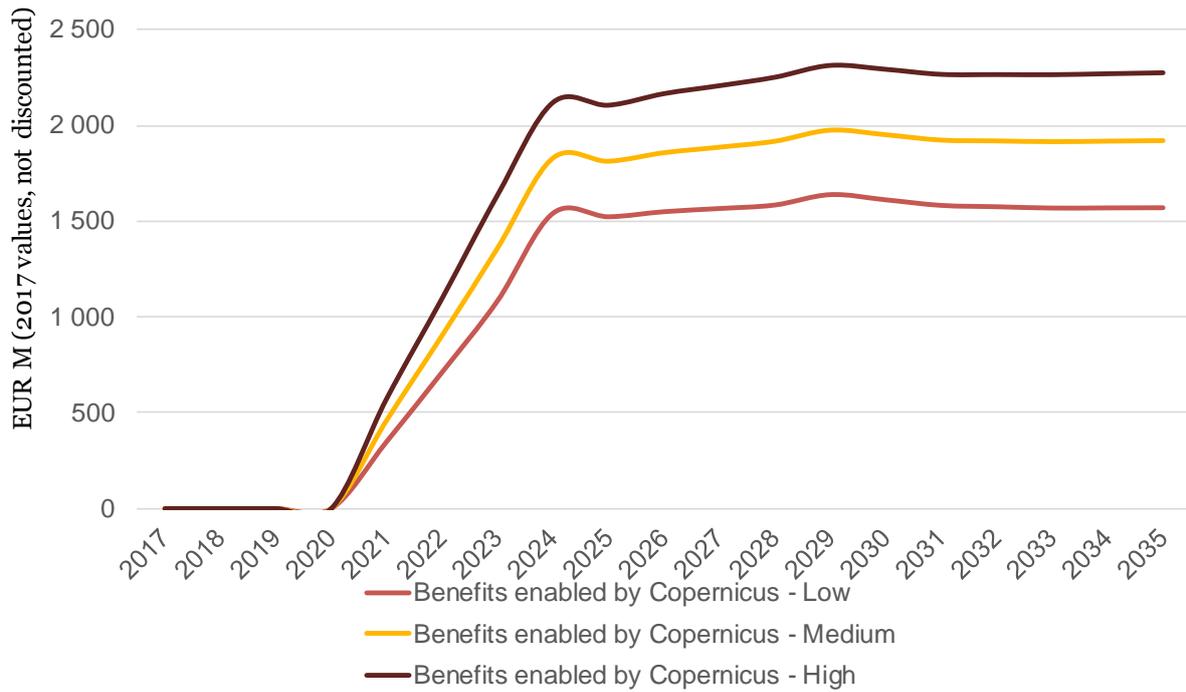


Figure 168 - Benefits enabled by Copernicus data and information for evolution option 4 (EUR M; EUR2017; undiscounted values) (Source: PwC analysis)

6 Conclusions

The study has analysed the different options under scrutiny for this impact assessment in support of the future EC impact assessment for the evolution of the Copernicus programme.

The present study focuses only on the impacts of the utilisation and exploitation of Copernicus D&I, and its spillovers on the wider European society. These benefits are split between intermediate users and end-users benefits, but it **does not take into account the cost of the options under scrutiny. Moreover, this report **does not take into account the GDP impact of the Copernicus programme**, including **upstream revenues** attributed to the **development of the infrastructure** (space manufacturing, ground segment manufacturing) and **downstream revenues attributed to services development and services operation**. Such benefits, together with the employment impact of the Copernicus programme, were assessed in a separate document. **Nevertheless, costs, GDP impact and employment impact were all assessed for the Copernicus programme and are provided in a separated document, together with the CBA analysis.****

The options under scrutiny for this analyse were the following:

- Option 1 – Baseline option: the Copernicus programme continues after 2030 (renew Sentinels after 2030)
- Option 2 – Shutdown option: the Copernicus programme is stopped after 2030, transferring ownership of remaining satellites and disassembling services
- Option 3 – Enhanced environmental services: the Copernicus programme continues after 2030 (renew Sentinels after 2030) and expands the scope of environmental services. This option is compounded of four different non-exclusive modules:
 - Option 3A – Anthropogenic CO₂ emissions monitoring;
 - Option 3B – Arctic (polar) & snow monitoring;
 - Option 3C – Additional thermal infrared capability;
 - Option 3D – Additional hyperspectral capability.
- Option 4 – Enhanced security services: the Copernicus programme continues after 2030 (renew Sentinels after 2030) and expands the scope of security services.

Following the investigation of the different categories of impacts, the potential options foreseen for the evolution of the Copernicus programme show different patterns of overall impacts. It is worth reminding that the purpose of this assessment is not to identify the option to be retained for the initiative, but only to provide the assessment of an order of magnitude of benefits derived from the various options under scrutiny that will support the decision-making, which remains in the hands of the European Commission.

The approach proposed for this study provides a robust and defensible methodology but it is important to stress that the assessment relies on many assumptions adding certain level of uncertainty on the outcomes. Applying ex ante impact assessment to Copernicus D&I utilisation & exploitation is challenging. In many domains, there is no baseline data to consult as there is no precedent for the service being performed. In other domains, even

where data exists on the expected experience by end users, it may not be possible to understand the extent of the impact at the EU or global level.

This challenge creates a number of issues for the development of quantitative valuations of the potential impacts. They can be grouped into four main areas and each is discussed in turn below.

1. The use/functionality of Copernicus D&I is not clearly understood by end users (i.e. most of the end-users are indirect users in most of the cases not even aware they benefit from Copernicus D&I);
2. The appropriate baseline against which to assess benefits is unclear (i.e. comparison what will have happen without the Copernicus programme);
3. The impact of Copernicus in terms of behavioural change is to estimate; and
4. Implementation will require additional costs on governments or businesses that are not covered by this study.

In this context, the results of the study should be understood as an **order of magnitude of impacts** rather than an exact and highly accurate financial assessment. The aim of this assessment is to show the existence of a phenomenon by assessing three different type of scenario (pessimistic, average and optimistic).

6.1 Results of the study

The three evolution options were analysed with comparison to the baseline option (Continue the Copernicus programme after 2030), highlighting additional benefits in the case of option 3 (Extend Environmental Service) and option 4 (Extend Security Service) and a reduction of benefits in the case of option 2 (Shutdown option)⁴¹⁹.

It is worth reminding that this impact assessment does not include a Cost-Benefit analysis (CBA), putting in perspective benefits and costs, preventing any comparison between evolution options. It is also worth noting the fact option 4 (enhanced security services) was not fully characterised when this study was performed.

Nevertheless, shutdown option (option 2) presents a net loss of benefits when compared with the baseline option for the period 2025 – 2030. Investments being already made in the programme until 2030, announcement of shutdown is expected to lead to a strong behavioural change in intermediate and end-users, pushing them to turn to alternatives options. After this period (2031 – 2035), additional benefits would be lost when compared to the baseline option, but a dedicated CBA needs to be carried out to carefully compare those benefits with the cost of assets renewal. ***The CBA was performed in a separated document.***

The next sub section presents the three evolution and the baseline option for the three scenarios under scrutiny.

⁴¹⁹ The assessment of the shutdown focuses on the benefits derived from Copernicus D&I but counterfactuals and alternatives solutions can potentially be found by intermediate and end-users to limit the loss of benefits. Our assessment does not take into account such possibility of adaptation.

6.1.1 Pessimistic scenario

The sum of all the benefits derived from Copernicus D&I for intermediate and end-users over the period 2017 – 2035 for the pessimistic scenario is illustrated in the chart below for all the options under scrutiny.

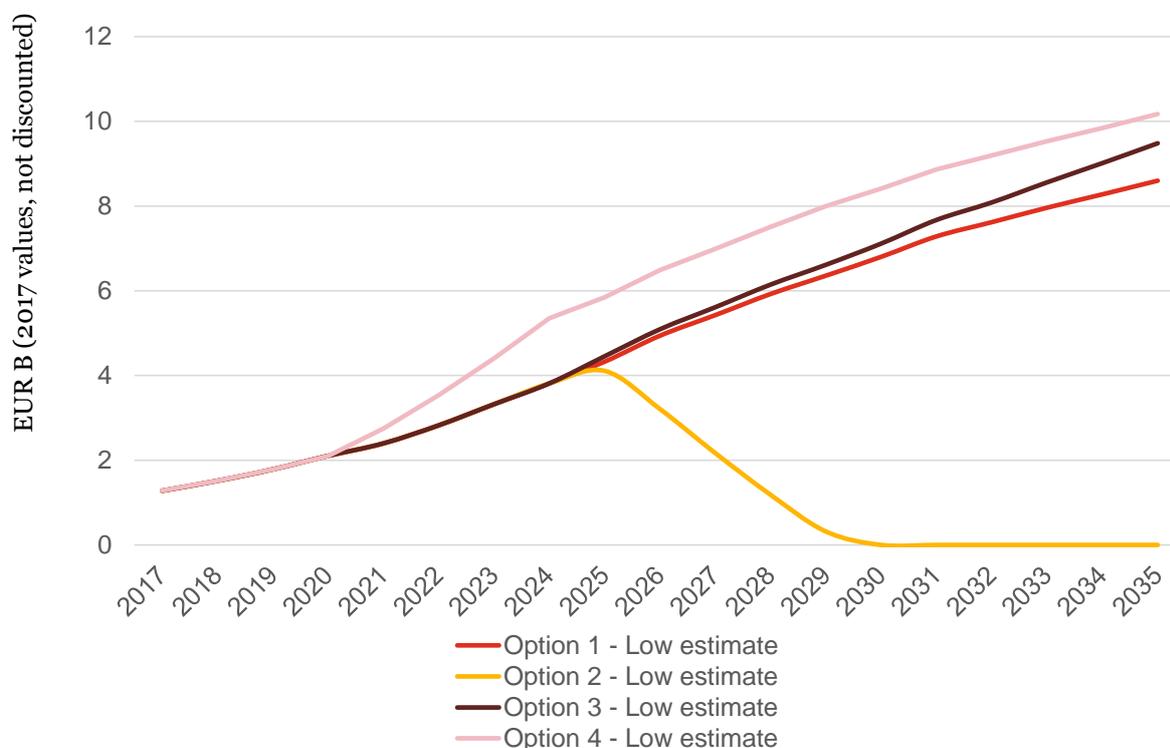


Figure 169 – Copernicus D&I benefits for all the options over the period 2017–2035 – Low estimate (Source: PwC analysis)

The separated results of the pessimistic scenario (2017 values, not discounted) are presented in the table below for EU only benefits. The benefits displayed for option 3 and 4 are additional to baseline option benefits.

Low estimate – EUR B	2017	2025	2035	Cumulative (2017 – 2035)
Option 1 (Baseline - EU only)	1.3	4.3	8.6	92.6
Option 2 (Shutdown)	1.3	4.1	0	30.0
Option 3 (Enhanced environmental services)	0	0.1	0.9	4.3
Option 4 (Enhanced security Service)	0	1.5	1.6	21.0

Table 54 - Copernicus total benefits of all options for the pessimistic scenario (EUR 2017, not discounted values) (Source: PwC analysis)

Once discounted, here are the cumulative benefits related to each option.

Copernicus cumulated benefits – EUR B	Option 1	Option 2	Option 3	Option 4
Low estimate	59.5	23.8	2.4	13.4

Table 55 - Copernicus total discounted benefits of all options for the pessimistic scenario (EUR 2017) (Source: PwC analysis)

6.1.2 Average scenario

The sum of all the benefits derived from Copernicus D&I for intermediate and end-users over the period 2017 – 2035 for the average scenario is illustrated in the chart below for all the options under scrutiny.

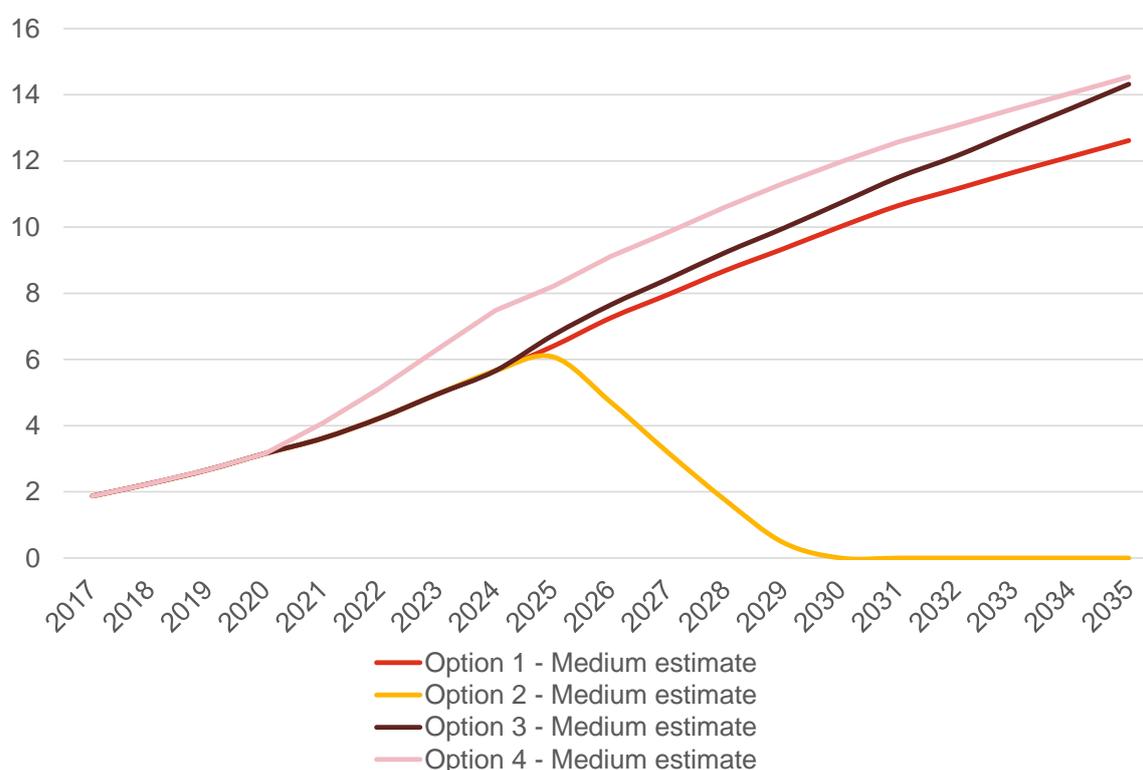


Figure 170 - Copernicus D&I benefits for all the options over the period 2017–2035 – Medium estimate (Source: PwC analysis)

The separated results of the average scenario (2017 values, not discounted) are presented in the table below for EU only benefits. The benefits displayed for option 3 and 4 are additional to baseline option benefits.

Medium estimate – EUR B	2017	2025	2035	Cumulative (2017 – 2035)
Option 1 (Baseline)	1.9	6.4	12.6	136.3
Option 2 (Shutdown)	1.9	6.1	0	44.6
Option 3 (Enhanced environmental services)	0	0.3	1.7	9.3
Option 4 (Enhanced security Service)	0	1.8	1.9	25.5

Table 56 - Copernicus total benefits of all options for the average scenario (EUR 2017, not discounted values) (Source: PwC analysis)

Once discounted, here are the cumulative benefits related to each option.

Copernicus cumulated benefits – EUR B	Option 1	Option 2	Option 3	Option 4
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Low estimate	87.8	35.4	5.3	16.3
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Table 57 - Copernicus total discounted benefits of all options for the average scenario (EUR 2017) (Source: PwC analysis)

6.1.3 Optimistic scenario

The sum of all the benefits derived from Copernicus D&I for intermediate and end-users over the period 2017 – 2035 for the optimistic scenario is illustrated in the chart below for all the options under scrutiny.

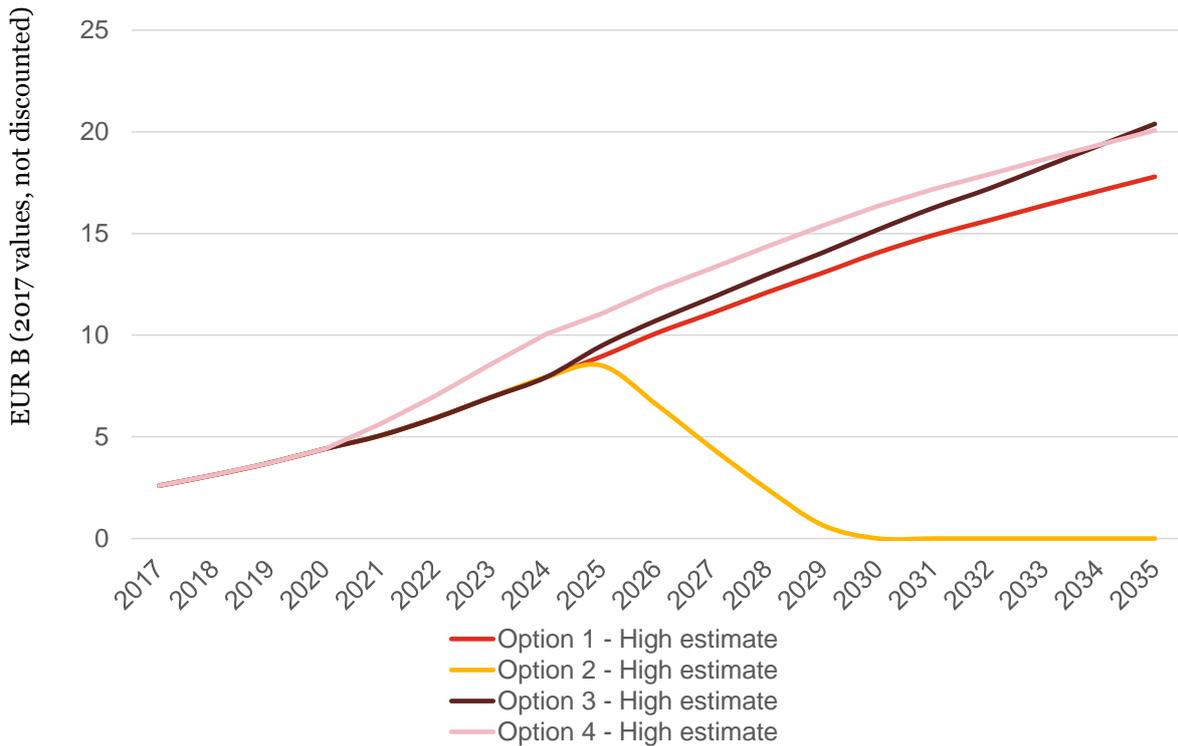


Figure 171 - Copernicus D&I benefits for all the options over the period 2017–2035 – High estimate (Source: PwC analysis)

The separated results for the optimistic scenario (2017 values, not discounted) are presented in the table below for EU only benefits. The benefits displayed for option 3 and 4 are additional to baseline option benefits.

High estimate – EUR B	2017	2025	2035	Cumulative (2017 – 2035)
Option 1 (Baseline)	2.6	9.0	17.8	191.0
Option 2 (Shutdown)	2.6	8.5	0	62.3
Option 3 (Enhanced environmental services)	0	0.5	2.6	14.5
Option 4 (Enhanced security Service)	0	2.1	2.3	30.1

*Table 58 - Copernicus total benefits of all options for the optimistic scenario (EUR 2017, not discounted values)
(Source: PwC analysis)*

Once discounted, here are the cumulative benefits related to each option.

<i>Copernicus cumulated benefits – EUR B</i>	Option 1	Option 2	Option 3	Option 4
Low estimate	122.9	49.5	8.3	19.2

Table 59 - Copernicus total discounted benefits of all options for the optimistic scenario (EUR 2017) (Source: PwC analysis)

7 Annexes

7.1 O&G appendix

Next sub-sections were directly extracted from PwC (2016)⁴²⁰ to provide context of the O&G activities impacts.

7.1.1 Generic Oil & Gas supply-chain

Oil and gas are always associated in the same value chain, even if they are two totally distinct energetic products. These two resources are, in most cases, located in the same underground or underwater reservoirs. Both were formed at the same time million years ago when large amounts of dead organisms were left trapped in sedimentary rocks, and were then subjected to intense heat and pressure. This very long process has led to the creation in the same reservoir of petroleum and natural gas released during the decomposition of organic material. These two materials are now the major sources of energetic consumption worldwide.⁴²¹

The O&G supply chain relies on three interconnected main stages, upstream, midstream and downstream activities. The upstream part gathers all activities related to exploration and drilling such as exploitation and appraisal, reserves development and drilling and production. Upstream also involves development activities, which means the construction of the infrastructure to drill the petroleum resources if the reserves are assessed to be interesting enough to be exploited. Midstream activities involve all the transport and storage, through maritime or land transport, from the extraction sites to the refineries. The transformation of crude oil and raw gas into derived products, petrochemicals and consumable oil & gas products is also included in the midstream part of the generic O&G supply chain. The third stage, the downstream part, involves all the marketing, distribution and logistics for the O&G market on commercial and domestic markets. Figure below summarizes the overall value chain.

⁴²⁰ PwC, 2016. Copernicus Downstream Study. European Commission. Brussels, Belgium

⁴²¹ Shell. Chapter 1: The origins of Oil and Gas in Shell in Alaska. Consulted November, 15 2015.

Link: <http://www.shell.us/content/dam/shell/static/usa/downloads/alaska/os101-ch1.pdf>

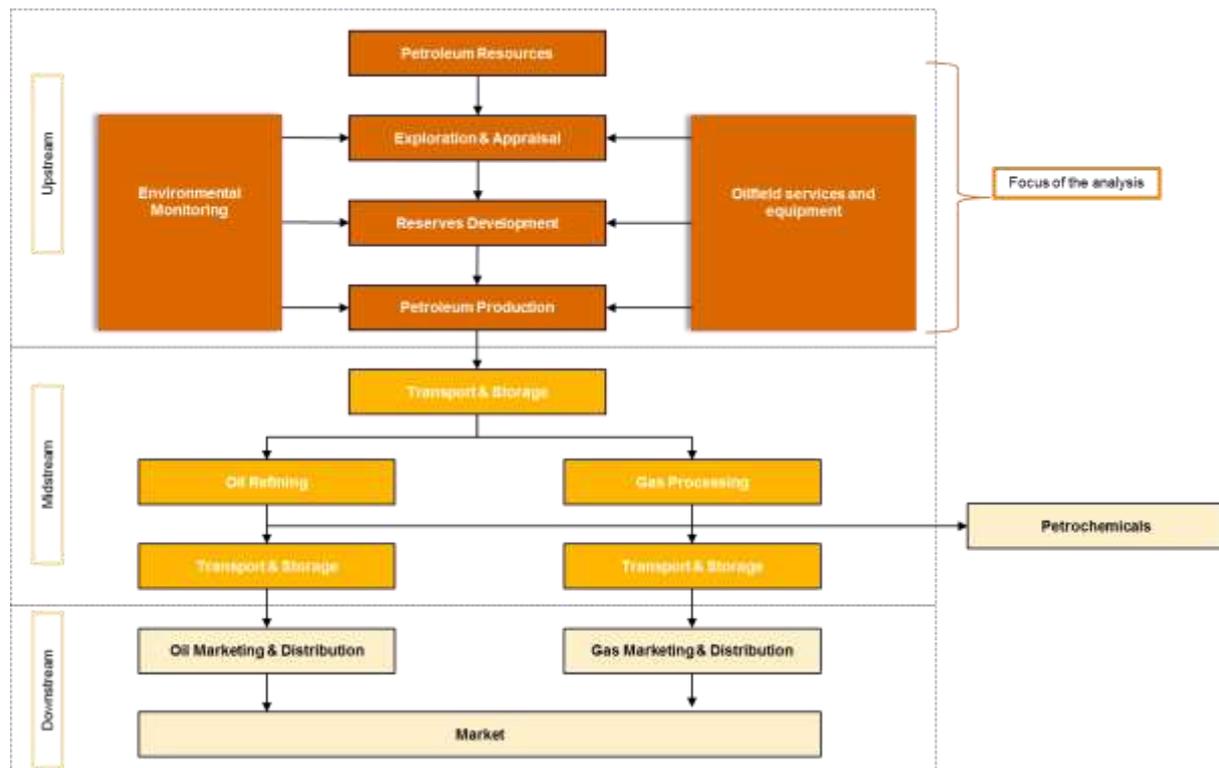


Figure 172 - Generic Oil & Gas supply chain (Source: PwC-Strategy& analysis)

7.1.2 The upstream Oil & Gas industry

The upstream part of the O&G industry is the core of the O&G market. Investments made in the upstream expenditures trickles down in all the other parts of the value chain. More expenses and revenues in the upstream lead to higher growth in the midstream and downstream market since these two ones depend on the flow of O&G extracted and its costs; the opposite is also true, less revenues in the upstream lead to a reduction of activities in the midstream and downstream.

The O&G upstream industry is consolidated, with very large players involved in most of the supply chain and dominating the market.

The following figure presents a characterisation of the upstream part of the O&G supply chain. This part of the supply-chain is split between three main types of activities:

- Main activities are performed by **large integrated operators**, also called **majors**. These large companies are vertically integrated and can be private companies such as BP, Statoil, Shell, Total, etc., or national monopolies such as Petrobras or Pemex. These large actors are able to perform most activities in-house, except for some very specific activities where they rely on oilfield services companies. They are usually fully integrated among the supply chain, from upstream to downstream activities. The world largest operators publicly held are called **super majors**;
- **Oilfield services** include all activities which require very specific and costly expertise or activities performed *una tantum*. For the so-called oilfield services, large actors rely on external companies to perform surveys, build specific oil well equipment & services, oil drilling & services and transportation. The market is dominated by the 5 oilfield classic (Schulmberger, Halliburton, National Oilwell

Varco, Baker Hughes and Weatherford) sharing one third of the worldwide market, letting the remaining two thirds of the market to a multitude of firms. Most of the actors involved in oilfield services are large companies, even if they are smaller than the majors O&G companies, a part from some very specific remote sensing companies working in the survey area that are very small (between 10 and 50 employees);

- **Environmental monitoring** is nowadays a very important part of the O&G activities. Many regulations were developed all over the world to prevent technological disasters⁴²² so O&G major actors have to be compliant with these new rules. For this purpose, they usually rely on external companies (consulting firms, remote sensing companies and/or clean technologies providers) to assess and reduce the environmental impact of their activities.

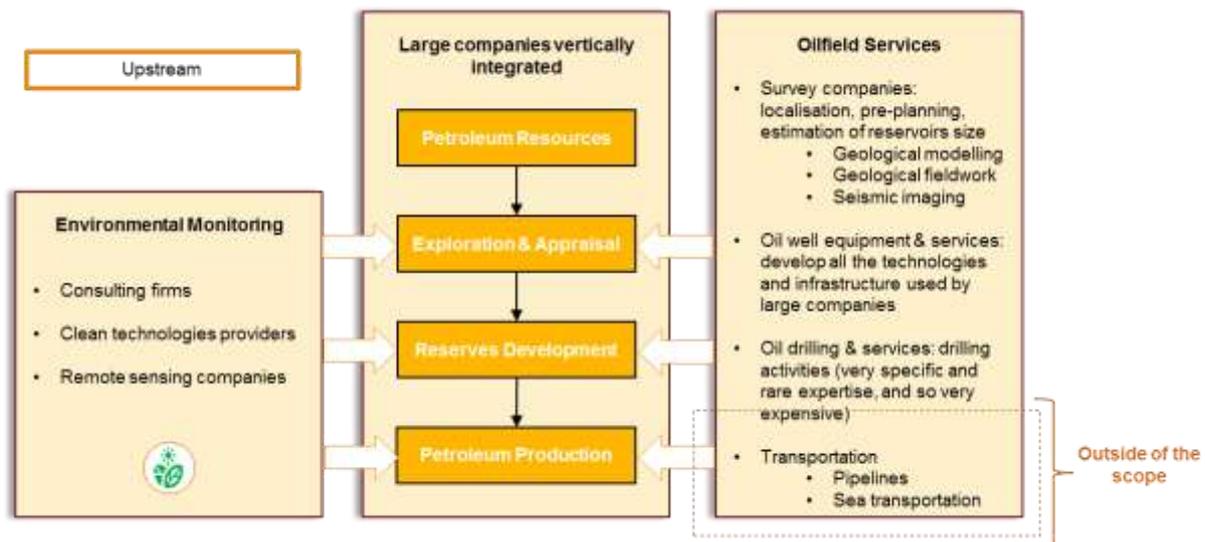


Figure 173 - Characterisation of the O&G upstream supply-chain (Source: PwC-Strategy& analysis)

A distinction between on-shore and off-shore activities can be made in the upstream part of the value chain since crude oil and gas can be both drilled underground (on-shore) or underwater (off-shore); technologies and practices involved vary a lot. The O&G upstream supply chain remains the same for both activities at a very high level of analysis. Once extracted, the value chain is basically the same for on-shore and off-shore activities.

- **Onshore activities** refer to O&G activities performed on land. O&G reserves are usually located several kilometres underground and require specific exploration, drilling, infrastructure development and exploitation activities. Risks of groundwater table contamination are very high during hydraulic fracturing or exploitation of natural gases, because of potential unintentional releasing of toxic gas in underground water. Social responsibility is nowadays more and more important for the O&G industry to mitigate environmental impacts of exploration and exploitation of O&G reserves.
- **Offshore activities** refer to O&G maritime activities. A large share of O&G reserves is located in deep water and need specific activities to be exploited. Exploration, drilling, infrastructure development and exploitation activities are performed very differently compared to regular onshore activities. Weather and sea condition (waves, wind, etc.) induce major risks for offshore infrastructures. In such context, damages

⁴²² A technological disaster is, by opposition to natural disaster, a disaster due to human activities such as oil spills, contamination of water or destruction of local ecosystem during exploration process.

to the infrastructure can produce important oil spills leading to tremendously negative impacts for the marine ecosystem and the environment.

The International Association of Oil and Gas Producers (IOGP), formerly OGP, represents the interests of the O&G upstream industry all over the world. Members of the association account for half of the world's oil production and one third of the world's gas production. IOGP aims at sharing best practices among the upstream O&G actors to achieve improvements in security, health, environmental protection and social responsibility. IOGP is promoting safe, responsible and sustainable operations in the industry. IOGP is notably engaged to promote an environmentally responsible Oil & Gas industry. Social responsibility is indeed nowadays more and more important for the O&G industry to mitigate environmental impacts of O&G reserves exploration and exploitation.

7.1.3 *The Upstream market function*

Major companies are the main players of the O&G upstream industry – they are also the main players of the midstream and downstream industry – and they are clients of all the other services (oilfield services and environmental services). All exploration activities are performed by the operators which buy prospection areas and perform most of the activities in-house. For very specific activities such as exploratory drilling or ex-ante environmental impact monitoring, they rely on outside companies performing oilfield and environmental services. The market is very well organised, very rational and very traditional. Most of the actors are not willing to take too much risk and the industry is strongly cost-oriented. **The main driver of the market is the price of oil:** higher price of the barrel is correlated to higher investments in the upstream and an increase in the drilling activities; the opposite is also true. Investments in new technologies, new methods, or new products – such as products based on Copernicus data – are strongly dependent on the Brent Crude Daily Price – this is the name of the indicator representing the price of oil on the stock exchange market.

7.1.4 *Macro-economic context of the O&G upstream industry*

Over the last two years, the price decline of the Brent Crude Daily Price was on the same order of magnitude than post financial crisis, losing 72% of its value. In June, 20 2014, the Crude Oil Brent was closing at US\$ 114.55/barrel while less than two years later, the price has fallen to US\$ 36.14/barrel on January, 1 2016. The figure below gives an overview of the Brent price evolution over the last 10 years, stressing out two periods of strong price decline.

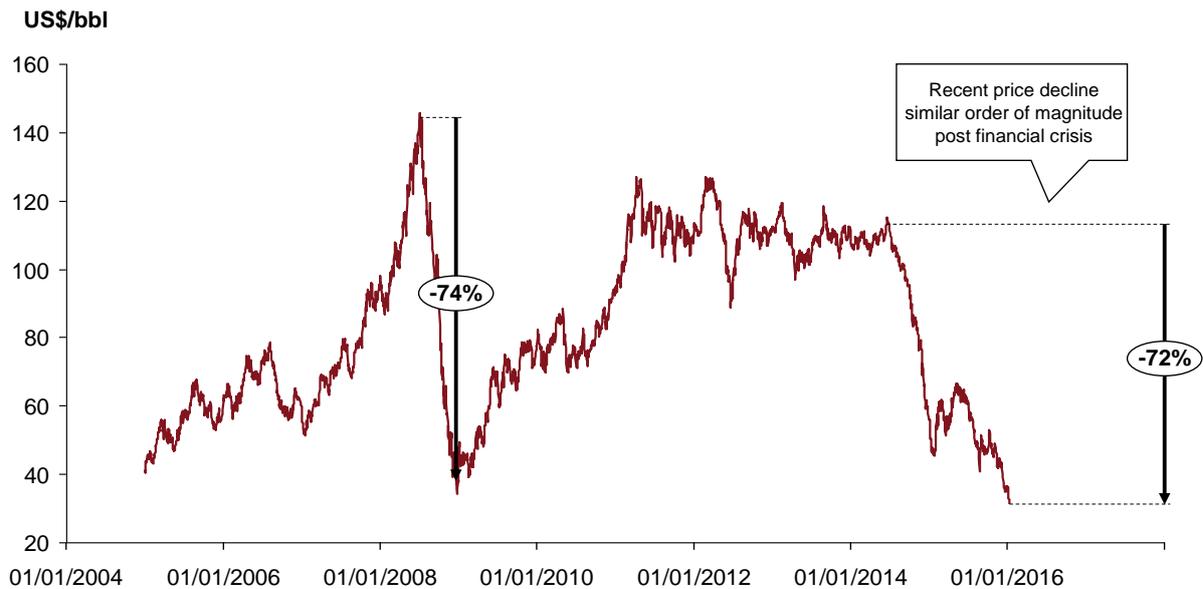


Figure 174 - Brent Crude Oil Daily Price on the period January 2005 - January 2016 (Source: Bloomberg, Strategy& Research)

Nowadays, the price of crude oil is still very low compared to summer 2014. The Brent has closed at US\$ 48.47 on July, 12 2016. The price of oil is expected to grow in the coming years.

Additionally, the price of crude oil was very volatile over the last months of 2015. The graph below gives an overview of the daily difference between high and low price of crude oil over the period January 2001 – January 2016. This volatility increases the risks for major companies and, in an industry where risk is considered as a major threat, investment in exploration are negatively impacted.

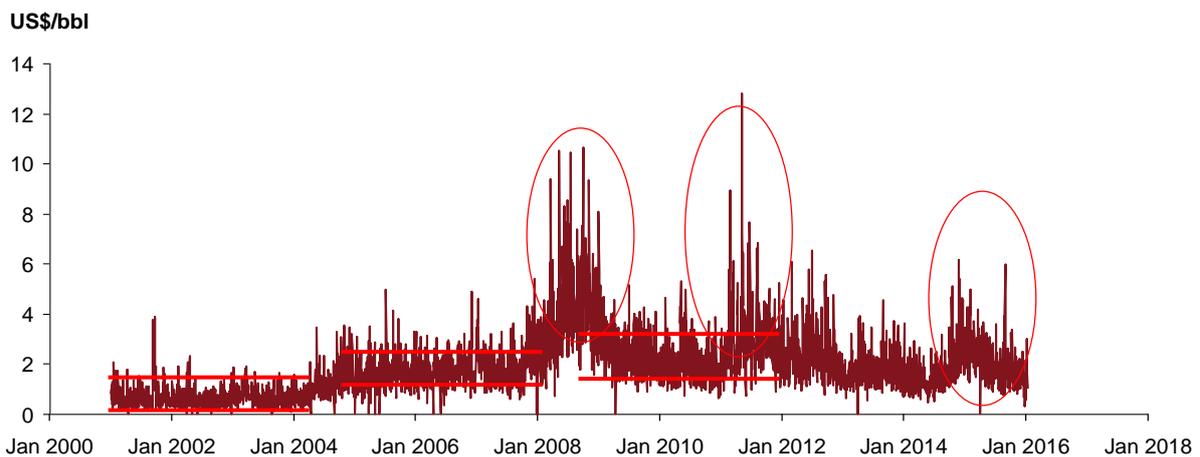


Figure 175 - Daily difference between high and low price of crude oil from January 2001 up to January 2016 (Sources: Bloomberg; Strategy& Research)

This important price decline and price volatility are heavily impacting investments made in the O&G upstream worldwide. Operators are expected to cut capital expenditures (CAPEX) by 30% in 2016, leading to postpone or cancel exploration projects for an amount of around US\$ 200 B. This pressure related to the price of oil increases the operators' bargaining power on the oilfield services companies, negotiating discount price ranging between 10 and 30%. While the barrel was still above US\$ 100 (end of 2014), super majors recorded net income of

US\$ 22.9 billion while twelve months later, same companies was not recording net incomes⁴²³. This context negatively impacts the overall revenues of the industry and inhibits investments in new technologies and new practices.

⁴²³ Strategy&, 2016. Oil Price Update Q1 2016. January, 2016.
Link: <http://www.strategyand.pwc.com/perspectives/2016-oil-and-gas-trends>