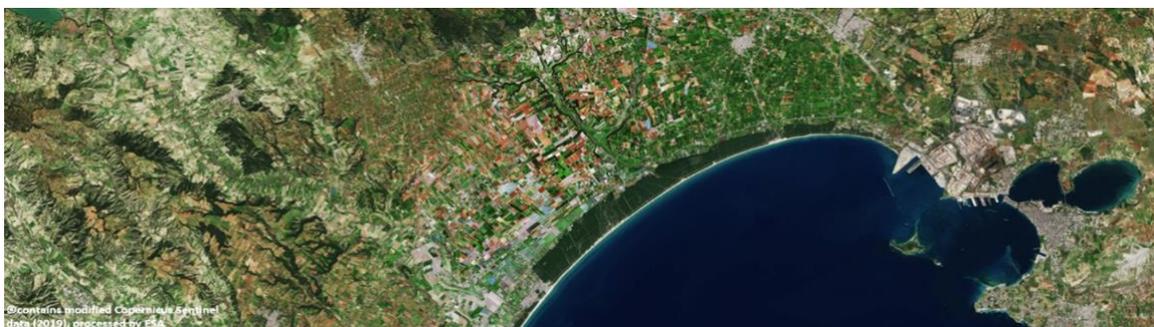European Association of Remote Sensing Companies

Sentinel Benefits Study (SeBS)

Sentinel Benefits Study

Demonstrating the value of Sentinel Data through Rigorous Value Chain Analyses and Powerful User Stories

October 2024

Client:	ESA
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Date of Delivery:	September 2024
Version:	Final
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Version	Date	Comment
01	September 2018	1st version giving a skeleton of the report
02	January 2019	Updated structure and notes on each chapter
03	May 2019	Revised report
04	July 2019	Consolidated 1st draft
05	March 2020	2nd version with enriched content
06	July 2020	3rd version with renewed structure to complement summary report
07	March 2022	Final version
08	September 2024	Revised Final version
09	October 2024	Revised Final version (v2.0)

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1 Introduction

1.1 Background

Satellites are touching every part of our modern lives. Their value has long been appreciated as a strategic asset whether for communication, navigation or surveillance, but as their commercial value becomes increasingly important, the value which they generate becomes a key issue.

Until recently, investments in developing observing systems were largely coming from the public purse, reflecting the strategic importance of the sector. Much of this strategic importance came from a defence and military imperative. Today, however, there is an ever-growing list of applications using Earth Observation data not just for other governmental uses, such as environment monitoring, humanitarian operations, disaster relief etc, but, increasingly, for other commercial sectors (agriculture, infrastructure monitoring, transport logistics etc).

Increasing private investment is based upon business plans with analyses of the projected market. But public investment, which is largely justified by meeting public needs, is based upon cost-benefit analyses. As far as Europe is concerned, the investment in Copernicus illustrates this very well. Constructed as a programme to serve the needs of public decision makers, it has become an economic instrument with the full, free and open data policy becoming a key tool to drive business.

Initially, the programme has been subject to cost-benefit analyses which have sought to convince policy makers to make the large investments necessary. These analyses have been, typically, macro-economic. Yet, alongside these studies it is important to develop a better bottom-up understanding of how the Copernicus Sentinel data is actually used and what benefits this brings to the actors in the value chain.

1.2 Project Objectives and approach

The objective of the **Sentinel Benefits Study (SeBS) is to demonstrate the value produced by the Copernicus Sentinels using a value-chain methodology**.

To achieve this, SeBS follows two streams of activity. The first entails the execution of **value chain analyses**, in which specific case studies are selected, analysed and presented with the aim to showcase the benefits brought by the usage of Sentinels data to society, environment and economy. The findings of these cases are not only contributing to creating a concrete picture of a wide range of benefits for different actors; they also help to strengthen the **methodological framework** for the execution of such studies. This methodological framework has been further enhanced by a number of **cross-cutting studies** carried out alongside the value chain analyses. The aim of these is to highlight the impact of the use of Copernicus Sentinels data across a wide range of topics. This includes analyses on the impact of Copernicus Sentinels data within Academic

Publications, as a key enabler for Innovation and Start-ups and a key resource in support of Environmental Compliance Assurance. Moreover, additional analysis relating to the Transversal Benefits across cases have been analysed.

The outcomes of the respective analyses are presented in the form of **publicly available reports**. These convey the importance of understanding, measuring and promoting the different types of benefits associated with the use of Sentinel data. In doing so, SeBS generates useful findings for:

- **Decision makers**: Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision makers not only to justify future investments but also to direct them towards the areas that most matter in their country or organisation.

- **Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. SeBS allows users to see how the data is used by actors with similar operational conditions, which decisions or activities it supports and what concrete (in quantified terms) benefits it brings. This can trigger the uptake of the data or empower better use.

- **Service providers:** Solid argumentation around the economic and all other types of benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective marketing tool for service providers seeking to promote their solutions. Moreover, the methodological guidelines developed in SeBS can drive the development of new cases by the service providers themselves as a tool to get more users onboard.

- **Citizens:** The analysis conducted within SeBS is presented in an accessible language for the wider public. In particular, the powerful storytelling and the explanation of how the data is used helps citizens to understand how public investments (in Copernicus Sentinels) return significant benefits to their everyday lives and to multiple neuralgic sectors for economy and society.

Beyond supporting the work and goals of these stakeholders, **the portfolio of analysed cases allows the extraction of meaningful lessons learned, the identification of common patterns, and, eventually, the articulation of insights that can inform future studies and activities**. In that regard, it is worth highlighting that SeBS has been contributing to the work done by the GeoValue community – an international group of practitioners developing best practices in the analysis of the value and socio-economic benefits of geospatial information in support of decision makers.

1.3 Scope of the document

By synthesising the findings and lessons learned during the execution of the different SeBS studies, we have been able to identify common patterns and draw cross-cutting conclusions. These insights and conclusions are presented in this report. The contents of the report reflect the progress and outputs of the project.

The report starts off with a presentation of the *raison d'être* of the SeBS study (Chapter 1) followed by a brief overview of the main components of the methodology (Chapter 2). It continues with a comprehensive analysis of the SeBS results (Chapter 3), focussing on who benefits and how. The report carries on by highlighting the lessons learned in the frame of the past 4 years (chapter 4) and closes with a future vision grounded in the conclusions of this study (chapter 5). The Annex dives into specific topics that have arisen over the course of the study.

Key highlights of the SeBS work presented in this report are summarised in the "Summary Report" which offers an entry point to the study.

1.4 References

Bernknopf, R., Brookshire, D., Kuwayama, Y., Macauley, M., Rodell, M., Thompson, A., et al. (2018). The Case of GRACE-Enhanced Drought Severity Index. Weather Clim. Soc. 10 (1), 187–203. doi:10.1175/WCAS-D-16-0044.1

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Pearlman, F., Pearlman, J., Bernknopf, R., Coote, A., Craglia, M., Friedl, L., et al. (2016). Assessing the Socioeconomic Impact and Value of Open Geospatial Information. Geol. Surv. Open-File Rep. 2016– 1036, 36. doi:10.3133/ofr20161036

Sawyer G & Papadakis D, SeBS Methodology: A Practical Guide for Practitioners to evaluating the benefits derived from the use of Earth Observation data. July 2024. https://earsc.org/sebs/wp-content/uploads/2024/09/SeBS-Methodology-2024.pdf

2   SeBS Methodology: rigorous analyses and powerful stories

Building on earlier ESA work by Geoff Sawyer and Marc de Vries in 2015[1], SeBS deploys a rigorous analytical approach to assess the **value of information** (for other relevant approaches see for instance Macauley 2005; Pearlman et al., 2016; Bernknopf et al., 2018) produced thanks to the use of Copernicus Sentinel data in well-defined operational scenarios. This earlier work included three case studies and mostly focused on economic benefits, whereas the new cases studied under SeBS include assessments of all **six dimensions of benefit**: economic, environmental, regulatory, innovation and entrepreneurship, science and technology, societal. In that regard, SeBS has developed a **balanced portfolio of cases whereby Copernicus Sentinel data is operationally used and contributes to better decisions or actions by different actors along the value chain**. It is therefore essential to understand how the EO service fits into the business process of the primary user and which decisions or actions it empowers along the value chain. Thus, for each of the cases SeBS sets out to conduct bottom-up quantitative and qualitative assessments of the benefits using different analytical tools appropriate for each case. The results of the analysis are presented with a **powerful storytelling approach**, which includes short cases using a simplified (and less rigorous) methodology than the full reports. The full reports also provide insights on the extrapolation of results and the attribution of the role of Sentinels. **SeBS also executes cross-cutting studies** which are often triggered by findings gathered in case studies. In turn these cross-cutting studies are often contributing to the development of methodological tools that strengthen the case studies. The interplay between case studies and cross-cutting analyses is shown in the graph below.
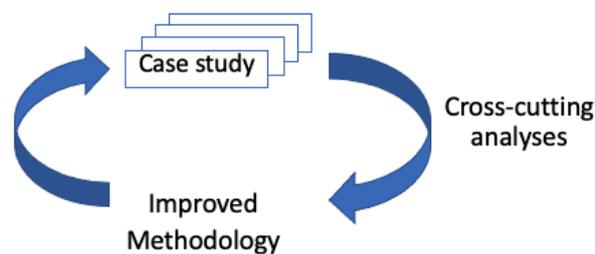
Figure 2-1: The interplay of case studies with cross-cutting analyses

2.1 SeBS Methodology: a robust approach to bottom-up assessments of benefits

SeBS has developed a robust methodology to perform bottom-up assessments of benefits stemming from the use of satellite data by users along a value chain. This methodology is described in detail in the dedicated "*Practical Guide for Practitioners to evaluating the benefits derived from the use of Earth Observation data*".

To aid the readers of the current report, we provide a visual representation of the overall methodology below, followed by a brief overview of some of its key aspects and complemented by short commentary.
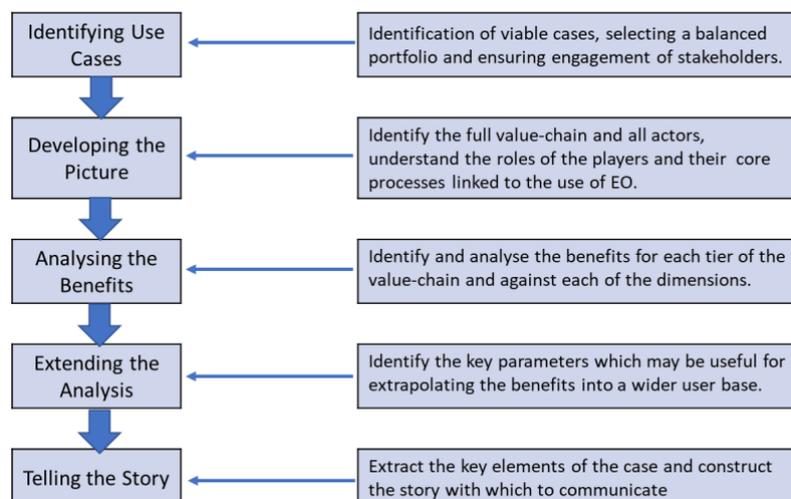
Figure 2-2: Overview of the SeBS methodology

Applying this methodology, SeBS has developed a rich database of cases (discussed in section 2.2); the analysis of several of these cases (see section 2.3), together with complementary studies (see section 2.4), has produced significant findings (see chapter 3).

2.2 SeBS database: a wealth of cases

From its very beginning, SeBS sought to develop an extensive database of potential cases for analysis. To do so, a wide search is made, and the list of potential cases is constantly refreshed and reviewed to identify candidates. This involves scouring all possible sources, including social media, for news of services or service providers promoting new products. Once good candidates are identified and in order to develop the desired diversity in the portfolio of cases and select the most promising ones, a rigorous selection process takes place according to the **following criteria**.

- **Use of Sentinel data**: this is a fundamental requirement. It does not mean that only Sentinel data is being used and indeed this would be unlikely, but there should be a certain dependence on the Sentinel data to be valid for our work. There may also be cases which are based on the prospective use of Sentinel data. In other words, a service has been built up using another data source which is or can be, replaced by data coming from one of the Sentinel satellites.

- **Operational use**: this criterion is necessary in order to engage value chain actors who can concretely speak about actual and not merely potential benefits. Being operational means that the primary user has enough experience to be able to provide figures or comment on our assumptions regarding the calculation of benefits with a practical background. At the start of the study, many cases were tied to R&D projects and hence did not effectively involve organisations who had operationally integrated Sentinel-based services in support of decisions taken under their normal operations.

- **Primary user engagement**: this has been found to be a critical step to a case being feasible and so is introduced as a criterion at the very beginning of the selection process. It is difficult to overestimate how important it is that the primary user is fully engaged, and not just the contact but their management hierarchy as well. It is extremely disruptive if the primary user moves to a different job or work on the case is suspended by management. Ideally, an initial conversation is held with the primary user but most usually, the supplier is asked to validate this point.

- **Willingness of the primary user organisation to openly discuss** their use of the products and their operational benefits. There have been several cases where Sentinel data have been operationally used but either the EO provider or the primary user were reluctant or simply not available enough to discuss. Whilst it has proven hard to recognise such occurrences early enough, we have eventually developed more robust checks that minimised its impact.

The importance of enthusiastic value chain actors

The last two criteria are especially important. A direct engagement with the primary user and their support in the analysis and to open doors down the value chain is absolutely essential. It is not always easy to judge this at the outset, but we always try to have two calls with the primary user before the case is fully committed so as to judge their support.

One danger is the post-box effect where the primary user asks for questions in writing and responds to these in writing. This strongly limits the dynamics of the exchange and risks to kill the case. We have experienced this in one case which is proving extremely problematic to complete.

A lesser danger but still to watch for is the time available to help. A face-to-face meeting is essential, and it is most effective if combined with other stakeholders who can be interviewed at the same time. A final round of interviews can be conducted later by telephone, but the core of the case should be resolved during the face-to-to-face meeting with the primary user and other meetings taking place at the same time. Nevertheless, each situation is different, and adaptions need to be made. For example, when we started the Potatoes in Belgium case, there was a biennial, trade fair taking place in Belgium; one of the leading ones in the world. This provided an excellent opportunity for primary research and to set up meetings. We anticipated to be able to do most of our research at this show, but people were so busy that we were unable to make the full progress expected.

A further risk is an enthusiastic contact who has not ensured the support of their hierarchy. In two cases, insufficient attention has been paid to this point causing delays and difficulties to make progress. The primary user must be challenged before the case is committed to communicate with their reporting line and ensure that they have the backing of their hierarchy.

Finally, all interviewees need to be able to review the written report. This can take quite a few weeks at the end of the case just when publication is felt to be imminent!

Applying the aforementioned criteria, we have developed a pool of potential cases, which has been growing steadily since the beginning of the project. In July 2018, we had 117 potential use cases of Sentinel data, **with this figure rising to over 300 by mid 2024.**

It should be noted that the SeBS team moved away from the use of an online database by mid to late 2023. The team decided it was more efficient at this stage of the project to target specific cases that they knew they were interested in covering based on both **the theme of the case** and the fact that **it was known that the service in question was well-established and mature enough to provide fruitful material**. It became easier to find cases at the later stage of the project in this manner due to the maturity of the market itself, meaning many more Sentinel-based services had "found their feet", they already had strong results to show and were known to the EO community.

The numbers in the tables below reflect only the information in the online database, (i.e., up to mid to late 2023).

About one fifth of these cases in the database were considered to have pre-mature status i.e. they are still in a form of R&D or project-related phase and thus non-eligible to be studied as a fully operational status is mandatory. Over 150 cases were in the long list meaning they could be studied in principle, but there is an aspect in the case that necessitates a longer waiting period. These are assessed periodically to ascertain if they can be moved from the long-list to the watch-list or even the short-list which would mean they are ready for analysis.

Case distribution	H1 2018	H2 2018	H1 2019	H2 2019	H1 2020	H2 2020	H1 2021	H1 2022	H2 2023
pre-mature list	50	53	56	58	56	56	54	54	53
long list	49	72	96	128	136	147	147	150	156
watch list	11	15	14	7	6	5	6	9	17
short list	7	1	2	1	3	3	4	3	4
Analysed / In-progress	6	9	11		15			25	23
total	123	150	179	194	216	215	215	216	253

Table 2-1: Summary of Full list of collected cases.

The majority of use cases are based on the usage of either Sentinel-1 (55) or Sentinel-2 (79). Also, many applications use both S-1 and S-2 (35). Only very few applications use S-3 (4) or S-5P (7) or are drawing upon various combinations of the Sentinel sources.

Sentinel (for some unknown)	H1 2018	H2 2018	H1 2019	H2 2019	H1 2020	H2 2020	H1 2021	H1 2022	H2 2023
S-1	26	35	40	44	46	48	48	50	55
S-2	28	41	46	52	53	54	54	58	79
S-3	3	3	4	4	4	4	4	4	4
S-5P	1	3	4	4	4	5	5	5	7
S-1/2	14	17	21	22	24	25	27	28	35
S-1/3	2	3	3	4	4	4	4	4	4
S-2/3	1	1	1	1	1	1	1	2	4
S-4/5	0	0	1	1	1	1	1	1	1

S-1/2/3	1	3	1	6	6	6	6	6	6
S-1/2/3/5	0	3	1	1	1	1	1	1	1
S-2/3/5	0	0	0	1	1	1	1	1	1

Table 2-2: Collected cases according to which Sentinel is used.

When it comes to geographic spread, most cases are located[2] in the UK (22), France (19), Italy (17) and Germany (16). The portfolio today covers virtually the whole of Europe, with additional cases found in Asia, Africa, Australia and Canada. Some could not be assigned to a single country due to their transnational, pan-European or global dimension.

With regards to thematic sectors, land applications – and especially agriculture with 60 – stand out by far. Within the land thematic, many applications have been or are being developed for the forestry (34), topography (19) or inland water monitoring (15). This is followed by cases for the built environment (40), the ocean & marine thematic sector (36), and the disaster & geohazards (23). Fewer cases could be found for the security sector, probably due to their sensitive nature.

Thematic Sector	H1 2018	H2 2018	H1 2019	H2 2019	H1 2020	H2 2020	H1 2021	H1 2022	H2 2023
Land	**66**	**84**	**103**	**114**	**118**	**121**	**122**	**128**	**151**
agriculture	37	44	49	52	54	55	55	57	60
land ecosystems	3	3	4	5	6	7	7	7	10
forestry	7	13	18	20	21	22	23	25	34
land cover	3	1	1	1	1	1	1	1	3
land use	0	2	3	4	4	4	4	4	4
topography	7	10	15	17	17	17	17	18	19
inland waters	6	8	10	10	10	10	10	11	15
snow & ice	3	3	3	5	5	5	5	5	6
Ocean & Marine	**18**	**21**	**26**	**29**	**30**	**30**	**31**	**32**	**36**
oil spills	1	1	1	1	1	1	1	2	3
ships	3	3	4	4	4	4	4	4	5
marine ecosystem	4	4	5	8	8	8	8	8	8
fisheries	3	3	3	3	4	4	4	4	5
metocean	4	5	8	8	8	8	8	8	8
sea-ice	2	4	4	4	4	4	5	5	6
coastal	1	1	1	1	1	1	1	1	1
Disaster & Geohazards	**12**	**18**	**19**	**21**	**21**	**22**	**22**	**22**	**23**

[2] Location is associated with where the service is used, i.e. either the location of the primary user or, for "global" cases the location monitored by the primary user.

floods	5	8	8	9	9	10	10	10	11
fires	6	8	8	9	9	9	9	9	9
volcanoes	1	2	3	3	3	3	3	3	3
Built environment	**13**	**17**	**20**	**27**	**29**	**31**	**31**	**33**	**40**
infrastructure	11	14	16	23	25	27	27	28	33
urban areas	2	3	4	4	4	4	4	5	7
Security	**2**	**2**	**3**	**3**	**3**	**3**	**3**	**3**	**3**
security	2	2	3	3	3	3	3	3	3
Atmosphere & climate	**4**	**9**	**11**	**12**	**12**	**15**	**15**	**15**	**17**
atmosphere	4	9	11	12	12	15	15	15	17

Table 2-3: Distribution of cases across sectors/applications
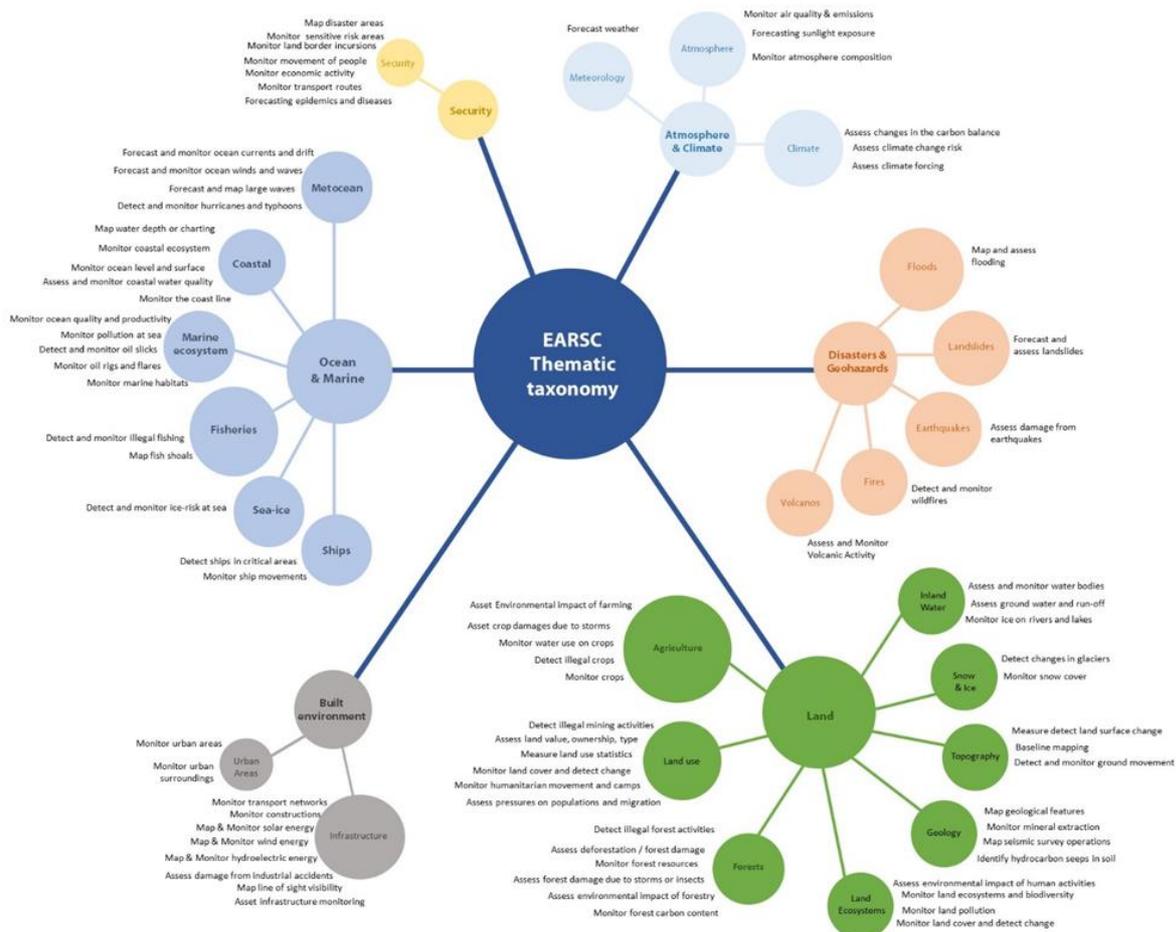
Figure 2-3: Visual representation of distribution of cases per sector/application

2.3 SeBS case studies: learning from real-life experiences

From all these cases, we have analysed a total of 22 full cases. The list of the full reports produced as part of this contract includes:

- Winter Navigation in the Baltic[3]
- Forest Management in Sweden[3]
- Infrastructure Monitoring in the Netherlands[3]
- Farm Management Support in Denmark
- Flood Management in Ireland
- Navigation through sea ice off Greenland
- Growing Potatoes in Belgium
- Farm Management Support in Poland
- Highways Management in Italy
- Ground movement monitoring in Norway
- Aquifer Management in Spain
- Water Quality Management in Germany
- Grassland Monitoring in Estonia
- Making Wine in France
- Deforestation Monitoring for Sustainable Palm Oil Production
- Clean Seas in the Mediterranean
- Air Quality Forecasting in Latvia
- Water Quality Management in Finland
- Invasive Species Detection in Croatia
- Water Quality Management in The Netherlands
- Motorway Maintenance in Portugal
- Water Resources Management in Spain

Alongside these full cases, 15 short cases[4] have been produced:

- Peatland Management in the UK
- Dredging in the Maldives
- Assessing geese damage in the Netherlands
- Illegal Wild Boar Activity in Lithuania
- Global Oil Industry Activity Monitoring
- Golf Course Monitoring in Italy
- Forest Management in Portugal

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[3] These full cases were previously developed by EARSC under a different contract

[4] Short cases (6 pages in length) have been introduced where a story exists but where detailed economic analysis is not possible.

- [Insurance and Risk Monitoring in Slovenia](#)
- [Monitoring Illegal, Unreported, and Unregulated Fishing in UK Overseas Territories](#)
- [Wildfire Management in Greece](#)
- [Renewable Minigrid Deployment in Ethiopia](#)
- [Ground Motion Intelligence in Romania](#)
- [Irrigation Detection and Mapping in Austria](#)
- [Sourcing Deforestation-Free Cacao in Peru](#)
- [Green Wellbeing Indicators in Poland](#)

Looking at the evolution of the portfolio of cases we can readily see that the SeBS study has taken us on a journey across multiple sectors (agriculture, emergency management, infrastructure monitoring, water quality monitoring, ecosystem monitoring to name a few), countries and stakeholders. By construction, the aim of the study has been to **develop a diverse portfolio of cases with regards to geography, application and Sentinel data type** and this has been already achieved. Yet, we should note that at the beginning of the study, we found that when cases are scrutinised more closely, they are often lacking the most fundamental parameters: operational maturity and steady access to the involved stakeholders. This can be attributed – to a large extent – to the fact that Sentinel data had not been around for long enough for companies to develop operational businesses in which benefits can be securely analysed and quantified. This realisation is – seemingly – no longer valid; with a few years now on their back, many cases have reached or are just reaching operational maturity. Thus, **the sector gives the overall impression of a dam ready to burst through; once across the threshold, Sentinel data are used in multiple applications bringing significant benefits not only to the primary users but also to the value chain around them.**

Figure 2-4: Several long and short cases have been published under SeBS

2.4 SeBS complementary analyses: widening the exploration of specific types of benefits

In going through the cases, we have uncovered topics which merited a deeper investigation. These topics would often resonate with developments in the grander ecosystem of Earth Observation activities in Europe. For instance, we have studied how Copernicus Sentinel data support Innovation and Start-ups. This is an issue directly tied to significant EU and ESA investment in fostering the creation of start-ups; it is also, however, a recurrent theme when looking into individual case studies, where the service provider is a start-up and highlights the importance of Copernicus Sentinels for the viability of their business models. Similar considerations of top-down (i.e. in connection to policy or investments) vs bottom-up (from the cases) triggers, apply to the rest of the cross-cutting studies performed. An overview is provided below.

Quick title	Trigger	Online Resources	Topic
Academic Publications	Top-down	Copernicus Sentinels contribute to scientific research - Analysis of trends and patterns in academic publications from the Scopus database – 2022	Scientific Research
Start-ups analysis	Top-down and bottom-up	Innovation and Start-ups powered by Copernicus Sentinel data – Preliminary Report – June 2019	Start-ups, Innovation and Research
ECA analysis	Top-down	Copernicus Sentinel data supporting Environmental Compliance Assurance – June 2021	Copernicus and Environmental Compliance Assurance
Transversal Analysis	Transversal	SeBS - Transversal Analysis – August 2024	Highways Management, Forest Managemet, Lake Water Monitoring

Table 2-4: Overview of ad hoc assessments under SeBS

For each of these studies, a meticulous analysis has been performed, involving extensive desk research, multiple interviews and several fit-for-purpose analytical tools. The findings of both case studies and cross-cutting analyses are discussed in the next chapters.

3 SeBS Findings: Sentinel-derived benefits along six dimensions

The use of Copernicus Sentinel data at the entry point of the value chain generates significant benefits for the service providers, their primary users and other actors further down the chain. Through the execution of value chain analyses, cross-cutting studies and workshops focussing on methodology, we have collected plenty of evidence about these benefits. This has been organised in a comprehensive manner following the criteria developed within the SeBS Methodology. In that regard, this chapter discusses SeBS results along the six dimensions of benefits: economic, environmental, regulatory, entrepreneurship and innovation, science and technology and societal.

For each benefits category, SeBS general findings are described in terms of the core value parameters. Relevant concrete examples linking to the case studies and/or to the cross-cutting analyses are summarised as available. These will be progressively expanded throughout the project lifetime.

3.1 Economic benefits

Looking at a subset of the analysed cases (see table below) economic benefits take various different shapes, as discussed in detail below.

	Water Resources Management in Spain	Motorway Maintenance in Portugal	Water Quality Management in The Netherlands	Invasive Species Detection in Croatia	Air Quality Forecasting in Latvia	Oil Spill in the Mediterranean	Water Quality in Finland	Highways Management in Italy	Deforestation Monitoring for Sustainable Palm Oil Production	Water Quality Management in Germany	Grassland Monitoring in Estonia	Making Wine in France	Aquifer Management in Spain	Ground Motion Monitoring in Norway	Farm Management Support in Poland	Growing Potatoes in Belgium	Navigation through Sea-ice off Greenland	Flood Management in Ireland	Farm Management Support in Denmark	Infrastructure Monitoring in the Netherlands	Forestry Management in Sweden	Winter Navigation in the Baltic
Economic Benefits	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Capital expenditure																				✓		

reduction																		
Cost savings	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓
Increased revenues			✓				✓						✓		✓	✓	✓	✓
Efficiency gains	✓	✓			✓	✓			✓	✓	✓	✓	✓	✓	✓		✓	✓
Reduction of risk	✓	✓	✓		✓			✓	✓	✓			✓		✓		✓	✓
Employment		✓	✓					✓	✓		✓		✓	✓	✓	✓		✓

Table 3-1: Economic benefits against selected cases

3.1.1 Capital expenditure reduction

This concerns situations whereby the use of Sentinel data has helped in reducing or avoiding capital expenditures. Most avoided costs we see in the portfolio of cases relate to operational expenditures (i.e., savings in data, fertilizers, pesticides, fuel, time, wages etc.), however, below is an example of where CAPEX was reduced.

Infrastructure Monitoring in The Netherlands	In this case we saw how Sentinel data can help in pinpointing areas that require gas connection replacements. By doing so, this helps to push unnecessary replacements to a time further in the future and thereby was found to save infrastructure replacement costs (CAPEX) of €41.3 million.

3.1.1 Cost savings

Spending less time, using less fuel, applying reduced inputs (e.g. water, fertilisers, pesticides) or deploying fewer people in the course of a specific operation translates into concrete financial benefits. This aspect often represents one of the most important economic benefits realised thanks to the use of Copernicus Sentinel data, as documented in every one of the studied cases. In fact, in every case, we see the avoided cost of having to purchase commercial EO data thanks to the use of free and open Copernicus Sentinel data. There are a large number of examples of saved operational costs throughout the portfolio of cases, below is just a sample of a few.

[Water Quality Management in the Netherlands](#)	Here we see how the NZV can avoid costs related to in-situ sampling of water bodies via the use of the Sentinel-enabled service. Cost savings in Lauwersmeer alone total €258k per year, and when extended to the whole country amount to €26.8 million per year.
[Oil Spill in the Mediterranean](#)	17 countries around the Mediterranean use EMSA's CSN service. By doing so, each country on average each saves 10 days of aircraft time in a year or rather, they are able to use the aircraft for other purposes for 10 days per year. This leads to an estimated average saving of €160k to €200k for each country each year, or a total saving of €2.7m to €3.4m.
[Grassland Monitoring in Estonia](#)	The Estonian Paying Agency used to send inspectors to perform on-the-spot checks for 5% of the grassland registered for CAP monitoring. Today, thanks to Sentinel-based services, the Estonian Paying Agency covers the totality of agricultural fields with minimised need for on-the-spot-checks leading to direct savings of €50,000 per year and a better use of its personnel's time.
[Winter Navigation in the Baltic](#)	Before the availability of Sentinel data, the guidance of ice-breaker ships was conducted using on-board helicopters. Thanks to Sentinel satellite data, shipping companies no longer have to rely on this, saving significant operational costs.
[Flood Management in Ireland](#)	With large part of the country flooded, the alternative use of a fleet of manned aircraft would simply not be economically viable for the national civil protection agency.
[Aquifer Management in Spain](#)	The Sentinel-enabled InSAR monitoring of the extraction operations in the Segura Basin allows quick reactions to potential excessive subsidence, thus protecting homes or business buildings in the proximity of extraction wells. This amounts to avoided costs from potential damages at the order of €3.25 Million per year.

3.1.2   Increased revenues

The generation of increased revenues is primarily associated to higher prices (over fixed volume of sales) or to higher volumes of sold goods and/or services. The latter concerns practically all service providers building innovative solutions that exploit Sentinel data and serving clients' needs in several market segments. Increased volumes are also met in the many agricultural cases we have analysed, whereby higher yield or higher quality products can be achieved through the use of satellite-enabled services.

[Deforestation Monitoring for Sustainable Palm Oil Production](#)	Agricultural commodity traders are using Sentinel-based services to establish objective evidence on deforestation-free production of palm oil. This allows them to reduce the occurrence of stranded assets, i.e. plantations that are suspended because of deforestation and associated volumes of produce not being sold since they don't meet deforestation-free production commitments.

[Making Wine in France](#)	In this case we saw how wine producers can distinguish better between different qualities of grapes and can thereby target different sections of vineyards for premium harvesting. This ultimately helps them avoid blending high quality and low quality wines, meaning they can charge higher prices for different product classes.
[Farm Management in Poland](#)	Here we observed the seemingly paradoxical example of major fertiliser companies incorporating into their offering satellite-based services which help farmers reduce their fertiliser input. Yet, the logic behind this is clear: at a time when regulation is pushing for more sustainable agriculture, fertiliser companies can better retain clients if they provide them with satellite-based products that help them better perform variable rate application of fertilisers. They can also enter new markets thus not only overcoming potential loss but effectively diversifying their portfolio.
[Growing Potatoes in Belgium](#)	In this case we see how potential yield increases of between 15%-20% as a result of using the Sentinel-enabled service.

3.1.1 Employment

In almost every case we have studied, we have found that for the service provider, the development and provision of Sentinel-enabled services has supported jobs or even led to the creation of new jobs. This is obviously an economic benefit to the people employed and can be considered an overall economic benefit due to the value creation of jobs.

Despite the clear evidence that the adoption of Sentinel data supports jobs, it should be noted that this adoption can, at times, result in the loss of other jobs due to new working practices replacing old ones. For example, in the case of [Winter Navigation in the Baltic](#), the use of Sentinel data replaced the need for helicopters to survey the ice, meaning the employment of helicopter service providers was no longer needed.

3.1.1 Reduction of risk

By reducing operational and safety-related risks, users of Sentinel-enabled services can avoid potential financial and even reputational penalties.

[Deforestation Monitoring for Sustainable Palm Oil Production](#)	Here we saw how by helping palm oil supply chain companies fulfil their sustainability commitments around no deforestation, these companies can ensure importation of deforestation-free products to Europe can continue, fines can be avoided and even access to favourable interest rates on sustainability-related loans can be maintained.

Motorway Maintenance in Portugal	Here we see how Sentinel data can be used to reduce the risk of road closures, which in turn brings with it economic benefits for commerce and society.
Ground Motion Monitoring in Norway	Again, we see how the avoidance of road and rail closures bring with them economic benefits for commerce and society.
Sourcing Deforestation-Free Cacao in Peru	Similar to the Palm Oil case, by using Sentinel-enabled services, importers of cacao can avoid potential fines, reputational damage and cessation of business.

3.1.2 Efficiency gains

Acting with high accuracy, at the right time and at the right place is critical to the success of many operational processes across different sectors. When this is coupled with optimised use of resources (see previous point on "reduced inputs") it translates into improved efficiency. The key here is the timely availability of reliable data. Sentinels are offering exactly that for a wide range of applications. The impact of improved efficiency has often a tremendous contribution to the magnitude of benefits experienced further down the chain.

Deforestation Monitoring for Sustainable Palm Oil Production	In this case the agricultural commodity trader can organise the inspection of suppliers against whom grievances have been raised in a much more efficient way, optimising the use of their operational resources. In practice, this means that they can either immediately establish whether suspicion of deforestation is well-founded, or investigate only the cases where satellite data point to potential harmful activity.
Infrastructure Monitoring in the Netherlands	Here the use of Sentinel-based services allows the detection of deformations and helps the infrastructure management company to fully focus on those pipeline connections that are very likely to malfunction.
Oil Spill in the Mediterranean	In this case we see how CleanSeaNet enables more efficient detection of oil spills and clean-up operations by acting quickly and effectively.

An overview of the different economic indicators is presented in Annex A. These indicators contribute to the overall assessment of economic benefits analysed for the different cases. These are shown below, taking in account both the current and potential economic benefits. Where assumptions are used, often a minimum and maximum value will be taken, and this leads to the low and high values.

Case	Estimates	
	Low	High
Winter Navigation in the Baltic	24	116
Forestry Management in Sweden	16.1	21.6
Infrastructure Monitoring in the Netherlands	15.2	18.3
Farm Management Support in Denmark	1.1	1.2
Flood Management in Ireland	6.5	30.3
Navigation through Sea-ice off Greenland	8.6	12.5
Growing Potatoes in Belgium	1.8	2.6
Farm Management Support in Poland	1.1	5.3
Ground Motion Monitoring in Norway	3.8	8.7
Aquifer Management in Spain	31.7	71.8
Making Wine in France	5	9
Grassland Monitoring in Estonia	0.1	1.1
Water Quality Management in Germany	4	7.8
Deforestation Monitoring for Sustainable Palm Oil Production	19	33.6
Highways Management in Italy	5.6	13.6
Water Quality Management in Finland	6.6	24.8
Oil Spill in the Mediterranean	41.7	81.1
Air Quality Forecasting in Latvia	0.2	3.8
Invasive Species Detection in Croatia	3.9	4.1
Water Quality Management in the Netherlands	33	38
Motorway Maintenance in Portugal	2.5	3.6
Water Resources Management in Catalonia	11	22.2
TOTAL	242.5	531

Table 3-2: Summary of the Cases Economic Benefits

The total benefits are quite significant with only 22 cases featured. A minimum figure of €242.5m (or €11m per case on average) has been calculated with the maximum extending to approx. €531m (or €24.1m per case on average). It should be noted here that in each case different economic models and assumptions have been used, thus this table serves only to give an overview. For detailed information on what is behind each of the projected numbers please refer to the individual cases.

3.2 Environmental benefits

The use of EO data can generate multiple environmental benefits. As mentioned in [SeBS Methodology](#), these are often extremely difficult to measure in a quantitative way. In most cases, they materialize several years later and so the attribution of value to EO can be very challenging. Nonetheless, the study of multiple cases where the operational use of Sentinel data empowers more informed decisions has allowed us to pinpoint a wide variety of environmental benefits. In fact, and opposed to the studies carried out earlier, the focus within SeBS is on indicators describing *environmental benefits* stemming from the *use* of satellite data, not on indicators describing the precise *state* of the environment or evaluation of benefits stemming from such a state. Therefore, the focus of the research is shifted from a static estimate to a dynamic context – describing a change induced by the *use* of satellite data, either directly or indirectly. Below we look into some of the environmental benefits.

3.2.1 Reduced pollution

The use of Sentinel-enabled services often leads to reduced amounts of pollutants in key resources (i.e. watercourses or the atmosphere). In SeBS, this was particularly evident in agricultural cases. Similarly, reduced use of fuel and/or emissions thanks to better ship routing can have a very positive environmental impact.

[Oil Spill in the Mediterranean](#)	In this case we see how CleanSeaNet enables better oil spill response, preparedness and oversight, thereby aiding in prosecutions and deterrence. As a result, the amount of oil entering the environment has reduced considerably over the last decade despite the increase in traffic through the Mediterranean.
[Farm Management Support in Denmark](#) [Farm Management Support in Poland](#)	Sentinel-enabled services can inform the amount of fertilisers and pesticides infiltrating into the groundwater and eventually affecting the occurrence of algal blooms.
[Winter Navigation in the Baltic](#) [Navigation through Sea-ice off Greenland](#)	Reduced use of fuel and/or emissions thanks to better ship routing can have a very positive environmental impact
[Water Quality Management in Germany](#)	Sentinel-enabled services can inform on the level of algal bloom in lakes as a result of fertilisers and pesticides runoff. It helps

Water Quality Management in Finland	authorities take initiatives to limit the use of nutrients where lakes are suffering from algal bloom in agriculture areas.
Water Quality Management in the Netherlands	

3.2.2 Reduced impact on biodiversity

Thanks to reduced pollution, as already discussed, Sentinel-enabled services can also help to protect biodiversity and critical ecosystems. This has been seen in a variety of cases.

Invasive Species Detection in Croatia	In this case we see how the eradication of Invasive Alien Species preserves the native biodiversity in precious landscapes across Croatia.
Water Quality Management in Germany	
Water Quality Management in The Netherlands	In these cases, Harmful Algae Blooms can be accurately identified and monitored allowing for better protection of biodiversity in various water bodies.
Water Quality Management in Finland	
Deforestation Monitoring for Sustainable Palm Oil Production	In this case we see that by helping palm oil supply chain companies to fulfil their sustainability commitments around no deforestation, Sentinel-based services also contribute to the preservation of local biodiversity such as Orangutans.
Flood Management in Ireland	Another consideration is that of the impact of natural disasters on the environment. This case highlighted where the civil protection agency and regional authorities have been able to perform better emergency management thanks to the use of Sentinel-enabled flood maps. This, in turn, has helped reduce the impact of flooding on important habitats and on wildlife.

3.2.3 Reduced natural resources depletion

The use of Sentinel-enabled services can also help competent authorities to prevent or reduce the depletion of natural resources.

Aquifer Management in Spain	In these cases we see that local authorities are taking advantage of the accurate, long-term monitoring of the operation of extraction wells, to optimise their use and promote more sustainable management of aquifers. This in turn helps to reduce the occurrence of effects such as ground erosion and the appearance of gullies.
Water Resources Management in Spain	
Monitoring Illegal, Unreported, and Unregulated Fishing in UK Overseas Territories	In this case we see how the protection of waters around UK Overseas Territories, preserves both fish stocks and local ecosystems from being depleted as a result of illegal activities.
Forest Management in Sweden	In this case, we see how the Swedish Forest Agency protects forests from over utilisation through efficient management of forest resources.

3.3   Regulatory benefits

The use of Sentinel data may have a profound impact on the design and implementation of regulatory measures and policies, as documented in several of the cases studied under SeBS. As described in SeBS Methodology, regulatory benefits can materialize at different stages of the policy development. A dedicated cross-cutting analysis was also made in order to strengthen the concept and structure the types of value (see Copernicus Sentinel data supporting **Environmental Compliance Assurance**). As part of SeBS, we found evidence of numerous mechanisms through which the use of Sentinels data supports the ability to develop, enact and enforce (environmental) policies and regulations, as described separately in the following sub-chapters.

3.3.1   Better regulations

By offering new measurements, EO data allows the design of regulations to be improved to reflect existing or new policy needs. Within SeBS, examples were found where regulations have been changed (or are planned) as a result of the availability of Sentinel data.

Forestry Management in Sweden	Availability of satellite monitoring provided the tool to change the regulatory basis completely to one of "freedom with responsibility" for the 300,000 owners of forest in Sweden.
Ground Motion Monitoring in Norway	Ground Motion Monitoring Identifying and measuring movement more precisely together with a long time series of measurements will allow future legislation to be drafted with clearer responsibility for the consequences of damage.
Aquifer Management in Spain	The ability to measure ground movement with precision over a large area enables Murcia to control water abstraction more precisely and establish responsibility for any damages caused, to be included in legislation.

A good example illustrating this aspect is the case of Aquifer Management in Spain. In this case, the operation of pumps extracting water from the aquifer may lead to significant land subsidence, which in turn may cause significant damages to buildings. To avoid this, the local authorities responsible for the operation of the pumps have to follow strict regulatory boundaries with regards to the specific extent of allowable land subsidence (e.g. 2cm per year). This number however has been defined many years ago using means available at the time. Today, thanks to Sentinel-enabled InSAR measurements this threshold can be refined (i.e. informing the specifications of the regulation) allowing the authorities to operate in a more evidence-based manner.

3.3.2 Improved monitoring

EO data is used by the relevant authorities to assess the level of alignment to the prescribed behaviour and/or its breaches. Within SeBS, examples were found where compliance with existing regulations is better monitored through the use of Sentinel data.

Water Quality Management in The Netherlands	In this case we see how the NZV Water Board can improve their ability to carry out their own institutional monitoring tasks in accordance with their legal statutes and regional and national laws.
Grassland Monitoring in Estonia	Country-wide imagery identifies grasslands and whether they have been cut according to regulatory needs. Farmers are rewarded for compliance which is visible to them through an on-line app.
Monitoring Illegal, Unreported, and Unregulated Fishing in UK Overseas Territories	Thanks to Sentinel-enabled services, regulation on illegal fishing activities can be enforced in a more effective manner. Organisations and territories can boast vastly improved operational efficiencies thanks to satellite-based remote sensing techniques, which in turn helps them to fulfil their role of protecting their waters.
Aquifer Management in Spain	Improvement through precise monitoring of ground surface movement over the whole water basin which links to the amount of water being abstracted in coherence with existing local/national limitations.
Forestry Management in Sweden	The Forest Agency is able to monitor where guidelines have been respected i.e. compliance with recommended best practice.
Oil Spill in the Mediterranean	International regulations control deliberate oil dumping in the seas. Sentinel data used in the CleanSeaNet service provides the only means to monitor where ships are operating illegally by washing tanks.
Water Quality Management in Germany	Sentinel data provides widescale measurement of lake water quality and provides indicators of compliance with the Water Framework

	Directive and the Bathing Waters Directive providing guidance on where physical tests should be carried out.

3.3.3 Improved reporting

EO data has the potential to improve the efficiency and effectiveness of agency reporting obligations. This aspect, however, has not featured prominently in the cases analysed in SeBS. This is in part because when legislation does not specifically include the use of EO data, public bodies cannot justify budgetary expenditure on non-referenced methods, even if this may ultimately result in greater efficiency and better use of resources.

In the Table below, the closest examples are mentioned.

[Water Management in Catalonia](#)	Sentinel-based observations help the ACA comply with EU Water Framework Directive provisions, ensuring regulatory adherence. Currently, EO measurements are not used for reporting, but their future use is a possibility. If implemented, these benefits are expected to increase significantly.
[Invasive Species Detection in Croatia](#)	The Sentinel-enabled service in this case helps in reporting against the EU's special Regulation no. 1143/2014 which requires the Member States, among other, to report on measures taken for the early detection and eradication of invasive alien species.
[Grassland Monitoring in Estonia](#)	Satellite imagery enables the Estonian Agricultural Registers and Information Board (ARIB) to report on the status of all the declared grasslands in an effective and transparent way.
[Sourcing Deforestation-Free Cacao in Peru](#)	The use of Sentinel data helps food importers adhere to the requirements of the EUDR and provide accurate and encompassing due diligence reports.
[Water Quality Management in Finland](#)	National legislation has recognised the use of Sentinel data provides a series of satellite-derived measurements for coastal waterbodies in the 2014 WFD assessment and later introduced satellite-derived metrics to support WFD assessments in the 2015-2021 reporting cycle.
Water Quality in Sweden*	Metrics for the 2014 WFD status classification. Sweden is incorporating satellite-based Earth observations of chlorophyll-a for the ongoing 2nd round reporting (2015-2021) for coastal waterbodies. *this has not been fully analysed as a SeBS case.*

3.3.4 Better enforcement

EO data can be used in enforcement-related proceedings (e.g., judiciary or audits) and to provide courts with evidence of illegal activities. We found limited examples of the use of Satellite data in courts due to the difficulty to overcome practical and legal obstacles. Aspects such as verifiability, traceability, and interpretation are always a concern requiring the implementation of more complex and top-down solutions, such as a certification system.

Only one example was found where Sentinel data is being used to support legally-based audits on public authorities.

Water Management in Catalonia	EO measurements in this case were found to help in improving policy enforcement and the overall implementation of public services (i.e., municipalities can do a better job).
Monitoring Illegal, Unreported, and Unregulated Fishing in UK Overseas Territories	Thanks to Sentinel-enabled services, entities engaging in IUU fishing can be prosecuted with objective and transparent data.
Illegal Wild Boar Activity in Lithuania	Sentinel data used in courts to settle disputes between hunters and farmers: "The use of such Sentinel data should become commonplace in all future crop-damage case". Judge Vitunskiene, Kouanas Regional Court
Oil Spill in the Mediterranean	Satellite imagery used to prove location of illegal discharge and, along with AIS, to identify the polluting vessel.
Sand dredging in Finland*	The example was found where local authorities and individual citizens are using Sentinel imagery in court in claims against sand extraction companies. *this has not been analysed as a SeBS case.*

3.3.5 Raising awareness

Deterrence by raising awareness amongst potential offenders of the ability to detect non-compliance (and the possibility to enforce if necessary). We found numerous cases where, communicating the capability to detect non-compliance coupled with public visibility of detections, plays a deterrent role vis-a-vis potential perpetrators.

Water Quality Management in Finland	In this case, the ELY centres and ministries can improve their accountability (and thus self-confidence and sense of mission fulfilment) through better transparency and better communication. This in turn allows them to do a better job in compliance to regulation and in policy making.

[Dredging in the Maldives](#)	Providing international visibility of actions where dredging damages protected sea beds (flora) so encouraging better environmental responsibility.
[Oil Spill in the Mediterranean](#)	Ships captains and owners are informed about the wide-area / regular and timely surveillance which acts as a strong deterrence to discharge illegally.
[Grassland Monitoring in Estonia](#)	Direct access and alerts to farmers provide transparency, promote fairness and encourage compliance.
[Forestry Management in Sweden](#)	Forest owners receive reminders from the Swedish Forest Agency if they have not followed required forest management practices. Freedom with responsibility.

3.3.6 Policy evaluation

The evaluation phase involves systematic or ad-hoc monitoring of the adequacy of the policy and the efficiency of its implementation. From the interaction with users, we have seen how Sentinel data can be used to assess and evaluate a "before and after" assessment of the impact of the policy.

[Water Quality Management in Finland](#)	The TARKKA service studied in this case is becoming recognised by SYKE and ELY Centres as an effective way to improve their ability to monitor the quality of water under their legal responsibility. The data helps the ministry to evaluate the impact of policies on water quality.

3.3.7 Accountability

Not a part of the policy cycle, but an important attribute linked to public authority performance and evaluation. We found several examples where the objectivity of EO data, and in particular the full, free and open access granted by Copernicus, contribute to the successful enacting of core principles such as transparency and accountability.

[Air Quality Forecasting in Latvia](#)	The service in this case is able to support local decision making linked to reducing pollution and to provide evidence to justify measures taken to the local population. Examples include regulation of cars and especially older diesel motors, suppressing installation of coal burning stoves in towns, introduction of "dust tickets" i.e. free passes for local transport when the level of pollution is high. Further measures discussed include controlling cars and lorries in sensitive roads i.e. where they pass by schools and car free days.

[Grassland Monitoring in Estonia](#)	Farmers access the Sentinel-derived data on grassland cuts which enables them to view the synoptic picture and promotes transparency and fairness under the regulatory regime.
[Water Quality Management in Germany](#)	Citizens are given access to information on lake water quality so building trust in the regional environment body.
[Dredging in the Maldives](#)	NGO's have access to imagery showing where dredging takes place and where protected marine grasses may be damaged to encouraging compliance by the dredging company.
[Deforestation Monitoring for Sustainable Palm Oil Production](#)	As well as making it possible to find non-compliant suppliers, the service provides objective evidence for certification or verification of authorised production. This evidence is essential when investigating grievances individually or together with NGOs and governmental authorities.
Sand Dredging in Finland*	Companies dredging sand are using satellite imagery to self-control the level of turbidity. *this has not been analysed as a SeBS case.*

3.4 Innovation and Entrepreneurship benefits

The availability of Copernicus Sentinel data has proven to be a strong driver for innovation and entrepreneurship. These aspects have been probed by SeBS in two ways: (i) through the execution of value chain analyses whereby the service provider is a start-up whose business model is enabled by the availability of Sentinel data, or where a value chain actor was able to innovate using Sentinel-enabled services, (ii) through a dedicated study on "[Innovation and Start-ups powered by Copernicus Sentinel data](#)".

Figure 3-1: The majority of respondents to the startup survey use Sentinel data extensively

The latter study was first conducted in 2019 and then enhanced/revised in 2021, yielding several interesting insights. Among them, as can be seen above, the fact that the majority of startups responding to the survey rely heavily on the use of Sentinel data.

3.4.1 Start-ups

Free and open Sentinels data can act as an enabler for viable business models. Without exception, all commercial service providers involved in the SeBS cases have underlined that without free and open access to the world-class Sentinel data their business model would not be viable. In such cases, the innovative service they currently provide can either not be delivered in another way (i.e. no counterfactual is available) or, instead, achieving the same service level with other means would lead to completely unfeasible scenarios (from a financial perspective). In fact, this perspective is responsible for the creation of many new start-ups who would have otherwise not been able to translate their innovative ideas into products with strong market fit. This reality has been illuminated via the startup survey too as can be seen on the graph below.
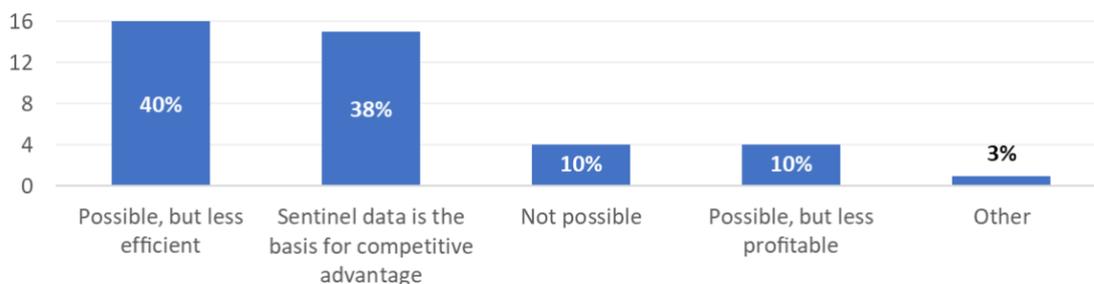

Figure 3-2: Would your business model be possible without Copernicus?

3.4.2 Changed business practice

Sentinel data can help to introduce innovative business models either within a single organisation or among multiple organisations along the value chain. Whilst this has not been studied in detail, SeBS cases have shed light into the contribution of Sentinel data to the establishment of innovative governance models. A few examples were found that provide evidence about this type of soft benefits.

Growing Potatoes in Belgium	The fact that several actors in the value chain (farmers, processors, agronomists) get access to a centralised platform that provides information (thanks to the use of Sentinel data) on key parameters about the cultivation of potatoes has enabled new alliances among these actors, including ones that foresee sharing of different datasets so as to improve provided services and increase transparency of processes over time
Deforestation Monitoring for	Sentinel-enabled services not only allow the primary user to ascertain deforestation-free production of palm oil (or identify potential breaches), but

Sustainable Palm Oil Production	also help a wider community (i.e. RSPO including prominent NGOs like WWF) striving for the same purpose.

3.4.3 Patents

Although not explicitly quantified through the analysis, monitoring patent creation associated with new services or tools based on Sentinel data could be strong indicator and metric of innovation. Patents serve as concrete proof of new ideas, products, or processes that meet certain criteria for novelty and utility. By tracking the number of patents filed or granted, it is possible to gauge the level of inventive activity associated with the use of Sentinel data.

3.5 Science and Technology

Sentinel data, and EO data at large, support advancements in Earth sciences and related technologies. In SeBS Methodology, we have identified different metrics through which we can identify potential signals for this type of benefits: **(i)** academic outputs, **(ii)** utilisation in R&D projects, **(iii)** human capital (researchers and students) and, **(iv)** applied science leading to operational services. At this stage of the SeBS study we can comment only on the first, the third and the last of these signals.

3.5.1 Academic publications

Academic outputs (i.e. articles in scientific journals and conference proceedings) are a very tangible way in which scientists make the results of their work visible. Through a dedicated study "Copernicus Sentinels contribute to scientific research - Analysis of trends and patterns in academic publications from the Scopus database" we have attempted to investigate the ways in which the availability of Sentinel data has been reflected in or given rise to scientific publications. In that regard, we focused on identifying the volume and nature of academic publications based on Copernicus Sentinel data. The analysis identified almost 12,000 publications in the period up to the end of 2021 and classified them according to their use of the data, the particular Sentinel involved, and they type of publication (i.e., an article or conference paper).
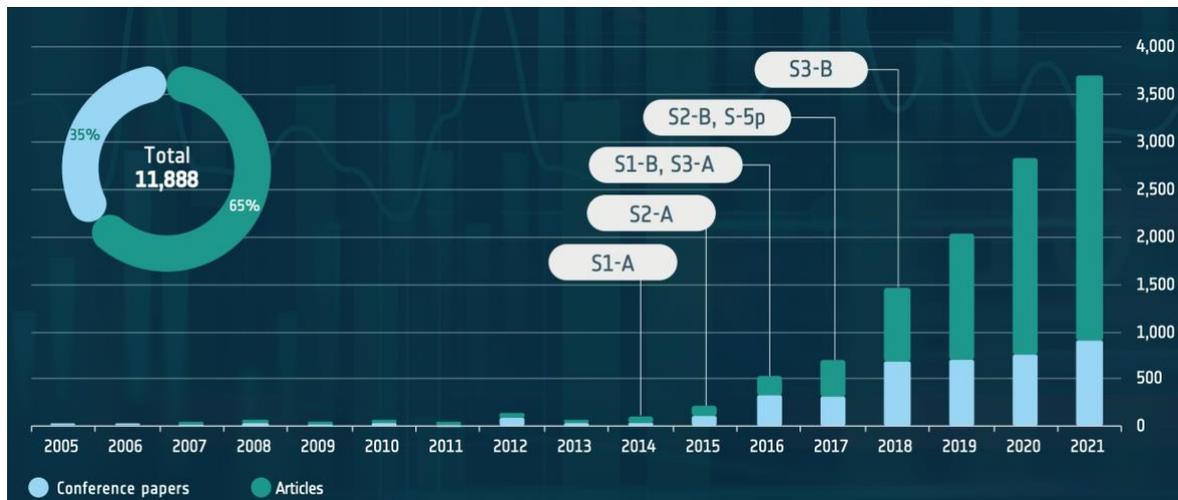
Figure 3-3: Publications by type. The flags indicate the launch dates of the various Sentinels.

The study also investigated the "focus" of the publications. To analyse these trends, we separated academic sources focused on Earth Observation or remote sensing (i.e., "remote sensing-focused") from those focusing on earth sciences or other thematic application areas ("application-focused"). In this analysis we focused mainly on journal articles rather than conference papers, as journal articles tend to require more thoroughness and rigour, thus representing more consolidated contributions to the scientific corpus. As expected, overall, the number of publications in "application-focused" sources is less than the "remote sensing-focused" ones, both for journals (41% of the total) and for conference papers (17% of the total). Of the 11,888 overall publications (journal articles and conference papers), 3,872 or 33% have been published in venues of an "application-focused" nature.

Figure 3-4: Publications by focus. The flags indicate the launch dates of the various Sentinels.

Some general trends can be summarised as follows:

- Overall, up to and including 2021, there have been 11,888 unique publications from over 150 countries relating to Sentinels-1, -2, -3 and -5p. This figure comprises of 4,194

conference papers presented at 475 conferences and 7,694 journal articles published in 890 journals.

- Year on year, we have continued to see significant increases in the volume of publications: of the 11,888 overall publications so far, 3,684 (31%) of these were published in 2021 alone.
- Among the Sentinels, Sentinel-2 has the overall largest total publication volume, accounting for 6,187 publications up to and including 2021.
- Sentinel-1 accounts for the second highest overall publication volume, with 5,505 publications in total up to and including 2021.

3.5.2 Research staff

Directly tied to the viability of business models discussed earlier (enabled by the free, full and open data policy of Copernicus), the hiring of researchers and scientists by both private and public sector actors in order to conduct applied research and contribute to innovative services has been a common theme among several of the studied cases. This includes not only remote sensing specialists but researchers from several other disciplines including but not limited to agronomists, environmental scientists, data analysts, oceanographers, etc. Thus, the employment of these specialists results in both business and academic outputs with strong roots on operational uses of scientific or technological breakthroughs.

Invasive Species Detection in Croatia	In this case we saw how Oikon, the service provider, enriched the scientific landscape through their efforts. As a research institute, they have developed novel methods and algorithms which utilise Sentinel data to detect various invasive alien species, including for both coverage and biomass analysis.
Aquifer Management in Spain	The geological survey enhances its scientific output thanks to an improved ability to perform geological studies and modelling with the use of Sentinel-enabled InSAR.
Grassland Monitoring in Estonia	KappaZeta have had a number of scientific research papers published throughout the development of the grass mowing detection service. These primarily focus on the use of Sentinel-1 SAR data in grassland monitoring applications.

3.5.3 Research budgets

Similar to the hiring of research staff, research budgets can also be increased to ensure work conitnues on the scientific understanding of how Sentinel data can be applied in various domains and in the development of novel remote sensing techniques.

3.5.4 Improved understanding

The use of operational Sentinels data can greatly support scientific understanding across different applications. In addition, services relying on Sentinel data can trigger further research or even contribute to meeting scientific objectives. As a matter of fact, **we found that it was not uncommon among the analysed cases for operational or commercial services originated from research activities**. This is particularly applicable to those cases for which a research institute plays the role of service provider or primary user.

Water Quality Management in The Netherlands	In this case we saw how Water Insight had been collaborating with various scientific institutions to apply new knowledge on the different subjects relating to improved understanding of ecosystem services and improvement of water quality monitoring algorithms.
Wine Making in France	ICV and TerraNIS have worked closely with the University of Montpellier department of precision farming to help develop a broader understanding of the use and value of satellite data to support farmers and in this case, vineyards.
Ground Movement Monitoring in Norway	InSAR Norway ground motion service has spawned improved algorithms for generating the InSAR measurements along with the computational side of improved data-handling, processing, storage, scaling and visualisation and other factors linked to the overall accuracy of the map and the efficiency with which it is generated.

3.6 Societal benefits

Whilst typically perceived as intangible, societal benefits are often considered by the interviewed stakeholders as essential aspects in the greater picture. **In many cases, they may even represent a key driver motivating the primary users to procure the Sentinel-based service in the first place**. Naturally, these benefits materialise mostly at Tier 4; however, in cases where Civil Society Organisations are active the associated benefits can materialise in earlier tiers too. Below we discuss some of these benefits alongside brief references to concrete examples we have encountered.

3.6.1 Public health

This is typically associated with less toxicological risk or exposure to health-threatening agents. For instance, when people are better informed about air quality, they can better protect themselves against outbreaks of pollen or other pollutants.

Air Quality Monitoring in Latvia	Using Sentinel data (along with many others) the Copernicus Atmospheric Monitoring Service can model air pollution and make forecasts for the coming

	days with increasing accuracy and confidence. This information, projected at city scale by the AirText service, enables citizens in Riga and London to make decisions in their daily lives. For vulnerable people, having a daily air quality forecast may become as important as having that for the weather.
Water Quality in Finland	In this case we see how, thanks to Sentinel-based services, citizens can reduce their health risks by being exposed to Harmful Algal Blooms.
Water Quality Management in The Netherlands	In this case we see how good water quality, thanks to the application of Sentinel data, reduces the complexity and cost of water treatment, ensuring the production of safe and clean drinking water. It also safeguards public health, upholds regulatory standards, and contributes to the sustainability of the country's drinking water supply.
Green Wellbeing Indicators in Poland	Here we see how GUS can fulfil its mission to provide information on citizens' wellbeing with the goal of increasing transparency and ultimately improving public wellbeing.

3.6.2 Civil Security

In several of the studied cases, the use of Sentinel-enabled services enables stakeholder decisions that can protect citizens and properties and contribute to an increased overall sense of civil security. This applies to cases dealing with the impact of natural phenomena (e.g. Flood Management in Ireland) or structural stability of buildings (e.g. all the InSAR ground motion cases).

Water Management in Catalonia	Municipalities benefit from Sentinel data to prevent subsidence and related damages, enhancing public safety.
Flood Management in Ireland	Improved preparedness and response to natural disasters directly contributes to public safety and security.
Wildfire Management in Greece	This case shows how Sentinel data is being used to help in assessing the impact of wildfires and efficiently planning related relief efforts. This means that the regional authority can conduct thorough post-event analysis, make effective decisions when it comes to the management of relief efforts, and plan impactful future mitigation measures.
Clean Seas in the Mediterranean	Here we see how the use of CleanSeaNet enables authorities to be more effective when using their aircraft for security and other purposes as well as for detecting oil slicks.
Monitoring Illegal, Unreported, and Unregulated Fishing in UK Overseas Territories	In this case we see how Sentinel data is fighting illegal fishing and contributing to the protection of human rights through the surveillance of human trafficking activities at sea.

[Ground Movement Monitoring in Norway](#)	The use of the INSAR service is reducing this risk by providing more constant and precise measurements of mountainsides where rockslides may occur.

3.6.3 Geostrategic value

Whether looking at the economic and geo-political independence of a country or the strengthening of its industrial, scientific and entrepreneurial output, Sentinel data have been shown to provide significant benefits. In the former case, the case of Greenland offers an excellent example: the ability to remain connected to Denmark all year long thanks to Sentinel-enabled ice navigation and provide the local economy with necessary supplies is of paramount importance not only for Greenland but also for Denmark itself and even for the EU.

[Monitoring Illegal, Unreported, and Unregulated Fishing in UK Overseas Territories](#)	Here we see how the Marine Management Organisation (MMO) uses Sentinel-enabled services to protect and enhance the marine environment and support UK economic growth through the management of sustainable marine activities. It also supports the Blue Belt Programme, which supports the UK Overseas Territories (OTs) with the protection and sustainable management of their marine environments.

3.6.4 Improved oversight

This refers to the ability to convey key messages to the involved stakeholders using the same means. In other words, thanks to the fact the different actors have access to the same information (typically satellite images or reports), a common understanding is ensured.

[Air Quality Monitoring in Latvia](#)	The AirText service in this case enables individual citizens, especially vulnerable ones, to know when to avoid exposure at times of high pollution. At the same time, the service is a tool to help local health professionals improve the service that they can offer their patients. It can also improve planning of hospital admissions, taking account of forecast peaks in pollution.
[Wildfire Management in Greece](#)	Here we see how the Region of Crete utilise "GIS Crete" for several applications, such as supporting the administration in planning and decision making. The platform allows an immediate and accurate assessment of an affected area, both in terms of area extent and land-type. This means the regional authority can make fast and effective decisions and communicate them easily when it comes to the management of natural disasters.
[Flood Management in Ireland](#)	The fact that different actors (emergency management personnel at strategic and tactical level, politicians, journalists, general public) had access to the same flood delineation maps provided a common point of reference. This helped the authorities to communicate in an easily understandable manner on the evolution and impact of the floods to all relevant stakeholders (political hierarchy, responders, media, citizens).

Growing Potatoes in Belgium	The fact that different potato industry stakeholders can access a common platform (WatchItGrow) and gain insight on the same topics ensures better cooperation among them and increased transparency.
Forest Management in Sweden	The availability of the clear-cut map generated by the Swedish Forest Agency allows it to communicate better with the County Boards and the Swedish Environmental Protection Agency, helping them to work together in identifying areas which should be protected for environmental reasons.

3.6.5 Public Awareness

A "common understanding" often helps to build trust between the involved stakeholders and particularly the public. The same level of awareness and common understanding cannot be easily achieved among stakeholders with numbers (i.e. measurements of the gauges or meteorological data). Using EO authorities can ensure greater transparency of their actions by sharing information that is a) accessible to all actors, b) retrieved with reliable, unbiased means. This, as well, contributes to building better trust between citizens and authorities or clients and providers.

Water Management in Catalonia	Increased visibility and transparency in water management improve public trust and awareness, encouraging water conservation.
Grassland Monitoring in Estonia	The fact that the interactive map and compliance data is completely free for anyone to interrogate online aids in the manifestation of a transparent check and balance dynamic between ARIB, the claimants (farmers and landowners) and the general public. This helps the creation of societal awareness and trust in ARIB's operations and their distribution of taxpayers' money
Flood Management in Ireland	In the case of flood management we saw that citizens will heed the instructions of the authorities more effectively, because they see with their own eyes the same information conveyed to them, making them more aware and eventually helping to reduce the impact of the flooding. This also significantly reduced the transmission of erroneous information, helping to make better operational decisions.
Deforestation Monitoring for Sustainable Palm Oil Production	Thanks to the actions of actors in the value chain, CSOs such WWF, Greenpeace and Global Forest Watch have much greater visibility over how corporations are behaving when it comes to their sustainability commitments. The transparency provided by the Sentinel-powered service allows CSOs to monitor the progress of environmental and ecological targets and ultimately aids in them reaching their goals.

3.6.1 Public Utility

EO can aid in the provision of increased access to a public utilities such as roads, lakes or energy, or in the reduction of withdrawn access.

[Water Quality in Germany](#)	Through better water quality and environment, local citizens can enjoy improved and safer access to water bodies, nature and its flora and fauna.
[Motorway Maintenance in Portugal](#)	In this case we saw how the Sentinel-enabled service reduces the likelihood of road closures due to better and more efficient maintenance routines.
[Water Quality in Finland](#)	In this case we see how, thanks to Sentinel-based services, citizens can enjoy better access to water bodies and reduce their health risks by being exposed to Harmful Algal Blooms.
[Water Quality Management in The Netherlands](#)	In this case we see how good water quality, thanks to the application of Sentinel data contributes to the safe access of water bodies for citizens.
[Ground Movement Monitoring in Norway](#)	InSAR Norway helps reduce the probabilities of roads being obstructed due to landslides or failing infrastructure. It also showed how the likes of rail tracks can avoid the same.

3.6.2 Community and quality of life

This benefit relates to the fact that better informed decisions by stakeholders along the value chain thanks to Sentinel data lead to the preservation of the local well-being. This may be associated with ensured access to necessary products (e.g. keeping supermarkets stocked during Winter),

[Water Management in Catalonia](#)	Better managing water resources helps in addressing fundamental societal aspects of fairness and social cohesion. Ensuring that water is distributed fairly helps prevent conflicts and promotes social harmony while maintaining and ecosystem services to citizens.
[Winter Navigation in the Baltic](#)	With winter navigation supported through satellite data, citizens can be assured that all year round economy can be supported. They can find goods in the supermarkets, pharmacies and petrol station. This has been assessed through an hypothetical Willingness to Pay.
[Invasive Species Detection in Croatia](#)	Here we see how the protection of a nationally significant park brings cultural, historical, and educational benefits to the people of Croatia. Moreover, the livelihoods of rural communities living in Lonjsko Polje are supported through redevelopment of overgrown lands into productive farmland.
[Green Wellbeing Indicators in Poland](#)	In this case we see how Sentinel data is being used to monitor and improve green spaces, which in turn provide opportunities to improve physical and mental health, promote community cohesion, and make cities and neighbourhoods more desirable places to live and work.
[Water Quality in Germany](#)	Through better water quality and environment, local citizens can enjoy improved access to nature and its flora and fauna. Citizens can enjoy a better environment and diversity and hence those looking for a nature walk or just a picnic can enjoy better amenities.

[Water Quality Management in The Netherlands](#)	The improvement in the quality of lakes and rivers translates to a pleasure shared by many whether it is for swimming, fishing or canoeing as discussed previously, or simply the appreciation of a natural landscape. Through better water quality and environment, local citizens can enjoy improved access to nature and its flora and fauna.
[Water Quality Management in Finland](#)	Again, improved water quality has multiple societal benefits. Citizens can enjoy a better environment and diversity and hence those looking for a nature walk or just a picnic can enjoy better amenities.

4 SeBS Insights: Developing deeper understanding through the study of similar cases

With a growing number of cases across different geographic and application areas, we are increasingly able to make comparisons between the cases which allows us to build upon the knowledge of the first case to help refine the analysis for the second. It also open up to additional findings through case-comparisons. The more cases which are available the richer such comparisons can become. Comparison across cases has led to the refinement and homogenization of the levels of benefits dimensions attributable to the single cases and an improvement in the interpretation of the cases themselves as well as their specificities and boundaries of application. A separate Transversal Analysis has been undertaken, which compares and contrasts cases within 3 application domains:

- Sentinel Driving Benefits for Highways Management

- Sentinel Driving Benefits for Managing Forests

- Sentinel Driving Benefits for Lake Water Management

In addition to these dedicated studies, we can also see comparisons between cases in other application domains:

- Agriculture
- Sea Ice Navigation
- Regulatory compliance

4.1 Highways Management

The transversal analysis on this topic has shown that the use of ground motion maps derived from Sentinel satellite data can provide significant benefits for the actors concerned and for society at large. This is especially relevant for monitoring ground movement over large areas and with high precision, since doing so with other means is not possible. When undertaking large construction projects, the risk of problems arising due to ground movement can be reduced. However, not many cases were found that showed a similar maturity as in the two core cases.

The benefits are similar in nature across cases (Norway, Italy and Portugal) and, whilst not all countries have the same degree of problems and can expect the same scale of benefits, it is clear that there are advantages to be gained from adopting ground movement measuring technology. However, we did find different priorities and additional types of use which are being explored in different countries which enrich the notion of the benefits derived from using satellite technology and also suggests that there remains more fertile ground for its exploitation.

The idea of sharing this knowledge seems obvious but there are no obvious platforms with the interest to do so. For an authority in charge of managing roads which is concerned with policies, there are many other priorities, an individual country has neither the resources nor the altruistic interest to lead such an effort. This could be an action more for those on the supply side to provide the means to establish a transversal platform through which results can be shared.

The challenge, as always, will be to get the interest of the relevant agencies and other stakeholders from the demand side to participate. Reports like those from SeBS case studies and this transversal report can provide valuable material to incentivise those who hesitate or who are simply unaware.

4.2 Forest Management

Based on our discussions, the experts on both demand and supply sides working on forest management are generally aware of the benefits that can be obtained from the use of satellite-based monitoring of forests. This technology provides the capability to monitor forests country-wide that is not possible using traditional in-situ measurements. The latter is not replaced but complemented and hence an investment and annual budget is required to take advantage of satellite information.

Further conclusions to be drawn are:

- The utility and potential benefits of using Sentinel data for forest management are mostly understood.
- Whilst the original example was centred around clear-cut monitoring, many other applications have emerged most notably for monitoring the effects of fires and the spread of infestation of bark beetles.
- The use of satellite-derived forest monitoring helps to address commercial interests in complying with regulations and ESG expectations.
- Several participants reported on national networks of forest experts which have been formed responding to the possibilities offered through the use of Copernicus.
- The benefits of satellite data use lie with being able to monitor forests country-wide cost-effectively, more frequently and with a better spatial sampling noting that in-situ monitoring is maintained for higher precision. For this reason, lack of investment in changing internal processes together with the (non) allocation of an annual budget are barriers to the uptake in many countries.

Finally, the increasing range of applications warrant further pursuit of the topic.

- To analyse commonalities and differences among different actors and potential uses of Sentinels data in different countries/regions.
- to extend the range of cases that can allow improving the current understanding related to the use of Sentinels data.

- To establish a set of best practices which can inform environmental agencies on the benefits of using Sentinel data.

4.1   Lake Water Management

We have seen from the three SeBS cases that the introduction of EO data has been a game-changer in lakes water quality monitoring. Satellites can provide broad-scale coverage, (almost) real-time data and historical data which all bring valuable insights for water quality monitoring, especially when it comes to HAB. In this matter, EO complements traditional sampling, offering a comprehensive picture of water quality over large areas, faster detection of events, and facilitating better decision-making and communication. However, geographical coverage of such use in Europe is still not optimal while improvements in terms of products and services are still needed.

From the three analysed countries, Finland has developed the technology over its entire territory while it is not yet the case for the Netherlands and Germany.

With regards to the products and services, improvements are expected from new AI methods for early detection and automated communication of HAB events (and other phenomena requiring special attention to those in charge and the public). Higher spatial resolution temporal frequency and measurement precision offered by commercial satellites and Copernicus next generations will also help improving the services.

One of the main barriers for such evolution is the lack of EO data acceptance explicitly for the purpose of reporting in the relevant regulations, especially with regards to the Water Framework Directive. In the Netherlands and in Germany, both regional authorities are advocating for the use of EO at national level and its implementation in the water plans/acts. Other barriers are linked to reluctance to change and implementation of new technologies in public organisations and the lack of "space" technology awareness.

Additional to the suggestion of a platform to share best practices as stated for the roads management case, better support to champions, raising awareness and advocating for EO data use for the purpose of reporting in the relevant regulations are a good starting point for widespread adoption of EO for water quality monitoring.

4.2   Agriculture

Agriculture has been the most prominent theme studied in SeBS. This is because several start-ups have perceived agriculture as a prime domain to develop Sentinel-based farm management support services and have managed to achieve good market traction in the past 6-7 years. They have recurrent customers – most typically farmers already exposed to advanced precision agriculture techniques and owning adequate equipment to make the most of it. This meant that agriculture

cases could be well studied as primary users had in depth exposure to the respective services. Another key underlying factor has been the regulatory framework. In the past few years, the management of subsidies under the Common Agricultural Policy (CAP) has been increasingly linked to the use of geospatial information providing objective evidence on the compliance of farmers' practices. This meant that the responsible authorities, i.e. Paying Agencies, have dedicated budgets which gave rise to mature value chains.

Against this background, the analysis of the complete portfolio of such cases studied in SeBS has allowed the identification of a few very interesting patterns but also some distinctive differences:

- In most of the cases (Farm Management in Denmark and Poland, Growing Potatoes in Belgium, Wine Making in France) the main driver for the use of Sentinel-enabled products/services is the possibility to reduce the used inputs (fertiliser, pesticides, water, labour).

- The service provision scheme is typically driven by a price per hectare of used services; Yet the actual provision differs from case to case. In Denmark, there has been a continuous evolution in the offering of the respective services through collaborations between different companies/organisations. In Poland and Estonia, it was start-ups that managed to develop a strong proposition *ad novo*. In Belgium and France, well-established companies with years of experience in EO service provision managed to develop a strong offering.

- The primary user can open the door to many additional customers. In Poland, the collaboration of SatAgro with Grupa Azoty has helped in the creation of a market for the former. In Estonia, working with the paying agency allowed KappaZeta to build a broader proposition it can deliver to additional customers. In Belgium, the whole potato industry has gathered around the services offered by VITO.

- Extrapolation of the benefits is relatively straightforward. Farm management support services relying on NDVI (produced with the help of Sentinels) are, to a large extent, transferrable to other countries. Of course, the specific crops, parcel size characteristics and climatology may confine this, but at first order meaningful extrapolation assumptions can be built.

4.3   Sea-Ice Navigation

In contrast, the sea ice navigation cases, have shown that **despite their similarities, they rely on services that are used in a different way by the main stakeholders**. Thus, in the Baltic, icebreakers are using the satellite imagery directly to help the captains determine the best routes <u>through</u> the ice. The benefits accrue through time being saved but also the predictability of the arrival time of ships in the ports and harbours which improve the just-in-time operations of the local factories.

In Greenland, the benefits come from avoiding the ice. Icebreakers are not used at all and the ships, whilst having some ice-protection, are less powerful than icebreakers. Hence, they need to know

where the ice is so as to be able to either sail around it or to go through low-intensity sea-ice. The benefits in the end are similar but focused more on the local community since there is little industry in the area.

4.4 Regulatory Compliance

SeBS has analysed a few cases driven by compliance requirements. This includes Aquifer Management in Spain where the local regulation foresees certain limits in the acceptable ground deformation around extraction wells so as to ensure no damages are incurred on buildings. In addition, we have studied cases driven by environmental compliance. This includes Water Quality Management in Germany, where EOMAP has developed the service eoLytics which allows subscribers to download water quality measurements for their areas of interest. These measurements allow the Baden-Württemberg State Institute for the Environment LUBW to monitor the quality of water in lakes throughout their region at an affordable cost and to an extent that is not possible using traditional sampling and testing. The success of the provided services has triggered interest across the whole of Germany in close link with the need to observe regulation requirements. Similarly, in Estonia, KappaZeta has been offering a grassland monitoring service that allows the Paying Agency to significantly reduce its operational costs for subsidy claims checks while managing to monitor 100% of the land (and not 5% as before).

A relatively different flavour of compliance-driven EO services is found in the case of Deforestation Monitoring for Palm Oil production. There it is corporates who seek to meet their ESG obligations that have turned to EO-based services as a source of objective evidence. On top of the individual cases, SeBS has produced a dedicated analysis of [Copernicus for Environmental Assurance](#) which provides in depth insights on the use of Sentinels in that context. With increasing attention being placed on environmental and climate change related issues (e.g. under the Green Deal) and with increasing technological maturity of the offered services, we can expect that such cases will become more widespread in the near future.

5   Lessons learned

Since its inception, the SeBS approach has been driven by the aim to measure different types of benefits experienced by a variety of actors across the value chain. In this process, we have been keen and vigilant to identify areas that can inform future improvements of the approach itself, of other studies and even of activities related to Copernicus at a larger scale. Beyond the question of extrapolating results from a single case (or group of similar cases), we have been asking ourselves several questions

- What are the **strengths of our methodology** and how can we further improve it?
- What are the **weaknesses and limitations** of the SeBS approach and how could they be overcome or addressed?
- Which insights shall we take home in terms of **capacity building for the EO sector** in Europe?
- What can we learn from individual cases that can **feed up to programmatic decisions** on Copernicus services or even the capabilities of the next generation of Sentinels?
- How does SeBS **link with other activities in the Copernicus ecosystem** and the greater context of measuring EO-related benefits?

In the next sections we attempt to shed light to these questions with the ultimate aim of informing future studies and activities.

5.1   The strengths of the SeBS methodology

The work carried out under the SeBS study has produced some valuable and widely appreciated results. The progressive analysis of cases has allowed the methodology to be refined and new approaches to the challenge of measuring value to be tested and assessed. The result is a streamlined process for analysing the value of EO data which can be applied to any source of data and indeed may even be applied in non-related fields. Below we discuss some of key insights around the strengths of the SeBS approach.

5.1.1   Building a "body of knowledge" thanks to exposure to multiple cases

SeBS has:

- Collected over 300 cases in which Sentinel and other satellite data is used in support of operational decision making.
- Analysed 19 full cases which together with the predecessor work (3 cases) amount up to 22 in total. In addition, 15 short cases have been analysed.

The wealth of information collected across these cases has allowed us to start **building a transversal picture** giving further insights into how value is being created. This is best exemplified by the

development of "**indicators**" (see Annex A), which allow to build a) build a detailed taxonomy of benefits, b) associate with specific usages of EO data, c) execute measurements that feed into the value chain analysis.

Another significant component of the greater picture is that of "**return on investment**". Thus, through the bottom-up view provided by the individual cases we can perform an assessment of the relevant investment in Copernicus core services or the applicable assets (e.g. Sentinel satellites) and the corresponding benefit from their use.

Furthermore, **thanks to the exposure to all these cases, and learning from the successes and failures we have had, we are now much better equipped to identify key success factors for the implementation of such value chain analyses**. In short, these are:

- Cooperation with the case **champion** is truly essential. Thus, having an actor with (a) genuine self-interest to make it work, (b) an ability to reach out to other stakeholders in tier 2 and 3, (c) availability for further interactions throughout the analysis, is a critical factor. Cases in which the identified champion fails in any of the above take much longer than planned to analyse, and often end up with assumptions of lesser strength[5].
- Each case has its own **dynamic** and **specificities**. Not only do cases often turn out to be different or more complex than initially thought, they are also progressing at different paces. Organisational culture, business-related developments (e.g. provider or primary user having a big business opportunity that demands most of their time) or even random events (e.g. even individual accidents or big new contracts signed) can impede the momentum of a case.
- The **richness of the analysis** relies on getting – early on – the views and voices of other actors such as academic researchers in the picture.

Even with these lessons learned in place, the complexity of this process should not be underestimated, as many cases that seemingly "tick all boxes" end-up being very hard to analyse. Nonetheless, the greater the traction with the market, and the deeper we go into analysing individual cases, the more we can support the evolution of the approach.

5.1.2 The power of storytelling

The importance of storytelling has become apparent throughout the execution of the study. From the get-go it has been serving as a primary tool to engage the different actors in the value chain, understand what the use of Sentinel-enabled services means in their operational reality, which decisions are improved and how, which actors linked to them are subsequently benefitting etc. Beyond the anecdotal passages in the main reports of full cases, we have attempted to channel the

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[5] In practice, this means that not only the key point of contact within the primary user organisation needs to be fully and steadily cooperative. It is also the hierarchy that needs to be on board throughout the execution of a study.

power of storytelling into attractive communication products. This gave rise to short cases (see two examples below) and the dedicated SeBS website. We have also produced videos for most of the full cases, that act as an excellent entry point for the work we have performed. It should also be noted that many cases were used by the subjects of the cases themselves (i.e., service providers and primary users) to showcase and promote their own work and achievements.

Figure 3-1: Examples of storytelling in the form of short-cases

5.1.3 Supporting the uptake of Sentinels and mobilising actors

Analysing a wide range of cases has brought forward time and again the same fundamental questions: Why is it that this actor, in this domain and country has decided to use Sentinel-enabled services? The answer to this question is essential as it can guide wider user uptake efforts around Copernicus Sentinels. This answer has several aspects to consider but the two most prominent are:

- **Champions**: Service providers are often the ones who convince primary users of the value of Sentinel-enabled solutions and manage to give rise to operational use. In that regard, the vision of service providers and their perseverance in seeing it materialise are most often the main guides. Similarly, primary user organisations and – very often – individuals in these organisations are the ones driving forward innovation that leads to operational use. In this case, the key question is how to groom more such champions and how to bring forward the best practices they adopt.

- **Regulation**: Many of the cases have as an underlying driver the need to meet regulatory requirements. In some cases, this need is explicitly tied to the use of geospatial information (e.g. for the CAP), but in most it comes down to service providers and primary users working together to showcase that Sentinel-enabled services meet the regulatory need.

SeBS has sought to address both these aspects through dedicated presentations and workshops. The project team has presented at the Copernicus User Forum on the topic of Copernicus for Public Administrations, has shared key findings with the Copernicus Relays and has organised a major final workshop inviting all case participants and key actors from the relevant Copernicus institutions. As a result of SeBS and its various activities and initiatives, a thriving community of likeminded stakeholders has been cultivated over the years, with several information and knowledge sharing events taking place which served as a testament to the value of this type of analysis. In particular, several workshops were held, including:

- [Workshops](#) in Frascati and Canberra in 2019
- An [online workshop](#) in November 2021
- A series of sectorial workshops in 2022 covering:
  - [Road Infrastructure Management](#)
  - [Forest Management](#)
  - [Water Quality Management](#)
- A workshop on [Transversal Benefits](#) in 2024

5.2 Boundaries of Application

The SeBS methodology has proven and further honed several of its strengths – as nicely recognised by the international community meeting in Frascati for the [GEOValue Workshop](#). Yet, it is perhaps even more important to identify factors that impede the execution of value chain analyses or confine the applicability of their results. Thus, as with any methodological approach, so too with SeBS, we **need to be careful about limitations that define the boundaries within which our findings are applicable**. In that respect, the experience of analysing the various cases and conducting *ad hoc* studies, all of which attempted to quantify different types of benefits associated with the use of Sentinel data, allows us to highlight the following limiting factors.

5.2.1 Access to information

The quality of input information directly affects the robustness of our results. In that regard, we have often found ourselves having limited or no access at all to information that would allow us to make better analyses. This is at times related to confidentiality issues; for instance, service providers or users do not wish (understandably!) to disclose certain financial figures as they consider them to be commercially sensitive. At times, we have also come across cases where service providers have a fully operational case with very concrete benefits for their users – which however

they are completely unable to discuss. A prime example for such cases comes in the area of Oil and Gas, where companies using Sentinel data for the detection of oil seeps are not able to disclose any information on the actual activities (location, actual user, financial figures).

Another factor limiting the quality of available information is simply the actual time over which Sentinel data has been used. Thus, we often see operational cases which would require several additional cycles of use to have robust data that can be used as inputs into the financial modelling. This means that we often have to make rather arbitrary assumptions for the quantification of certain benefits. This is best exemplified when considering the willingness of citizens to pay for a certain "public good". In Ireland, such an argumentation was developed around the reduction in the risk of the impact of flooding.

Finally, as far as case analyses are concerned, the lack of applicable information may be associated with the novelty of the study itself. For example, in the case of flood management in Ireland, we sought to assess the value of satellite data as an early warning trigger. Studying the relevant literature, we found only one study of early warning systems – but not early intervention enabling systems, so we had to build our assumptions from scratch. The upside of such situations is that SeBS helps to identify areas where novel scientific research could be conducted.

5.2.2 Applicability of the models

Every case is different. This simple yet powerful fact, means that for every value chain analysis we need to develop an applicable model for the analysis of benefits. In other words, we **cannot simply resort to "off the shelf" solutions, as these typically do not exist**. In this process, we have often found the need to introduce reasonable, yet subjective assumptions, driving the statistical, economic or environmental impact model. With more cases being studied, our ability to cross-analyse and compare will eventually help towards reducing the impact of such "subjectivity" factors. Moreover, further traction with experts in "adjacent" fields (e.g. environmental scientists, statisticians) would allow the robustification of the models used and their increased precision/applicability. This would apply, for example, to:

- The ship arrival time (statistical model) used in the Baltic,
- The reduction of fertiliser input cost in farming cases
- The quantification of benefits associated with "common understanding" as in the case of Ireland
- The causal connection of environmental impacts with the use of Sentinel data at the entry point of the value chain

It also extends to more macroscopic analyses such as the one done for the impact of Sentinels on academic publications, whereby manual classification introduces bias.

5.2.3 Assumptions driving the quantification of benefits

Whether driven by the unavailability of relevant data, or simply as an intrinsic aspect of building a model, the **development of relevant assumptions that drive the quantification of benefits lies at the core of the SeBS approach**. In that regard, clearly stating our assumptions and how we got there has been our doctrine from the start. This allows the readers to follow them clearly and challenge them as needed. The nature of assumptions is manifold:

Attribution of the contribution from Sentinels

We often have to introduce a percentage (or coefficient) related to the actual contribution of Sentinels in the experienced benefit. This seems to be a common pattern across the vast majority of analysed cases. The reason for this is that Sentinel data are often only one of the sources used to produce an information product/service. It is therefore hard – and sometimes simply impossible – to decouple the constituents of a composite product and assign a well-justified contribution to each of them. Recognising this limitation, we have always opted to make very modest assumptions (and clearly stated) on what part of the benefit can be directly associated to Sentinel data.

Actual versus potential benefits

The benefits experienced today in a certain case are typically calculated on the basis of the existing clientele (or otherwise usage volume). If the actual data is not available (either it doesn't exist or the actors are not willing/able to disclose it) we need to make assumptions using similar data in other cases or deducing from other available information. When it comes to potential benefits the importance of assumptions is even greater. The extent for example to which the analysed service will manage to penetrate the market is, by nature, hard to quantify. Similarly multiplying factors such as the ability of the users to make optimal use of the provided services also have to be modelled using assumptions. Meanwhile, limiting factors such as future competition, potential economic stagnation, etc. are typically not entering our calculations. Thus, the potential benefits projected over time, should be considered as indicative (in terms of order of magnitude).

Benefits experienced further down the chain

The further we go down the chain, i.e. beyond the primary user, the more we need to make assumptions informing the quantification of benefits. Nonetheless, whilst the contribution of Sentinel data is diluted when reaching secondary or even more general public users, its impact might be equally profound as for primary users. In that regard, we have seen that even if the economic value may be the first sought, non-economic or nonmonetary benefits may be even more important than ones quantified in monetary terms. Such benefits are typically experienced further down the chain.

5.3 How can SeBS link with other activities and support improvements in the Copernicus ecosystem?

The discussions we have had with several value chain actors in the course of SeBS have generated rich insights on the value of Sentinel data, Copernicus, its core services and downstream applications too. These insights could be used by the actors involved in the management, design and delivery of Copernicus and its services. We structure our findings in 4 different categories.

SeBS feedback with regards to observational capabilities

The very high quality of the data generated by Sentinel satellites has been underlined by service providers and users alike, on several occasions. Yet, improvements have been proposed when looking at the evolution of market needs.

Improvement required	Relevant case(s)	Explanation
Rapid delivery of data / shorter latency	Navigating through sea ice in Greenland	A key challenge found in this case lies in dealing with the latency associated with the satellite imagery i.e., the time from when the satellite passes over to when it is delivered to the user. The locations of the sea-ice in the image reflects the situation at the time of acquisition but this might have changed by the time the image is delivered to the users.
	Wildfire Management in Greece	Stakeholders in this case need to quickly map an area that has been affected by wildfires as time is of the essence when coordinating an emergency response. Again, latency is a key factor.
More frequent observations	Most cases	In almost all cases, having more frequent observations would add value to to the service in question.
New sensor types	Water-related cases	LIDAR sensors can help provide better information on underwater topography. Thermal sensors provide insights into temperature changes in lakes, rivers, and coastal areas, which can affect biological processes like algal growth.

		LIDAR sensors can provide vertical profiles of the atmosphere, helping to monitor the distribution and concentration of aerosols and other particulates.
	[Air Quality Forecasting in Latvia](#)	

Such recommendations typically come from well-versed users of EO data. For instance, farmers involved in the cultivation of high-value crops (e.g. Making wine in France) have a need for higher-resolution data even to the extent of monitoring the status of single vines. Similarly, forest management authorities may want to observe small-scale and short-lived forest change due to selective logging, something currently not viable only with Sentinel data.

SeBS feedback on Copernicus Core Services' products

In the case of "Flood Management in Ireland", the local players expressed the view that they would like to have a map covering the whole of Ireland as flooding in one area is usually associated with flooding elsewhere in the country. They also would like to be able to provide on-line access to the information such that more emergency workers can use the maps as well as the general public. The evolution of the respective Copernicus Services has been moving into such directions.

Raising awareness in the EO community about organisational challenges in the user uptake of Copernicus data

Copernicus is an important asset when considering the implementation of certain EU-wide policies. In that regard, the ability to effectively incorporate Copernicus-based monitoring capabilities in the operational workflows of key authorities (e.g. paying agencies in the context of CAP) is not merely a technical issue. It often entails organisational aspects related to awareness raising and also to practical support such as guidelines for the organisation of procurement.

Informing efforts to capture user requirements or market data

By going under the skin of each case, SeBS has shed light into the operational challenges and needs faced by the various users and how Sentinel-based solutions help to address them. In this regard, SeBS is a rich source of input for efforts trying to capture user requirements. Similarly, the analysis of the market/business/operational context for the different value chain actors provides tangible insights that can inform market studies around the use of EO data.

5.4   Strengthening the SeBS approach in the future

By performing a cross-cutting analysis of the rich portfolio of studied cases we can point to the following areas that call for improvement.

- The 6 dimensions have proved to be robust in the cases we have analysed. Sets of indicators have been generated but these are non-exhaustive and future work could build upon them.
- Developing a portfolio of cases opens up deeper analysis leading to insights into how organisations incorporate and adapt to the use of EO derived information services. Cross-cutting analyses looking at for example the benefits to public administrations have been possible as a result of the portfolio. Further development of this methodology would be highly promising to improve our understanding of how EO data is perceived by others.
- The science of placing value on natural resources and their loss when damaged or extracted has developed significantly over the last few years. Natural Capital Accounting or Ecosystem Accounting can be a useful tool to help analyse the benefits of actions being taken using EO data. Introducing specialists with the knowledge of how to make these analyses would be a useful step to broadening the SeBS capability.
- As noted above, significant benefits have been observed through the ability to compare and contrast cases and to develop transversal or cross-cutting analyses. Refining this to select cases which can throw a spotlight on specific ideas could be a very effective extension of the SeBS case work. The example of benefits to public administrations has been widely appreciated and helps to show why public administration at all levels (regional, national, local) should adopt new tools and how this can drive their operations.
- Our cases are bounded by national administration i.e. countries. This has been quite deliberate to enable a reasonable estimation of value as well as providing consistent market conditions within a fixed regulatory environment. Particularly the latter which with small changes can have a significant impact on the benefits. Further research could be conducted to understand the limitations of this and to seek to develop new tools with which to extend analysis to a wider geographical base.

6   Conclusions and future vision

The SeBS study has been **showing the great value which is being unlocked and delivered using the Copernicus Sentinel satellites across a diverse portfolio of cases and areas (i.e. for publications, for start-ups, etc.).** At this point in time, SeBS will be entering a new phase whereby additional cases will be analysed following common themes.

Overall, the studied cases are showing that the use of Sentinel data is generating outstanding value and often in quite different ways. The economic benefits are primarily financial and can be associated with avoided costs, improved efficiency and reduced use of inputs. The economic numbers for each case demonstrate the original premise that, showing a benefit from a single product and then showing that there are many cases, is a valid way to demonstrate large benefits for the policy makers. Whilst such economic benefits are more straightforward to quantify, other aspects such as improved quality of environmental resources (water, air, soil) or societal

perspectives (e.g. strategic positioning of a country, confidence built between public services and the public at large, etc.) should not be neglected. In fact, **it is often these socio-environmental benefits that drive the use of Sentinel-based solutions**. Such qualitative issues have been also underlined in the various studies performed and are further complemented by non-case assessments (under the SeBS cross-cutting studies).

In light of these observations, we can certainly underline that the Sentinel Benefits Study, has taken us on a journey where the "road is a long one, full of adventure, full of discovery"[6]. **Not only has SeBS demonstrated the strength of a bottom-up methodological approach in quantifying benefits associated with the use of Sentinel-based products and services. It has also allowed us to develop a deeper understanding** of the processes, actions and decisions faced by primary and secondary users and how Sentinel-based services truly contribute to their improvement. **The power of storytelling has helped to convey tangible information** on these benefits to other actors in the ecosystem that can benefit from this knowledge: companies that are trying to reach out to users and sell their innovative solutions; users that are trying to understand the specifics and the real value of using new services that will bring change to their workflows; decision makers that need concrete examples that will guide them in defining the strategic vision and practical implementation of a programme like Copernicus and its exploitation at national level too.

Now, looking ahead we shall:

- Continue to engage practitioners in the international community to share best practices and lessons learned from the implementation of SeBS.
- Apply the methodological approach developed in SeBS to other relevant activities.
- Promote the findings of SeBS at relevant fora.
- Look forward to the next phase and/or future implementation of SeBS.

Thanks to the work done by SeBS, we can see the rich benefits the Copernicus programme has provided to our economies, our environments and our societies. We also look to the future with confidence that more benefits are to come. Moreover, the methodological lessons learned can be applied across a multitude of future activities and the profound findings of the project will continue to be promoted both within the EO community and to the world at large.

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[6] The quoted references point to *Ithaka*, a poem by C.P.Cavafy

Annex A: Indicators along the 6 dimensions of benefit

The tables below present the indicators used to analyse the benefits along the 6 dimensions of value.

Economic	Impacts related to the production of goods or services, or impacts on monetary flow or volume, such as revenue, profit, capital and (indirectly, through turnover generation) employment.
Capital expenditure reduction or avoidance	Aversion/reduction of capital expenditure which would or could otherwise have been incurred.
Cost savings	Aversion/reduction of operating expenditure which would or could otherwise have been incurred.
Increased revenues	Income through the commercial exploitation of EO-enabled value-added services.
Efficiency gains	Time or material saved through the use of services.
Reduction of risk	Reduction of risk and consequential costs.
Employment	Increased employment in the service provider (which is not a cost in the value-chain).
Environmental	Impacts related to the state and health of the environment, particularly as regards the ecosystem services on which human societies depend.
Reduced pollution	Reduction of unwanted material in the environment (water, air, marine etc.)
Reduced impact on biodiversity	Denotes whether an intervention has an impact (positive or negative) on the local ecosystems or on the biodiversity of its fauna/flora.
Reduced natural resource depletion	Reduced destruction or consumption of natural resources.
Regulatory	Impacts linked to the development, enactment or enforcement of regulations, directives, and other legal instruments by policymakers.
Better regulations	By offering new measurements, EO data allows the design of regulations to be improved to reflect existing or new policy needs.
Improved monitoring	EO data are used by the relevant authorities to assess the level of alignment to the prescribed behaviour and/or its breaches.
Improved reporting	Improve the efficiency and effectiveness of agency reporting obligations.
Better enforcement	Provide courts with evidence of illegal activities - EO data are used in enforcement-related proceedings (e.g., judiciary or audits).
Raising awareness	Deterrence by raising awareness amongst potential offenders of the ability to detect non-compliance (and the possibility to enforce if necessary).
Policy evaluation	Evaluation phase: regarding systematic or ad-hoc monitoring of the adequacy of the policy and the efficiency of its implementation.
Accountability	Objectivity of EO data can contribute to the successful enacting of core principles such as public transparency and accountability.
Innovation & Entrepreneurship	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market and/or business process

Changed Business Practice	Improvement of efficiency or effectiveness in existing business processes.
Start-ups	Creation of new business as a result of the use of EO data (importance of the data in that process).
Patents	Are there any patents taken out relating to the service of the user business processes?
Science & Technology	**Impacts linked to academic, scientific or technological research and development, the advancement of the state of knowledge in a particular domain.**
Academic publications	Publications, relevant to the service, linked directly to the actors or the EO service.
Research staff	Working on topics directly linked to the EO service or application.
Research budgets	Increasing level of budgets dedicated to research linked to the EO service and/or its application.
Improved understanding	Ability to pursue research objectives which are difficult or impossible without the use of EO data.
Societal	**Impacts related to broader societal aspects, such as public health, citizen security and welfare.**
Public Health	Improvements to public health through reduced exposure to pollutants, reduced disease etc.
Civil Security	Reinforcement of citizens' sense of safety and protection.
Geostrategic Value	Support to broader political or strategic goals.
Public Awareness	Provision of information to the general public with the aim of supporting public duties, raising awareness of hazards or danger, or improving transparency.
Public Utility	Provision of increased access to a public utility, or reduction of withdrawn access (e.g. mobility, energy, water).
Community and Quality of Life	Increased sense of community and the quality of life through enhanced perception of the country/region/town etc as a place to live.
Improved Oversight	Contribution to stakeholder coordination and improved governance through a common a operational picture.

Annex B The evolution of the SeBS approach

The evolution of the SeBS approach is not confined to expanding or enriching the portfolio of cases. It is also driven by the ability to see and analyse patterns across the different cases. This process, first triggered by the analysis of individuals cases is then complemented by non-case specific *ad hoc* analyses. Through these analyses we have been able to investigate additional dimensions in the assessment of Sentinel-enabled benefits and to produce an overall methodological framework (more on this in chapter 2). At this point, a number of *ad hoc* assessments have been already launched, whilst others are in the pipeline. An overview is provided below:

These studies are an essential component of the overall SeBS study, as they complement the case studies by testing some of their methodological approaches, enhancing their findings and introducing new aspects. The outcomes of the *ad hoc* analyses, together with the insights gained from the analysis of cases, feed into methodological discussions with the global community working on the measurement of EO-related benefits. Several workshops were held, including:

- Workshops in Frascati and Canberra in 2019
- An online workshop in November 2021
- A series of sectorial workshops in 2022 covering:
    - Road Infrastructure Management
    - Forest Management
    - Water Quality Management
- A workshop on Transversal Benefits in 2024

These processes give rise to methodological updates. In that regard, we can already pick out some key highlights:

- **Introduction of short cases**: Whilst scouting for appropriate cases to be analysed, we often encountered situations where the service provider/user was either reluctant to disclose specific details (that would allow economic assessments to be made) or simply unable due to the complexity of the case. Nonetheless, the "story" associated with the use of Sentinel data was too powerful to neglect. Thus, "short cases" were introduced, i.e. brief summaries of cases, which do not provide in depth economic analyses but still highlight the benefits of using Sentinel-based services. These cases proved to be an excellent marketing tool and a first step towards the deeper analysis of cases.

- **Conceptualisation of "return on investment":** Copernicus as a whole and the Sentinel satellites in particular have been set up and are operated using EU budget (i.e. EU taxpayers' money). It is thus interesting to reflect on the "return on investment" for this public investment as seen through the "eyes" of SeBS. Starting with the case of Flood Management in Ireland, we started investigating how such an analysis could be performed. This could be further developed and substantiated in upcoming cases.

- **Development of indicators across key areas:** When looking at the different cases that are being analysed (but also cases that have been discussed in some extent with stakeholders but not actually analysed), it becomes apparent that certain patterns arise. These are related to "indicators" by which we can perceive the different types of benefits. Thus, for example, economic value can be discussed in terms of avoided costs, increased revenues, reduced inputs, etc. Having reached a critical mass of cases by the time of writing, the SeBS team moved ahead to develop methodological frameworks for EO value estimation. In this regard, a dedicated *ad hoc* analysis is currently underway; at the same time any new case is analysed using this framework already (more on this in chapter 2).