European Association of Remote Sensing Companies

Sentinels Benefits Study

Demonstrating the value of the Copernicus Sentinels

Transversal Analysis

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Contents

List of Tables:

James stood over his ball with a 2m putt to square the match. He struck it cleanly, but it just slid past the hole. *"Well done,"* he said to John and Johan as they shook hands, *"the evening is on me then."* He and George walked off the green to the clubhouse. *"Great shot from you at the last,"* he said to George, *"sorry I could not convert it into a win."*

The four friends met at the bar after showering and changing. With drinks in hand, they sat at the table with a view over the 18th green and mused over the weekend golf. They all had stories to tell of their endeavours; with congratulations for fine shots and commiserations for "bad luck!"

The four men had maintained their friendship over the years and each spring, they had a weekend of golf together, rotating between each of their local courses. Last year they had been in Rome at the wonderful Marco Simone course where this years' Ryder cup had been hosted. John, that year's host, works with the European Space Agency in Frascati.

This year they were in Jornkoping, home of the Swedish Forest Agency where James worked. After his studies he had met and then married Annika who had been on an Erasmus exchange in Leeds. When her mother became ill, they had moved back to her family home, swapping rural England for the equally, wonderful lakes of Sweden.

James turned to John saying, *"we were talking earlier about your new satellites. We are still using your Sentinel-2 data to help us manage our forests. Recently, we have been having a lot of problems with bark beetle and we can get a good idea of where infestations are breaking out from the images. We are now working very closely with the Environment Protection Agency in Sweden. In fact, your data has helped us work more closely with them on many topics linked to land resource management."*

Johan looked interested, "*are they using the data to monitor the lakes in Sweden?" "No,"* answered James, "*that is not their responsibility, but they do work very closely with the Water Management Agency. Since the government started to build a collection of images over the whole of Sweden, all the agencies have been working much more closely together. It has strongly improved our co-operation."*

"That is really interesting," said Johan. *"I am doing some consultancy work at the moment for the German Finance Ministry. We have a project to increase the use of digital technology throughout the German public administrative bodies, the Ministries, the Länder, Agencies, local councils etc. One of their working groups is looking at the use of satellite data. I have a friend working in the group. Thomas is monitoring water quality in Baden Wurtenberg. He is a strong advocate for using satellite data and keeps asking the ministry for more money to do so! Other Länder are also looking at doing the same, but they do not have anyone like Thomas to champion the use."*

"I think it is similar in Sweden," added James. "*The Water Management Agency have run several trials but are not yet convinced enough to commit to the necessary changes. The mountainous landscape leads to technical problems. I expect the EU will change the legislation at some point soon which will make it easier to introduce these new techniques."*

"By the way," John laughed, *"the greenkeeper at the Olgiata golf club near Rome is using the images as well to keep his course in good condition but reducing his use of water! I'll take you there next time that we are weekending in Rome."*

It was time for them to return to their hotel or home and get ready for dinner. Their wives, who are not golfers, had been enjoying a day cruise on the lake. Annika is a cold-water swimmer, but John wondered if Claudia, or Helen would have joined her in the water. Unfortunately, George and his wife had separated a few months ago, so this weekend they were only 7.

At the hotel, each retired to their rooms to change, whilst James went back home to do the same. At 7h30pm they all met in the bar. Seven champagne flutes were placed on the table and the waiter carefully served each of them in turn. The women had spent a good day on the lake and in the end, everyone had swum. The guys said that they would definitely NOT be joining them next time! The ladies laughed and there was a lot of banter about men losing mishit golf balls in lakes and whether they would wade in to find them.

With refilled glasses in hand, they were shown to their table. They were soon served with an amuse-bouche, and their wine glasses filled with a very pleasant Carricante from the slopes of Mount Etna. As the conversation paused, George, who is the finance officer in the Austrian roads' agency, turned to John saying, *"that was an interesting discussion about satellite data this afternoon. Even we are starting to investigate its use to help us manage the roads in Austria. One expert in the agency has been running a trial looking at the Schottwien bridge. He tells me that it may be possible to monitor it and other bridges for cracks using a satellite. It seems incredible that a satellite flying 700km above our heads, can see cracks in a bridge. He tells me that we can save money – which always interests me. Is this true? Do you know anything about it?"*

John smiled, he explained that he imagines that George's colleague is talking about a product called InSAR. *"It uses radar images to measure very small movements of the ground. It cannot see a crack, but they can see if unusual movements are taking place and indicate if there is likely to be a problem at which point, engineers are sent out to carry out an inspection. The roads agency in Italy has been doing this, as well as monitoring their construction sites. They can even "look back in time" to see if an area is stable or is subject to movements which helps with their road planning."* He offered to put George and his colleague, in contact with an expert in ANAS to see what could be done.

The dinner continued with a fine bottle of Chateau Gravaliere. James picked up the bill as he had come fourth in their competition and talk turned to next year when Johan would be their host in Berlin. But he surprised them with a suggestion that, as it would be their 10th annual weekend together, they should do something different. He had always wanted to play at the home of golf in St Andrews how would they feel if he were to organise a weekend in Scotland. Maybe they should add a few days to take in some whiskey distilleries? It would also be a great opportunity for the ladies to go cold swimming in a Loch!

They all agreed that it was a great idea and so it was, that 12 months later, John and George were walking down the first fairway on the old course at St Andrews. They were exceptionally lucky to have a sunny day with only a moderate wind. John would play first but before doing so he turned to George, *"did you contact ANAS after our talk last year?"* George smiled, *"yes, we did and have met with them twice. We are planning to establish an international group of road experts to exchange once per year. We have a lot to learn from each other. Normally, we are lucky to talk with colleagues from different counties let alone from different countries!"*

John replied, *"that is really great news. I'll add that to our list of successful benefits which arise from using our Sentinel data. All the state sponsors will be really pleased to hear about these indirect benefits. Everyone talks about numbers and saving money, but we are finding that many of the benefits are not easily expressed in monetary terms. Nevertheless, they are no less tangible. We are preparing a report to be published shortly. Maybe you could send me a picture of your group when it first meets?"*

With that he selected his club, addressed the ball and drove a magnificent 5 iron to the heart of the green, coming to rest just 2m from the hole. He smiled, *"this is a good start to the weekend and a chance to redeem myself after my miss from that distance last year."*

With each SeBS case, we have included a short anecdote to explain the overall story to readers which story to set the scene for the case. The anecdote is entirely imaginary, although realistic based on our knowledge gained through the case interviews. The places are real, although the characters, the conversation and the situation are entirely fictional.

1. Introduction

Background to SeBS[1].

Over the last 8 years, Europe has invested more than €6B in the flagship Copernicus programme. Through its system of Sentinel satellites and Copernicus services it provides data and information for Europe's policy makers and other European users. It also provides tools as well as being a tool for developing the business of Earth Observation in Europe. Copernicus is now considered to be the world's most advanced system for gathering Earth Observation data and delivering information services. Have the European taxpayers received value for money for this investment?

The Sentinel Benefits Study (SeBS), run by ESA and executed by EARSC with its partners, is designed to provide some answers to this question, through a bottom-up, value chain approach. Previous, top-down studies have shown value creation of €2 for each Euro invested[2]. But these macro studies are certainly underestimating the return which is only now beginning to be felt in many areas. Further, since the benefits are accruing mostly in public administrations, they are often not easily measured in monetary terms.

Hence SeBS uses a bottom-up approach to capture the various ways in which benefits are being generated. It shows that society benefits in many different, and often unexpected, ways. We have found ways to assess these benefits and, whilst they cannot all be quantified – at least without a disproportionate effort and cost – simply identifying that they exist is itself a demonstration of value.

Furthermore, as the number of cases analysed has increased, along with our understanding of what makes them tick, so we have been able to recognise new ways in which value is being created. As a result, our methodology[3] has evolved. Through the portfolio of completed cases, we are able to develop the understanding even further, by identifying benefits which are associated with different players in the value chain, for example to public agencies.

Transversal Analysis

This leads on to a further question regarding the development of the services. The cases studied are by definition limited; they are bottom-up and trace the impact of a product derived from Sentinel data along an extended value chain. Geographically, they are bounded by national borders reflecting the public service nature of many of the products and that markets and regulations are generally coherent within national boundaries but differ from one country to the next. We have a snapshot view and would like to understand if this can be extended further, to other EU/Copernicus countries. In doing so, we

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[1] Sentinel Benefits Study – Showcasing the use of Sentinel Satellite Data.

[2] According to the 2016 study of the European Commission "Study to examine the socioeconomic impact of Copernicus in the EU", "*the EUR 7.4 B invested in Copernicus over 2008-20 is estimated to have yielded benefits of 10.8b to 13,5b*.

[3] SeBS methodology, https://earsc.org/sebs/wp-content/uploads/2020/12/SeBS-Methodology-2020.pdf

may also understand what the barriers to the uptake in these countries are. Why is a product being successfully used in one country but not in another?

In this report, we attempt to answer some of these questions. We have taken 3 of the application domains analysed using the SeBS methodology[4] and extended the analysis to investigate some of these less obvious benefits. We have also sought to widen the investigation by looking at what is happening in each of these domains across Europe. This has revealed some additional ways in which the Sentinel data is being used and hence further benefits.

Through a series of workshops and interviews, we have been able to discuss with experts in a number of countries and by so doing have learned about new use-cases. These help "widen the picture" and give a deeper understanding of why the technology has been adopted – or why it has not. Overall, this leads us to a rich picture of how the data from Sentinel satellites is delivering value for Europe.

This Report

The report has four main chapters; one for each of the 3 applications, and a further chapter which draws conclusions across them. Each of the 3 chapters describes briefly the SeBS core case and the benefits that have been identified. A description is given of further knowledge gained for the countries which have generously provided time for discussion. This leads us to insights which are more global in nature on the progression of the use of Sentinel data for the particular application.

In the 4th chapter, the separate insights are reviewed for general lessons of interest to policy makers. We hope the knowledge gained will be useful for all stakeholders to develop their use of the Sentinel data for the benefit of all citizens.

We wish to thank all those who have contributed whose names can be found in the Annex. Table 1-1 provides an overview of the organisations consulted during this work. If experts in other countries not currently featured would like to provide further inputs, please contact us (see page 2 or conclusions for details).

Relevant SeBS Cases.

- Highways Management in Italy
- Ground Motion Monitoring in Norway
- Forest Management in Sweden
- Forest Management in Portugal
- Global Deforestation Monitoring
- Water Quality Management in Germany
- Water Quality Management in Finland
- Water Quality Management in the Netherlands.

[4] SeBS Methodology: A Practical Guide for Practitioners to evaluating the Benefits derived from the Use of Earth Observation Data

All SeBS cases can be found at earsc.org/sebs as well as the other reports produced in the study. A visual final summary report can be found here.

Widening the Picture

In order to develop a wider consultation based on the core case studies, a number of workshops were organised to which relevant organisations in each country were invited to participate. A first series of fully virtual sector workshops took place in June and September 2022; one for each of our selected domains. Invitations were extended through the Copernicus User Forum and through ESA delegates to the PB-EO.

Once our preliminary findings were mature, and a first draft of this report had been issued, it was circulated to all those attending the workshops as well as through the two representative bodies mentioned above. Comments were invited and it was also used as the basis to invite further participation to a workshop in June 2024 which was organised into 3 sessions:

- Session 1 (6th June): The European Users' perspective
- Session 2 (13th June, morning): The Regional / public authority users' perspective
- Session 3 (13th June, afternoon): An international perspective.

Reports on these can all be found on the SeBS website.

Feedback obtained during these 6 separate workshop sessions as well as through further contacts generated by interest in the events has been used to update this report from 1st to 2nd issue.

	Roads Infrastructure Management	Forests Management	Water Quality Management
Austria	ASFINAG - Autobahnen und Schnellstrassen Finanzierungs Aktiengeschellschaft, AIT (Austrian Institute of Technology.	Austrian Federal Forest Office, Umweldbundesamt GmbH, BFW (Bundesamt für Wald)	International Water Protection Commission for Lake Constance (IGKB)
Belgium			VITO
Czech republic	Directorate of Roads and Motorways (RSD) GISAT	Czech R. Forest Institute (UHUL)	
Cyprus		Cyprus Department of Forests	Cyprus Telecom Institute
Finland		Finnish Forest Institute	Finnish Environmental Institute (SYKE)
France		Ministère de la Transition écologique	Les Agences de l'eau (Water Agency)
Germany	Bundesanstalt für Straßenwesen, (BASt),	Tühnen Institute (TI)	Environmental Institute of Baden Wurtenberg (LUBW),
Italy	ANAS	Italian Minstry for the Economy (MISE)	Institute for Environmental Protection and Research (ISPRA) CNR
Netherlands			Noorderzijlvest Water board
Norway	Norwegian Geological Institute (NGU), Statens Vegvesen Norway Space Office (NSO)	Norwegian Environment Agency, Norwegian Space Office (NSO) Norwegian Institute of Bioeconomy Research (NIBIO)	Environment Agency (Miljødirektoratet), Norwegian Institute for Water Research (NIVA)
Poland	Directorate for Roads and Motorways, Polish institute of geodosy and Cartography	State Forests, Institute of Geodosy and Cartography	
Portugal	Infrastrutures de Portugal EGIS	Portuguese Forest Agency (ICNF), CELPA, Portugese national mapping agency	
Romania	Romanian Space Agency (ROSA)	Ministry of the Environment	
Spain		Cartographic and Geological institute of Catalonia (IGCC)	Cartographic and Geological Institute of Catalonia (IGCC)
Sweden	Swedish Transport Administration (Trafikverket (TV))	Swedish Forest Agency, Swedish Environmental Protection Agency (SEPA) Skogforst	Swedish Agency for Marine and Water Management (SWAM)

Table 1-1: Organisations consulted during the study

2. Sentinels driving benefits for Highways Management

2.1 Introduction

Highways are an integral part of modern life enabling fast transportation of people and goods, with flexibility to accommodate complex logistics and rapid displacement of citizens. If a highway or motorway is closed or restricted for any reason, many suffer the consequences, and the "societal cost" is high. Hence avoiding such closures or restrictions is a priority for those responsible meaning that the operating risk must be well understood, and that the engineering construction is sound. However, lack of tools to understand risk driven by unstable ground has led to many projects with heavy unforeseen costs over budget and sometimes only revealed many years after the construction is finished.

The management of roads and highways in most European countries is the responsibility of a national agency together with local and municipal authorities. Generally, this is split with highways (multi-laned, limited-access roads) and motorways being managed by the national body with minor and interconnecting roads managed by the local and urban authorities. Both work closely with engineering companies which contract for construction and maintenance work and, in the case of national highways, service companies which take on the operation of the highways both under contract and against revenues from toll fees collected from the transport sector and private motorists.

Our focus has been on the highways which are most often managed through the national body often formulated as a state-owned company. This is the case in both Italy and Norway where our core cases are located but also in many other countries (see Table *2-1*). The highways "agency" operates under the policy structure of the government as well as negotiating with many local and regional administrations through which the highways pass.

2.2 The Problems to be Addressed.

One of the key problems faced by those dealing with highways is movement of the ground whether triggered by natural phenomena (floods, landslides etc) or whether due to geological instability. This lies at the heart of our analysis and is applicable during all phases of highways management: planning, design, construction and maintenance.

Using traditional survey methods, monitoring large areas of land for ground movement is complex and expensive whilst either subsidence or heave can cause significant problems for highways engineers. Differing geologies across Europe means that the causes of the movement can vary, and priorities change according to the underlying geology of the country.

Hence, destabilising ground movement is often only discovered as the project advances or even after it has finished. Indeed, the construction work for a project may itself trigger movements. If movement occurs, then a detailed investigation is required to understand what is causing it and how best to introduce remedial measures to eliminate its impact on the highway infrastructure. This may take many years as was the case with the Tonsberg tunnel in Norway[5].

In our case studies, we have found several ways in which movements can affect the work of highways management.

- during the planning phase of the project, it is important to know if any of the site has been subject to past movements – indicating potential movement in the future.
- During the design phase to understand any instability and adapt the design accordingly.
- During the construction works to understand if movement is being triggered in some way by the works.
- After the infrastructure is completed to understand if longer term movements are likely to cause problems or if there is a risk from natural phenomena.

As we shall see, satellites offer precise measurements of even a few millimetres of movement and over very large areas of ground, which may provide the only way in which such movements can be detected and diagnosed.

2.3 How Satellites Can Help

Surprisingly, satellites can help to address some of these problems. A technique called InSAR, which uses data coming from a Synthetic Aperture Radar (SAR) generates maps showing any vertical movement of the ground between each time the satellite passes overhead. Sentinel-1 carries a SAR which performs this task very well.

The accuracy depends on the strength, and what is called coherence, of the radar signal which is reflected from the ground. These are both greatest when metallic or man-made objects are present. With a good signal, movements with a precision of a few mm can be measured using the satellite SAR data. Some measurements can be made over open ground, but the signal and hence the accuracy is strongly reduced where there is only vegetation and soft soil.

Happily, most highways have many good reflectors from metal barriers, signs, bridges, even sometimes the hard road surface itself which enables accurate measurements to be made of a few millimetres of movement. Depending on the location, observations can be made every few days allowing a picture to be built up over a few weeks, months or years as to whether there is any movement.

To improve the precision further, a special tool can be used called a corner reflector. This is a man-made object designed to give a very strong reflecting signal. Several of these can be placed at the site of interest to ensure that a precise detection of movement in both scale and location is assured independent of any lack of natural reflectors.

1. Risk of Ground Movement:

The primary problem addressed through the use of Sentinel data in relation to highways management is to better understand the risk of ground movement. This is valid at any point of the construction cycle;

[5] SeBS case Ground Motion Monitoring in Norway.

planning, implementation, maintenance including, where data exists, any historic movement. This is very hard to do using traditional methods due to the need for multiple, accurate surveys carried out over a relatively large area.

Ground movement affects the construction methods such that if it is not known beforehand, sub-optimum stabilisation techniques may be used leading to later problems. Traditional surveying techniques may take a long time to reveal any movement and/or the extent of the site to be surveyed is large such that a limited number of in-situ measurements may not show up the problem.

The ground movement may arise due to a number of factors. This includes geological stability (in Italy), moraines (in Norway), deep sandy soil (in Oslo, Norway), clay (in the Netherlands – pipeline infrastructures), underground watercourses or flows (in Spain for aquifer monitoring) etc. The last of these have not been found in relation to highways but are included as examples of where problems may be found.

2. Settlement (precision measurement)

Construction work will often include the need to use ballast to create a stable platform onto which road structures e.g. bridges can be built. This may be particularly true where the road is crossing a stretch of water or very wet ground.

After dumping of ballast, it takes several weeks or even months to settle to the point where it is sufficiently stable for construction to proceed. To determine this, settlement measurements must be taken periodically to see when the rate of settlement has fallen to a tolerable level. In remote areas, this can necessitate surveyors, travelling to the site regularly. The use of SAR with corner reflectors can remove the need for site visits.

3. Landslides

Landslides are a risk in all countries but especially those with steep mountainsides and are a consequent risk to the road infrastructure. In Norway, the risk of rockslides falling into fjords and causing local tsunami, has led the Norwegian Geological Institute (NGU) to use ground motion monitoring to give an early warning of this possibility. Corner reflectors have been mounted at critical points on mountainsides. This was the basic driver for starting the ground motion monitoring service in Norway.

In Italy, landslides are mostly triggered by heavy rains. Several projects have sought to find techniques to monitor areas at risk, but the efficacy of this is yet to be proven due to the speed of the event and the lack of early warning signs.

4. Bridges and Tunnels

There is a lot of interest in the use of the SAR imagery to detect movement in bridges or at the surface above tunnels. Movement around tunnels is similar to any other type of ground movement whilst, for a bridge, the distinction must be made between movement caused by the ground on which the bridge is built and movement due to structural stresses or failures within the bridge. The former can be readily detected, while movement in the bridge itself is much harder to detect due to the need to distinguish between movements caused by traffic vibrations, thermal effects which change on a daily basis as well as a seasonal basis from those due to structural causes.

Whichever of these mechanisms is being targeted, corner reflectors will almost certainly need to be installed to measure precise points on the bridge (or other structure). The man-made structure is likely to give rise to many reflecting points which will defocus the InSAR image and prevent precise measurements. The corner reflector gives a strong signal which dominates the weaker ones surrounding it and allows a precise measurement. Some success has been seen with this technique as we shall discuss later.

These are the four conditions that have been identified during our work, where satellite-derived ground motion data can be used to help in the process of highways management.

2.4 SeBS Benchmark cases

Two core SeBS cases have been completed with a full analysis in Italy and Norway. They highlight very nicely the various ways in which the data from Sentinels can help the highways agencies in their work and also highlight a number of issues which influence the take-up and use of the technology. In both cases (as well as many others) the importance of the individuals as champions stands out really strongly as a key factor.

In both countries, the organisations responsible for highways management are now using InSAR to measure quite precise vertical movements of the ground (subsidence or heave). Maps showing ground movement are being produced and routinely used in their daily activities to address one or more of the problems identified in the last chapter.

Each of the core cases is based on the use of a nationally developed tool. In Norway it is essentially institutional in nature driven by the Norwegian Geological Institute (NGU), whilst in Italy it comes from a commercial development by Planetek Italia known as Rheticus.

Core Case - Norway:

The case in Norway derives from a specific concern of the NGU which seeks to monitor steep, rocky slopes for early indications of a landslide. In the past, rockfalls have fallen into fjords causing Tsunami-like waves which in the worst case can flood homes and even cost lives. Using the ground motion map, movements can be detected over large areas, leading to earlier warnings. If some movement is detected, more concentrated monitoring can be applied if there appears to be a danger.

The roads are also threatened by falling rocks and so it was a natural development that the Norwegian Public Roads Administration (NPRA) or Statens Vegvesen became interested to use the product which then drove its further development. Since then, the NPRA has used the maps to help improve a number of projects. One of the main drivers of instability in Norway is the many moraines which can be found at the end of ancient glaciers which are both deep and unstable meaning that structures built upon them are subject to movement.

A good example of this is the tunnel leading to the town of Tonsberg 100km south of Oslo. It was constructed in 2006 but has been repaired due to cracking many times since. Surveys had failed to recognise the problem which was revealed through the use of the ground motion map. The tunnel emerged from the hillside above the town of Tonsberg which had been built on an ancient moraine. The InSAR map showed that whilst the mouth of the tunnel was relatively stable, the moraine was slipping down into the sea causing fractures at the tunnel mouth. Had this been known at the time of construction, different stabilising measures would have been used so saving time and money on both rework and maintenance. However, since this concerned a large area, in-situ measurements of the movement would have been difficult and very expensive to make whilst the more-recently available, wide-area ground motion maps were able to expose the problem immediately.

Other examples include construction of road tunnels and buildings in Oslo. The capital has been built upon marshy ground and long wooden piles have been used for many of the older buildings; for example the railway station. Newer constructions disturb the ground and cause movement. Using the ground motion map, it is possible not just to detect the movement but also to pinpoint when it has occurred which is very useful when it comes to planning projects and to establish any legal consequences should movement be triggered in neighbouring buildings.

In Norway we also learned about an application where a new causeway was being constructed across the head of a fjord. Ballast in the form of rocks was dumped into the waters to build up a platform upon which a road would be constructed. The ballast needs to settle to a relatively stable position before the construction work can begin. This is determined by regular surveying of the ballast to ascertain the rate at which it is settling and requires the presence for observation of highway surveyors.

As a test of the method, the engineering contractor had deployed corner reflectors to measure the settlement. Corner reflectors provide a stable reference point for the radar allowing precise measurements to be made where there is no existing infrastructure. By taking regular measurements, the rate of settlement of the causeway is known and consequent works planned with better certainty. Large corner reflectors, fixed into position enhance the measurement made using Sentinel data and avoid the need for surveyors.

This practise is most effective and beneficial in more remote areas as is often the case in Norway. The cost of the corner reflectors and the preparations necessary for their fixing in place offset the cost of surveyors. An alternative is to use smaller reflectors, cheaper to build and install, but commercial data (which must be paid for). The free Sentinel data seems to be the better option.

For each SeBS case, according to our methodology, we develop a value chain picture to help identify the stakeholders and to structure the benefits analysis. The generic value chain for highways management is shown in Figure 2-1.

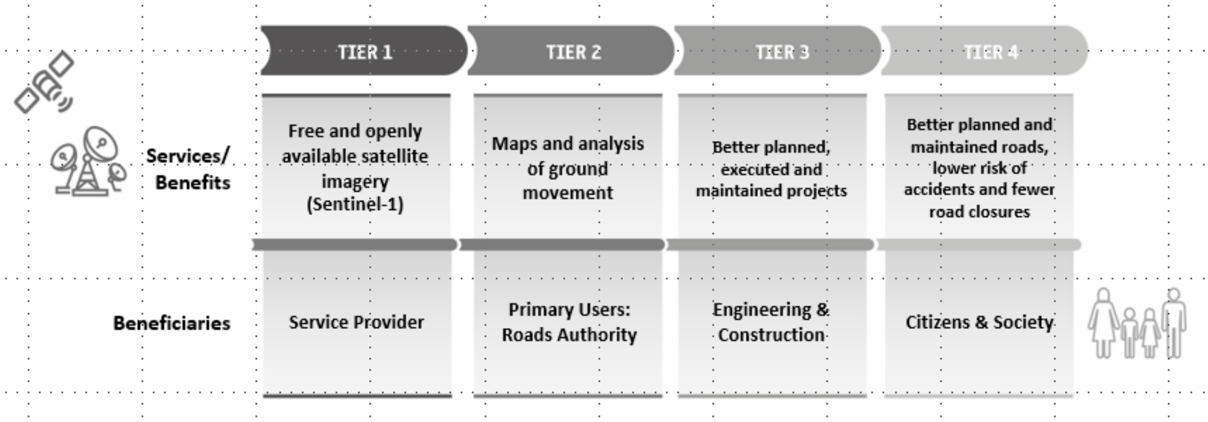

Figure 2-1: Generic Value chain for highways management.

The value chain is largely generic in that is mainly the same for cases in different countries. However, the involvement of different actors or variations in the use, may bring alterations to it. Notwithstanding it is one of the first elements to develop as a case is constructed.

Core Case – Italy:

The Italian Geological Survey has identified 620,000 landslides which have occurred in the country showing how Italy is a geologically, young country. It means that infrastructure must be carefully planned and monitored. Bridges and tunnels are especially vulnerable and new routes need to be carefully chosen. ANAS, the state-owned highways authority in Italy which operates 32,000km of roads and highways, has been using Rheticus for a few years such that it has now become standard practice for new projects. Until recently, stability surveys of proposed routes were limited but now, systematically use ground movement maps where the terrain is difficult.

Several case studies in Italy show the utility and potential for the application. ANAS is using it for:

- Monitoring unstable areas near bridges, viaducts and tunnels present along the highway network.
- Designing new routes, being able to better evaluate costs and critical issues in advance.
- Monitoring the areas most subject to increasing effects of climate change and realize more resilient structures.

One example is the construction of a new road near Palizzi in southern Italy. Historically, there have been several landslides over the territory where the planned road will pass including several which happened after work on the road and tunnels had started. As a result, the Rheticus ground motion service was introduced to ascertain where movements were taking place. This highlighted several slopes which were slowly sliding.

To improve monitoring during subsequent construction, 18 corner reflectors were installed on the hillside which has enabled precise monitoring to take place. This shows the outcome of stabilising work as the movement can be seen to be slowing over time.

Damage can also be caused through landslides triggered by heavy rains. On the national road 20 connecting from Italy into France, the tunnel Colle del Tende is to be rebuilt. In October 2020 excessive rainfall caused a landslide and washed away part of the access road. A new bridge is to be built as well as enlarging the tunnel. The ground motion map has been used to assess where future vulnerabilities may lie and to avoid them where possible or to re-enforce the construction where this is not possible.

Learning from this experience, ANAS is moving from emergency maintenance towards predictive maintenance. Some 2,400 vulnerable points where the ground is slowly moving have been identified covering 500km of the road network. These sites will be monitored for any change and remedial works planned before a landslide can occur and restrict the road access.

2.5 Widening the Picture

The two core, full cases have looked in some detail at the pictures in Norway and in Italy. In comparing these we find a lot of similarities and one or two differences which we shall examine further in chapter 2.7. But before looking at the benefits, what is happening elsewhere? Is the technology being applied? Are there further lessons that we can learn by looking elsewhere in Europe? How far are the findings obtained for Italy and Norway extendable to other countries?

Table 2-1 shows the various agencies in the EU Member States and contributors to Copernicus. We also include the number of km's of highway reported in each of the states {source Wikipedia interrogated using ChatGPT}. Note these are generally roads with controlled access points ie motorways and protected multi-lane carriageways. Spain has the most recorded highways, followed by Germany and France.

As briefly described earlier, we reached out to countries through the Copernicus User Forum and the ESA EO Programme Board. These are made up of national representatives who have a focus on space or EO rather than on the domains in question, but they can themselves reach out to those who are focused on the domain in question. Our goal being to engage with experts in forestry, highways or water. Through these channels, we are most likely to find experts who are aware of the technology, and we try to leverage this to find experts in each domain who are familiar with the application.

To provide a focus for exchange, we organised a dedicated workshop[6] in September 2022 with representatives from a number of EU countries. We also contacted countries representatives through both the ESA and EC channels mentioned above, both to invite them to the workshop and to solicit interviews. The workshop was fully virtual, and many countries participated either through their road's agency or their Copernicus focal point and the new information gleaned from this is summarised for each of those who engaged with us.

Austria

In Austria, the Autobahn and Schnellstraßen-Finanz-Aktiengesellschaft (ASFINAG), is responsible for the planning, financing, construction, operation and toll collection along almost 2,249 kilometres of motorways and expressways. As part of a collaborative research project with their neighbours in the

[6] SeBS Sector Workshop on Road Infrastructure Management. https://earsc.org/sebs/sector-workshop-1-road-infrastructure-management/

Czech Republic, ASFiNAG has been trialling the use of INSAR measurements coupled with corner reflectors mounted on bridges. This has successfully shown that movement of the bridge can be detected and that cyclical movements (daily/seasonal) can be separated from unexpected movements which are the ones that cause risk. The approach is interesting as it avoids the need to install in-situ sensors and associated power and cabling.

Notwithstanding, only a limited number of the bridges in Austria are considered appropriate for this type of monitoring and it is proposed to extend the trial to between 5 and 10 bridges in total. It is anticipated that this will allow more bridges to be monitored at an affordable cost.

Highways	km's of highway[7]	Operational / Management Organisation
Austria	2249	Autobahnen- und Schnellstraßen-Finanzierungs-Aktiengesellschaft (ASFiNAG)
Belgium	1772	Flanders: Agency for Roads and Traffic (AWV) Wallonie: Public Service of Wallonia Mobility and Infrastructure
Bulgaria	852	Bulgarian Road Infrastructure Agency.
Croatia	1313	Croatian Motorways (HAC)
Cyprus	1240	Ministry of Transport – Department of Public Works
Czech Republic	1724	Ředitelství silnic a dálnic ČR" (Directorate of Roads and Motorways of the Czech Republic) (RSD-CR)
Denmark	1750	Danish Road Directorate (Vejdirektoratet)
Estonia	1602	Estonian Road Administration (Maanteeamet)
Finland	1050	Finnish Transport Infrastructure Agency (Liikennevirasto
France	11882	Autoroutes de France" (ADF)
Germany	13000	Bundesanstalt für Straßenwesen, (BASt) Autobahn GmbH & Federal Trunk Road Authority (FBA)
Greece	2500	Hellenic General Directorate for Highways
Hungary	1464	National Infrastructure Development Company Ltd. (NIF Zrt.)
Ireland	4000	Transport Infrastructure Ireland (TII)
Italy	6758	National Autonomous Roads Corporation (ANAS)
Latvia	5000	Latvian State Roads (Latvijas Valsts ceļi)
Lithuania	1650	Lietuvos automobilių kelių direkcija Lithuanian Road Administration (LRA)
Luxembourg	147	Administration des Ponts et Chaussées, National Roads Administration
Malta		Infrastructure Malta
Netherlands	5000	Rijkswaterstaat
Norway	744	Statens Vegvesen - Norwegian Public Roads Authority (NPRA)
Poland	3300	General Directorate for National Roads and Motorways
Portugal	2900	Infrastruturas de Portugal, S.A. (IP)
Romania	853	National Company of Administration of Road Infrastructure (CNAIR)
Slovakia	766	Národná diaľničná spoločnosť, a.s. (NDS)
Slovenia	1251	Družba za avtoceste v Republiki Sloveniji (DARS)
Spain	17100	Dirección General de Carreteras
Sweden	2000	Trafikverket (Swedish Transport Administration)
United Kingdom	6920	Highways England, Transport Scotland, Welsh government, Department for Infrastructure Northern Ireland.

Table 2-1: Highways Agencies in the Member States contributing to Copernicus.

[7] Km's of motorways/ highways (protected access roads) in each Member State

Czech Republic

In the Czech Republic, the Road and Motorway Directorate of the Czech Republic (RMD) is the state organization which is responsible for the construction and maintenance of Class I roads (state roads) and motorways. Class II and III roads are owned by regions, which have established special organisations for management purposes. Institutional tasks of the RMD include ensuring the operability of the road, ensuring repairs and maintenance (including winter maintenance), ensuring toll collection, operation of telematic systems, etc. At present, space-based solutions are not regularly used but are being trialled. A pilot demonstration was conducted for bridge monitoring in 2015-16 from which the results were non-conclusive due to a limited time series of data. As a result, the Highways Agency are not convinced of the benefits. However, there is interest for understanding the stability of the land chosen for road routing as well as monitoring the risk for landslides which can block the roads. Consideration is being given to the introduction of legislation which will require the use of InSAR for stability mapping.

Perceived benefits arising from the use of satellite data are identified as:

- Risk reduction through ground anomaly detection.
- Increase efficiency through better control of defined routes of construction, new construction or obstacles that would complicate preparation.
- Control of permanent encroachments and secured temporary encroachments as black sites or greenfield sites for future construction.

Germany:

In Germany, the Bundesanstalt für Straßenwesen, (BASt) is the German federal highways research institute has been looking at the use of satellite technology, including InSAR, for highways management. The operational agency is the Federal Trunk Road Authority (FBA) is an executive agency of the German Federal Ministry for Digital and Transport (BMDV) which manages 13,000km of highways. However, the utilisation of satellite data for road infrastructure management is at an early stage and, currently, these data are not being used for roads maintenance, but are used in the case of hazards (floods, fires, landslides).

Recently in April 2022, the Copernicus Network of Transport was founded in Germany with the objective to connect and pool stakeholders at federal and regional levels. The group will organise workshops, foster dialogue between the ministries and other offices and stakeholders (including railway sector) and promote best practices as a result of the research conducted by BASt.

Norway:

The Norwegian Geological Institute (NGU) and the Norwegian Public Roads Authority (NPRA) named Statens Vegvesen work together on the ground motion service. As discussed in chapter 2.4, NGU has developed the service whilst the NPRA are its major user for both highways and railways management.

In addition to the core case, some research by the NGU is showing that (snow) avalanches may be detected in satellite imagery. The change in the nature of the snow surface as rocks are churned up with the snow, can be seen in radar images. This may be useful in remote areas to show when roads are blocked, but the time lapse between the event and its detection, coupled with the uncertainty of detection, are significant limitations to overcome.

The strong interest in Norway has also been one factor leading to the introduction of the European Ground Monitoring Service (EGMS) which is being led by the European Environment Agency. This will provide annual updates showing ground movement at around 20m resolution.

Poland:

In Poland, the Generalna Dyrekcja Dróg Krajowych i Autostrad or General Directorate for National Roads and Motorways is the body responsible for the 3,300km of highways in Poland. Satellite data are not yet used directly with regards to road infrastructure management as in the two core case studies. However, satellite data is being used in the framework of land cover monitoring and land cover changes. Responsibility is divided into national, regional (voivodeship) and cities.

However, its wider use in the future and especially the use of InSAR is being investigated by the Head Office of Geodosy and Cartography (GUGiK) which comes under the Minister for Development.

Portugal:

In Portugal, Infraestruturas de Portugal (IP) is a state-owned company which manages the national road network spanning 14,000 km including 2,900km of highways. IP is not yet using satellite data in their daily operations. However, in several pilot projects, they have used EO data for vegetation encroachment to mitigate risks - especially regarding wildfires - and complying with regulations aimed at resilience (against wildfires) and asset management – where the monitoring of displacement in structures was studied in bridges and slopes. The motivation behind these pilot projects to adopt new techniques, such as satellite data, was certainly due to the acquisition of improved and more abundant data, consequently allowing for more cost-efficient monitoring of larger areas, thereby altering the paradigm of monitoring solely at specific points.

A separate thread of interest has been found which links Portugal and France. EGIS, is a French industrial engineering and construction group managing many km of highways in Europe including in Portugal. EGIS has recently started working with a Portuguese company Spotlite, following a bad experience in Portugal where a landslide caused a partial road closure. As we shall discuss, road closures are very costly not just for the operator but also for the local community which relies on fast transport networks. Learning that it is possible to monitor the ground movement alongside the highways, EGIS has contracted with Spotlite to provide a service to give alerts if a potential problem is perceived.

Romania:

In Romania, the uptake of satellite data in the sector is at an early stage, with various studies and research ongoing into the usage of these data in the sector. The Romanian Space Agency (ROSA) gives advice to the different organisations in the use of satellite data including road infrastructure stakeholders and authorities.

Sweden:

The [Swedish Transport Administration (Trafikverket (TV)]) is responsible for 100,000km of roads including 2,000 km of highways and 15,000 km of railways. TV is using satellite derived ground motion measurements to support specific projects. Sentinel data is used for background monitoring whilst higher-resolution measurements are made for projects using data from commercial sources.

Trafikverket (TV) works closely with Statens Vegvesen (NPRA) in Norway and is also following the EGMS (European) service as it is introduced. Notwithstanding, TV mostly requires more regular updates than the European Ground Monitoring Service (EGMS) will provide and generally is looking for higher detail than is available using Copernicus Sentinels. As a result, the main use of InSAR is through TerraSAR in support of specific project needs.

For example, the Westlink project for the railways in Gothenberg involves tunnelling through 30-100m depth of clay which is unstable. InSAR is used to monitor the project and support any adaptions. TerraSAR-X was used by SkyGEO (EO services company in the Netherlands) to provide regular high-resolution updates. As a result, TV are using data from Sentinel 1 for background monitoring and then TerraSAR-X to examine in more detail if a possible problem is detected.

More recently, TV has internalised the expertise and now has 4/5 persons working with InSAR. This is a transversal resource which provides a centre of excellence in TV. There are a further 40-50 technical engineers who are working on the implementation of projects. For construction projects, the engineering companies are increasingly expected to bring their own expertise for monitoring ground movement and whether it is likely to cause any problems. This includes:

- pre-project when a historic of site movement is established.
- During construction when works triggered movement may be seen as well as legal issues that may arise and can be investigated using InSAR.
- Post-project to monitor if stabilisation measures have been successful.

Sweden is subject to heave (rising of the land surface). EGMS data will provide good indications of where this is problematic for roads or railways and is anticipated to be used. In this respect, the Lantmäteriet is further promoting the use of EGMS and is installing a network of corner reflector to improve accuracy and develop more geodetic applications along with the appropriate infrastructure.

International Experience:

For each of the three domains, a perspective from around the world was sought during the workshop session 3 on 13th June. An introduction was made by rapporteurs from the session 1 to provide the international audience with a brief summary of our findings in Europe and to place the international view into context.

Concerning roads management, EGIS a French company is operating roads in several countries including in Portugal (see section above) and in Turkey. In the latter, they are responsible for a highway of 500km. EGIS has taken its experience in Portugal and applied it to Turkey. A historical analysis has been made of ground movements along the motorway and a maintenance plan developed based on the assessed risk. To this has been added vegetation information and landslide risk to prioritise maintenance works. This shows how experience can be used internationally, and EGIS support the idea for an expert network as a platform for exchanging best practices.

2.6 Understanding the Benefits

The main beneficiaries from the application of the ground movement maps are the highways agencies (tier 2 in the value chain) whilst citizens and society (tier 4) benefit from fewer road closures and transport delays. Some agencies are now using the ground motion maps for each phase of their work:

- Planning: to look at historical movements and avoid unstable areas.
- Design: to adapt the design to the local conditions taking account of instabilities
- Construction: to monitor impacts over a very large area, not possible by traditional means
- Maintenance: to move towards a predictive maintenance and averting emergencies.

Economic	**Norway**	**Italy**
Cost savings	Improved surveying reducing project costs. Reduced project times.	Reduced survey costs and project risk
Efficiency gains	Improved maintenance planning Improved surveying methods Reduced road closures	More efficient design with lower risk.
Risk reduction	Reduced risks to projects and communities	Reduced litigation costs
Environmental		
Reduced pollution	n/a	n/a
Regulatory		
Preparation of Legislation	Improved design of legislation	Improved legislation
Compliance monitoring	Improved monitoring of regulations.	Improved monitoring
Innovation		
Changed business practice	Development of new innovative products.	Improving business processes
Start-ups	Opening new market opportunities.	
Research & science		
Academic publications	Enhanced scientific and technical knowledge.	Research into new applications
Societal		
Public utility	Increased public security and roads accessible.	Reduced road closures & improved access.
Community & quality of life	Reduced time loss from delayed traffic flows	Reduced time loss from delayed traffic flows

Table 2-2: Benefits from Sentinel use for highways management.

The range of benefits identified can be seen in Table 2-2. These are categorised into the 6 dimensions which we use to structure each of our analyses.

Economic benefits:

The economic benefits derive from cost savings, efficiency gains and from reduced risk of remedial work due to an unforeseen problem. The scale is the same in both countries analysed with a total of around €5m-€10m in each. With around 50% of the benefit being accrued by the agencies and 50% by society at large.

	Tier 1 Service Provider	Tier 2 Primary User	Tier 3 Secondary Beneficiaries	Tier 4 Citizens and Society	Total
Italy	n/c	€3.8 – 8.6m	€1.0-2.0m	€0.8-3m	€5.6 – 13.6m
Norway 1 (highways)		€2.4 – 4.9m	€0.1m	€1.3 – 3.4m	€3.8 - 8.7m

Table 2-3: Economic Benefits along the value chains for core cases of highways management.

For the agencies, the primary driver of the economic benefit is to avoid costly engineering rework as we have seen in the two core cases. For the society at large and indeed for highway operators, the primary driver is the reduced road closures leading to fewer delays and lost hours in the transport network.

In addition, in Austria, tests are highlighting the possible approach to reduce the cost of monitoring bridges, whilst in Portugal, EGIS shows the benefits to an operator of reducing or avoiding road closures. The use of InSAR as an alternative to in-situ measurements is more efficient as seen in Norway (monitoring of ballast settlement) and in Austria (simpler to install a corner reflector than a connected sensor) and regular observations allow historical trends to be generated.

Environmental Benefits:

Few benefits are perceived linked to the environment. There have been suggestions that ground movement may indicate where water courses have been disturbed through construction work. This may prove correct but will only be assessed once more projects have been monitored using InSAR. If it is found to be correct, then some environmental benefits could arise by avoiding potentially destructive impacts caused by construction works in a susceptible geology.

Regulatory Benefits:

The application of ground motion measurements for policy design and legislation is seen as a potential benefit in many countries. Construction works can lead to damage to adjacent buildings and infrastructure which is often disputed. Where this has been triggered by the construction works, knowing when the movement took place can be as important as knowing the location. The regular observations by Sentinel 1 means that a time history can be established. Knowing that this is possible can improve the regulatory controls around construction works.

Innovation and Entrepreneurship:

The use of InSAR technology is in itself quite innovative and the organisations which have adopted its use have shown this through their actions. It is also probably fair to say that the adoption of InSAR and the resulting ground motion maps is a driver of innovation in the agencies concerned – but which may also be a barrier to its uptake in organisations more resistant to adopting innovative practices.

Regarding the suppliers, one key difference between the two core cases concerns the service provider. In Norway, this is provided by a team of experts from the University of Tromso, supported by outside technical consultants, working under contract to the public geological institute. In Italy, the service is provided by an Italian SME, Planetek, which has developed the service called Rheticus. Planetek have invested heavily in developing the Rheticus service which they are exploiting in the wider market. The commercial interests of a company act as a strong incentive to help their customers adopt new technology.

By way of contrast, in Norway, as the product has been developed by a public agency and, in-line with the principles of a free and open data policy, the ground motion maps are available for use at no charge by other organisations in Norway. The commercial interest to press for, and support adoption of the service is less present, even if the technology may be exploited further by others as a basis for further business.

There is also evidence of the InSAR technique being used to detect/monitor (snow) avalanches and to help traffic routing especially in remote areas. Rocks, disturbed by an avalanche can show up as a disturbance in the InSAR images. We heard about the transport of a lorryload of fish which need to be delivered within a few hours and where, if an avalanche has blocked the road, the transporter has to return but with a high risk to the cargo due to the delay.

Scientific Benefits:

We did not come across many scientific benefits generated by the use of InSAR explicitly for highways management although we have not searched for them outside of the cases being analysed. However, there is evidence that there is a fairly active research activity around the use of Sentinel data for looking at ground deformations and disturbances using InSAR. The last 4 years (2020-2023) show around 45 scientific publications each year with over 3000 citations[8]. Although these are not necessarily linked to roads management, the knowledge gained is contributing to how it can be usefully applied through:

1. The algorithms used to generate the maps can be improved as a result of greater use and subsequent investment. This potential may be higher in Norway due to the university presence in the development.
2. The ability to measure ground movements over large areas is unique to InSAR and could be a tool for research into other geological disciplines.

Societal Benefits:

[8] Private communication between Nikolay Khabarov, International Institute for Applied Systems Analysis.

Finally, the societal benefits are identified clearly. The use of ground motion maps can help reduce the risk of problems to the highways and hence reduce the risk of closures. Road closures or restrictions lead to significant economic loss as transport networks are disturbed and, as far as the satellite data can help avoid or reduce periods when roads are closed is one of the more significant benefits.

There may also be a benefit from improved security. Damage occurring to highways due to landslides, avalanches, or ground motion presents a risk for the road users. If this can be avoided, the risk of an accident is reduced. Note that this is speculation and that no instance of this risk being reduced has been presented to us.

2.7 Insights

Each case delivers some amazing insights into how EO data from Europe's Sentinel satellites is making a difference. Yet, despite this strong evidence, the take-up in the European countries is still limited. Further to this, the InSAR derived ground motion maps provide the unique method whereby movements can be detected and measured over large areas of land. On the one hand, this shows the potential for benefits which may still be unleashed from the use of Sentinel imagery. On the other hand, it is curious that public administrations in other countries have not yet instigated its use. Why might this be?

If we compare not just those countries which have adopted the use but all of those with whom we have talked, an interesting picture emerges. We have identified the following factors, in no particular order, as being important to instigate and adopt ground movement monitoring from space:

- **Geography/geology**. The two countries which have adopted the technology both have very specific geological conditions which cause instability. These conditions are not present in all countries but are certainly present in some others. Hence the presence of mountains, glaciers and moraines is not unique to Norway but does create interest in monitoring ground movements. In Italy, it is the overall geological conditions which are a driver for monitoring the ground movement and which raise the susceptibility to landslides. In other countries, other conditions which can lead to instability are strongly relevant for the highways, for example, clays in the Netherlands, but factors other than geography, have not been influential in driving the adoption – as we shall examine.
- **Governance / Administrations**. Highways agencies are or have been governmental bodies with operational responsibilities. They are quite large organisations with set procedures for doing things. Introducing new technologies into their processes is not an easy task. In both ANAS and NPRA we saw quite clearly the difficulties our interlocutors had in convincing a conservative organisation to adopt change. In both cases, the new technology had been introduced by a person with the support of their supervisor but who (either the person or the supervisor) was then moved to a different role in the company or whose responsibilities were changed. In both cases this led to delays and difficulties to proceed with the use of the new technology.
- **Culture**: the willingness of the organisation and specifically its management to embrace change is a key factor. If there is a history of successfully adopting new methods, processes or tools this can help significantly.

- **"Space" awareness**. Space technology is often perceived as complex and expensive. An awareness in the organisation of its utility makes the introduction easier. In Norway, the NGU and the National Space Office were working closely together and the NSO was able to help raise awareness inside the NPRA. As a minimum, the space office is able to support the "champion" and to help them convince their hierarchy.
- **Industrial Presence**. The existence of a company, as was the case in Italy, which is keen to sell the technology (or service) can promote its use and help convince others through examples and supporting material as well as making presentations within the organisation. In this sense they have acted as a complementary vector to a national space office.
- **A champion**: as briefly mentioned above, a champion is highly important if not essential to bring the ground motion mapping to the organisation. In turn the champion needs to garner support from the hierarchy to succeed. We saw this in both Norway and in Italy. In Norway, the champion was an enthusiast for InSAR and participated to an international group of experts. However, shortly after we started the case, he was moved to a new job in which he could no longer champion the new service. Fortunately, he had already been able to show some of the benefits and his supervisor stepped in as a new champion.
- **Network of Peers:** Germany has established a network of peers in different national and regional organisations concerned with road transport infrastructure. This will drive awareness and enable the sharing of best practices. We are not aware of any other similar network ion this domain but consider it to be the most effective way to drive uptake – as discussed in chapter 5.

2.8 In Conclusion

The transversal analysis 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.

Two countries (Norway, Italy) have adopted the technology and others (Sweden, Austria, Portugal) are following. The benefits are similar in nature 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 i.e. bridges in Austria, landslides and wildfires in Portugal, 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.

3 Sentinels Driving Benefits for Managing Forests

3.1 Introduction

Forests are an important resource for many reasons and are key for many countries with large areas of existing forests. They are a strategic asset given their role as carbon sinks which mitigate the effects of climate change, and they are also an important economic resource, a fertile environment for nurturing and protecting biodiversity and a place of recreation for citizens.

Management of forests against each of these societal goals requires strategies to be put in place backed up by policies which can enforce actions. This is very clear in the case of Sweden which, for some years, has been a leader in forest management using satellite data but is also true in other countries which are currently using different means.

Forests, by definition, cover large areas of ground. This makes them well suited to monitoring on a regular basis using satellite data. While not all the desired parameters are visible through Sentinel imagery, or indeed that from other satellites, policies and management practices need to be adapted to take advantage of satellite observations.

Policies concerning forest management are driven by multiple and diverse national interests:

- to maximise the long-term production of timber which feeds an important economic sector.
- to preserve the natural environment by protecting habitats and promoting biodiversity,
- to support the effort to maintain carbon stocks and, increasingly, by sustainability concerns.

Under SeBS, two cases in Europe have been analysed on this topic; one full case in Sweden and a short case in Portugal, leading to some interesting lessons relevant beyond these countries and supported by interviews with experts from other European countries. Each of these countries is primarily addressing commercial issues through maintaining timber stocks but facing also environmental concerns.

In addition, a third case has been analysed whose focus is outside of Europe and which is focused on climate and sustainability issues associated with the production of palm oil. Natural forests that are complex ecosystems and support rich biodiversity, are being cleared in developing countries in order to plant palm oil trees. Political pressures reflecting societal environmental concerns are causing large food processing companies to wish to demonstrate that their business is ecologically sound and meeting Environmental, Societal and governance (ESG) goals. As a result, they seek to monitor the land being used over time to prove that they are adhering to international good practices.

3.2 The Problem to be Addressed.

The large areas occupied by forests make information on their state and health difficult to gather. The problems faced by forest managers differ according to their interest and perspective. These may be acting on behalf of the state (national interest) or of a company (commercial interest), to which we could add the many individual or family owners.

National interests are mainly reflected in legislation which control the management of the forests. National priorities are largely focused on maximising the long-term value of timber stocks for an important segment of a national industry whilst balancing this with environmental considerations. The latter may be reflected in preserving natural forests and establishing a balance between older woodlands and commercial forests.

Commercial interests are more short-term and are concerned with maximising the return on investment. These may conflict with environmental interests and certainly are controlled by the state legislation. A growing area of concern for all companies is what is called Environmental, Social and Governance (ESG). This calls for companies to act ethically or to face pressure from society to change, against the threat of tougher regulations. The acknowledged role of forests as a source of biodiversity and as a store of carbon brings a significant focus on this aspect.

Both the national and commercial interests above are also concerned with the state of the forest both for its health, faced with disease threats and from damage due to fire or storms which both destroy the timber stocks but also threaten the safety of citizens. These threats require timely information especially faced with fires, to help manage the danger.

Two factors influence the forest management practices and are reflected in legislation. The first concerns the timeframe. Depending on the variety, latitude and growing conditions, trees take between 35 and 120 years to grow to maturity before being ready for harvest[9]. Consequently, forest owners and policy makers need to take a long-term view to manage their forests effectively. This means taking decisions e.g. replanting, ground clearing, for which they may not see the direct benefit themselves.

Secondly, in many countries, private ownership of the forests is quite common and involve large numbers of owners. Whilst a few owners may be companies, institutions or the states themselves, controlling large areas, many tens or hundreds of thousands are individual or “family” owners, including indigenous populations, who own the rest. Whilst the former may take decisions on commercial grounds, the incentive for individuals to take action is mainly driven by cultural and/or legal pressures. For them, knowing that they will not directly benefit from actions, but that only their descendants may in the future, reduces their incentive to invest in the replanting and management once they have harvested. Hence, they must be incentivised by the state to ensure a sustainable forest management in the long term.

Reflecting the above, we can identify 4 types of information that should be gathered for supporting authorities responsible for ensuring sustainable forest management:

- Forest inventories to maintain acknowledge on the state of the forest and its evolution over time. This includes the state of thinning or replanting and whether this is conducted according to required (best) practices.
- Clear-cuts, or where areas of forest are cleared. Authorities need to compare the reality with permitted clearing. Divergence indicates an illegal action.

[9] https://www.skogsstyrelsen.se/en/laws-and-regulations/skogsvardslagen/

- Forest health and the presence of pests or disease. Recently, the bark beetle has invaded many forests in Europe and authorities and owners seek to control and prevent its spread.
- Forest damage due to storms or fires. Strong winds and lightening strikes causing fires may lead to undesired felling whilst wildfires are also a safety risk for people and property and therefore should be controlled rapidly.

This information is used to inform decision making by the key stakeholders whom we classify into three categories:

- Regulators control when and where forests can be cut and use the information both to inform legislation and to monitor compliance by the owners. This information should be able to distinguish between forest damage caused by storms and human-driven change The regulators also monitor for disease outbreaks and provide rules and guidelines on how to respond.
- Companies use the information to help their planning for timber volumes to be processed. Increasingly, they also seek to show that their operations are conducted legally and in accord with sustainability principles and ESG considerations.
- Emergency services use geospatial data e.g. maps to identify where fires are a high risk and a threat to citizens, businesses, and property. Sometimes, the services will seek to know if fire damage has been caused by illegal human actions. Maps also show to gain access to fight the fires, when necessary, which can be augmented by near-real time data helping to guide operations.

These are the high-level needs, many of which are supported by using knowledge gathered by rangers on the ground, from in-situ sensors or from aircraft and drones. How can satellites help?

3.3 How Satellites Can Help

Historically, maps of the forests are compiled by surveyors and/or the forest rangers which know the areas that they manage. Forest management and inventory is, traditionally, an extremely demanding work for forest managers, necessitating frequent field inspections and/or aerial surveys of the plantations on a regular basis to keep information updated. For example, because of its extensive workload and associated cost, the Portuguese National Forest Inventory is only updated every 5 years.

Aircraft and more recently drones are flown with cameras, lidars and sometimes other sensors (radar, spectral imagers) to take "pictures" of the forests but for large forest areas this rapidly becomes very expensive and hence the flights and "pictures" are limited to one every few years or for very limited areas of specific interest. These can provide fine detail and, with Lidar, can map the height and maturity of the tree canopy, but the cost limits this to typically 5 yearly intervals as is the case in Sweden and many other countries.

Sentinel-2 satellites carrying optical sensors (cameras) can provide regular coverage every 2 – 3 days, over large areas, at a resolution (10m) adequate for many types of information. Cloud cover reduces the regularity of imaging, but this deficiency is partly countered by processing every image[10] and

[10] Recent (June 2024) discussions in the context of the user workshop, with the Swedish Forest Agency shows that they have moved from working at large scale images producing one or two useful, full country maps each

extracting good data at the pixel level. This allows stands (small groups) of trees to be imaged and a partial classification carried out. The sensor also images in the near infra-red which provides good information on the health of the vegetation. The imagery, increasingly coupled with AI models, provides extremely useful information, weekly, about land use (changes) and status of the tree plantations over the whole of Portugal.

Even if cloud obscures some of the observations, the frequency of observation which is possible using Sentinel-2 offsets that the resolution is not high enough to detect some problems. For example, where satellites are used to detect diseases. This problem is more complex as it requires a higher resolution than that offered by Sentinel-2 to detect the disease in a single tree. A cluster of diseased trees can be detected and provides a useful indicator for the forests. With frequent imaging, a trend may be detected.

Storm and fire damage caused by lightening and high winds are a further threat to the forests and, in the case of fires, provide additional threats to people and property. Detecting the fires in near-real time is very demanding and well outside the context of what we are examining here. Nevertheless, accurate and up to date maps of the forests, showing access routes or barriers are valuable for those fighting the fire. Additionally, regular maps show up the damage caused by undetected fires and from storms which can help guide actions to mitigate the long-term consequences.

Monitoring clear-cuts is required to detect cases where a forest owner has cut trees illegally. Similarly, where forests are being preserved, the authorities need to ensure that illegal clearing is detected and if possible punished. The same principle can support companies working in or near protected forests. Following ESG principles means that their operations should not engender illegal cutting. As a result, companies like the multi-national food processor Bunge, are increasingly willing to monitor areas around their fields to ensure and prove that they are operating sustainably.

Overall, satellites can play a strong and key role in providing information to support sustainable management of forests while enabling countries to maintain commercial interests. Three different cases are discussed below, and which have highlighted different facets of forest management to meet the various interests concerned.

3.4 SeBS Benchmark cases

The three SeBS benchmark cases differ quite significantly in their characteristics and consequent benefits, even if the underlying product being used is quite similar.

- The Swedish case is about encouraging 300,000 individual forest owners to meet regulatory requirements leading to increasing timber stocks and preservation of ancient forests.
- The Portuguese case is about companies reacting to threats to their forests by early detection of disease or damage.
- The global, or “ESG” case is about helping a multi-national food company, Bunge, demonstrate their will to adhere to sustainability principles and ESG.

year, to acquiring and processing all images which are then combined at the pixel level and provide much more forest imagery with a much-reduced latency.

The users of this information provided by Sentinel satellites are different for each of the cases which leads to differing benefits to be discussed in chapter 3.6 and 3.7. But firstly, let's describe and understand each of these 3 cases.

Sweden

Sweden was very early in seeing the advantage that satellite imagery could bring to their national management of forests. A new policy was implemented in 1996 which placed the responsibility on forest owners to manage their forests effectively. The goal was to increase the stocks of timber whilst preserving important ancient forests rich in flora and fauna.

The Swedish Forest Agency (SFA) introduced the use of satellite imagery already back in 1999 for yearly coverage. Nowadays, all Sentinel-2 data are collected and made publicly available through free and open change maps, meaning change detection maps between all cloud free areas which are now provided monthly or bi-monthly by the SFA. Being partly automated, a comparison can be made between collected imagery and the information submitted by forest owners. Moreover, the SFA helps and recommends forest owners how to go about it (e.g., proposals to forest owners to do pre commercial thinning which increases the value of forests). The benefits consist in knowing exactly where and when something is happening. The SFA can focus its attention on those cutting locations where it is needed the most (legally, biologically, environmentally) and thus make its operations more efficient.

The (SFA) employed 90 rangers to inspect sites and to provide information on the state and health of forests. The rangers would identify where clear-cut notifications from the owners differed from the reality. Using Spot and Landsat data before Sentinel 2 was launched, the SFA found that the information coming from the rangers could be bettered through satellite data use.

At this time, the Swedish government wished to reduce the regulatory burden which they did through what they called "Freedom with Responsibility". In brief, this meant that owners did not need permission to cut trees but are required to notify the SFA before they could do so. The SFA had to react if the cutting would be contradictory with ecological or overall forest management principles.

One factor driving this change was the very large numbers of individuals who own parts of the forest. In Sweden, there are some 330,000 owners, of which 300,000 are individuals or families. Shifting the burden of responsibility from requesting approval to simple notifications, made sense and reduced the compliance monitoring function of the SFA. The 90 rangers were mostly redeployed to other more productive activities. The SFA also found that they could encourage rather than force owners to replant and to clear brushwood simply by reminding them of what they should do.

Before the introduction of the principle of "Freedom with Responsibility", the SFA (and especially the rangers) thought that they knew what was happening in "their" forests. Once the satellite imagery became available, they realised that this was not the case and the willingness to make the transition to the new regulation became stronger. At this time, the maps were based on data coming from SPOT and Landsat. The introduction of Sentinel-2 in 2016 changed the quality of information immensely. Images were available at 10m resolution (Landsat was 30m at the time) and every 1 to 3 months. The capability to monitor and hence manage the forests was greatly increased.

More recently, the approach has changed from selecting images to selecting pixels. This has greatly improved the performance and rapidity of detection of anomalies. Data is processed the same day as collection. Significant investment in infrastructure was required to achieve this but it allows much faster processing of clear-cuts.

Portugal

In Portugal, it was 25 years later than in Sweden, that the forest owners decided through their trade association that a regular series of images could help them manage their land more effectively. In this case, the motivation comes from larger industries rather than the government and the interest is primarily commercial rather then strategic. This is coupled with the presence of a collective body which can federate the interest amongst its members in a non-competitive environment.

CELPA[11], which represents the Portuguese pulp and paper industry, monitors the eucalyptus and maritime pine forests on behalf of its members. Naturally, it promotes the industry as being responsible in terms of ESG and the contribution made to the Portuguese economy. The forests are monitored with reports on a quarterly basis providing information on cut or damaged areas. CELPA is the primary user in this case as shown in the value chain which was established – see Figure 3-1.

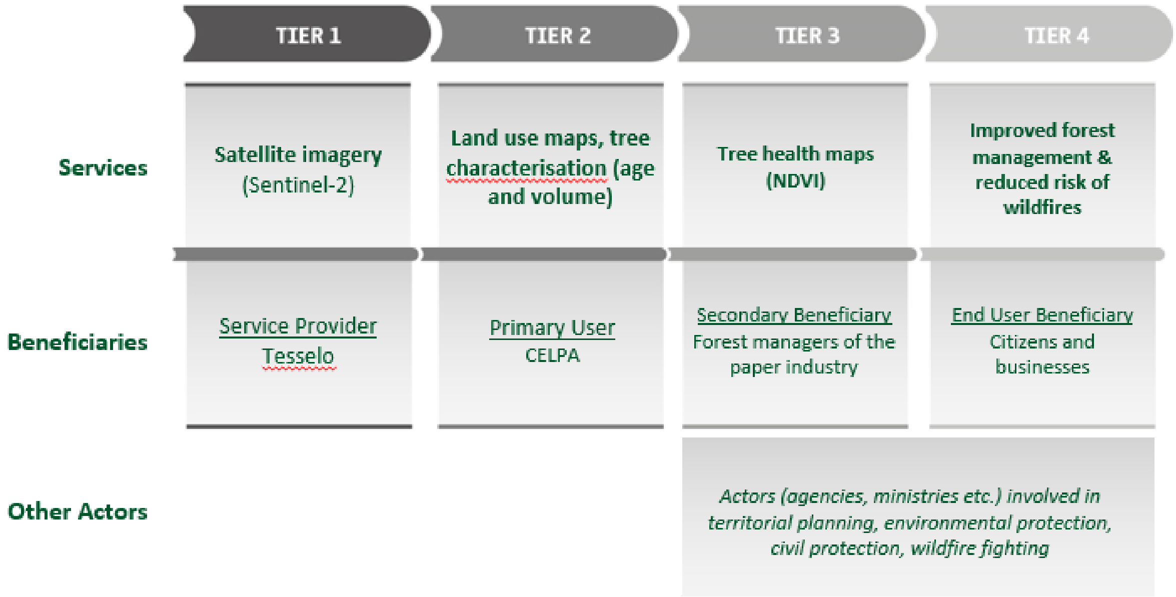

Figure 3-1: Value chain for the case of forest management in Portugal.

CELPA's members manage around 200k ha of land (mainly Eucalyptus trees) which makes up 18% of all eucalyptus forest in Portugal. CELPA regularly conducts forest inventories because the national inventories are not enough and not suitable for its needs. CELPA associate companies need more information to manage and monitor their forests as well as to help private owners to fine tune their forest operations. Therefore in 2018, CELPA started a cooperation with Tesselo to see how to get the

[11] At the time of the case study, the Portuguese Pulp and Paper Industry Association was known as CELPA. Since then, it has changed to Biond – (Portuguese) association of Forest-Based Bioindustries. We shall continue to refer to CELPA in this report to maintain consistency with the relevant case study report.

information that was collected but in a more effective and efficient way. By using Sentinel data, Tesselo provides information on land use (yearly) and land use changes (quarterly), burnt areas, health index, tree stand age and volume information as well as tree density per hectare throughout the country. This information is available for both CELPA and its members.

Certainly, one of the main advantages of using the Sentinel satellite data is its **frequent global coverage** and thus the provision of fresh data and updated insights over the Portuguese tree plantations every 5 days; a frequency that could never be achieved with other remote sensing methods, let alone field visits, at this cost and regularity. The ability to have a **synoptic view** over the plantations, accessible efficiently via the web, is a great advantage that provides timely and full information according to information needs. CELPA's interest is in rather large-scale market developments in Portugal to support their market analyses as well as individual member companies seeking timely and efficient information on parcel level. Furthermore, thanks to satellite data archives (Sentinel-2 goes back to 2015 but can be complemented with Landsat data going back decades), companies can look up **historical information** of the tree plantations. Since parts of their tree plantations are leased and historical knowledge and experience on the part of the forest companies of a particular tree plantation may be missing, historical satellite data will shed light on which potential areas will provide them with the biggest timber volumes and thus greater return of investment. Moreover, using satellite data is a **non-intrusive method** of retrieving data i.e. in-situ data and field inspections are not permanently necessary, while **seasonal and long-term trends** can be monitored. To sum up: using satellite imagery provides actionable insights that facilitate and improve the forest managers' decision-making.

Thanks to employing Sentinel-2 data, CELPA is now in the position to understand **exactly how much** the industry needs to import to satisfy the demand coming from the paper factories. On the regulatory side, CELPA is able to check **compliance with government regulations and requirements** (such as distance to settlements or maximum allowed area of eucalyptus plantations) more easily and cost-effectively since no field inspections are needed and which may not provide a holistic picture anyway.

Through the process of monitoring tree health and care, CELPA and member companies can save up to 25% on average on trips to often remote areas all over the country. This type of monitoring can be done now from a mobile device or laptop. Knowing the exact age and timber volume gives companies an effective tool and "strategic intelligence" to more effectively do their planning and logistics for the paper production.

ESG Forest Monitoring

Finally, the third case looks at how Sentinel data is being used to monitor unwelcome deforestation activities associated to palm oil production. It considers the Dutch global, food processing company Bunge, and their commitment to demonstrate compliance with sustainable practices.

This case revolves around the palm oil industry, an industry that is extremely lucrative but can often be associated with negative connotations and linked to environmentally damaging practices. These negative associations are not unfounded. By 2016, it has been estimated that almost 11 million hectares of forest has been lost to oil palm plantations worldwide, with over 80% of this occurring in Indonesia and Malaysia. The transition from natural forest to palm oil plantation has also been a major issue for endangered wildlife such as orangutans and tigers in Sumatra. By destroying the habitats of the orangutan and Sumatran tiger (both critically endangered species) as well as numerous smaller animals, the expanding palm oil plantations are threatening biodiversity.

Oil palms have less than 20% as much above-ground biomass as rainforest trees and hence a lower capacity to absorb carbon dioxide from the atmosphere. That effect is exacerbated for the estimated one-third of Indonesian and Malaysian plantations located on formerly, waterlogged, carbon-rich, peaty soils. Draining such soils, which is necessary for the oil palms to grow, exposes the peat to oxygen, causing it to decompose and release huge quantities of carbon dioxide into the atmosphere.

Satelligence, a Dutch remote sensing company has developed services using Sentinel-1 and Sentinel-2 data which can detect and monitor deforestation activities associated with the production of palm oil. In this case, Satelligence are helping Bunge, a huge player in the food industry to ensure the palm oil they source from Malaysia and Indonesia is coming from reputable sources (i.e. suppliers complying with sustainability principles) and is not contributing to deforestation, habitat loss and climate change. If deforestation is detected and linked to a plantation or mill associated with their supply chain, Bunge can take appropriate action to deselect a supplier and to help stop deforestation, helping to bolster the sustainability of their supply. The food products Bunge produce are then passed on to manufacturers and customers, meaning the ecologically friendly benefits are passed right down the value chain.

3.5 Widening the Picture

The core cases have looked in some detail at the pictures in Sweden, Portugal and sustainability of palm oil production globally. When considering the wider picture, in our extended analysis, we have been looking at the situation in other European countries.

We reached out to other countries through the Copernicus User Forum and the ESA EO Programme Board. These are representatives who have a focus on space or EO rather than on the domains in question, but they come from national bodies which can themselves reach out to those who are focused on the domain in question. Our goal was to talk with experts in each of the domains of management of forests, highways and lake-water quality. Through this route, we aimed at finding experts who are at the minimum aware of the technology, but we recognised that not all those experts are sufficiently well-informed, and we certainly find it harder to reach those most knowledgeable.

To provide a forum for exchange, we organised a workshop[12] in September 2022 with representatives from a number of EU countries. We also contacted countries representatives through both the ESA and EC channels mentioned above, both to invite them to the workshop and to solicit interviews. The workshop was fully virtual, and many countries participated either through their forest agency or their Copernicus focal point and the new information gleaned from this interaction is summarised for each of those who engaged with us.

In comparing the inputs from the countries' representatives in the workshops, we find a lot of similarities and one or two differences which we shall examine further in chapter 3.7. But before

[12] SeBS Sector Workshop on Forest Management. https://earsc.org/sebs/sector-workshop-2-forest-management/

looking at the benefits, it would be useful to develop a more general understanding by posing the question - what is happening elsewhere? Is the technology being applied? Are there further lessons that we can learn by looking elsewhere in Europe? How far are the findings obtained for Sweden and Portugal extendable to other countries?

Mostly, further information addressing these questions is coming from a dedicated workshop held in September 2022, with some additional interviews with stakeholders who were unable to participate in the workshop. A following discussion took place in the June 2024 workshop which looked at the results of the study addressed in this report (preliminary version).

Table *3-1* shows the various agencies in the EU Member States and contributors to Copernicus. We also include the number of hectares of forests in each country {FAO/Our world in data compiled with the assistance of ChatGPT}. Note no distinction is made for the type of forest which does change significantly within Europe.

Firstly, at the level of the EU, the **European Environment Agency (EEA)** gathers information from national bodies and assembles a European-wide picture which may be used for reporting against EU objectives. They also provide guidance to each MS where recent developments are going in the direction of improved methodologies, increasing degrees of automation as well as annual updates of their products. The EEA is an Entrusted Entity for the Copernicus Land Service which means they also have a responsibility regarding the use and exploitation of Sentinel data.

The EEA's Forest applications are focused on forestry, carbon sequestration, productivity monitoring, climate impact (drought, forests) and disturbance monitoring (storms, fires). The EEA also produces vegetation indices and their seasonal trajectories as well as phenology and production indicators. In particular, the HR VPP (High Resolution Vegetation Phenology and Productivity) products will continue well past 2023 and move closer to monitoring biomass as well as disturbance monitoring which however is more complicated as local data is needed. One specific product, unique to the EEA, is the HRL Small Woody Features which is part of the EU Copernicus Land Monitoring Service and which provides harmonised information on linear structures and focuses on forest connectivity relevant for biodiversity and which will integrate additional landscape features in the future.

Austria

In Austria, overall responsibility for all forests lies with the BFW **(Bundesamt für Wald)** in which the Institute for Forest Inventory works with a department dedicated to Remote Sensing to gather information on the Austrian forests. In Austria there are around 3.5mha of forest owned by 120,000 forest owners comprising individuals, companies and church funds. 15% of the forest or 510kha is state owned and managed by the Austrian **Federal Forests Office** (OBF).

	Responsible Organisation	Area of Forests (Mha)	% of land area
Sweden	Swedish Forest Agency (Skogsstyrelsen)	23	51%
Finland	Metsähallitus - Finnish Forest Administration,	22,3	66%
Spain	Ministry for the Ecological Transition and the Demographic Challenge	18,6	37%
France	National Forests Office (ONF)	16,9	31%
Norway	Norwegian Forest Agency (NFA)	12,2	38%
Germany	Federal and Regional ministries for food and agriculture State Forest Services	11,4	32%
Italy	State Forestry Corps (Corpo Forestale dello Stato, CFS)	9,6	32%
Poland	State Forests National Forest Holding (State Forests)	9,5	30%
Romania	National Forest Administration (Administrația Națională a Pădurilor - Romsilv	7	29%
Austria	Department of Forestry (Forstabteilung)	3,9	46%
Greece	Greek Forest Service (Υπηρεσία Δασών)	3,7	28%
Bulgaria	Ministry of Agriculture, Food and Forestry - Executive Forest Agency (EFA)	3,6	32%
United Kingdom	Forestry Commission (England)	3,2	13%
Portugal	Institute for Nature Conservation and Forests (ICNF)	3,1	34%
Lithuania	State Forest Service (Valstybinės miškų tarnyba or VMT)	2,9	45%
Latvia	State Forest Service (Valsts meža dienests)	2,8	43%
Croatia	Croatian Forests public company	2,7	48%
Czech republic	Ministry of Agriculture - Department of Forestry and Game Management	2,7	34%
Estonia	Estonian Environmental Board	2,2	49%
Slovakia	State Forests of the Slovak Republic (Lesy Slovenskej republiky, a.s.)	1,9	39%
Hungary	Hungarian National Forest Directorate (Országos Erdészeti Egyesület),	1,8	19%
Slovenia	Slovenian Forest Service (Slovenska Javna Agencija za Gozdove)	1,2	60%
Belgium	Agentschap voor Natuur en Bos (Flanders), Département de la Nature et des Forêts (Wallonie)	0,7	23%
Ireland	Irish Forest Service (part of Ministry for Agriculture, Food and the Marine)	0,7	10%
Denmark	Ministry of Environment and Food - Danish Nature Agency,	0,6	14%
Netherlands	Staatsbosbeheer (Forestry Commission)	0,4	10%
Cyprus	Ministry of Agriculture, Rural Development – Dept of Forests	0,1	11%
Luxembourg	Nature and Forest Administration	0,1	40%
Malta			

Table 3-1: Forest Agencies in the EU and Copernicus partner countries and national forest areas.

The forest is inspected on a 10-year cycle with 10% of the total being visited each year by a team of between 5 and 10 persons under the lead of a forest ranger. Each ranger is responsible for 3000ha of forest. Rangers have a list of sites to visit for inspection.

For this application, Sentinel data does not offer sufficiently high resolution to be useful. Hence, an inventory of the forest is produced every 3 years based on airborne data gathered through an annual campaign. Each year, 1/3rd of the country is mapped leading to the 3-year cycle. As well as tree types and species, the forest inventory is taking account of diseased trees, wind blown and fire damaged.

The imagery is processed into maps showing forest areas classified by age. Further information extracted includes the stand heights, timber volume and species. Clear cuts in Austria (including for privately owned forests) are managed by the Forestry Commission (FC). Owners wishing to make cuts greater than 0,5ha, are required to inform the FC. Follow up activity ie replanting and thinning is left to each of the forest owners.

The approach is thought to have brought many benefits to the forest sector including more effective and efficient reporting, improved monitoring of regulatory compliance, better transparency (and trust) of public stakeholders and better communication between the key stakeholders. It also provides better information to the general public on the state of forests.

Finally, it is important to highlight something which is becoming a serious problem in the area and indeed throughout Europe: infestations of bark beetles. In one area near the border with the Czech Republic, the OBF has established an informal working arrangement with the equivalent agency in the Czech Republic to seek to contain the outbreak.

Czech Republic

In the Czech Republic, Sentinel-2 data is being used to create a national forest inventory. All historical data from 2015 up to the present is used to create the underlying map and to analyse trends in land cover, tree classes, health etc. Aircraft data provides the baseline from which deviations and trends can be analysed including for clear-cut monitoring. Satellite data complements that from the aircraft – not just Sentinel but also commercial data from Planet. The latter is being used to identify areas of bark beetle infestation.

Cyprus

The main objective of the [Cyprus Department of Forests] is the protection of state forests from forest fires and the preservation of biodiversity. They have recently started using Sentinel data for habitat and burned area mapping. In the past, the aforementioned mapping was conducted via field visits with GPS. Currently, there are first attempts to map Natura 2000 areas via satellite imagery (Sentinel 2 data); similar to similar efforts elsewhere[13].

Finland

The use case for Sentinel data in Finland (Finnish Forest Institute) is quite similar to that of the SFA in Sweden but has not started so early. It is mainly used to monitor clear-cut notifications and if they are correctly followed. There are some 100k to 130k notifications each year and since the use of satellite data was introduced, compliance has significantly improved through better targeting of suspected non-compliance. Recently, bark beetle has become a significant problem. Sentinel data can detect large areas and forest owners are notified. To detect earlier and more precisely higher resolution commercial data is necessary.

France

In France, the **French ministry for the environment** ([Ministère de la Transition écologique]) informed that the Ministry in charge of forests (MASA), the National Forests Office (ONF) and the CNPF (Centre National de la Propriété Forestière) are monitoring the bark beetle crisis which occurs mainly in pine forests, an intensifying crisis due to recurring droughts. They have a need to map affected areas,

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[13] Čahojová, L., Ambroz, M., Jarolímek, I. et al. Exploring Natura 2000 habitats by satellite image segmentation combined with phytosociological data: a case study from the Čierny Balog area (Central Slovakia). Sci Rep 12, 18375 (2022)

however, they face a major limitation: the frequency of revisits enables precise information on the evolution, but the very small areas remain difficult to detect.

Germany

In Germany, the Tühnen Institute (TI) is responsible for the national forest inventory in Germany as well as the Copernicus network office for forest, a project that was initiated by the German Aerospace Centre (DLR). The TI is a scientifically independent research institution at the interface of science, politics and society. Most of the ongoing work is research-based, however slowly the results are becoming more applied and operational. Recently (2024) results of some of this work has been reported by TI in collaboration with other institutes.[14]

Norway

The Norwegian Space Agency has reported that Sentinel data are not yet being used for forest management in an operational manner. The Norwegian Environment Agency is using some (satellite) data, but this is more research-based. A cooperation between Sweden and Norway is planned where both countries will pool resources and map and test using the same methods.

The Norwegian Institute of Bioeconomy Research (NIBIO) reported a data fusion application employing Sentinel-2 data for mapping forest age in Norway[15]. The NIBO is developing a bark beetle damage monitoring system using Sentinel-2 data to alert forest owners to clear affected areas. For now, a test is running for some Sentinel-2 tiles, while the plan for the future is to scale this up. There are planned to be two test areas on the border between Sweden and Norway, one in the middle (close to Trondheim) and one further north. The same methods as for the Swedish Land Cover Database will be used.

Poland

Poland has 17 forest regions with over 400 management areas. The state owns 77% of Poland's forests while approximately 20% is privately owned. The state forests are managed by local administrations. For all forest areas a (simplified) forest management plan is generated every 10 years by each local administration.

The Centre for Applied Geomatics at the Institute of Geodesy and Cartography has run and is running several projects regarding forests. These include Sat4Est which has the goal to develop services which can support the local administrations in their forest management tasks for non-state-owned forests. It shows how Sentinel 2 data can provide alerts when changes are detected due to fires, disease or illegal activities. The centre has also developed with the State Forest a system using Sentinel data to provide early warnings of forest decline.

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[14] Lukas Blickensdörfer, Katja Oehmichen, Dirk Pflugmacher, Birgit Kleinschmit, Patrick Hostert, National tree species mapping using Sentinel-1/2 time series and German National Forest Inventory data, Remote Sensing of Environment, Volume 304, 2024,

[15] Schumacher, J., Hauglin, M., Astrup, R. et al. Mapping forest age using National Forest Inventory, airborne laser scanning, and Sentinel-2 data. For. Ecosyst. 7, 60 (2020).

In Poland, local administrations are generally responsible for the management of forests in their districts. They are broadly aware of the value that Sentinel data can provide in support of their responsibility to provide a plan every 10 years. However, they have no funds to use the satellite data on a regular basis. As a result, some forest rangers are using it in an ad hoc fashion. The Centre for Applied Geomatics is seeking to improve the use by developing specific tools including for the procurement of external expertise.

Portugal

We learned of a number of separate initiatives in Portugal. Firstly, the Portuguese Forest Agency (ICNF) **(Instituto da Conservação da Natureza e das Florestas**) is using Sentinel-2 data to map all burned areas above 10 hectares, mainly by photo-interpretation, burn severity mapping, using automatic algorithms to get severity index, monitor fuel breaks and clear cuts (work in progress).

Secondly, in response to a series of devastating fires, Portugal has established a dedicated **Agency for Integrated Rural Fire Management (AGIF)**. AGIF's main use of Sentinel data is focused on monitoring and detecting fires and clear cuts as well as for fuel management and fuel collection. Another use case is the support of forest management with regards to buffer zones between forests and villages in case of fires.

Thirdly, the **Portuguese National Mapping Agency** declared that Sentinel data are used to produce land cover maps (which not only focus on forests). They are currently in the process of releasing new products that make use of Sentinel-2 data such as the annual land cover map. The agency supports various Portuguese institutions and focuses also on the identification of tree species. In that regard, there is some overlap with the Tesselo service provided to CELPA (see above). Moreover, their interest is in land cover changes due to e.g. clear cuts or fires. Most of their work is however preliminary and more developments are needed before moving to operational products, while there are results of scientific developments available relative to Portugal[16].

Romania

In Romania the **Ministry of the Environment** used to keep track of forest (over)exploitation by using satellite data and making the results publicly available (https://inspectorulpadurii.ro/#/). Currently, the entire procedure is reconsidered, and satellite data are part of the process. The approach proposed to the Ministry of Environment by the Romanian Space Agency (ROSA) is quite complex. It is a monitoring process aimed at generating monthly monitoring products related to coverage, cuts, disease, fires etc. Recently, the ministry announced the award of a contract to develop a forest monitoring system that uses satellite imagery to track cuttings in local forests[17].

Spain

[16] Mohammadpour P, Viegas DX, Viegas C. Vegetation Mapping with Random Forest Using Sentinel 2 and GLCM Texture Feature—A Case Study for Lousã Region, Portugal. Remote Sensing. 2022.

[17] Romania to use satellite images to monitor forests" dated 22 November 2023

Specifically, in the region of Catalonia, **Cartographic and Geological Institute of Catalonia (ICGC)** is the geoinformation agency that must produce operational products and services. For forest management, the main purpose of the products provided by ICGC relates to fire mapping and to supply the fire fighters and land managers with up-to-date information on forest status and burnt areas. IGCC within a consortium of 34 partners, is part of a green deal project (FIRE_RES) looking at resilience of the forest areas.

Sweden

The use of Sentinel data by the SFA (as described in the main case) to generate forest maps was picked up by the **Swedish Environmental Protection Agency (SEPA)** which is now using Sentinel data for their land database and for internal work and analyses. SEPA's first product emerged in 2018. Currently there are discussions for an updated product to be released in 2023 including much more satellite data including Sentinel-1 and -2. Moreover, they are cooperating with an agriculture university and the SFA with regards to the use of satellite data.

The Swedish and Finnish Forest organisations in both public and private sectors are stepping up their use of Sentinel data. This has been in particular due to the ongoing bark beetle crisis. Also, several countries in Central Europe are quite active in this regard.

International Perspective.

For each of the three domains, a perspective from around the world was sought during the workshop session 3 on 13th June. An introduction was made by rapporteurs from the session 1 to provide the international audience with a brief summary of our findings in Europe and to place the international view into context.

In Japan, some 65% of the land is covered with forest with 65% of that being planted/managed forest and the rest is ancient, natural forest with a rich biodiversity. Increasingly, the emphasis in Japan is on holistic land management including forest and agriculture. Overall responsibility lies with the Japanese Forest Agency which has developed a portal – FAMOST –to provide land cover information to users. In February 2024, the agency has prepared a guidebook for regional and municipalities on forest management recognising the importance of consistency across the levels of government as well as the lack of specific skills throughout these parts of government.

In Brazil, the national space agency (INPE) provides information on the Amazon forest to the government. PRODES is a long-established platform which is used to monitor the Amazonian forest. DETER is a more recent addition which uses satellite data to provide daily updates which are sent to the local authorities. In 2023, Sentinel data became the primary source following agreements signed between the EU, ESA and Eumetsat.

In the USA the strong focus is on land management and wildfires. Most of the forest in the west of the US is state-owned whilst in the east it belongs mainly to private owners. The US Forest Agency provides maps of the fuel potential indicating the potential risk of a fire and near-real-time monitoring of fires.

3.6 Understanding the Benefits

Significant differences in the nature of the primary user and the application of forest mapping, means that the benefits are also quite varied. The transversal nature of our analysis allows us to explore these further and in the next chapter to draw some insights from these differences.

As a start, the benefits are shown in Table 3-3 against the set of common indicators. These are grouped into each of the 6 dimensions for further discussion.

Economic Benefits

Co-incidentally, the economic benefits in Sweden and for global deforestation through Bunge are assessed to be in the same scale at around €20m per annum. However, as shown in **Error! Reference source not found.** they arise in very different ways, at different points and to different actors in the value-chain.

	Tier 1 Service Provider	Tier 2 Primary User	Tier 3 Secondary Beneficiaries	Tier 4 Citizens and Society	Total
Sweden	n/c	€10m	€5-11m	€1m	€16.5 – 21.6m
Portugal	Not Assessed				
Global	€1.5-6.3m	€5m	€12.5-22.3m	n/a	€19-33m

Table 3-2: Economic Benefits along the value chains for core case studies of forests management.

In Sweden, the public agency, which is the primary user, achieves most (around half) of the economic benefit through efficiency savings and the redeployment of forest rangers. Secondary beneficiaries gain by the longer-term increase in timber volume and hence raw material for processing.

In the case of Bunge, assurances that the palm oil is coming from sustainable sources gives them a pricing edge over competitors and enables an increase in revenue and this effect is multiplied by their customers selling to the public.

In Portugal, even if the scale was not assessed, it was recognised that the companies behind CELPA, are able to increase their revenues. Plus, efficiency gains are seen through more efficient use of labour resources reduces the need of field inspections by at least 25% while the redundant time can be used more productively. Instead of inspecting randomly or according to strict time plans, forest managers can focus their time on areas of the forests that need care and maintenance increasing the yield.

Environmental Benefits

The environmental benefits are quite important for each of the cases. Clearly, in the ESG/Bunge case the impacts are quite direct and act to dissuade the clearing of tropical forests to create farming land. This in turn supports biodiversity through maintaining critical habitats and carbon sequestration in the trees.

In Sweden, the regulatory process backed up by the satellite derived maps of the forest help to preserve ancient forests and areas of importance for wildlife. Of increasing interest in Sweden and many other countries (examples in Austria, Czech Republic and others) is the invasion of bark beetles which cause dramatic damage to natural forests and plantations.

Economic	Sweden	Portugal	Global Deforestation
Cost savings		Through efficiency savings	
Increased revenue	Increase in resource volume and value	Increased commercial stocks	Increased pricing capacity
Efficiency gains	Improved modelling of forests	More effective forest visits	
Employment	Redeployment of forest experts	Increased employment	
Environmental			
Reduced biodiversity loss	Maintain diversity of forests		Maintain forest variety for species
Reduced natural resource depletion	Preservation of forest habitats, ancient forests etc.		Reduced clearing of forests
Reduced pollution		Reduced fertliser use.	
Regulatory			
Preparation of Legislation	Enabled the freedom with responsibility policy		
Compliance monitoring	Used to reduce the regulatory burden.	Improved monitoring of protected areas	Improved monitoring of compliance
Compliance reporting	More accurate agency statistics		
Enforcement	Light regulatory enforcement		
Compliance promotion	Targetted letters make forest owners aware of their responsibility.		
Innovation			
Changed business practice	Improved co-operation between agencies.	Changed business practices	Driving innovation and new business practices
Start-ups		Start-up developing new business	
Research & science			
Research staff		Increased research through partnership with supplier.	Contribution to new techniques for monitoring deforestation
Societal			
Geostrategic value	Increase value of tree stocks	Support sustainable national industry	
Community & quality of life	Improved quality of forest for recreation		Protection of rural communities

Table 3-3: The Indicators of Benefits in the case studies on Forest Management and the ways in which those benefits are achieved.

In Portugal, the environmental impacts are less pronounced since the case is about the management of commercial plantations and not the managing of natural forests as in the other two cases. Nevertheless, companies using the maps of plantations have a clearer idea of where actions that they may take could impact on the ecosystem more severely and be contradictory to Portuguese legislation.

Regulatory Benefits

These are pronounced in all cases and reflect the strong interaction between the type of regulatory regime established and its implementation. In other words, the forest monitoring systems supports the measurement and verification aspects of the legislation.

In Sweden, the use of the satellite maps was tied to a change in regime coupled with the local situation. The large number of forest owners, and the importance of the forests to the society, were behind the objective to reduce the regulatory burden whilst increasing the timber stocks. This led to further benefits as in the more effective use of SFA staff.

In Portugal, the maps give companies a better visibility of the situation and help them adhere to the regulations.

In the ESG/Bunge case, the direct goal is linked to maintaining important tropical forests leading to better monitoring and enforcement of sustainability commitments.

Innovation & Entrepreneurship

Mostly, the forest maps are enabling innovation in the organisations which are using them. In all cases, the processes associated with the underlying business model of the primary user have been adapted knowing that the forest maps could be generated regularly and reliably.

With regard to fostering entrepreneurship, whilst the SFA processes the data using its own internal resources, the other cases are based on commercial suppliers; Tesselo and Satelligence respectively.

Science and Research

In these particular cases, we have not found a strong contribution to further science or research. The commercial suppliers and the public agency (in Sweden) are working with academic partners on aspects of improving algorithms and understanding deforestation. But satellite images themselves do make a major contribution to research in these areas and there is a growing body of literature emerging in this domain[18].

Society and Citizens

Forests are important amenities for citizens and a lot of leisure activities are based in and around them. They make an important contribution to society and improving their quality has a significant benefit. In Sweden, we had a discussion about the impact of good forest management on local house prices! Clearly, the large extent of forests in Sweden mean that they are an important part of the countryside

[18] A search on Sentinel AND forest yielded 500 papers published since 2020 compared to only around 250 in the previous 5 years i.e a doubling of results. Source, private communication N Khabarov/G Sawyer.

that citizens enjoy. Effective management increases the leisure value and the quality of life of everyone, not just the owners. Putting a value on this is hard and with our limited resources beyond the scope. Nevertheless, we did employ a thought experiment on the willingness to pay which led us to include a €1m in the economic assessment.

But, for all the cases, the "softer values" are clear in terms of the quality of life, the richness of the biodiversity and the value to society more broadly. This extends to global forests where concerns about illegal destruction and loss of these amenities are linked to changes in carbon stocks with the implications for climate change.

3.7 Insights

As noted at the start of sub-chapter 3.4, the characteristics of the 3 presented core cases are quite different even if the underlying applications of satellite data used are quite similar. The main reason for this is the role of the primary user and the way in which forest mapping creates value for the organisations concerned. That this is the case is not surprising, but the different use-cases do yield some further insights. These are complemented by findings from the largely public bodies with which we consulted. We have identified the following factors, in no particular order, as being important to instigate and adopt the changes towards a wider use of satellite-derived information:

- **Awareness**: based on our interviews most public agency users are aware of the potential for using satellite data for forest monitoring. Whether these data are actually used depends on the scale, how much forest there is in the country and long-standing practices. For many countries with smaller areas to monitor, aircraft data provides better information, at reasonable cost, than can be obtained from satellites and especially those from which the data is freely available. Aircraft or drones can provide imagery down to tree level which is more effective for detecting disease or storm damage. On the other hand, the cost of aircraft limits the number of imaging passes, and it is a trade-off between the frequency of data updates (temporal resolution, its regularity, and a higher spatial resolution.
- **Primary User role**: It is not surprising that the role or business of the primary user is a strong determinant of the way in which the Sentinel-derived service is used. In the three cases analysed we have essentially the same product i.e. forest maps, being used albeit with some variation of the information exposed to improve/support the activity of each primary user.
  - The Swedish Forest Agency is a public agency concerned with implementing regulation. The main focus is on clear-cuts but also the ecological balance and the health condition of the trees are important for the Agency.
  - CELPA is an industry umbrella association which is providing a collective service for its members. It supports the companies with information that can affect the value of the plantations. This includes tree health and storm damage and information linked to regulatory aspects.
  - Bunge is a commercial food processor seeking to ensure it maintains a good reputation for sustainable development. Information is sought to "prove" that land in use by their suppliers has not been cleared illegally.

- **Geography** does not have a major impact on the use of Sentinel data for forest mapping beyond influencing the growing conditions and volume of timber in any given country. The forest area, its location and the importance of forestry to the national economy plays a much stronger role. The latitude of areas of interest influences the types of trees and timber value, the regularity of images that can be collected as do the meteorological conditions and the presence/absence of clouds.
- **Regulatory impact** has a significant influence on the use and benefits of the use of satellite data irrespective of the role of the primary user. Furthermore, the link between legislation and the capability to monitor the implementation is clearly shown in the case in Sweden. This linkage could be usefully explored further in other domains. The use of satellite imagery to monitor regulatory compliance is as important for the private sector as it is for the public stakeholders. This is further amplified by ESG practices applying to companies and especially the larger ones with significant international business.
- **Organisation and traditional practices**. We have found in many cases that the knowledge about the use of satellite derived products is often only possessed by a champion in the organisation. If this person moves to change jobs, then the knowledge is often lost. Building an organisation memory and "institutionalising" the use of EO is critical to its successful use. In fact, the case of forest management in Sweden is a good counter example of this. problem The "champion" has remained in the same position for some years such that the use of satellite technology for forest monitoring is well recognised and established.
- **Infrastructure investment**. In Sweden and elsewhere the importance is exposed regarding finding investments to develop IT infrastructure which is capable of handling the large volumes of data. For this reason, outsourcing the production of maps or other products may be favoured.
- **Network of experts**. Under the umbrella of CELPA, a group of companies can collectively organise themselves to gather and use the results of processed satellite data. The existence of the collective body, in this case at national level, has been able to drive the uptake of forest information gathered using satellites.

3.8 In Conclusion

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 Sentinels Driving Benefits for Lake Water Monitoring

4.1 Introduction

Lakes are an important feature in our natural environment. Some lakes are natural, others are manmade, but all play an essential role in our society. They are a source of drinking water and irrigation for crops, they provide leisure facilities, and they are a strong factor in maintaining biodiversity and sustaining both flora and fauna.

Whilst the quantity of water is becoming a major concern in many countries, and especially due to rainfall changes attributed to climate change, our focus here is on the quality of the water[19] and especially that in our lakes (and rivers). Water quality is affected by many human activities of which farming has perhaps the biggest impact. Fertiliser spread on the fields leaches into the water courses where an excess of nitrates can cause harmful algae to bloom. Pesticides and other chemicals used on the fields or released from industrial centres cause further problems. This has been recognised and legislation introduced which controls their use.

Nevertheless, the quality of the lake water can easily become degraded. In Europe, the quality of water is controlled by the Water Framework Directive[20] and the Bathing Waters Directive[21]. In each EU country, public agencies are responsible for controlling the quality which involves monitoring the water in lakes. To do this, the agencies responsible send teams of experts out to take water samples to be analysed in the laboratory. However, the lakes are numerous and only a few samples can be taken each year and for a limited number of the lakes because in-situ water sampling implies costs related to the field visits and laboratories processing the water samples. For the larger lakes, much of the water remains unsampled simply due to size while sampling sites need to be carefully chosen in order to be as representative as possible of the entire lake condition. The cost of extending this effort would be rather high.

In most countries, a central agency reporting to the Ministry of Environment is overall responsible and provides guidelines to the local and regional bodies which are directly responsible for the water quality and the gathering of samples. This hierarchical and sometimes complex governance leads to barriers in the adoption of satellite data products, as we shall see.

But satellites can help. Data from Sentinel 2 and Sentinel 3, as well as other satellites is being used to develop a wider and more accurate picture. As a result, it helps the agencies do a better job and to provide, better, more accurate information to policy makers.

[19] Sentinel data is also used to support the management of water availability and use. The case of aquifer management in Spain looks at one aspect of this issue, whilst other cases relevant to this problem, have been identified and could be analysed in the future.
[20] https://environment.ec.europa.eu/topics/water/water-framework-directive_en
[21] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32006L0007

In SeBS, cases have been analysed looking at how water quality is managed using Sentinel data in Germany, in Finland and in the Netherlands. The comparison between them and other EU countries leads to some interesting insights.

4.2 The Problem to be Addressed

Lakes and their shores not only offer several environmental benefits, but they contribute to our quality of life and support the economy. Lakes can mitigate the impact of floods and droughts by storing great amounts of water and releasing it during shortages. Lakes replenish groundwater, positively influence water quality of downstream watercourses, and maintain biodiversity and habitat of the area. When the ecological state of a lake is good it can provide major opportunities for recreation such as swimming, other water sports or fishing, tourism, and residential living. Both natural lakes, as well as dams and water reservoirs, can be a source of drinking water for a municipality, a water supply for industry and an irrigation source for agriculture. To sum up, they are important ecosystems that can sustain a healthy balance of aquatic life, enjoyment and support our socio-economic needs in the long-term if used sustainably.

Pollution entering the lakes can come from many industrial and agricultural sources. Perhaps the most pressing is the seepage of nutrients supplied through excessive or otherwise incorrect application of fertilizers (e.g. before a heavy rainfall and/or in a field part close to a water body) applied by farmers and which cause growth of unwanted plants and algae in the lakes where the pollutants accumulate. A typical algal phenomenon is called **Harmful Algal Blooms (HAB)** which create toxins that may cause various health problems for the exposed wildlife, home animals, and humans.

Managing the quality of the water in the lakes and rivers is largely the responsibility of the local authorities. The level and scope of this responsibility varies between EU countries. Measuring and monitoring the water quality normally falls under the responsibility of an environmental agency sometimes at the national level and sometimes at local or regional level. The results of the measurements are reported to the national government and, in the EU, to the European Environment Agency[22].

Assessment of water quality using satellite data is not explicitly recognised in the EU WFD and its use is left to the judgement of Member States[23]. In practice, assessments are made mainly using traditional sampling measurements which provide high precision estimates of the various biological, physical and chemical parameters as required by the EU WFD and the EU Bathing Directive. These measurements, however, only provide information about the status of the water quality in a precise location and for a specific point in time. In addition, this way of sampling and analysing in the laboratory is very time-consuming, very expensive due to the large amount of labour and capital-intensive infrastructure. These limitations give rise to important challenges and high potential costs (that current budgets would not be able to cope with) faced by the authorities should they wish to extend measurements to more

[22] https://www.eea.europa.eu/publications/bathing-water-quality-in-2021

[23] Satellite-assisted monitoring of water quality to support the implementation of the Water Framework Directive

locations and/or make sampling more frequent. In-situ sampling measurements are limited with regards to:

- **Constructing a broader picture**: lakes are dynamic systems with spatial variations in water quality parameters. In-situ sampling at only a few locations, especially for larger lakes, may not fully represent the entire lake's condition, leading to potential inaccuracies in the overall assessment of water quality.
- **Real-time monitoring:** in-situ sampling typically provides discrete data points at specific sampling times. It may not offer real-time or continuous monitoring capabilities required to detect rapid changes or pollution events.
- **Facilitating common understanding**: communicating on the evolution of water quality is important both between the corresponding public authorities (across borders, federal, regional and local level), but also to the public, media and political hierarchy. This cannot be easily achieved with a limited number of station samples.

4.3 How Satellites Can Help

Water bodies show specific reflectance characteristics measured at differing wavelengths of light, based on the absorption and scattering properties of particular constituents. These are directly related to relevant water quality parameters such as turbidity and suspended matter, phytoplankton and its main pigment Chlorophyll, and detritus and dissolved coloured organic matter. By knowing their optical characteristics, it is possible to retrieve quantitative values for the concentration of these water constituents solely based on the light reflectance measured by satellite sensors. Multi-spectral satellite sensors can be used for measuring these water constituents by analysing the reflected sunlight as it penetrates the water body.

Satellite-based measurements support the management of lakes by providing information on a number of critical parameters, including those listed below, all being indicators of the water quality:

- **Chlorophyll-a levels**: The level of Chlorophyll-a (Chl-a) - a pigment included in phytoplankton provides a proxy for the level of algae in natural waters.
- **Turbidity** is a key parameter of water quality and is linearly related to the backscatter of natural light by organic and non-organic suspensioned materials (SPM) in the water. Light in the range of 450nm to 800nm wavelength provides the best results for measuring turbidity.
- **Total Absorption** is a measurement of the absorption of light at 440nm, indicating the level of organic material.
- The **Harmful Algal Bloom Indicator (eoHAB)** is an indicator of the presence of specific pigments associated with HAB's. Measurement does not yet indicate the quantity which is provided by typical in-situ measurements but provides an indicator of the presence of these pigments.

Cyanobacteria[24] can be detected by satellite, separated from the broader pigment group with Chlorophyll-a as an additional indicator.[25]

- **Surface Water Temperature** is calculated from thermal infrared channels recorded by optical satellites – e.g. Sentinel 3 and Landsat 8. It measures the top skin temperature of the water body.

These indicators can also be obtained by traditional sampling on top of other indicators of water quality that only traditional sampling can obtain. However, EO data offers **broad coverage** which enables the monitoring of large areas, providing valuable insights into spatial variations of factors such as Chl-a distribution in large lakes, which would be expensive and impractical to obtain through traditional in-situ methods. The fact that satellite imagery offers a broad picture also facilitates **common understanding**, making it easier for everyone involved in decision-making to share insights and understand the situation. Additionally, satellite data usually offers **better temporal resolution** compared to in situ sampling, making it useful for detecting sudden ecological changes like harmful algal blooms. **Historical data** from Earth Observation enables the understanding of long-term trends and the impacts of human activities and climate change on water bodies, benefiting research and water resource management.

All in all, EO allows quantifying elements of environmental status such as frequency, onset, duration and extent of algal blooms as well as measuring inter-annual variability. It also allows potentially for better standardisation of monitoring methods. Satellite data cannot replace the in-situ sampling, but equally, there is no other method available today to provide wide-scale measurements of the water quality across a whole region or country. Satellite data represents therefore an effective complement to in-situ sampling.

4.4 The SeBS Benchmark Cases

Three SeBS core cases focused on water quality monitoring, in Germany, Finland and the Netherlands, have been subject to a full analysis. They highlight very nicely the various ways in which the data from Sentinels can help agencies in their work and also a number of issues which influence the take-up and use of the technology. In comparing the three cases, we find a lot of similarities and one or two differences which we shall examine further in chapter 4.7. In these cases (as well as many others) the importance of the individuals as champions stands out really strongly as a key factor for promoting exploratory work and the use of the technology within their organisation.

In the three countries, organisations responsible for water quality, use Sentinel 2 and 3 (and other sources such as Landsat 8) to monitor their inland water. Maps showing algal bloom and other events are being produced and routinely used in their daily activities to monitor key parameters as identified in the last chapter.

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[24] While not all algae generate toxins in the water, the HABs are caused by a high concentration of cyanobacteria, which is also called blue-green algae.

[25] https://www.epa.gov/cyanohabs/health-effects-cyanotoxins

Only the case in Finland is based on the use of a nationally developed tool. In Germany and the Netherlands, the cases are based on regional authorities buying products from private companies, i.e. EOMAP in Germany and Water Insight in the Netherlands.

Germany:

In 2015, the State Institute for the Environment in the region of Baden-Württemberg (LUBW) initiated an internal research project to understand how satellite data could help their work. This established a relationship with EOMAP, the service provider - a German SME -, which now provides reports every 3 months for 20 lakes which are defined by LUBW. In addition to their subscription to these reports, LUBW licenses the EOMAP software to run their own satellite data processing.

The largest lake of Baden-Württemberg is the Bodensee (Lake Constance), it attracts visitors from all over Germany, and from neighbouring countries, bringing income to the region. But the region has over 260 lakes of a significant size (>10ha) and the health of the lakes and the quality of the water is of primordial importance.

Whilst the regional environment agencies report on the status, managing the water quality is the responsibility of the regional and local authorities. One of the key issues they face is the presence of chemicals and nutrients in the water coming from farms. Controls on the level of fertiliser use are imposed by the Ministry for Agriculture in co-operation with the Ministry for the Environment. This leads to limits on the quantity of fertiliser that can be used and to buffer strips alongside each water body where the farmer may not apply any fertiliser.

Data from both Sentinel 2 and Sentinel 3 is used by EOMAP to deliver a water quality monitoring service, which enables the LUBW and other stakeholders to access the environmental information for the water bodies in their region. This service is starting to be used in multiple ways with a number of potential benefits for the region:

- To monitor the water quality of lakes and ponds in complement to in-situ measurements and to provide guidance on where in-situ measurements should be made.
- To implement measurements of small lakes and ponds which are too numerous to be realistically monitored using traditional, in-situ techniques.
- To identify when an algal bloom is likely or already taking place in order to firstly deploy in-situ water sampling and ultimately to close the water to leisure use, so protecting citizens from harmful toxins.
- To monitor changes in water quality from year to year and covering large territories in order to inform policy makers and over the long-term trends in water quality to inform agriculture regulations on the use of fertiliser and other chemicals and environmental laws linked to biodiversity.
- To trigger a direct response in the case of a lake becoming too polluted, to protect fish-life. Response can be to modify the water flows and especially mixing of different layers, oxygenate the water, provide chemical treatment, or in the extreme to drain the lake and remove the polluted sediment.

- To inform water supply companies in advance on the quality of the water entering their collection areas and hence to plan on the level of treatment necessary in water plants.
- To inform on the longer-term accretion of nitrates and phosphates and support more precise legislation and/or its implementation.

Overall, the capability to monitor water quality more effectively can lead to actions being taken to support a better quality of life for the citizens. Information derived from the satellites can potentially be made directly available to the citizens of Baden-Württemberg and other regions, so improving transparency and trust. Furthermore, it has the potential to improve environmental compliance in Germany through future regulatory changes.

The LUBW is a pioneer in the use of satellite-derived water quality products for lake monitoring in the region and is supporting its introduction throughout Germany. One of the main platforms for this is the water coordination group – Länderarbeitsgemeinschaft Wasser or LAWA - which brings together representatives from each of the environmental institutes of the 16 German regions to exchange on common interests and best practices. This helped LUBW to launch a state project in 2019 under the digitalisation agenda of Baden-Württemberg which is supporting the development of IT tools which can integrate the data from EO based measurements with the in-situ measurements.

Finland:

In Finland, a service utilising satellite data is particularly relevant because of the very high number of lakes. Finland is widely known as the "land of a thousand lakes". In fact, Finland has more than 187K lakes and ponds larger than 500 m2 - and its land surface is covered by about 10% of water (to compare with previous case, only about 2,2% of German territory is covered by water). As a result, using traditional sampling would be extremely costly which makes EO monitoring very relevant in this country. In addition, lakes are culturally very important for most Finnish people who can, for example, enjoy for ice-fishing in winter or spend a summer break at a cottage by a lake.

The EO service to monitor water quality was developed at national level in 2018 by Syke, the environmental institute of Finland. Copernicus Sentinel observations are used coupled with machine learning processes to provide information on water quality and water temperature with visual satellite true colour imagery. The results are visualised on a user-friendly and intuitive platform, which Syke has opened up to the public so that anyone can have access.

Syke is using the platform – called TARKKA for its own research and monitoring tasks, but it also supports other actors along the value chain. The primary users of Syke's services are the Regional Centres for Economic Development, Transport and the Environment (ELY Centres). The ELY Centres are local offices of the Finnish government placed in each of the regions of Finland.

The use of TARKKA outputs is similar as in the German case. For instance, one of the common issues faced by regional centres is the presence of fertilizers and other chemicals in the water coming from agriculture. Excess nitrogen and phosphorus in the water can lead to algal bloom and especially, to Harmful Algal Blooms (HABs) which can be dangerous to wildlife and humans. In this specific case, Syke's TARKKA service enables the regular monitoring of most lakes (greater than one hectare). In addition, it offers the possibility to go back in time to analyse the evolution of the algal bloom. TARKKA images also help ELY Centres (together with Syke) to communicate to the general public (through local newspapers or websites). This helps citizens to avoid going to algae-infested lakes for recreational activities.

In order to prevent algal bloom in lakes, ELY centres and other authorities also take initiatives to prevent excessive fertiliser use in nearby agriculture areas (e.g. promoting the use of gypsum). Additionally, regional centres report to the Ministries of Environment and of Agriculture and Forestry who have access to better information – thanks to satellite imagery – on which to support the development of new policies. At the end of the value chain, citizens and society greatly benefit from better quality water and better information. Additionally, the TARKKA service does not only serve water quality, but also the monitoring of a wide range of issues such as watercourse restorations and its impact on nearby fields, litigations over specific dredging events, prevention of spring floods prevention or mitigating their impact fishing opportunities, etc.

This exemplary use of Sentinel satellite data in Finland generates positive impacts on the environment, the economy, society, innovation and science. Such impacts are going to be much more pronounced in the next five to ten years. This growth should be induced by regulation foreseeing the wide adoption of satellite data (i.e. the use of EO data for reporting in the relevant regulations which is not the case yet but under discussion), additional AI tools to predict and prevent events such as HABs, more accurate satellite data/images, long-term trends analysis to overcome polluting events as well as improvements of the underlying scientific knowledge (e.g. relevant algorithms).

The Netherlands:

In the Netherlands, EO monitoring of water quality is important because intensive agricultural practices combined with high population density and shallow lakes are critically affecting water quality. In this matter, water quality management and monitoring in the Netherlands faces important challenges.

In 2014, the **Noorderzijlvest Water board** (the public body in charge of water management in the North of the country) initiated a collaboration with Water Insight, a Dutch SME developing new methods for water quality monitoring. The Noorderzijlvest Water board is one of the 21 water boards in the Netherlands. Both institutions, being keen to develop innovative approaches to monitor water quality, are well fitted to work together. Both of them understood the added value of modernising traditional methods - by introducing satellite and in situ optical monitoring - as well as the impact it can have on water quality and its contribution to safeguarding public health, preserving ecosystems, and ensuring sustainable water resource management.

As in the previous cases, Water Insight's EO service enables the regular monitoring of lakes in complement to in situ monitoring techniques. Amongst others, it offers the possibility to go back in time to analyse the evolution of the algal bloom which allows to take innovative decisions such as managing a pumping station to improve water quality.

Additionally, the Noorderzijlvest Water board – as well as other water boards in the Netherlands - uses innovative in-situ methods to monitor water quality. The first one is the portable WISP-3 optical tool which is developed by Water Insight for quick scanning and monitoring of water quality. The second one is the WISPstation which provides high-frequency accurate water quality measurements at a single location. Both methods base their measurement on the colour of the surface water, it determines the most important bio-physical water quality parameters, such as chlorophyll, cyanobacteria pigment, suspended matter, presence of scums and transparency.[26]

The complementarity between the three methodologies (in situ sampling, optical in situ and remote sensing) makes the water monitoring particularly efficient in the Noorderzijlvest region. As with the case in Germany, the Noorderzijlvest water board advocates for the use of remote sensing at national level, notably through implementation of the use of EO in the national water plan. The stakeholders also foresee future evolutions of the product which will increase the benefits. For example, automated communication to the public about the current status of the bathing water is planned to help citizens to avoid going to infested lakes for recreational activities.

4.5 Widening the Picture

The core cases provide detailed information for a limited number of countries. How do other countries in Europe compare? Are there additional lessons to be learned?

We reached out to other countries through the Copernicus User Forum and the ESA EO Programme Board. These are representatives who have a focus on space or EO rather than on the domains in question, but they come from national bodies which can themselves reach out to those who are focused on the domain in question. Our goal was to talk with experts in each of the domains of management of forests, highways and lake-water quality. Through this route, we aimed at finding experts who are at the minimum aware of the technology, but we recognised that not all those experts are sufficiently well-informed, and we certainly find it harder to reach those most knowledgeable.

To provide a forum for exchange, we organised a workshop[27] in September 2022 with representatives from a number of EU countries. We also contacted countries representatives through both the ESA and EC channels mentioned above, both to invite them to the workshop and to solicit interviews. The workshop was fully virtual, and many countries participated either through their forest agency or their Copernicus focal point and the new information gleaned from this interaction is summarised for each of those who engaged with us.

In Table *4-1* we show the organisation or agency responsible for monitoring water quality in each European country. Note that the situation is rarely simple and whilst these organisations have overall responsibility, the execution of water quality measurements often involves other actors at a more local level of administration. As a guide, we also indicate the number of lakes with a surface greater than 1 hectare. However, this information is indicative and stated where it is openly accessible.

Austria

[26] https://www.waterinsight.nl/
[27] SeBS Sector Workshop on Forest Management. https://earsc.org/sebs/sector-workshop-3-water-quality-management/

In Austria, lake water quality is not being systematically monitored using satellite data. Nevertheless, EURISY reports[28] that the Lake Neusiedl on the Austro-Hungarian border is using satellite imagery at the Biological Station as a tool for monitoring and understanding the impact of changing temperatures (in the context of climate change. It raises awareness in the local community of environmental pressures.

Lake Constance (Bodensee) sits on the boundary of Austria with Germany and Switzerland. The International Water Protection Commission for Lake Constance (IGKB)[29], was founded in 1959, with the goal to document the development of the lake and determine the impacts. The IGKB brings together representatives from Baden-Wurtenberg, Vorarlberg and the Swiss cantons bordering the lake. Technical support is provided by the LUBW to store all data which is collected with costs paid by the Commission. The IGKB is investigating the use of satellite data within an initiative led by LUBW. Consequently, the IGKB provides recommendations for policy actions in case of environmental pressures on the lake. A current issue is the rapid growth of the population of Quagga mussels in the lake.

As an aside, during our discussion we learned that Austria is using Sentinel data in the wider context of water management. Project AREAL[30] is examining how to better manage water resources and is monitoring water use for irrigation. This has become a SeBS short case for those interested[31].

Belgium

In Belgium, monitoring lake water quality falls under the regions meaning almost wholly Wallonie and Flanders. In Wallonie, the Public Services of Wallonie (SPW) department for Agriculture, Natural Resources and the Environment is responsible but mostly implemented through the communes. In Flanders, the Flemish Environment Agency (Vlaamse Milieumaatschappij or VMM) has the responsibility.

In both regions, the agencies measure and monitor the quantity and quality of the water. In the Flanders region of Belgium, some research has been made on using satellite data for water monitoring, but this is not yet implemented as a part of the operational process. An operational viewer (WaterMonitor) has been developed and is under evaluation for its accuracy.

Czech Republic

We have not learned of any work specifically looking at lake water quality. However, some work has been done on extraction and the ground movement oscillations associated with abstraction.

[28] Lake Neusiedl: monitoring water quality with satellite imagery, EURISY 2015

[29] https://www.igkb.org/#

[30] https://info.bml.gv.at/service/publikationen/wasser/projekt-areal.html

[31] Irrigation detection and mapping in Austria.

	Responsible Agency	Lakes >1ha
Austria	Umweltbundesamt - Environment Agency Austria (EAA)	2900
Belgium	Flemish Environment Agency (Vlaamse Milieumaatschappij or VMM) Walloon Public Service (Service Public de Wallonie or SPW)	
Bulgaria	Executive Environment Agency. ExEA	
Croatia	Agency for the Environment and Nature (Agencija za okoliš i prirodu or AZOP)	
Cyprus		
Czech republic	Czech Environmental Inspection part of Ministry for the Environment	1.620
Denmark	Danish Environmental Protection Agency (Miljøstyrelsen)	30-40
Estonia	Environmental Board (Keskkonnainspektsioon)	1.400
Finland	Finnish Environment Institute (SYKE)	188.000
France	Agence de L'Eau	22.000
Germany	Regional Environmental Agencies	12.000
Greece	Hellenic Ministry of Environment and Energy	10.000
Hungary	Hungarian Environmental Protection Agency (KÖVIZIG)	3.000
Ireland	(Irish) Environmental Protection Agency (EPA)	4.933
Italy	Institute for Environmental Protection and Research (ISPRA)	2.000
Latvia	Latvian Environment, Geology and Meteorology Centre (VĢMC)	12.000
Lithuania	Lithuanian Environmental Protection Agency (LAAA)	2.800
Luxembourg	Administration de la gestion de l'eau (Water Management Agency)	
Malta		
Netherlands	Rijkswaterstaat and Regional water boards	
Norway	Norwegian Environment Agency (Miljødirektoratet)	
Poland	National Water Management Authority (KZGW)	9.300
Portugal	Environment Agency, Agência Portuguesa do Ambiente (APA)	
Romania	Agenția Națională pentru Protecția Mediului (ANPM)	
Slovakia	Slovenská agentúra životného prostredia (SAŽP}	1.600
Slovenia	Agencija Republike Slovenije za okolje (ARSO)	2.000
Spain	Ministerio para la Transición Ecológica y el Reto Demográfico	1.500
Sweden	Swedish Marine and Water Management Agency (Havs- och vattenmyndigheten)	95.700
UK	Environment Agency (EA) in England Scottish Environment Protection Agency (SEPA) in Scotland Natural Resources Body for Wales (NRW) in Wales Department of Agriculture, Environment and Rural Affairs (DAERA) in Northern Ireland	

Table 4-1: Agencies responsible for Lake Water Management in Europe and estimated number of lakes greater than 1 hectare.

Finland

Finland with its 190,000 lakes is one of the most advanced in the use of satellite data for lake water monitoring. The situation is fully described in the case presented in this chapter and for which a full report is available. The Finnish Environment Institute or Syke is responsible for monitoring and reporting.

France

In France Les Agences de l'eau (Water Agency) is organised into departments covering 6 regions each reporting into the Ministry for the Ecological Transition and Territorial Cohesion. A wide-scale research project has been recently established to gather water quality measurements for the whole territory (including the overseas departments). A range of users are foreseen in both public administrations and the private sector for information on water quality to provide early warnings of degradation and support policy for managing water resources.

Since 2023, the Ministry coordinates a project in partnership with French Space Agency (CNES) using space observation data in line with this strategy of deploying decision support tools for management of water at the local level. These services will be aimed at government departments and all local players involved in the issue. The tools and services developed focus on the quantitative and qualitative management of surface water. The project is divided into blocks, one of which is specifically dedicated to water quality. Another block is dedicated to water quantity addressing the severe stresses on water availability for agriculture and the population.

Weekly measurement updates are to be provided through an on-line portal supplemented by reports detailing the situation at local levels.

Italy

Responsibility for maintaining water quality in Italy lies with the Regional Environmental Protection Agencies (ARPA) within each region of the country. These gather the data on lakes and water courses in their region as specified under Italian / EU regulations and provide these to ISPRA.

ISPRA (Institute for Environmental Protection and Research) is a national body which compiles the national environmental report for the Italian Ministry for the Environment. Required measurements and statistics for defined indicators are reported to the EU Environment Agency. In addition, ISPRA supports the ARPAs with specific expertise and scientific consultancy and undertakes relevant research activities. ISPRA also works with local authorities and ARPAs to promote the use of Copernicus and Sentinel data.

The primary legislation links to the EU Water Framework Directive (WFD) and Flood Directives needing information on both water quality and quantity. This requires sampling of the major lakes and rivers by each ARPA but is not so far done using satellite data and is limited to one in-situ sampling each year unless problems are discovered.

Some ARPAs are going beyond this. For example, Lombardy which is the region with most large lakes (e.g. Maggiore, Como, Garda…) is using satellite data, as well as in-situ measurements, to generate monthly maps of the concentrations of toxins and bacteria including Cyanobacteria as well as chlorophyl-a for each water body in their region. This information is used by the region to prioritise the taking of in-situ samples and to support policy decisions but is not yet an operational practice.

Hence, even if no Sentinel data is currently used for reporting purposes, it does support monitoring of lake waters and the Lombardy ARPA's experience is demonstrating how this could be used for reporting against the WFD.

Scientific research is carried on alongside uptake in ARPAs and at ISPRA, with the National Research Council (CNR) providing scientific expertise and interacting in projects with experts at European level e.g. EOMORES project. In particular, CNR provides consultancy for some regional agencies such as Lombardy and Umbria for pilot projects related to the use of Sentinels data for monitoring lake water quality.

Norway

In Norway, the Environment Agency (Miljødirektoratet) has the responsibility to monitor the lake water quality. Execution is the responsibility of the 9 water regions which are supported by the Norwegian Institute for Water Research (NIVA) which is contracted by the Norwegian Environmental Agency to provide the national water quality monitoring as well as advice on the technology. They have several research projects but no operational use. Norway has many lakes which would favour the use of satellite data, but clouds, shadowing by mountains as well as the small size of many lakes makes monitoring a challenge and require dedicated algorithms - currently part of the underlying research.

Spain (Catalonia)

In Spain, the Ministry for the Ecological Transition and the Demographic Challenge takes overall responsibility for water quality monitoring and reporting with implementation devolved to the regions. For example, in Catalonia, the Catalan Water Agency (ACA), looks at water quality in lakes, rivers and coastal areas through a taskforce with the Cartographic and Geological Institute of Catalonia (IGCC) providing the technical expertise including for mapping of chlorophyl-a and sediments.

Sweden

The Swedish Agency for Marine and Water Management (SWAM) is responsible to protect, restore and ensure sustainable use of freshwater resources (as well as seas including fisheries management). Satellite data is being used but largely for research purposes and water quality monitoring and reporting is performed on the basis of laboratory analysed samples.

An impressive number of lakes are monitored for their water quality. Within the national monitoring programmes SWAM monitors 110 lakes each year for both chemical and biological parameters, with each of the 110 lakes sampled 4 to 8 times each year. In addition, a further 4800 lakes are monitored by SWAM on a 6-year cycle, but only for chemical parameters.

Further testing is made by the 21 county boards and the 5 water districts. The county boards are responsible for monitoring to complement the national monitoring according to regional needs. The main responsibility for the water authorities, in the five water districts, are coordination of the monitoring and compilation of reports according to the national and European standards defined by the Water Framework Directive (WFD) and the Bathing Waters Directive (BWD).

Additionally, polluting industries (paper/pulp, food processors....) are required to monitor their water emissions and have knowledge of their effects on the environment which therefore sometimes includes sampling in the recipient, which provides further samples which are collated and reported by the water districts.

These processes use data collected on the ground or using helicopters which allows sampling of a large number of lakes. No satellite data is used for this purpose. However, satellite-based products are being bought by SWAM from a private company and are planned to be used as basis for expert assessments under the Water Framework Directive, when traditional monitoring is lacking (esp. chlorophyll-a and secchi depth). Data has also been used for looking at the wider picture regarding trends (ie worsening quality in lakes esp. chlorophyll-a and turbidity) and prioritising of other activities (where samples should be taken) and the impact of changing regulations.

The agency has not used satellite data on a more operational basis due to lack of budget – similar to the case in Germany. There is also generally a lack of expertise within the agency and a lack of budget to buy in a full service. This is expected to change if the WFD is updated to include the possibility to use satellite data for reporting. Some R&D projects have been undertaken with the SMHI (Swedish Meteorological and Hydrologic Institute) where the expertise does exist, but this has not been sustained. This is important since Swedish waters contain a lot of organic material which requires dedicated algorithms to process the satellite data. Discrepancies have been found between measurements taken on the ground with those from satellite data hindering the adoption by SWAM.

The comparison with Finland is interesting as the geographical situation is very similar. The accumulated expertise in Syke (Finland) has enabled that agency to move more strongly to the use of satellite data for reporting purposes. Syke compiles the national report to send to the EU which gives them a stronger stake in the process and hence interest to use satellite data. Syke also has the internal technical expertise which helped with integrating the satellite data products into the operational process.

In addition to water quality, SWAM monitors water temperature for Sweden's many coastal bathing areas and for this, Sentinel data is being used. Daily temperature forecasts are downloaded from the Copernicus Marine Service and used to provide citizens with a perspective on each bathing area. These are made available through their website for example for Gothenberg. SWAM report that this is popular with the public and they wish to extend it to cover lakes as well as the coast.

SwAM also sees great potential in using satellite data in other areas such as monitoring of lake and reservoir water level and, if possible, to model water flow in rivers (i.e. hydromohological quality elements). Also, for environmental compliance monitoring, of companies with operations that influence the water quality, of dredging and other activities causing high turbidity. In addition, data from satellites have been used by the county boards to detect and monitor the invasive alien species fringed water lily (Nymphoides peltata). A method that would be of interest to develop further.

In summary, Copernicus-based solutions are currently not routinely used in Sweden for monitoring water quality. However, SWAM is exploring their use and foresees possible benefits related to increased information and guidance for improved ground sampling. The most important expected value added would be in the capability to analyse trends over vast geographic areas and over all lakes holistically.

International Perspectives

For each of the three domains, a perspective from around the world was sought during the workshop session 3 on 13th June. An introduction was made by rapporteurs from the session 1 to provide the international audience with a brief summary of our findings in Europe and to place the international view into context.

The International Water Association (IWA)[32] brings together a network of professionals interested in all aspects of managing water resources. Based in London, the IWA has members from around the world and has established a working group to look at the use of satellite data and sharing best practice. Members are integrating satellite data with traditional methods showing advanced use and operational maturity. This is leading to a growing recognition of the value of using satellite data across Europe. Regulation is a key driver for uptake. Factors influencing uptake include; data reliability, cost-effectiveness, technical infrastructure, national efforts and collaborations.

In the final workshop, representatives from both Canada and South Africa presented how satellite data is being used. Responsibility across multiple layers of government has led recently to the formation of a Canadian water agency. Satellite observations are used for algal bloom monitoring. Data is accessed in near-real-time delivering daily and 14-day updates on levels of chlorophyl-a through a dedicated portal (EOLakeWatch). Results are also used to optimise in-situ sampling and guide and monitor the effectiveness of policy actions.

In South Africa, Inkomati-usuthu catchment management agency (IUCMA) is one of 9 agencies set up in 2012 to deliver sufficient, equitable and quality water resources for all. The IUCMA covers 3 countries. Satellite data complements in-situ sampling. 10 lakes / reservoirs are monitored by sampling and 11 with satellite data. Historical data is processed to predict blooms which provides information which is 80% accurate, 1 week in advance. https://riverops.iucma.co.za/ .

4.6 Understanding the Benefits

Some significant differences in the nature of the primary user and the application for monitoring water quality, means that the benefits also vary considerably. The transversal nature of our analysis allows us to explore these further and to draw some insights which are presented in the next chapter.

Before we dive into the subject, it is worth noting that the link (or causal effect) between EO monitoring of lakes and the benefits is not always clearcut and specific actions/decisions are often required in order to realise some benefits.

For example, in the three SeBS cases looking at water quality monitoring, the process of decision-making is improved through the use of EO data. More specifically, the access to better information - more comprehensive reports and data - on which organisations in charge base their decisions may, for example, relate to the sources of pollution through the release of nitrates from farming, the magnitude of eutrophication in lakes or the impacts of HABs on local wildlife and biodiversity. This comprehensive information helps the decision makers to improve policies linked to water quality, for example policies

[32] https://iwa-network.org/

to reduce nitrogen emissions from farms. While this process undeniably requires time, it involves enormous impacts on water quality, which in turn improves the environment, biodiversity, quality of life of citizens, ecosystem services, etc.

In the case of the Netherlands, the Noorderzijlvest Water Board is currently discussing the implementation of an innovative action based on an analysis of EO data. It has, in fact, shown that the reversing of direction of a pumping station in an area (in which we find bathing sites and natural reserve sites) could greatly improve the water quality. Making the decision on whether to implement this action is not possible without a full historical view of the lake offered by EO. It is a timely process but could induce great benefits on water quality.

As a start, the benefits are shown in **Table** 4-3 against the set of common indicators. These are grouped into each of the 6 dimensions for further discussion.

Economic Benefits

The estimated economic benefits are mainly due to high-cost savings for avoided in situ monitoring costs. They are further supported by savings in important ecosystem services due to better water quality. These benefits are higher in Finland than in Germany due to the very large number of lakes while they are even greater in the Netherlands because of the higher pollution in water requiring more intensive monitoring. In addition, better quality water would make an important difference in terms of improving ecosystem services in the Netherlands due to generally more polluted water. An increased monitoring (conditional on a timely action) could also reduce the risk of paying fines to EU authorities for low water quality.

In Finland and in Germany, information about HAB is shared with the general public but not yet in the Netherlands. This helps citizens to avoid going to algae-infested lakes for recreational activities. The time saved by citizens can be translated into economic benefits and wellbeing.

The benefits attributed to each primary user, and reflected in the total benefits, are strikingly different for the three countries so illustrating an important finding. In Germany, the data is used to inform the local population as well as complementing the formal reporting required under the WFD but does not replace the current sampling methods. In Finland, the Environment Institute has adopted the use of EO-derived data for reporting against the WFD and replacing the in-situ measurements, which, given the size of the country and number of lakes, leads to significant savings potential. In the Netherlands, the nature of the lakes being shallow and subject to stronger anthropogenic pressures than is the case in Germany or Finland, sampling is more demanding leading to the higher benefits even if the country is smaller and lakes more accessible.

The lesson from this is that whilst it is possible to use counterfactual data from one case to evaluate others, the results can be quite divergent and hence in general, knowing how benefits accrue in one case (or country) gives a strong base on which to understand another case (in another country**)** and to have a better understanding of where benefits lie. But **each case is different and must be treated on its own merits**.

	Tier 1 Service Provider	Tier 2 Primary User	Tier 3 Secondary Beneficiaries	Tier 4 Citizens and Society	Total
Germany	€1.4m	n/a	€1.7-3.64m	€3.1-6.2m	€4 – 7.8m
Finland	n/a	€5.82-17.46m	n/a	€0-7,36	€6.62 – 24,82m
The Netherlands	€167K	€26.83m	€100-200k	€6.36-10.61m	€33.46 – 37.81m

Table 4-2: Economic Benefits along the value chains for core cases of water quality management.

Environmental Benefits

In the three core cases, Sentinel-enabled service supports the monitoring of water quality, giving rise to significant environmental actions and consequently to benefits. This includes:

- Improved ability to track the possible consequences of pollution and ultimately support reduction of pollution through limiting excessive fertiliser run-off, watercourse restoration or other actions such as reversing a pumping station.
- Enhanced capacities to detect environmental issues connected to HABs and their evolution which allows to act in a timely manner.
- Strengthened capacity in preserving nature and biodiversity.

Regulatory Benefits

The ability to improve regulations seems to be a very strong potential benefit coming from the use of Sentinel data in the three cases. In that regard, the EO services are being recognised by regional and environmental centres as an effective way to improve their ability to monitor the quality of water under their legal responsibility. The data helps:

- to improve their ability to carry out their own institutional monitoring tasks in accordance with their legal statutes and regional and national laws.
- to advocate for the use of EO in national regulatory framework.
- to improve their accountability (and thus self-confidence and sense of mission fulfilment) through better transparency and better communication. This in turns allows them to do a better job in compliance to regulation and in policy making.
- to more comprehensively evaluate the impact of policies on water quality.

The further advantage that could be derived from better and streamlined reporting (at the federal and the EU levels), however, does not currently materialize because of the lack of explicit recognition of the use of EO data in the present form of the respective regulations. This potential change is subject to much debate. 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.

Economic	Germany	Finland	The Netherlands
Cost savings	Avoided in-situ monitoring costs	Avoided in-situ monitoring costs	Avoided in-situ monitoring costs
EU, national and private fundings		Innovative environmental project receiving EU and National fundings	Expertise in EO and water quality is getting attention from investors
Ecosystem services	Better quality water allows all types of ecosystem services around lakes	Better quality water allows all types of ecosystem services around lakes	Better quality water allows all types of ecosystem services around lakes
Time saved	Time saved for not going to an algae-infested lake thanks to better warning	Time saved for not going to an algae-infested lake thanks to better warning	
Avoided fine			Reduced risks of fine for poor water quality
Environmental			
Maintenance of natural habitats and ecosystems	Better water quality	Better water quality	Better water quality
Reduced pollution	Better management of fertiliser use	Better management of fertiliser use	Better management of fertiliser use
Regulatory			
Better decision-making and better regulation	Improved decision making and design of legislation	Improved decision making and design of legislation	Improved decision making and design of legislation
Additional data on adherence to the EU and national regulations	Improved monitoring	Improved monitoring	Improved monitoring
Innovation			
Changed business practice	Development of new innovative products.	Development of new innovative products.	Development of new innovative EO and in situ products which are complementary.
Start-ups	Start-up developing new business.		Start-up developing new business
Research & science			
New research and academic publications	Enhanced scientific and technical knowledge.	Research into new applications	
Societal			
Better health and quality of life	Reduction of water pollution (HAB)	Reduction of water pollution (HAB)	Reduction of water pollution (HAB)
Common understanding	Better communication of information	better communication of information	better communication of information

Table 4-3: Benefit Indicators found in the Water Quality cases analysed under SeBS.

Innovation & Entrepreneurship

The development of the new products combining artificial intelligence and remote sensing, combined with in-situ data, are important in the three cases. In the Netherlands, an additional element is the optical in situ tool data which is also combined and provides more effective monitoring of water quality.

In all cases, organisations providing EO services for water quality monitoring contribute to significant research into the techniques for extracting water quality related information from satellite data. This has been followed by many steps of technical development to make the service more accessible by their users. Furthermore, there is still a tremendous potential of development of the service in the future.

Furthermore, the introduction of new processes into public agencies is never easy. Organisational barriers as well as lack of technical know-how restrict the innovation capacity of any organisation. One factor driving innovation in public agencies especially, is the introduction of new software tools and IT infrastructure. We have seen in Germany how a national initiative to digitalise the public sector has provided a bootstrap for introducing the use of satellite data for water quality monitoring but also we are sure for other satellite data products. We also find that the presence of a technical agency, such as in Catalonia, greatly facilitates the uptake of the new services and the development of new processes in all organisations.

Science and Research

There is a great deal of research into the impacts of water quality on human health, the environment, biodiversity and the economy. In the three cases studies, the extensive research surrounding ecosystem services, lakes and rivers is based on this new, large-scale data derived from the satellite measurements. Part of this research is directly performed by the environmental/regional authorities in charge of water quality but also by the service provider (EOMAP and Water Insight).

Three types of research are supported by the Sentinel data:

- Improved understanding about ecosystem services (and the importance of water quality) and how they contribute to the global environment and their value in economic terms.
- Understanding of water supplies and how sustainable these may be especially in fragile regions of the world.
- Improvement of technology and algorithms for estimating water quality related indicators based on the use of satellite-derived data.

Society and Citizens

The benefits to citizens and to society are possibly the most salient ones deriving from the three SeBS cases – and naturally, there is also a strong overlap with the environmental benefits.

The improvement in the quality of water in lakes and rivers translates to a pleasure shared by many whether it is for swimming, fishing or canoeing, or simply the appreciation of a natural landscape. Through better water quality and environment, local citizens (and tourists) 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.

In addition, the wide-scale nature of EO data and maps can be shared internally as well as through websites, social media, and national/local press. This gives rise to important benefits such as improved coordination and communication both within organisations and vis-a-vis the general public. This in turn helps to improve reputation and accountability of environmental and regional agencies through better transparency. The society as a whole can only benefit from this trust in its public agencies which in itself represents an important pillar of a healthy and well-functioning society.

4.7 Insights

The three SeBS core cases deliver some important insights into how EO data from Europe's Sentinel satellites is making a difference as it improves cost-efficiency of the water quality assessment while offering a better overview of water bodies. Yet, despite this strong evidence the take-up in the European countries is still limited. On the one hand, this shows the potential which is still to be unleashed from the use of Sentinel imagery. On the other hand, it is curious that other administrations have not yet instigated its use. Why might this be?

If we compare not just those countries which have adopted the use but all of those with whom we have talked, an interesting picture emerges. We have identified the following factors, in no particular order, as being important to instigate and adopt the changes in the domain of water quality management:

- **Geography**. The Netherlands and Finland have specific conditions which create monitoring needs of water bodies. In the Netherlands, intensive monitoring of water quality is important because of the environmental pressures due to intensive agricultural practices and to high population density. Further, the lakes, coming often from reclaimed sea, are relatively shallow leading to higher density of pollutants aggravated by higher water temperatures. In Finland, which is also known as the land of a thousand lakes, EO monitoring is particularly relevant because of the very high number of lakes, spread over a large area, remote from population centres. Using traditional sampling for all these lakes would be extremely costly. Such conditions are not present in all countries but are certainly present in some others.

- **Governance or Administrations.** Water quality and environmental agencies are public bodies. They have usually a set of well-defined and approved rules and procedures prescribing how they should operate. Introducing new technologies into their processes is not an easy task, especially when it is not specified by national or EU regulation. In both Germany and the Netherlands, the new technology had been introduced by a person with the support of their supervisor and with specific help from innovative water quality companies (EOMAP and Water Insight). In the case of Finland, the national environmental institute, Syke, benefits from strong national support and financial resources while it comprises about 700 competent experts and researchers who work in close and stimulating co-operation with Finnish and international partners. The key advantage of EO data is to provide better and wider coverage but with an investment cost. The motivation for managers to apply EO-based water quality measurements is weak where regulation does not prescribe its use and neither the technical resources are available. In Syke, the nature of the responsibility together with the technical means to implement new tools has led it to be the leading agency with regard to using satellite data for water quality compliance purposes.

- **Culture**: the willingness of the organisation and specifically its management to embrace change is a key factor. If there is a history of adopting new methods, processes or tools this can help significantly. This is for example the case in Finland where one of the 5 main roles of Syke is clearly established as "*developing new approaches for reaching a good state of the seas and inland waters and achieving sustainable use of water resources*"[33]**.** Such explicit target-setting for an organisation is therefore optimal in the development of new EO services.

- **Trust**: Closely linked to culture is the question of trust in the service. Indeed, this cuts across several of the factors identified such as the standing of a champion, the awareness of the technology etc. A study into the behavioural aspects[34] and engagement of users shows a high degree of trust in the information derived from satellite data. The study, which sampled opinion among practitioners of water management, globally, also examined the links with policy directives and through the GeoAquawatch project developed a network of experts with whom to continue a dialogue.

- **Legal Framework**. The EU Water Framework Directive places obligations on all EU countries to maintain a high-level of water quality. Some countries manage this better than others due to different pressures on water bodies and the relationship between the different stakeholders (especially farmers, citizens and water monitors). Currently, the WFD does not explicitly recognise the importance of using satellite data as a measurement tool. This inhibits the investment necessary to add this data source and accompanying technical resources to the monitoring toolbox. In the next few years, this may change and already the EC is making proposals to adopt the possibility of using Copernicus in the legislation. Some of those interviewed are members of an expert group which is advising that this should be done. This is an extremely important step as the general perception and modality for the introduction of EU legislation into national law plays a strong role in the uptake or not of satellite technology.

- **"Space" awareness**. Space technology is often perceived as complex and expensive. An awareness of its utility makes the introduction into an organisation easier. In Germany, first discussions about EO products to support water quality started in 2000-2002. Although these failed at the time, it raised awareness leading to a successful research project in 2015. In the

[33] https://www.syke.fi/en-US/Current/SYKEs_vision_is_Sustainability_Transform(61826)

[34] Perspectives on user engagement of satellite Earth observation for water quality management, Lara Agnoli et al, Technological Forecasting and Social Change, April 2023.

Netherlands, the initial motivation came from a space enthusiast inside the water board who had the chance to find support inside the organisation and from the company, Water Insight. Additionally, this space awareness is also raised by other environmental organisations or research institutions within the country/region. Usually, there is a whole EO-friendly ecosystem of research and services in various environmental topics (e.g. water, forestry, …) in the country for further tools to be developed.

This can be seen internationally as well. In a study looking at barriers to adoption[35], the **perception that the data is expensive** is reported by the researchers who also note the need for reassurance on **continuity of data** and the need for **hierarchical support** – which we have identified in this study.

- **Industrial Presence.** The existence of a company, as was the case in the Netherlands and Germany, which is keen to sell the technology (or service) promotes EO data use and helps convince others through examples and supporting material as well as making presentations and pilot projects within the organisation.
- **A champion**: as briefly mentioned above, a champion plays a very important role which is very necessary if not absolutely essential to bring EO services to the organisation. In turn the champion needs to garner support from the hierarchy to succeed. We saw this in the three cases although it was needed less in Finland as there was already support from a national level and hierarchy. In the Netherlands, the champion is an enthusiast for EO technology for water quality in lakes and other water related subjects, i.e. information about aquifers through soil moisture measurements.

An important accelerator of change towards more usage of EO for water quality is the increased attention from legislators and decision makers as well as increased pressure from activists on water quality. This is for example the case in the Netherlands. By signing the WFD, the Dutch government has pledged to improve significantly the water quality by 2027[36]. Such engagement allowed activists to launch legal initiatives to additionally stimulate the water boards. It in turn involves enormous consequences for the level of water quality monitoring in the Netherlands.

A further factor which increasingly plays a role in raising awareness, but less so in the uptake of services, is the influence of climate change. Changes in rainfall patterns as well as development factors such as soil sealing, are bringing a greater focus on the availability of water. Less a quality issue and more one of quantity, the measurement needs are not the same. A better water management and knowledge of the status of water reservoirs, becomes paramount and a key use of space data in countries under severe climate change conditions and increasing drought scenarios.

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[35] Barriers to adopting satellite remote sensing for water quality management; Blake Schaeffer et al. International Journal of Remote Sensing August 2013.

[36] https://www.h2owaternetwerk.nl/h2o-actueel/mob-zegt-provincie-en-wetterskip-de-wacht-aan-over-beroerde-waterkwaliteit-in-friese-wateren

4.8 In Conclusion

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. Further, the differing geographies and sampling and analysis requirements shows up in quite different economic benefits. This illustrates clearly the principle that, whilst it is possible (with great care) to take parameters from one case for a similar one in a different country, this is only a starting point, and it is necessary to analyse and understand each case on its merits.

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.

5 Transversal Views

5.1 The Basis for the Analysis.

Our work on SeBS has been driven by the desire to demonstrate or showcase the value being created through the use of the Sentinel data. We have built a portfolio of case studies which covers a diversity of applications and countries. Most of the SeBS cases employ the fact that both legislative and market conditions are pretty much uniform within a country. Sometimes a second country is also referenced if there are comparisons to make if the conditions are similar yet differ in a meaningful way that can be accounted for with reasonable accuracy. In the cases featured in this report, there are no examples of adapting a study rooted in one country to another country, but for one example, see Air Quality Forecasting in Latvia for a comparison between UK and Latvia.

Building upon the growing portfolio of SeBS cases, we wished to dig into the findings to establish where there are similarities or disparities which can lead to a deeper understanding of the benefits deriving from the use of Sentinel data – or the challenges to realising these benefits. This led us to certain insights which are described under each thematic area and lead us to investigate more deeply the cases in the three domains covered in this report. How much are the cases connected? How much can the findings of a case be extrapolated to address the same application in different countries? Is there any read across between application domains for different cases?

We find that the particular set of benefits in each case is largely unique. Each case has a certain "pattern" reflecting the application, the resources of the country concerned, the legislative environment and the role of the primary user. These are largely reflected in the value chain which lies at the heart of our approach. There are similarities between cases in the same application domain but even here the nature of the users and the resulting value chain can, and often will, lead to differences. If we carry this analysis further, then the similarities between different application domains become very limited because the particular set of indicators and the reasoning behind them are quite specific to the application domain.

Hence, extrapolation from one case to another must be treated very carefully. To take a simple case, the economic benefits from forest management in Sweden could be extrapolated to other countries simply by scaling them on the area of forest in each one. This would be a valid approach and would lead to a realistic but uncertain answer. The accuracy of this could be improved by making a categorisation of the forests into evergreen, broadleaf, deciduous etc. Or even further by the type of tree i.e. larch, pine, or oak. Each refinement leads to a more accurate result but will need more cases to be studied where the specific characteristics concerning the management of larch, pine or oak woodlands, as well as any regulations, can be analysed and understood.

Or in the case of water quality, we can scale based on the number of lakes, but the more accurate picture will take into the account the location and sizes of lakes since remote or large lakes will cost more to monitor using traditional means. Monitoring costs have been used as a counterfactual in all three of the cases reported but whilst we can learn from these, we also learn that the costs are not the same in each country, no doubt driven by the factors just mentioned.

This reflects how a bottom-up approach brings insights and accuracy. Whilst our goal in SeBS is to get better accuracy through a bottom-up approach, we have seen also that this requires considerable effort to gather all the necessary information. However, we have also seen that this approach brings a deeper understanding of the use-cases including about the benefits which are not so visible. So, judgements always need to be made and traded -off with a reflection on the objectives of the analysis.

This does not mean that we cannot learn more from a deeper examination of the portfolio of case studies. Certain conclusions can be drawn which are common to two or more of the cases. A number of observations or broader insights can be revealed this way and these we shall address in this section. It is also interesting to see that the reasons why a particular organisation has adopted the service may be characterised. In a sense, the public bodies which feature in this report are the pioneers for adopting the use of Sentinel derived services to support their operational activities. What has led them to do so and are there further lessons to encourage others to adopt it in their organisations? In the next section, we shall look at factors which influence the adoption of services based on Sentinel-derived data.

5.2 Common benefits and common challenges

Indicators provide the basis on which the benefits are analysed. In generic form, these are applicable to virtually all cases, but some indicators will play a stronger role than others. The most significant are the ones which are addressed in each case study. Which indicators dominate in each of the dimensions?

The indicators are organised in the 6 dimensions to provide a framework for the analysis. All indicators used in the cases discussed can be seen in the three tables included (Table 2-2, Table 3-3, Table 4-3). Many indicators are common to cases within the same domain but equally there are differences depending very much on the "pattern" of the case.

No strong pattern emerged from our analysis that can be applied a-priori to a set of cases – even ones in the same application domain. This implies that each case tends to preserve quite a number of specificities that prevents straightforward generalization. Nevertheless, the "pattern" for an established case does provide a good starting point for subsequent ones and can both simplify the process (by building on existing knowledge) and increase the accuracy of the result (by providing more detailed results which may be extrapolated to other cases). Understanding the specificities of a case is what we refer to as "getting under the skin of the case".

Some common themes may be identified.

Economic Dimension: Cost savings or enhanced capabilities?

Are the economic factors arising coming through cost savings or through enhancing the capability of the organisation? The first reflex when looking at economic benefits for any project, particularly those which are publicly funded, is "how much money can be saved?" and in fact savings are one of the most ubiquitous economic benefits observed when using EO data – or at least the ones that can be more easily quantified. Savings may take the form of reduced equipment costs e.g. monitoring stations or of personnel costs. In some cases, the profile and effectiveness of capital expenditure can be improved. Particularly when considering the primary user, two indicators stand out. These are either saving costs by reducing monitoring actions or enhancing the capability (or capacity) of the organisation. Where an organisation is already monitoring, the new technology becomes a substitute for equipment or manpower, and the savings are relatively easily calculated.

The case of forest monitoring in Sweden, whilst driven by regulatory interests, provides one example where the introduction of the satellite data led to a reduction in cost. Forest rangers who were monitoring where clearcuts were taking place were redeployed into new positions. The Forest Agency saved on manpower costs but in reality, was able to transform its operations to do more with the same number of people.

For highways management and for water quality monitoring, the use of satellite data enables roads or lakes to be monitored in new and better ways that is not feasible or even possible by conventional means. To monitor all lakes in a region with adequate spatial and temporal sampling is just not feasible at an affordable cost. As a counterfactual, we calculate what these costs would be, but in reality, they would not apply because the monitoring would not take place. Instead, the capability of the agency is enhanced, and it is able to offer a better service to its citizens.

Monitoring large areas for ground movement is just not possible using traditional surveying techniques. The fact that such movement can be detected means less risk for construction projects. By employing new (satellite-derived) measurement techniques, the capability of the organisation in charge of road construction or maintenance is enhanced.

Environment: Reduced pollution or Mitigating Impacts?

The environmental dimension comprises indicators which are either to reduce pollution or to mitigate the impacts on biodiversity or natural resources. Monetizing any of these is very difficult and hence the focus is on the qualitative nature of the benefits. Of the three application domains considered in this report, water quality has a strong environmental dimension, forest monitoring to reduce illegal clear-cuts and deforestation also has benefits, whilst for highways management we do not identify any direct benefits. In all these cases we are of course talking about the benefits arising from the use of Sentinel data and there may well be other factors which drive these benefits to be greater. Indeed, the data generally supports the monitoring activity, whilst other actions may be required additionally to protect the environment.

This can be illustrated by thinking about the water quality where there is no direct impact of measuring water quality on pollution levels but monitoring water quality in lakes allows better design and implementation of legislation as well as ensuring compliance of engaged actors, which all together do lead to cleaner waters. It is a good example of where satellite data can help monitor something, which leads to positive impacts on society in other ways. So, understanding the pollution levels can lead to better controls which may in turn mitigate the damage caused.

Forest monitoring is similar in that improved monitoring allows better controls to be put in place which then lead to protection of tree species or standing timber and reduces the disturbance to forest ecosystems caused by avoidable logging.

Regulation: Better Regulation or Better Compliance?

Reflecting the importance of satellite data to public sector users, many uses of satellite data are linked to regulation, but does the data help primarily with the design of legislation or with compliance monitoring? For forest management and water quality monitoring the link is very strong whilst for highways management the link is weaker but is present.

We have shown[37] that the **data supports all phases of the regulatory cycle** (as shown in Figure *5.2-1*) which can essentially be categorised as contributing to the legislative process, or to the implementation including monitoring and policing (compliance) of it. These two aspects are represented in the cases analysed.

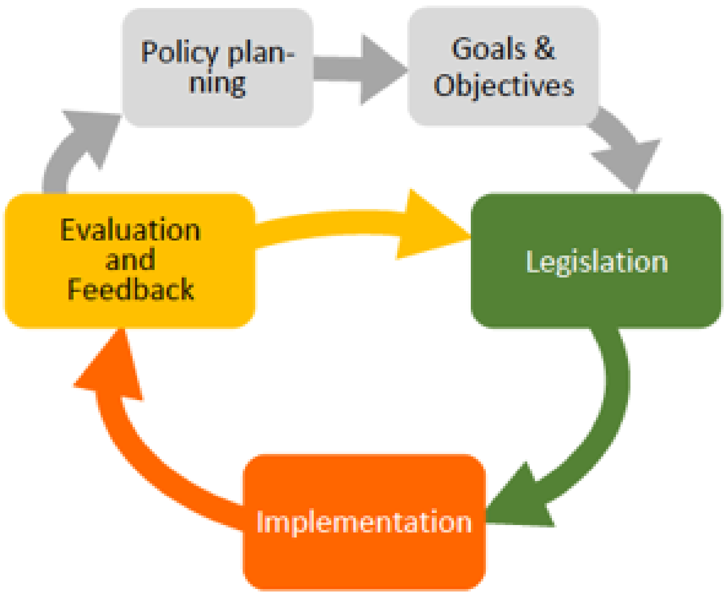

Figure 5.2-1: Representation of the Policy Cycle.

The focus for forests and for water quality is on monitoring **leading to better policing of the legislation** being applied and respected. Improved monitoring can also then help design an improved policy which was at the origins of the case in Sweden. For highways management, there is also a potential benefit linked to where historic information on ground movement can be used to control third party damages.

Innovation & Entrepreneurship: Innovative Processes or Creating Business?

In this dimension, the data is both driving innovation in organisations, both public and private, as well as enabling businesses and especially start-ups to emerge and develop. These findings are generally applicable and are not limited to the applications addressed in this report. The benefits are different depending on whether the actor is a private company or a public agency.

[37] SeBS overall report,

For the supplier of services, if this is a private company, then innovation is key to developing new business as we see in a number of the cases (shown in Table *5.2-1*). Whilst for public organisations, the innovation driver is towards new internal procedures and services. For the private companies, establishing a service with a public authority is a strong factor to develop their business further as it provides a reference for future customers as well as direct experience of the data use. This is considered to be a factor which helps public bodies overcome some of the barriers to uptake (see chapter 5.3).

Application	Case Identity	Supplier	Nature of supplier
Highways	Italy	Planetek	Private
	Norway	NGI plus partners	Public
Forests	Sweden	Swedish Forest Agency	Public
	Portugal	Tesselo	Private
	Global/ESG	Satelligence	Private
Water Quality	Germany	Eomap	Private
	Finland	Syke	Public
	Netherlands	Water Insights	Private

Table 5.2-1: Nature of the suppliers in the selected SeBS cases

Adoption of new (EO-based) services into the operations of public agencies is almost always innovative as it means changing some of their internal processes. This is a difficult change to manage as has been highlighted in all the relevant cases. For public bodies, the difficulty of driving innovation in public bodies is recognised by the OECD which has established an observatory[38] to highlight these difficulties and to help organisations to innovate. A report is also available on Fostering Innovation in the Public Sector[39].

For the primary users, innovation is key to the introduction of a new process and the willingness to innovate is identified as one of the critical factors to drive adoption, which we shall discuss in the next section.

Research & Science: Enabling new research?

The ability of the data to drive research and scientific analysis is mostly linked to the application area. Note we are considering research to be beyond that linked directly to the service. Water Quality Monitoring provides a good example of this where it would not be financially feasible to monitor all water bodies where these are numerous. The evolution of poor water quality, its possible causes and potential solutions, on a country-wide scale can only be undertaken using satellite-derived water quality maps. Hence there is strong benefit for research in this area.

The situation is somewhat similar for forestry linked to monitoring the spread of disease. Monitoring all the forested area using rangers would be very costly and hence we could imagine a strong driver to

[38] OECD Observatory of Public Sector Innovation - https://oecd-opsi.org/publications/tackling-policy-challenges/
[39] Fostering Innovation in the Public Sector. OECD 2017.

adopt the use of satellite images. However, the available resolution (from free Sentinel data) is unable to provide detection at the tree level and hence the disease must have spread to a small stand of trees before it can be detected in imagery. We have heard in all countries that Sentinel data is being used to develop a better understanding of the spread of bark beetle for which patches of diseased trees can be seen in images. This helps develop a better understanding of the threat and thus to plan a response.

Since the disease knows no borders, there are examples of international co-operation being engendered by the use of Sentinel data. These cooperations are very important for making scientific progress in the complex field of forest management: while there are obvious negative effects of bark beetle infestation e.g. increased tree mortality (leading also to dead fuel accumulation increasing in turn the risk of forest fires), there can also be positive effects like creation of canopy gaps enhancing the species richness or enhancing biodiversity and foraging habitat of native bees.

Social benefits: Improving Lives or Societies?

A number of different indicators of benefits are grouped together under the social dimension of value. Very broadly, these can be categorised as improving the lives of citizens directly, or of providing wider benefits to society. Many applications address both of these levels.

As an example, in the highways management cases, we see benefits to individual road users through reduced delays resulting from remedial work caused by ground instability, but which also give broader benefits by making the movement of goods more efficient. Forest management increases the value of timber stocks whilst preserving woodlands for biodiversity and the greater enjoyment of citizens.

One factor in common for many cases is, what we have termed, the “platform” effect which has a wide benefit by encouraging different organisations to work together. By platform we mean a group of experts – a “network of peers” - coming together to work on a specific issue or problem. The platform becomes the basis for exchange of knowledge. This may involve different organisations within the national administration – as is the case in Norway, or even those in different countries – as is the case with addressing the problems of bark beetles. It may even be on a more parochial level by bringing together different parts of the same organisation – as we have seen in Italy.

This “platform” effect appears to be quite powerful and one conclusion from studying the various cases is that more of these could be built. This is an effective way to build trust in new technology and to exchange knowledge on best practices to improve implementation and adoption. One of the key problems found in the process to adopt the use of Sentinel data is the dependence on champions who may come and go.

5.3 A common challenge: the adoption of new services by Public Users

At the outset of this report, we framed the analysis as being concerned particularly with the benefits to public authorities. We have analysed this in relation to 3 different application areas and developed some insights into how public bodies are benefiting from the use of Sentinel data. We then looked at the current situation in a number of other countries – beyond those on whom the cases are focused.

This has led us to develop some ideas as to why a service has been adopted by some primary users but not others. Let's take this analysis further to seek to understand what has led to its adoption in the organisations where it is now used operationally. Note that whilst we talk about public users, we would consider that the arguments apply to commercial organisations.

In order for any organisation to integrate a new technology into its operational processes, several conditions should exist that deploy according to a fairly recognizable pattern:

1. **Rationale**: Recognising a need for improvement of service in the organisation which may be addressed using the new technology.
2. **Agent for change**: a trusted person (a champion) or organisation who/which drives or co-drives the change. More than one agent may be present – for example in Norway.
3. **Raising Awareness:** the agent for change is actively raising awareness in the organisation about the new technology and how this may help to meet one or more of the organisation's needs.
4. **Validation**: evaluation of the technology's fitness for the purpose of the organization and preparation of the organisation for subsequent change if the evaluation is successful.
5. **Adoption**: having proven its suitability, the new technology is adopted and implemented into the internal processes of the organisation.

The process leads to a better performing organisation reaping the benefits as described earlier. The process is shown schematically in Figure *5.3-1*.

Let's look at these in turn.

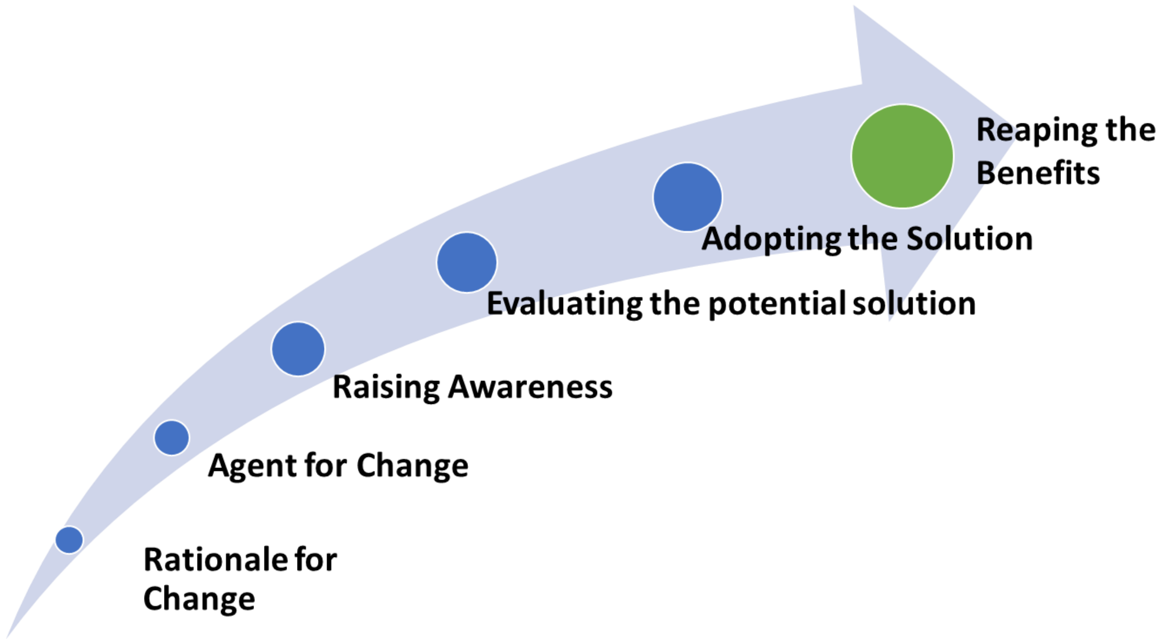

Figure 5.3-1: The process to adopt a Sentinel-based service into the public organisation.

- **The rationale to bring change in the** organization may arise through recognisjng a need in the organisation or an improvement in the service it can offer. This is largely driven by increasing pressures on the public authorities to support governmental decision making and policy. Very frequently, this pressure comes direct and top down, for instance where new regulations are introduced, and which specify or require the use of satellite derived information services. There are some examples of this even if there are many more where changes are pending or under discussion. Examples where monitoring is carried out to support legal requirements include the SeBS cases of water quality monitoring in Finland (at EU level), forest management in Sweden (at national level), or for aquifer monitoring in Spain's Segura basin[40] (at regional/local level). Indeed, these three examples also highlight where the use of satellite data for monitoring has pre-empted the legislative changes which have been made possible by its availability.

  Other reasons for change can be through external pressures on the public authority due to e.g. growing anthropogenic influences on natural resources, shrinking budgets (reduce costs) or impacts from climate change. It seems likely that these factors will only intensify, hence lead to a growing recognition of the role that Sentinel data can play to alleviate them can be useful.

  Notwithstanding, whilst the use of Sentinel data can support public administrations to reduce costs and improve efficiency, it frequently results in improvements in the services being provided to citizens and society. This is surely the case with water quality measurements but also for highways management even if the benefit is more indirect and less visible and extended along the value chain due to reduced delays for road users as the duration of roadworks may be reduced.

  In the case of private sector organisations, the company may be responding to legislation and wishing to prove its compliance (as in the case of Bunge in the Netherlands) or support its activities (ie CELPA in Portugal).

- **An agent for change** can be through an individual or an entity with formal responsibility for an organisations' obligation linked to legislation but, in the cases that we have examined, this is mostly not the case. The drive for change has come either from an individual within the organisation who has taken an interest in the new technology or from an outside agent which may be a research institute, a related agency (i.e. a mapping agency) or it may be a commercial service provider. It seems likely that the former will engender more trust than a company proposing its services, yet we have seen examples of both of ways of driving organisational change in practice. To take two examples associated with highways management, in Italy, ANAS was approached by service providers whilst in Norway a research institute together with another executive agency (NGI) developed the service. Its adoption was then helped by the presence of an internal champion within Statens Vegvesen.

  To develop this point further, the absence of a change agent is clearly a strong barrier to understand the function of the satellite data. Sometimes an already enlightened enthusiast within

[40] SeBS case, Aquifer Monitoring in Spain.

the organisation may push for change (see Forestry in Poland as an example, or Highways in Norway), but in their absence, the organisation needs to develop a new internal expertise which is a high barrier to cross. This factor was also identified during a workshop organised by Nereus where Local/Regional Authorities (LRA's) in the Azores reported exactly this problem[41].

Trust in the agent is important. If both the agent and the implementing organisation are public, they are more likely to speak the same language – both literally and figuratively – and trust is likely to be easier to develop. It is interesting to notice that none of the cases discussed in this report involve organisations, as supplier and primary user, coming from different countries, which probably signifies the tendency for a public organisation in one country to favour working with someone who also has the same national base. For completeness, we wish to mention that in the other SeBS cases we had examples with parties from different countries (e.g. German company Eomap serving the Dutch company Van Ord or Hungarian company Geo Sentinel providing services to Romanian company Geo Search) but they were not numerous, and they mostly involved commercial actors.

Another factor which may be relevant here is the international reputation and even the size of the service provider. One can be reminded of the expression that "no one got fired for buying a Microsoft solution". Larger organisations tend to engender trust more than small ones simply from the point of view of business stability. A large organisation can be "trusted" to still be in business in 5 years time. However, we note that most of the commercial EO service providers in Europe are small[42], and this also may lead to problems with trust.

Very often, "EO-related innovation" is carried forward internally by enthusiastic individuals whom we often refer to as "champions". We have noted in several cases the importance of a champion and we do consider this to be a very important factor in making innovation happen. The champion, with greater or lesser support from their hierarchy, is instrumental in driving the project of adoption forward. In this regard, one risk factor is related to organisational change. A reorganisation can mean that the job of the "champion" changes and either becomes no longer relevant, or their new hierarchy are unwilling to support the project. We have seen this in several cases: one, where the champion moved to a new job and was no longer supported – despite his strong enthusiasm – whilst in another case, the champion's hierarchy changed above them and was slow to provide support. We derived from looking at these experiences the importance of embedding the project in the organisation – but we recognise that this is often difficult and, if no such embedding occurs, then it can become the ultimate barrier to adoption.

An agent for change may also come from elsewhere within the administration. A good example of this is the digitalization of public services in Germany driven by the Ministry of Finance. The interest in Baden Wurtenberg to use EO data for water quality monitoring fitted well with the wider objectives coming from the digitalization project. This unblocked some funding with which

[41] Improving Copernicus take up among Local and Regional Authorities (LRAs) via dedicated thematic workshops. Final Report June 2016.

[42] EARSC Industry Survey 2023. 66% of companies in Europe have less than 10 employees. Over 95% of companies classified as being an SME (<250 employees).

it was possible to develop the use of the water quality mapping using EO data. This project, reaching across national and regional administrations also provided a platform allowing to share knowledge and experience – a recurrent theme.

- We also looked at how **awareness of the new technology originates.** How did the organisation become aware of the solution? What led to someone in the organisation being ready to test it out? We have several examples here, but no systematic conclusion, as most cases seem to rely largely on individuals. What we noticed, however, is that research institutes may play a crucial role in driving innovation in public administrations: where a research institute is involved then they will likely have become aware of the new technology potential through their running research activities, and it is then appropriate that they can promote this towards the relevant organisations in their country. This leads to two interesting observations: firstly, a public research organisation is much more likely to promote in their own country and not outside, primarily due to their national remit and responsibilities, although this does not prevent the spread of awareness to other countries since research often involves international cooperation (e.g. for Horizon Europe[43] it is mandatory). Secondly, it is helpful if policies are in place which encourage the sharing of the research results both with public administrations inside a country and among research institutions across different countries. This may be certainly obtained through Europe-wide innovation initiatives, but national policies are also important to reach national administrations.

  European research projects are an excellent tool to share knowledge and build upon existing partnerships, internationally. We have some examples of this in the cases concerned. In Norway an international team developed the ground motion service and similarly in Finland, Syke work on many international projects including with Water Insight in the Netherlands. These are just the tip of the iceberg and, European projects sponsored by the EC or ESA require international teams, leading to building awareness, and ultimately to testing solutions, within the public organisations (especially the operational / executive agencies).

  A related factor is the role played by agencies at the EU level, which may drive standardisation as well as knowledge sharing and best practices. As a prominent example, we like to mention the EEA (European Environment Agency) which collects and makes available data across 38 European Countries (e.g. see EEA Datahub)

- **Validation of the solution and recognition of its fitness for the purposes of the organization:** This marks a major step forward**,** moving from being aware of a new technical solution to being ready to integrate it into the business processes of an organisation. To measure the impact, an evaluation procedure is essential. The presence of a trusted agent for this step is very important.

  Evaluation involves understanding the performance and limits of the potential service but more importantly how it can work within the organisations' constraints and regular practices. We have seen this in many of the cases. For example, in Italy, ANAS was supported by Planetek for the development of the service. Trust was built internally between the internal promoter and the

[43] Horizon Europe, the EU's framework programme for research and innovation, is one of the main tools to implement the European Union's Strategy for international cooperation.

manager of a road project. But evaluation went beyond this single step to testing the technology with several projects. This required hierarchical support to cover the bridge between two parts of the organisation concerned with overall planning of resources and the project manager and to allow the additional investment that was needed. As a result, the ground motion service is now being used across the organisation and has become a well-established process and has been reported in both internal and industry magazines[44].

In Germany, the use of the water quality monitoring service in the LUBW required investment. This was made easier by a wider project across the whole of the German administration to digitalise processes as much as possible. Whilst the investment did not directly support the core role of monitoring water quality, it did provide additional funding to provide digital services to the local population. The much larger digitalisation project, supported as it was by the German Federal Finance Ministry, enabled the adoption despite the absence of legislation (ref WFD) requiring its use.

In another example, we learn of a local authority (Veneto, Italy) which has a centralised Geospatial Information (GI) department. In this case knowledge regarding the use of EO is concentrated and can be deployed across the organisation. This would seem to be an effective way to build trust and awareness.

Evaluation may include an ex-ante assessment of benefits drawing upon similar SeBS cases. If no relevant case exists, the methodology is available and can be applied. In the case of pipelines in the Netherlands, the internal champion developed an impact assessment which was presented to the board for a final decision on adoption. We were working together on developing the case as part of his preparation.

In case the organisation does not have the internal competence, the existence of a cartographic institute (or organisation specialising in GI) is a positive factor. Several countries have such a public organisation i.e. Spain, Poland, Portugal, which have expedited the take up of Sentinel data.

A further tool, not encountered in any of the specific cases studied but worth mentioning, is pre-commercial procurement (PCP). This allows an organisation to test a technology adapted to their use before committing to a full procurement – which we shall look at in the next section.

Evaluation and ultimately adoption requires a significant level of innovation within the organisation. This may be directly affected by the overall culture as being ready to innovate and adopt change. The difficulty of innovation in public sector bodies, which conflicts with a bureaucratic role, has been recognised by the OECD which has established the Observatory for Public Sector Innovation (OPSI)[45].

- **Adoption and integration of the solution into the work processes of the organization:** at this point, the decision has been taken to adopt the technology and to embed it into the organisation

[44] https://www.lestradedellinformazione.it/rubriche/le-strade-della-tecnica/anas-storia-e-sviluppo-del-dato-satellitare
[45] OECD Observatory for Public Innovation, OPSI.

processes. The performance has been proven and the path to adoption, including full institutional buy-in, has become clear. Nevertheless, there are still some hurdles to cross!

Firstly, and probably the main concern is the budget. Knowledge gained through the evaluation will have led to an understanding of the budget required. This may take the form of Euros to procure a service or of people (employees) either constrained within a headcount or by the budget, to run the service internally – for examples, see the SeBS cases for water quality monitoring in the Netherlands and in Germany.

Secondly, are there adequate technical skills to make it work? Especially if the service is to be internalised, sufficient number of experts will be needed to run the service. Depending on its precise nature, this may require a service to operate 24/7 and good staff cover will be necessary. While not all services are linked to urgent tasks, there may be special skills required to develop a service. These skills are different to those “normal” for user organisation (foresters, surveyors, laboratory technicians etc) and the presence of a trusted agent may help in recruitment and deployment.

The implementation may even be external to the organisation. In the case of highways management, in Italy and in Sweden, the use of a ground motion service is mandated upon engineering companies tendering for a construction project.

Even if the technical skills are available within the organisation, training of staff will be needed to adapt existing processes to the new technology service. Provision for recruitment and training must be made as a part of the investment case. Again, this is facilitated by the involvement of a trusted agent from either the public or private sectors.

A further consequence linked to the introduction of new skills into an organisation, is where the service leads to efficiency savings – translated as a potential reduction of staff. This may be complex in a public body which may be reluctant to reduce its number of employees – especially where recruitment of new skills is also needed. For our three domains addressed in this report, only that for forest management leads to significant efficiency savings and we found this to be the case in Sweden. Foresters who managed the forests and monitored the clear-cuts before the introduction of satellite images, were all redeployed onto other aspects of forest management. As a result, the Swedish Forest Agency was able to do a better job once the satellite data was being used whilst maintaining the employment.

In some circumstances, further equipment is needed to make the technology effective. This is particularly the case for highways management where corner reflectors are deployed to make precise measurements of ground movement. These are equipment in a niche market, but which should become more readily available once more highways authorities are making use of them. Not just highways authorities but also in the realm of water management where underground aquifers are being exploited and ground surface movement is an issue.

At different stages of adoption, certain considerations apply which may make the task easier. Based on information gained in the informal discussions with SeBS case studies stakeholders, the following observations may apply:

- **Create a Digital Platform:** satellite data and derived information services are inherently digital products. Sharing of the services can increase their use whilst reducing associated costs. This may be most effective as part of a wider strategy to increase the use of digital technologies across the organisation or even across the administration as for the case in Germany. The platform could form part of a Spatial Data Infrastructure (SDI) which enables the imagery to be shared as is the case in Sweden. Where SDI's have been established, the knowledge and competence to integrate satellite imagery and maps into working practices is advanced. Of even more benefit is where a department has been established to provide geospatial data to the organisation. This concentrates the competence and enables wider use by those within the organisation.
- **Extending the uptake of the solution within the organization or across different organizations through digital platforms:** A further factor which appears in many of the cases, is that the uptake of EO solutions is often linked to the development of digital platforms that facilitate the exchange of the information. The use of common wide-areas maps allows to create a common reference across different departments/actors. For example, in Sweden, the decision to create an archive of satellite images, led to a closer collaboration between the forest agency and the environment agency. In Germany, the platform established to digitise the administration has led to better exchange between the regions and supported the adoption of the satellite-derived water quality monitoring service by the LUBW in Baden Wurtenberg.
- **Improve Conditions to Innovate:** the use of satellite imagery brings change to organisations both in its use and in the benefits which it can stimulate. Yet, the ability to innovate is often missing from public organisations as reported and addressed by the OECD[46]. This report from the OECD makes a number of key recommendations to increase innovation including specific trainings of administrators, facilitating the exchange of information, improving capacity to work across organisation pillars, and revising internal rules and practices to avoid bureaucratic barriers.
- **Establish an Internal Centre of Excellence:** within many public organisations the skills needed to **process** satellite data (or to procure satellite-based services) are not likely to be available internally. They do exist in specialist agencies dealing with cartography or Geospatial Information more generally as well as in universities and companies. With larger organisations[47] where the needs and use may be spread across many departments and/or partners, a centralised competence will be effective in driving benefits. For smaller organisations, an industrial presence may be an effective way to approach this.
- **Make links with external experts**: even if the organisation offers training and creates internal competences, this does not prevent the outsourcing of the activity to an agency or to a company. This limits the extent of the expertise required internally but does not remove it altogether. Procurement of external services requires that some knowledge is held within the organisation in order to be effective and efficient in the use of new services. External experts can partially but not entirely fill the role when the processing of data is externalised.

The findings described above are those we find relevant based on the 8 SeBS case studies highlighted within this report, plus additional interviews either in the context of the workshops or made

[46] OECD report "fostering Innovation in the Public Sector".
[47] This has been evident in ANAS and Statens Vegvesen which are large organisations with offices throughout the country. Indeed, both have addressed the issue of centralising competences, not necessarily for the use of satellite data, but to create a strong body of knowledge within an internal department.

individually, made for this analysis. They do not constitute a complete set of actions which may be taken.

5.4 Workshop Consultation

In a limited attempt to validate these findings and the model presented, a workshop was organized with representatives from OECD, 3 European regions and the CEO of a leading EO services company. Their views are useful to provide a reflection on the findings and to highlight certain of the factors identified.

The OECD, which has established a group to look at the use of technology by public organizations provided a perspective on the barriers for use of satellite data by public sector users. Key steps to be addressed involve greater co-operation between users for technical understanding, exchange of knowledge and best practices and consideration of co-operative procurement.

The region of Veneto in Italy has established a spatial planning directorate which has overall responsibility for the use of EO data within the region administration. This has a number of benefits including better planning policy, cost savings and the stimulation of small service businesses in the region. The necessary skills are gathered into one department. Nevertheless, uptake would be improved if a national initiative could establish a common procurement approach and knowledgeable resource.

The region of the Azores in Spain has identified a number of applications of interest but has so far not been able to adopt them as operational services. Examples were given of coastal algae blooms, air quality and marine debris. The latter was part of a project looking at pre-competitive procurement. A platform (an expert, multi-disciplinary, advisory council) was set up to address the challenges but has been frustrated through changes to the government and new membership of the council.

IMT Atlantique, a technical university in France covering the regions of Atlantique and Brittany, has established a support group to help overcome technical difficulties to adopt services by local authorities in the regions. One product for coastal vegetation monitoring has proved successful and has been introduced as an operational service. It has also been adopted by a region outside Brittany so helping to create new business for the supplier company concerned.

The commercial sector representative highlighted the need to make users aware that the services are now sustainable, thanks to large volumes and diversity of EO data. Most importantly, a closer intimacy is necessary between companies and the regional users. In this respect, EUGENIUS is a platform comprising a network of EO service providers, set up to help achieve this and it could be useful to boost and to develop the platform further.

As a result, several conclusions can be drawn with reference to the model for adoption:

- The use of high volume, EO derived digital products requires an investment in IT infrastructure which is often beyond the capacity of local and regional authorities. In this case, reliance on external suppliers can overcome the barrier if generalized (ie not specific to a region) products can be used. Otherwise, funding needs to be found to make the necessary investment or to procure services from an external supplier.

- The skills needed to procure and use EO services are quite specific and not normally available in regional organizations. This can be overcome through a partnership with a technical agency (ie cartographic or IT focused) which do have these skills available.
- This can be made easier also by creating a dedicated internal service department, as is the case in Veneto. Such a department provides greater awareness of the potential as well as a focus for skills and IT infrastructure which serves the wider organization.
- Changes to the governance structure delay or prevent progress. The oversight of regional agencies requires political support which, if changed, can be lost leading to the need to rebuild awareness amongst the decision makers.
- Procurement is an issue for many regional bodies which are not familiar with the specifics of Geographic information or EO services. Centralized government can help by providing guidelines and consultative expertise to provide advise and support to the regional bodies.
- There seems to be a significant benefit according to the OECD in establishing groups or networks of experts in the specific user domains. These can stimulate innovation as well as leading to the exchange of best practices and mutual support for adopting new processes which are driven by the use of satellite data.

These findings complement those found through the SeBS cases and provide additional support to the model of uptake and the barriers to overcome.

6. Conclusions

The SeBS methodology has proven to be an extremely useful tool, reaching its original goal to showcase the benefits of using data from Sentinel satellites, whilst enabling further analysis of common themes transversally, across the cases. Other SeBS reports[48] have covered many of the specific application details and our goal through this transversal analysis was to look at what further lessons could be learned by examining certain of the cases analysed within SeBS with a comparative perspective. We are able to draw some significant conclusions.

As well as the cases exposed, we have been able to broaden our understanding through workshops and discussions with representatives in countries not featured in the core work. It is important to highlight that all the SeBS cases feature, by definition[49], knowledgeable users and so there is a bias inherent in the analysis towards situations / organisations which have confronted the issues surrounding the adoption of the new services. This provides us with some insights into the experiences they have had but certainly misses situations where an organisation has not succeeded. In part, this lacuna has been covered by the workshops and discussions with countries where adoption is not yet realised. It is certain that, with further discussion in the future, some more lessons could be drawn from subsequent adopters.

It is important to recognise that our focus is on the experience of successful users i.e. those which have successfully integrated the use of satellite (Sentinel) data into their operational processes which is inherent in our methodology. We can learn from their experience, but we should also consider those users which have not been successful or have not even tried. Further work in this area could be productive.

The analysis presented in this report has looked at cases with common applications in three different topics. The benefits to public authorities coming from the use of satellite data are many and, whilst the first goal was to consider monetary / economic benefits, often qualitative, non-monetary benefits are even more interesting. Given the strong presence of cases where public organisations are the primary user, many benefits arise through the regulatory aspects. But benefits can also materialise elsewhere and at all tiers of the value chain – although not all tiers equally - for all cases.

The overall analysis of the SeBS cases leads us to conclude that **each case is different and must be treated on its own merits**. Even if some, or even most, of the same benefits can be found in cases dealing with the same problem but in different countries, several factors may cause divergence between apparently similar cases so the findings for one case cannot be applied "tout-court" to another one, without due considerations of the boundary conditions. These include – but are not limited to - the geography, the nature of the public organisation concerned and their precise role and governance in relation to other organisations, the accessibility of knowledge, the presence of EO service industry in the country and the receptiveness of the organisations to innovation. Each of these

[48] In addition to the case studies, the SeBS Overall Report, the SeBS Methodology Report and the SeBS Summary Report provide further information.
[49] One basic rule of our methodology is that the use of the Sentinel-based service is operational so that its use is understood by the experts within the organisation.

factors change the way in which the new service may be introduced and whether barriers exist to its adoption.

This does not mean that cross-comparisons do not lead to a deeper understanding. Quite the contrary, in fact. Many of the indicators that characterise cases are common with others and **knowing how benefits accrue in one case (or country) gives a strong base on which to understand another case (in another country)** and to have a better understanding of where benefits lie. But it does show that the results in one country cannot be simply extrapolated to another one. As discussed in section 5.1, this is generally possible, but with limited accuracy. However, understanding each case and what drives its benefits is a strong foundation on which to base the analysis in other countries.

The underlying conditions will also dictate whether – or how far - a service is beneficial or if other services may be given a higher priority. For example, we can think of the differences between the cases for forest monitoring in Sweden (primary user is the national forest agency) and in Portugal (the primary user is a trade organisation acting for industry) as well as the fact that monitoring stress in bridges is of more interest to Austria whereas in Italy and Norway the focus has been more on tunnels. This is not to say that the same interests do not exist rather that they are given different priorities. The countries have therefore derived expertise and experience on different aspects of the application. This is not contradictory but emphasises the specificities of the cases and also **the interest to exchange between agencies in different countries in order to build on each other's experience** and obtain a richer picture of what is possible and what works.

Another core aspect of the SeBS methodology is that cases are examined where the key organisation – the primary user – has adopted the technology in their processes. In other words, the service is operational. Hence, one of the most concrete results of the transversal analysis is to contrast the experience from these "innovated" organisations with regards to those that have not or that are still in a testing phase. The uptake process has been described in Section 5.3, and the analysis of where the different organisations stand in it helped to investigate the factors that lead to the adoption of the service by an organization. Are there core barriers to the uptake of space-based solutions? What factors help to reduce the barriers? We have discussed these factors as they feature within a possible adoption of the service into the organisation and how these may be addressed. We conclude that, the **challenges largely depend on the adoption level of the organization** and that the benefits only fully accrue once the service has been fully adopted. This should be taken in due account in every analysis**.**

In consideration of the above and reaping from the experience of the workshops and the interviews, we noticed that one common factor appears many times, which is the **benefit of a forum for exchange amongst peers**. One could observe that many of the agencies mentioned in this report already exchange in specialized fora, but the participants to the fora are not fully aware of the possible impacts of EO technologies. Introducing the topic in small fora would allow some preliminary quick **sharing of best practices** and a better understanding of the difficulties which may be met or overcome. Through our transversal analysis and the exchanges that we had with the various volunteers, we received generally positive feedback on holding these exchanges. Interestingly, the networking was found beneficial not only for the organization who have not yet developed competencies but also for the ones who are most advanced because there is a value in the capability to benchmark their own activities.

Our overall conclusion is that establishing such **networks of peers** should be made a priority for Copernicus and for those seeking to increase the uptake of satellite data into public organisations.

Furthermore, we see in a number of cases that co-operation can benefit by extending across national borders. Common problems arising in neighboring countries provides a strong stimulus for working together. The clearest example we find is that to address the bark beetle, but it is equally relevant for other problems such as water resources, flooding, forest fires and other emergencies as well as pollution. A **Network of peers addressing these issues could develop a momentum where success in one domain can encourage similar achievements in others**. Where European agencies exist, e.g. the EEA for the environment, EMSA for marine pollution, then there are structures which naturally promote such co-operation and exchange and indeed both the agencies mentioned above do sustain international networks of experts. However, in many of the domains there is no European body and hence no basis on which to build a network of peers. This could be a useful step to take with Copernicus as its focus.

A common message concerned the lack of skills. Smaller organisations which are often devolved responsible for data gathering for reporting as well as management of assets whether forests or water, do not have the skills available to them. This can be partially overcome through proximity of specialist organisations (cartographic institutes), sharing of knowledge (network of experts) and centralized resources being made available to local/regional administrations. **A centralized resource should be built up to give support and guidance to regional bodies**.

In conclusion, the methodology developed and followed by SeBS allows a rich understanding of cases where Sentinel data has been used in operational services to support organisations in many domains. Building a portfolio of cases permits a broader analysis over and above the cases themselves and provides insights into how the Sentinel data can be used. In this report, we have followed this process to elucidate findings in three domains (highways, forests and lake water quality) which we hope may be useful to other organisations interested in adopting Sentinel data and Copernicus services for their benefit as well as for society and the environment.

Please feel free to contact the authors or ESA for further information or discussion.

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