Copernicus and Environmental Compliance Assurance

European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

Showcasing examples of regulatory benefits

Copernicus and Environmental Compliance Assurance

SEBS Analyst Task 2.2

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1 Background

4.1 The Sentinel Benefits Study

This analysis is carried out in the context of the 'The Sentinel Economic Benefits Study' (SeBS). This 4-year study is developing cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The current report supports deeper refinement of the methodology for assessing regulatory benefits, narrowing the focus to the specific context of environmental compliance assurance, and providing insights on new potential cases from this domain.

4.2 Environmental compliance assurance within the EU and within the Copernicus programme: legal framework

Legislation on environmental compliance has a long history. Over several decades, countries have signed treaties and implemented provisions at national or local level in order to achieve global or localised environmental goals. From the Montreal protocol and the UNFCCC, to regional and local measures: a multitude of initiatives of varying scope, and with greatly variable success has been put in place. At a time when the adverse effects which human activities have on the environment and the climate have never been more prominent in the global media, the domains in which environmental compliance is required have broadened significantly. The sources of these requirements and the range of means with which to both implement and assure compliance have also grown more numerous.

Of note in this regard is the Copernicus programme, which collects and combines vast amounts of validated data from space and in situ sources and makes it freely and openly available, as well as providing a range of services related to the environment, emergency management and civil security. Not only has the programme itself been originally and purposefully created with an environmental mission, it provides impetus to a growing downstream applications sector.

The proposal for the EU Space Regulation[1] has opened the door for developing methods to support the monitoring of compliance by public authorities, whenever an appropriate legal framework allows it. New ways to use Copernicus data for such monitoring applications are being developed, tested and applied in both the public and the private sector.

In order to effectively enact compliance, both monitoring and enforcement must be considered, altogether with the promotion and dissemination of policies. In general terms, enforcement, whenever possible, has a notable deterring impact on potential offenders, but is inefficient without regular monitoring. Both monitoring and enforcement of environmental compliance vary in their implementations, due to the various limitations that are encountered in specific cases, such as lack of jurisdiction or funding.

The European Union (EU) and consequently its Member States, maintain some of the world's highest environmental standards, whilst aiming to promote these further and engage stakeholders even beyond the Union's borders. The EU's environment policy thus, has solid legal grounds and is based on the explicit

[1] *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the space programme of the Union and the European Union Agency for the Space Programme…* COM/2018/447 final - 2018/0236 (COD)

commitment to combat climate change[2] and on the EU's commitment to sustainable development as an overarching objective and to a "high level of protection and improvement of the quality of the environment"[3]. As a result, promoting and assuring environmental compliance is a cross-cutting and fundamental element of numerous EU policies[4].

In 2018 the Commission presented a Communication announcing EU actions to improve environmental compliance and governance[5], containing an **Action Plan** aiming at creating a "*smart and collaborative culture of compliance with EU environmental rules on activities such as industrial production, waste disposal and agriculture*" through "*prohibitions, general binding rules, permits and other measures put in place to protect the environment, public health and society's long-term resource needs*". The Communication estimates the annual costs of non-implementation at EUR 50 billion[6]. The Action Plan requires:

i) **compliance promotion** (e.g. with EU's air quality index),

ii) **compliance monitoring** (e.g. on maritime security and oil spills) using inspections (in situ or remote) to provide solid evidence for enforcement, incl. examination of complaints by the public,

iii) **follow-up and enforcement** (e.g. with infringement cases as experienced with the Habitats Directive)[7].

An overview of the intended goals is presented in the table below[8]:

EAC type	Compliance promotion	Compliance monitoring	Follow-up action and enforcement
Principal goals	❖ Communicate to the general public, media and duty-holders the importance of compliance, in particular for protecting the environment and human health;	❖ Verify compliance; ❖ Identify, detect and characterise the nature and extent of non-compliance, identify those responsible and establish a causal link to	❖ Bring non-compliance to an end as soon as possible; ❖ Prevent, limit and remedy or offset the harm caused

[2] Art 191, TFEU
[3] Art 3, TEU
[4] Notable recent examples of such legislation include The Green Deal and the Recovery Plan for Europe. Fore more instances, see *The EU Environmental Implementation Review 2019: A Europe that protects its citizens and enhances their quality of life* SWD(2019) 111 final
[5] *Communication from the Commission to the European parliament, the Council, the European Social and Economic Committee and The Committee of the Regions – EU actions to improve environmental compliance and governance* COM/2018/010 final
[6] *Id.*
[7] Kucera, J., Janssens-Maenhout, G., Brink, A., Greidanus, H., Roggeri, P., Strobl, P., Tartaglia, G., Belward A., M. Dowell, *Copernicus and Earth observation in support of EU policies - Part I: Copernicus uptake in the European Commission*, EUR 30030 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-14559-2, doi:10.2760/024084, JRC118879
[8] For further description of the aspects of environmental compliance assurance, ANNEX 4 COM/2018/010 final- *Supra 5*

	❖ Provide advice and guidance to duty-holders on how to comply with relevant obligations; ❖ Help duty-holders to achieve and maintain compliance as efficiently as possible, thereby reducing costs; ❖ Recognise and reward excellence in achieving compliance; ❖ Facilitate and encourage self-monitoring, self-certification, self-reporting of compliance and non-compliance, and voluntary environmental auditing by duty-holders.	the non-compliance detected; ❖ Analyse the causes of non-compliant conduct; ❖ Contribute to compliance enforcement and promotion, and rule-setting	to the environment or human health; ❖ Apply the polluter pays principle and ensure that non-compliance does not bring economic advantage to the culprits; ❖ Deter and prevent future non-compliance

Table 1-1 Description of the goals of environmental compliance assurance

In order to fulfil the above goals, the Action Plan defines nine concrete actions, summarised as follows:

1. Improve the deployment of environmental compliance assurance expertise across the EU, through, for example, peer reviews, joint enforcement actions and compliance assurance visits
2. Encourage professional training
3. Facilitate the sharing of good practices and knowledge
4. Help the fight against waste and wildlife crime
5. Better ensure compliance in rural areas (land and water)
6. Prepare technical guidelines for inspections of extractive waste facilities
7. Prepare documentation on good practices in the handling of environmental complaints and citizen engagement at Member State level
8. Build up the capacity and use of geospatial intelligence for compliance assurance and promote good practice projects (e.g. using Copernicus data)
9. Provide Member States with better feedback on how they are doing

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The more recent **Endorsed work programme 2020-2022 to improve environmental compliance and governance**[9] lists a set of actions "*designed so that Commission services, Member State authorities and environmental compliance assurance networks work together in areas of mutual interest with the aim to help foster better environmental compliance and governance at national, regional and local level*"[10][11]. The nine actions build upon the 2018 Action plan, and are the following:

1. Strengthen inter-actions with EU-level environmental compliance assurance networks
2. Environmental compliance and governance for the European Green Deal
3. Create and support tools for sanctioning environmental criminals and offenders, and for making the polluter pay
4. Work together on access to justice in environmental matters
5. Being smart – using geo-spatial intelligence
6. Prepare a compilation of CJEU rulings on the obligation for Member States to remedy failure to carry out environmental assessments
7. Establish a strategic approach to training and deliver tailored training activities through the networks of environmental inspectors, police, prosecutors and judges
8. Strengthen cross-network cooperation and development of environmental expertise
9. Strategies for verification of self – monitoring and reporting

Of special interest is Action 5, aimed at *"helping Member States and network members optimise their use of geo-spatial intelligence and make it operational for environmental compliance assurance. It will seek to strengthen capacities, promote good practices and prepare an inventory on GEOINT use"*.[12] It introduces the notion of "Geospatial Intelligence" (GEOINT) as "actionable knowledge" and a tool for environmental compliance purposes.

Furthermore, environmental compliance assurance has a special place in the **regulation** on the EU Space programme, where, starting from the preamble, it is foreseen that Copernicus should deliver environmental compliance assurance (among others, through prevention activities)[13]. This shall extend and

[9] *Endorsed work programme 2020-2022 to improve environmental compliance and governance Environmental* Compliance and Governance Forum, 2019
[10] *Id.*
[11] The timeline of the work programme concerns the period 2020-2022 and as of now, the status of the realisation of the foreseen paths towards ensuring environmental compliance is unclear .
[12] *Supra 9*
[13] *Supra 1,* (53) from the preamble: "*In particular, Copernicus should deliver, at the local, national, European and global scale, information on the state of the atmosphere; information on the state of the oceans; information in support of land monitoring supporting the implementation of local, national and Union policies; information in support of climate change adaptation and mitigation; geospatial information in support of emergency management, including through*

encourage the use of Copernicus data and services for environmental compliance assurance beyond the current fields of applicability. Further in the proposal, the most notable re-appearance of the term "environmental compliance assurance" occurs in Article 50, where it stands hand-in-hand with monitoring and reporting, the traditional pillars of the European Earth Observation programme. This recognises the independent value of the concept of environmental compliance assurance, as well as its relevance across the environment-focused Copernicus services (CAMS, CMEMS, CLMS, C3S) - whose data have on numerous occasions provided, and will continue to provide, significant contributions towards the EU environmental policies.

2 Scope and Objectives

This study will attempt to explore the multi-layered (current and potential future) relationship between environmental compliance assurance and the Copernicus programme, stemming from the use of Sentinel data across a number of case studies. It will do so by looking into various environmental legislations and policies, and illustrating through factual examples the role Sentinel data play, or could play, in their implementation, monitoring, and enforcement.

The task will seek to elucidate value chains in the case studies, and demonstrate how bodies and professionals such as inspectors, auditors, police officers, judges, prosecutors and the duty holders[14] themselves, might reap non-economic regulatory benefits from the Sentinel data along these value chains.

3 Methodology

The activity has been approached through the following subtasks:

1. **Identify policy areas for investigation.** There are certain domains which benefit from environmental compliance assurance supported by Copernicus or the Sentinels, or which have strong potential to do so. For the purposes of the study, we have examined regulations linked to:
    - The Common Agricultural Policy
    - The Water Framework Directive
    - The Marine Strategy Framework Directive
    - The Habitats Directive
    - The Clean Air family of directives

prevention activities, environmental compliance assurance, as well as civil security including support for the Union's external action."

[14] i.e. natural or legal persons, including public authorities, who must respect obligations derived from EU environment legislation when carrying out activities that involve emissions into or other physical impacts on the environment.

- The Ship Recycling Regulation

While a wide-ranging analysis in this respect is beyond of the scope of the study, a brief overview has been crucial for the selection of a few prominent showcases demonstrating the roadblocks in the respective fields, and how (and if) these can be removed in order to fully reap the benefits available through Earth observation. The exercise connected established **policies that require environmental assessment**, and **Copernicus-based solutions currently employed** to tackle these problems.

2. **Select use cases demonstrating the potential benefits of Copernicus Sentinel data and services to environmental compliance assessment stakeholders**.

Amongst the case studies considered are the following:

- Illegal logging in the Białowieża forest
- Monitoring ship recycling facilities located outside of the EU
- Use of Copernicus data by the European Maritime Safety Agency (EMSA) to detect oil spills
- Use of satellite data in detecting potentially harmful algae blooms and water quality
- Monitoring subsidence thresholds for aquifers
- Use of satellite data to assess the temperature of cooling water released from nuclear power plant
- Use of satellite data for biotype-type mapping
- Use of satellite data for wetland functional assessment[15]

Each case study incorporated the elements below.

a) **Identify the benefits which Copernicus has already demonstrated in the context of environmental compliance assurance.** This sets the scene in order to identify areas for further development.

b) **Clearly identify value chains** (where possible), showcasing the immediate and extended benefits of Copernicus/Sentinel data.

c) Seek input from stakeholders to **better understand their experience with Sentinel data**. Practitioners, networks, and institutions and other parties from both the private and public sector are directly interested and invested in the assurance of environmental compliance. This task is therefore focused on exploring the needs of the demand side, with the ambition of identifying common ground, or specific obstacles, and potential for expansion.

[15] For more instances see for example "*The ever growing use of Copernicus across Europe's regions*", Nereus, 2018, available at: http://www.nereus-regions.eu/copernicus4regions/publication/

Candidates include:

- European Network of Prosecutors for the Environment (ENPE)
- European Union Network for the Implementation and Enforcement of Environmental Law (IMPEL)
- Environmental Crime Network (EnviCrimeNet)
- European Maritime Safety Agency (EMSA) in relation to both CleanSeaNet and the Copernicus Maritime Surveillance (CMS)
- The EU Forum of Judges for the Environment (EUFJE)
- The European Organisation of Supreme Audit Institutions, specialised working group on environmental auditing (EUROSAI)
- The European Network of the Heads of Environment Protection Agencies (NEPA), in particular the Better Regulation Interest Group (BRIG)
- The European Investment Bank
- Private companies providing Copernicus-based instruments for environmental monitoring such as CybELE and 20tree.ai

3. **Draw conclusions and extrapolate findings.** Bring together a comprehensive overview of the ongoing environmental compliance assurance instances and of the benefits offered to them by the Copernicus programme: as currently standing, or on the road to consolidation.

4 Mapping of stakeholders

The field of environmental compliance assurance spans local, national, and international institutions. The stakeholders actively involved by the European Commission in the implementation of these policies are **environment agencies, inspectorates, police officers, prosecutors, and judges**[16].

- **Environment agencies and institutes** are in charge of implementation and monitoring of environmental compliance within the Member States. While their mandate is established and subject to national legislation, often the latter reflects EU principles and norms, and sometimes the two are not necessarily distinguishable. *E.g.* within the EU environmental agencies are the state bodies in charge of reporting for water quality, as dictated by the EU's Water Framework Directive.

[16] These stakeholders are also present within the Environmental Compliance and Governance Forum – in charge of assisting the Commission with the coordination and monitoring of the implementation of the actions to improve environmental compliance and governance as well as in the preparation of legislative proposals or policy initiatives in the field of environmental compliance and governance and other similar tasks.
https://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=3574

- **Inspectorates** are responsible for monitoring compliance and for identifying contraventions. Relevant are the supreme audit institutions (SAIs) – national bodies auditing other public authorities on their actions, including environmental aspects. (*e.g.,* overseeing construction works close to protected areas and potential overpassing of permits).

- **Law enforcement entities** such as police forces, marine guards and task forces work together at local and regional levels. Their aim is to make sure that binding legal norms[17] are respected, and perpetrators identified, pursued, and deterred.

- **Judges and prosecutors** have jurisdiction over potential environmental crimes, and the challenging task of verifying whether laws and regulations have been breached, and to what extent. While prosecutors generally hold inquisitorial functions, it is the judges who impose appropriate sanctions, or provisionally suspend suspicious activities, pending decisive proof.

Other notable stakeholders in the field of environmental compliance assurance include the following:

- **Legislators** create norms and systems of environmental legislation. National legislators within EU Member States both create laws and incorporate principles transmitted through international or EU law. In a field as technical as environmental compliance assessment, this is done in (ideally close) liaison with the scientific community.

- **The private sector** provides services and products (to other interested stakeholders) contributing to environmental compliance assessment. In the field of Earth observation, private companies often find themselves in a position to fill gaps in the available resources of public stakeholders, *e.g.* by providing data for monitoring and as evidence in stage of enforcement.

- **The scientific community** provides services and recommendations to legislators and other stakeholders and develops R&D applications, some of which eventually result in new standards for compliance monitoring, reporting, and forecasting.

5 Analysis: Case studies

The analysis has been implemented through case studies exploring the experiences of various stakeholders using Copernicus[18] and Sentinel data for environmental compliance assurance and the obstacles they encountered in the process.

[17] Legal norms encompass laws and other binding obligations imposed by legal sources, *e.g.* EU directives and regulations, regional/local legislative and normative acts, etc.
[18] Throughout this document, "use of Copernicus" implies the use of any data and service information from the Copernicus programme, including satellite data from the Sentinels or the Contributing missions, modelling data, or information from the Copernicus services.

5.1 Use of Copernicus in environmental crime court proceedings

Court proceedings for environmental compliance assurance within the EU fall under a number of very different jurisdictions, and while there has been some harmonisation through EU legislative efforts[19], the Member States have implemented these in their own ways, and within differently structured legal systems. For instance, some consider environmental crime a criminal offence, others view it as an administrative (civil) matter, with diverging consequences in these two cases[20].

The **potential of satellite imagery for use in court for environmental cases** spans a vast range of topics: illegal logging, waste, and any other form of violation of environmental laws and regulations that can be assessed from space, even more in cases when historical data is also available. Nonetheless, there are some **obstacles arising around its use**, connected to the **verifiability and traceability of data** shown within satellite imagery and simply, to its **interpretation.** All these factors are crucial for the **admissibility of the evidence** (being judged acceptable or valid for use in the court case, according to the applicable laws) **and its probative value** (being sufficiently convincing to prove an argument). For the purposes of our analysis, we take a closer look at each.

Awareness of the potential of satellite data in the context of environmental compliance assurance is an important consideration. There is some awareness amongst specialised stakeholders (*i.e.* environmental judges, prosecutors). However, specialised environmental profiles within European jurisdictions are rather rare and the use of satellite imagery in courts remains uncommon. In practice, even when it has actually been used as proof of illegal activity, satellite imagery is rarely used alone, but rather as a complement to other evidence. This brings us to the question of **precision and adequacy of satellite imagery.** For instance, in the case of oil spills from ships, satellite data alone cannot differentiate between a natural phenomenon or human-induced pollution. It is necessary to further cross-reference it with other types of data, such as weather, surface temperature, winds, algae bloom cycles etc. Furthermore, there is the need for more detailed data to be presented in court (*e.g.* specific chemicals, units and levels within the oil spill) which satellite data cannot provide.

[19] For instance, *Directive 2008/99/EC of the European Parliament and of the Council of 19 November 2008 on the protection of the environment through criminal law*

[20] In practical terms, for instance, criminal law tends to preserve more guarantees around the right of the persons (physical or legal) involved. Civil and administrative procedures offer less guarantees and aim at sanctions perpetrators, while oftentimes ignoring figures relevant under criminal law, such as inciters and abettors.

Precision aside, admissibility of satellite imagery or data in court is also dependent on the **accessibility of the data, and on assurances of its authenticity throughout, and as a result of, the interpretation process**. Obtaining an image (or data) from a satellite requires a certain degree of technical expertise, which can often act as a barrier. Although some satellite imagery is available on the Internet, it is often historical, and in most cases, litigants need recent imagery. Finally, the acquisition of these images can pose a significant cost, and thus a significant barrier for individual victims, unlike for insurance companies or public administrations. Another determining factor is that litigants most often need data in a processed and analysed form; while software offers the possibility of producing "tailor-made" images highlighting the information that the user needs, it is not possible for a court to ensure the reliability of this image. Hence the **need for a certification system;** save for rare cases provided by law, no certification system for authenticating Earth observation data currently exists. This problem arises mainly because of the data processing and interpretation phases: while primary data are relatively indisputable, processed and derived data are not, as they represent the result of a series of more or less complex operations involving transformations carried out by software and/or through human intervention. To ensure that these interventions do not affect the veracity of the imagery, each step would need to be individually controlled. A body (or bodies), at national or international level, which would be responsible for the certification and standardization of data, could be an appropriate solution in the future.

While judiciary proceedings play an important role in the assurance of environmental compliance, they are not the only factor. In fact, the concept is much broader, and national, international and European bodies have the mandate of assuring compliance in realms where Copernicus/Sentinel data can contribute to both monitoring and enforcement, to different degrees and in different cases. They are numerous, and a few of them – with regards to their importance, innovativeness and the obstacles encountered, are discussed in the context of the case studies which follow.

5.2 Use of Copernicus in environmental audits conducted by supreme audit institutions

The supreme audit institutions (SAIs) are independent state structures with the mandate to audit public bodies. The nature of the audit varies by country and by subject matter, but is similar when it comes to environmental auditing – within EUROSAI and its umbrella organisation INTOSAI (of which EUROSAI is a regional branch).

An environmental audit, according to these stakeholders, is a complex and thorough process, which is executed and planned *ad hoc*. **Data availability** and **access to the data** are crucial, and so is independence of the auditors and of the data sources. This represents an excellent match for Copernicus, which aims to benefit primarily European public bodies[21], and which has the potential to provide valuable tools for cross-checking the results of the audit, obtained by different means.

[21] The core users of the Copernicus programme are identified as: "*policy-makers and public authorities who use the information as a basis for developing policies and legislation, such as in the environmental field or civil protection in the event of a natural disaster or humanitarian crisis.",* source: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM%3A2702020

Two reports attest to the **evolution of the awareness** of possible uses of satellite data for environmental auditing: from 2013 and from 2019. The earlier one[22] discusses the use of satellite data and GIS in a chapter dedicated to "*Future directions in the use of environmental data"*, presenting a number of success stories[23]. In the 2019 report[24], the use of remote sensing is far more prominent, and it introduces the practice and the techniques to benefit from it. One chapter focuses on the open environmental data available from satellites, where the Copernicus program is barely mentioned. This can be explained by the international character of INTOSAI which goes much beyond the European borders, and possibly by the fact that the report was led by the SAIs of non-European countries (India and the USA).

Throughout contact with the chair and members of the EUROSAI WGEA, as well with a member of the INTOSAI WGEA, we had the opportunity to discuss their previous experience with the use of Sentinel – and broadly, satellite data. The shared cases can be divided into a few categories:

- Cases where satellite data have been used: e.g. asserting the overcoming of the boundaries on permits to dig sand; illegal forest logging.
- Cases where satellite data were considered, but not used: e.g. due to the **lack of capacity to make cross-analysis.**
- Cases where satellite data could be useful but were not considered.

The majority of cases fall into the last group. The following factors were identified by the SAIs as potential obstacles to the use of satellite data in the audit work of the SAIs:

- **Access to data** should not be an issue for SAIs within EU countries - as designated Copernicus core users, nor for countries benefiting from data exchange under a cooperation agreement with Copernicus. In these instances – in principle - other state institutions already work with satellite data and the SAI could either spontaneously collaborate with them, or request data and services through these other actors. In practice, however, some interviewed SAIs were uncertain if they would have a mandate to request data and what would be the precise path to follow to obtain them.
- **The cost of data** should, likewise, not be an issue in the context of the Copernicus programme's full, free and open data policy[25]. Costs remain a concern for EO data provided outside the Copernicus programme.

[22] *Environmental Data: Resources and Options for Supreme Audit Institutions (INTOSAI WGEA,2013)* available at: https://wgea.org/media/2942/2013_wgea_environmental-data_view.pdf

[23] E.g. see *"Conservation Group Uses GIS to Help Save Rare Ethiopian Wolves" available* at: http://www.esri.com/news/arcwatch/0510/feature.html

[24] *Training Tool on Environmental Data: Resources and Options for Supreme Audit Institutions (INTOSAI WGEA,2019)* available at: https://wgea.org/media/113693/23g-wgea_environmental-data_2019-fin.pdf

[25] It is worth noting that the 2019 INTOSAI report references cost as one of the downsides of using satellite data. The report does not, however, refer to Copernicus.

- **Data processing** poses further challenges as such competencies are not often found in-house. Within certain constraints, SAIs are authorised to subcontract when necessary. This represents an additional cost and SAIs indicated their interest in investing in cases where the satellite data itself can provide decisive proof, without the need to be cross-referenced with other information sources.

- **Awareness of the potential of satellite data** is limited. While abstractly aware of the possibility to use satellite data, some SAIs do not have knowledge of either the practicalities or the concrete benefits. For example, a case that easily falls under the scope of Copernicus does not necessarily appear to the SAIs as a case in which satellite data can be used, despite the overlap between fields of interest of environmental and realms where Copernicus data have proven to be - fully or partially - useful. Satellite data becomes interesting if i) the data cannot be obtained by other means, and ii) the data is decisive and self-sufficient as an evidence in the audit.

5.3 Use of Copernicus by EU Member States implementing the Water Framework Directive

Water quality monitoring in Europe aims at providing means and procedures for controlling pollution and enforcing protection legislation. The Water Framework Directive (WFD)[26] prescribes regular monitoring and reporting of a series of parameters relevant for determining the ecological and chemical status of a water body. Traditionally, the monitoring activities of Member States are largely dependent on **in situ measurements, as often these cannot be replaced** by other means. Other times, however, Earth observation, and **Copernicus in particular, provide feasible solutions for using the programme's full free and open data to assess water parameters**[27] [28] by aggregating EO with in situ data. This could lead to more precise measurements and could even reduce manual labour and the related costs[29] of traditional in situ monitoring, both for public authorities in charge of monitoring and reporting under the WFD (*i.e.,* environmental ministries, agencies and similar bodies) and the interested private sector (*e.g.*, tourism and fisheries associations).

Notwithstanding the potential benefits, **few countries use Earth observation to monitor and report water qualities**, even for parameters where this is a suitable alternative. **The main obstacle is the fact that the reference methods provided for in the Directive do not include Earth observation**. This missing formality precludes its use by many public bodies, who cannot justify budgetary expenditure on non-referenced methods, even if this may ultimately result in greater efficiency and better use of resources.

[26] *Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy*, OJ L 327, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060

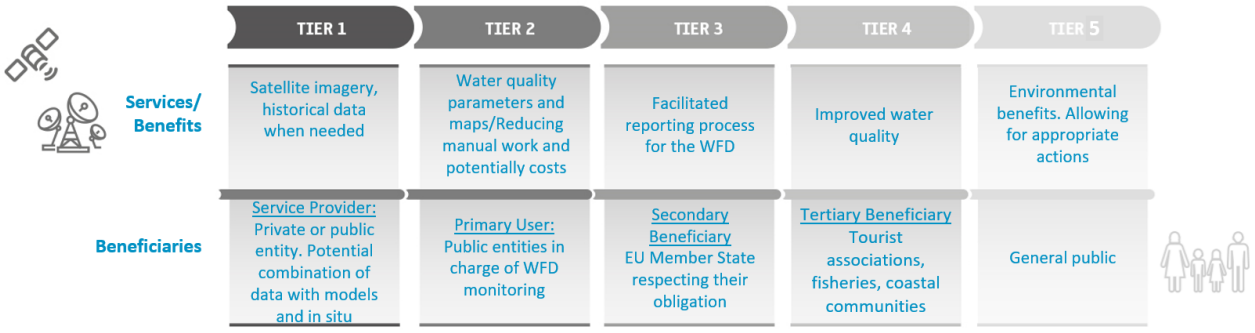
[27] Among others, macrophytes and chlorophyll-a. Transparency or turbidity can be easily determined, even from high-spatial resolution sensors.

[28] *White paper*: *Satellite-assisted monitoring of water quality to support the implementation of the Water Framework Directive.* available at: https://zenodo.org/record/3556478#.XtYqNTozZhG.

[29] Especially for episodic phytoplankton blooms; EO could offer a better cost-benefit ratio compared to the number of site visits required otherwise, as well as optimising the location and timing of samples for better representativeness.

A prominent example of a country which has successfully used satellite data for reporting under the WFD is **Finland**, whose use of EO in the field dates back to the late 90s[30]. The country used chlorophyll-a time-series of satellite-derived data for coastal waterbodies in the 2014 WFD assessment and later introduced satellite-derived metrics to support WFD assessments in the 2015 – 2021 reporting cycle[31]. **Sweden** also used satellite observations (from the MERIS instrument, 2002 – 2012) to provide phytoplankton (from chlorophyll-a) and transparency metrics for the 2014 WFD status classification. Sweden is incorporating satellite-based Earth observations of chlorophyll-a for the ongoing 2nd round reporting (2015 – 2021) for coastal waterbodies[32]. In another SEBS study[33], a deep analysis of a case has been carried out, where the local responsible authority in Baden-Württemberg has employed a private remote sensing company providing EO services for water quality assessment. While this is not a country-wide practise, the case nonetheless raises an interesting point on the **emerging market of private companies** providing to institutions and other interested parties satellite-data-based products for the purposes of inland water quality assessment and monitoring and potentially reporting under the WFD.

Moreover, Sentinel-2 and Landsat data can be used for monitoring of riverine impact areas and assessing how small and medium rivers flowing into the sea impact the nutrient content of coastal waters, and thus assessing compliance with the Nitrates directive, aimed at protecting against water pollution from agricultural sources[34].



Use of EO data and beneficiaries in the case WFD-related water quality reporting

[30] *Water quality monitoring using remote sensing in support of the EU water framework directive (WFD): A case study in the Gulf of Finland* – available at: https://www.researchgate.net/profile/Martti_Hallikainen/publication/6888706_Water_Quality_Monitoring_Using_Remote_Sensing_in_Support_of_the_EU_Water_Framework_Directive_WFD_A_Case_Study_in_the_Gulf_of_Finland/links/0deec52e2464f6d8e7000000.pdf

[31] The Finnish success is partially due to the presence of in-house users: the Finnish Environmental Institute provides EO data and products, as well as being the user/consumer of such services. Moreover, the Finnish Presidency of the EU in 2020 ran several campaigns for the use of EO for environmental assessment.

[32] *White paper,* supra note 28

[33] Full case will be published here: https://earsc.org/sebs/

[34] *Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/EEC);* available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1561542776070&uri=CELEX:01991L0676-20081211The nitrate directive is an integrate part of the WFD.

5.4 Use of Copernicus by the European Maritime Safety Agency: gaps and opportunities

The European Maritime Safety Agency (EMSA) provides the **satellite-based oil spill and vessel detection service CleanSeaNet** to participating states. It uses **synthetic aperture radar** (**SAR) data from Sentinel-1**[35] (as well as from RADARSAT-2 and from TerraSAR-X) in order to:

- Detect and trace oil pollution on the sea surface, and contribute to the identification of potential polluters;
- Monitor accidental pollution during emergencies;
- Support specific oil spill monitoring operations and pollution related exercises.

CleanSeaNet products are delivered in quasi-real-time to users (20 minutes after satellite acquisition) and are useful for detecting oil spills and hence for assuring compliance to the MARPOL convention[36] (and more specifically to *Annex I - Regulations for the Prevention of Pollution by Oil*) of which all EU Member States are parties, and whose standards are being held in high regard by the EU[37]. Moreover, and albeit the main purpose of CleanSeaNet is the monitoring of oil spills, the service is also currently detecting and reporting other types of pollutants, such as sewage or garbage (Annex IV and Annex V of the MARPOL convention).

Satellite data allows frequent and wide-scale observations and so allows the coverage of very wide areas. Moreover, the main advantages of **SAR-based satellite information are the ability to monitor in all weather conditions, and during day and night**. On the downside, SAR satellites data cannot be used to distinguish the type of oil, nor to provide quantification of the volume of the spill, which can be crucial in assessing if a discharge is legal or not.

Sentinel-2 can potentially be used for providing additional information on oil spills (such as type and volume estimation), which is currently being assessed in terms of research and development and can potentially be deployed into operations in the medium term. Furthermore optical satellites can also support the the characterization of other substances (e.g. sewerage, garbage and Hazardous and Noxious

[35] EMSA uses data acquired through the two main acquisition modes (IWS and EWS) of the Sentinel-1's SAR instrument. More than 85% of the data use in CleanSeaNet is from Sentinel-1

[36] *International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto and by the Protocol of 1997*

[37] Environmental protection, which is the subject-matter of MARPOL and its amendments, is a shared competence between the EU and Member States (art. 4 TFEU). This has allowed the union to legislate through echoing, and oftentimes through dictating even higher standards for Member States: Directive 2005/35/EC on ship-source pollution and on the introduction of penalties for pollution offences, as amended by Directive 2009/123/EC, provides that any intentional or seriously negligent infringement of those standards, whether in the coastal waters of Member States or on the high seas, shall be effectively dealt with and should even be regarded as criminal offence. The enforcement is on Member States, whose coastal authorities are encouraged to collaborate between themselves and with the assistance of EMSA.

Substances – HNS). However, this activity still requires extensive research and development efforts, ongoing on behalf of both private companies and research institutions[38].

Optical imagery could also potentially be used for monitoring marine litter. Sentinel-2 can possibly be used - in areas with high accumulation of plastic on the surface, and contingent to further R&D activities on the feasibility.

Time is a valuable asset in maritime imagery: independent of whether SAR or optical. The time needed to acquire the imagery can vary; **currently, near-real-time acquisition is possible within the coverage of the ground station masks** in Europe. However, it is not available for areas outside from the continent. Such problem could potentially be overcome through the use of the Space Data Highway (previously known as European Data Relay Satellite System (EDRS). At present, commercial missions are used to complement the Sentinels in order to improve the coverage rate as well as to improve the timeliness of availability.

The contribution of EMSA to environmental compliance assurance does not stop with the detection of the source and the identification of possible polluters. While enforcement is in the hands of participating states, EMSA is ready to support them if needed, *e.g.* by providing experts for the interpretation of satellite-based evidence before national and other courts. Moreover, withing it environmental compliance efforts, EMSA collaborates with the North Sea Network of Investigators and Prosecutors, on matters including the use of satellite information for oil spill monitoring.

Ship dismantling or ship scrapping is another field that is currently monitored by the agency under the scope of Copernicus Maritime Surveillance. European companies own 35% of the world fleet and it is their responsibility to ensure that scrapping is carried out responsibly and within the boundaries of the appropriate EU laws. The procedure of scrapping a ship is a very laborious activity with heavy negative impact on the health of the workers and with deteriorating effects for the environment. While the EU takes the matter seriously[39], shipowners - in order to reduce costs - often send ships to be scrapped in third countries where monitoring and enforcement of European regulations are more difficult (despite their applicability remaining unquestioned, as the perpetrators are European actors). EMSA has been tasked by Member State national authorities to monitor ships making their last journey to a facility outside of the EU-approved list. This verification is performed with very high-resolution optical imagery (as the individual ships need to be identified) - and therefore Sentinel data is not used.

[39] *Regulation (EU) No 1257/2013 of the European Parliament and of the Council of 20 November 2013 on ship recycling and amending Regulation (EC) No 1013/2006 and Directive 2009/16/EC,* available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02013R1257-20180704 requires all large sea-going vessels sailing under an EU Member State flag to use an approved ship recycling facility included in the European List. Several of these approved facilities, are however, situated outside of the borders of EU, and their conformity with EU rules is more difficult to monitor. On-site inspections have been executed to assess compliance of candidates to enter the List, and there will be need of more inspections, once candidates have been approved, to make sure that these conditions are persistent. On-site inspections are subcontracted by the EC and their cost is estimated at EUR 50k each. In alternative, a big portion of that same data, can in principle be obtained through satellite imagery, or other source of remote sensing, but not with the Sentinels optical resolution. There are already private companies filling the gap in the sector.

EMSA also offers a Remotely Piloted Aircraft Systems-based (RPAS) service, which consists in deploying RPAS in order to monitor possible violations related to maritime pollution and emissions monitoring (as well as illegal fishing, anti-drug trafficking, illegal immigration, and search and rescue operations). **The RPAS service is used in tandem with the CleanSeaNet service, as the latter may be used to detect possible oil spills, to be further inspected by the RPAS.** Beyond the field of oil spills, RPAS are also used for monitoring of air pollution from ships as they can be equipped with a "sniffer" instrument which can specifically measure if the levels of sulphur oxides (SOx) in plume are higher than those permitted (hence, if the fuel used surpasses the maximum allowed sulphur content)[40].

5.5 Use of Copernicus by EU Member States for monitoring and enforcement of local environmental measures: dredging in Finland

Dredging practices, especially in harbour areas, can bring up toxic products with detrimental effects to flora, fauna, and recreation. Sediment released into the water body in these ways is spread out by currents and thus **increases the turbidity over a larger area, making them visible with EO instruments**.

Few years ago, a dredging event near the harbour of Rauma in South-West of Finland, raised a lot of attention. The works were exhibiting worrying consequences, with potential negative impact on the nearby Natura 2000 site. The large extent of the dredging was captured through EO data and the image received wide publicity, raising nation-wide awareness. Nonetheless, since there were no formal imitations imposed for the maximum turbidity extent of the dredging works, they were not be considered in breach, and could not be stopped.

A dredging event identified by Tarkka –service by SYKE. Increased water turbidity caused by dredging near the city of Rauma, is clearly visible in the Sentinel 2 provided images. Before the dredging (image on the left), the waters appear darker on the satellite images. The dredged locations are marked with red circles on the two other images and the event clearly affects water turbidity as demonstrated by the change in water colour. Sediment material dislodged during dredging spread with water currents, first to the South-West (middle image) and a few days later to the North-East (image on the right). Credits: Contains modified Copernicus Sentinel data, processed by SYKE.

[40] Annex VI to MARPOL deals with the matter of SOx, as well as NOx and PM emissions. While in practice Sentinel-5P also detects GHGs and PM with numerous benefits showcased within the Copernicus CAMS service, it does so on a macro-level and the data is not localised enough to identify possible individual polluters.

Ever since the awareness-raising Rauma case, **permissions for dredging emitted by local authorities contain maximum thresholds for turbidity, which cannot be trespassed. This new regulatory practice allows authorities to monitor and enforce the limitations in case they have been overpassed and helps the dredging party to periodically assess their work in relation to these limits.** The primary provider of satellite data in these cases is the Finnish environmental institute – SYKE. The images are based on Sentinel-2A and 2B, combined with Landsat 8 (and from next year, with Landsat 9 as well), as this combination allows for accurate and frequent observations. However, when the turbidity limits are suspected to have been exceeded during small dredging events (for instance, around the Finnish archipelago comprised of over 40,000 small islands) the resolution of Sentinel and Landsat has been insufficient, and very high resolution data has been acquired from commercial providers.

Satellite imagery has been requested from SYKE to be used in court on numerous occasions, by local authorities, but also by citizens who were claiming, for instance, that a dredging event authorised by the local authorities was deteriorating the conditions in a lake close to a villa zone, and exceeding the turbidity threshold. The imagery proved that the turbidity was, in face, well within the limits. Companies executing massive dredging works around Helsinki in the summer of 2020 have also expressed interest in monitoring through regular EO data. This emphasises that satellite data can also support accountability – a regulatory benefit further elaborated in *Task 2.1 Methodological frameworks for EO value estimation.*

SYKE is looking to is expand their **operational EO service capabilities and products portfolio with high resolution temperature data**. These are currently based on Landsat 8 Thermal Infrared Sensor (TIRS), with a resolution of 100m, and from the spring of 2021 shall be supported by Landsat 9[41]. Applications include the following cases:

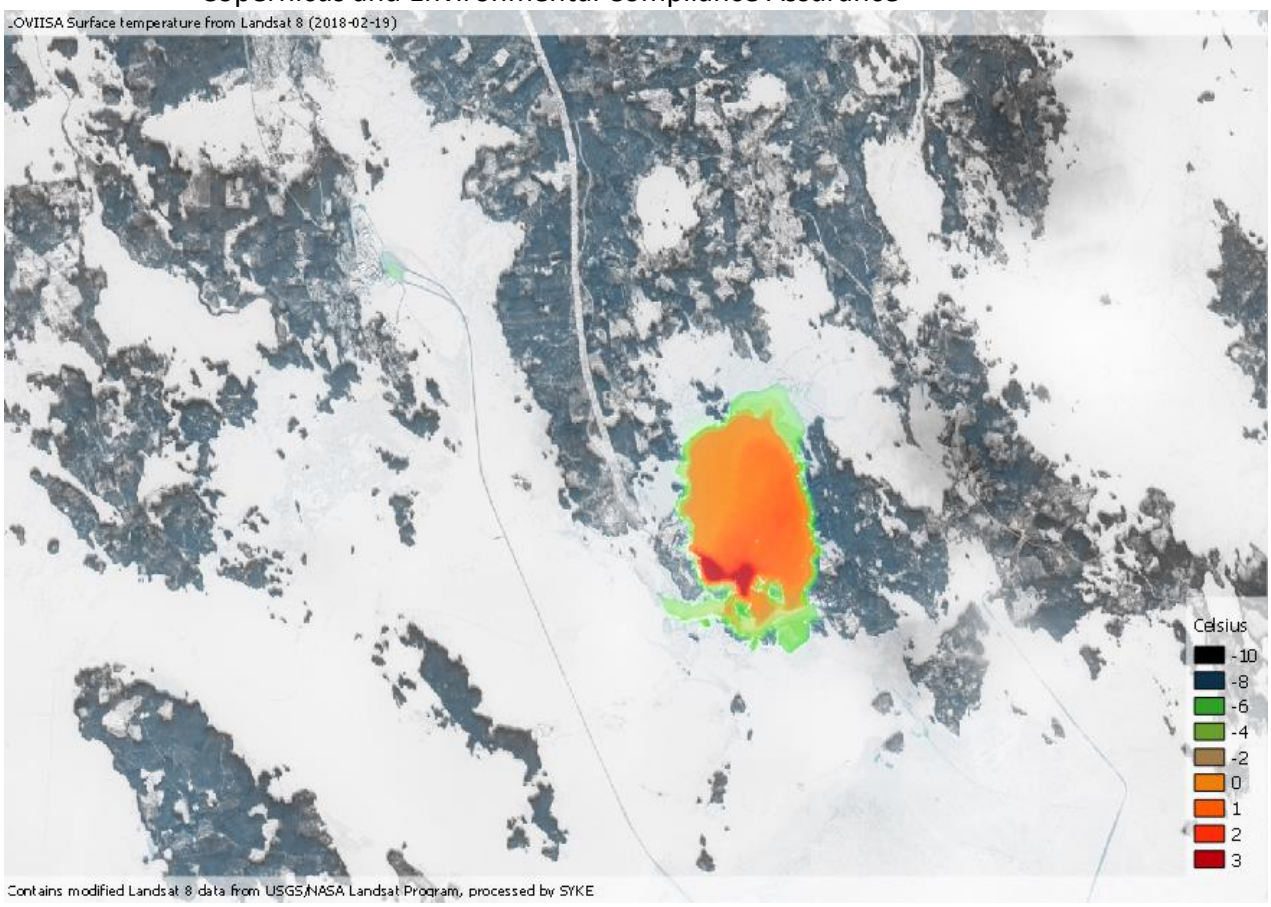
- **Upwelling** is an oceanographic phenomenon that involves wind-driven motion of dense, cooler, and usually nutrient-rich water towards the ocean surface, replacing the warmer, usually nutrient-depleted surface water. The upwelling of nutrients is particularly dangerous in shallow waters as it increases the risk of cyanobacterial blooms.

- **Assessing water temperature near nuclear power plants.** Cooling water from nuclear power plants can be released into the sea/rivers as long as it does not surpass a certain temperature threshold[42]. Monitoring of the temperature of water bodies warmed by cooling waters is expected to be particularly efficient through EO, as soon as the temperature data is provided in (near) real time, and in high enough resolution.[43]

[41] Copernicus Sentinel-3's SLSTR 500m resolution does not provide temperature measurements at an appropriate scale.

[42] The Radiation and Nuclear Safety Authority of Finland has set the limit for water outflow temperature to 34°C. This is challenging during summertime when the incoming water is already warm, and the power plant needs to work on lower capacity and cannot be as productive as in other seasons.

[43] Over very big nuclear power plants Sentinel can be used, but for many others the resolution is too low.



Surface temperature nearby a Finnish nuclear power plant during wintertime, when the surrounding areas are covered by ice and snow. Credits: Contains modified data from UGSS/NASA Landsat Program, processed by SYKE.

	TIER 1	TIER 2	TIER 3	TIER 4
Services/ Benefits	Satellite imagery, historical data when needed	Water turbidity maps/ images	Accurate determination of legitimacy	Environmental benefits – enforcement of thresholds
Beneficiaries	Service Provider: SYKE	Primary User: Public entities or private persons against a dredging company	Secondary Beneficiary Dredging companies	General public

Value chain: Use of EO data and its beneficiaries in the context of implementing local dredging regulations

5.6 Use of Copernicus-based products by national institutions: monitoring of CAP grassland mowing compliance in Estonia[44]

The Common agricultural policy[45] (CAP) is arguably among the most important policies of the EU, both economically[46] and politically. **The CAP is a key tool in unlocking agriculture's potential to fight climate change**, and around a quarter of the CAP funding for the 2014-20 period goes towards actions relevant for the climate[47]. The case under consideration looks at the monitoring and enforcement of one of the CAP's "greening" initiatives[48] and how farmers who implement environmentally friendly practices, specifically, the maintenance of permanent grasslands are monitored, evaluated and rewarded. The underlying policy on direct green payments foresees that farmers would receive subsidies if compliant with certain rules, such as keeping areas of permanent grassland and undertaking the required maintenance – i.e., mowing at least once per year, within a certain period.

In Estonia, like in every other Member State, compliance to greening initiatives had traditionally been monitored via in-field inspections undertaken by personnel within a responsible agency. After inspections are complete, subsidy payments are granted to the farms which are deemed compliant and held back from the farms deemed uncompliant. **In-person inspections can consume a lot of person hours and can only be applied to a sample of fields, usually around 5% of the total number of fields eligible for compensation**. The Estonian Agricultural Registers and Information Board (PRIA) is the public body operating under the authority of the Estonian Ministry of Rural Affairs and responsible for, among other things, organising the granting of national subsidies, European Union agricultural and rural development subsidies, European Maritime and Fisheries Fund subsidies, and maintaining national registers and databases related to agriculture. Since 2015 PRIA has been collaborating within various nationally and EU funded projects towards implementing satellite data to more efficiently monitor grassland mowing compliance[49]. Nowadays, **PRIA relies almost entirely on a commercial service developed in collaboration with a private remote sensing enterprise to monitor compliance on grassland mowing monitoring**. The satellite data

[44] Full case will be published here: https://earsc.org/sebs/

[45] For more info on CAP, see: https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy_en

[46] In 2020 the budget for the CAP made up over one third of the entire EU budget. The vast majority went to income support, including payments for greening practices.

[47] For detail on the relation of the CAP to habitats, landscapes and diversity, see "*Evaluation of the CAP on habitats, landscapes and biodiversity"* (EC, 2019), available at: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/ext-eval-biodiversity-final-report_2020_en.pdf, and for environmental benefits in the post-2020 CAP see: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-post-2020-environ-benefits-simplification_en.pdf

[48] The "green direct payment" (also simply referred to as greening) supports farmers who adopt environmentally friendly practices with direct payments and is covered under EU Regulation No. 1307/2013

[49] EU Regulation No 2018/746 encourages EU Member States to use satellite data in their CAP monitoring and verification activities, specifically mentioning the relevance of the Copernicus Sentinel programme for this application thanks to the free and open nature of the data.

used are both radar and optical (from, respectively, Sentinel-1 and Sentinel-2) and the information for each monitored grassland field is publicly accessible through an online platform[50] [51].

Prior to the use of Sentinel data, distinguishing the compliant claimants from the uncompliant claimants was an extremely challenging job. In theory, it was relatively easy for a claimant to apply for the grass mowing subsidy, then not comply by the requirement and still receive the payment based on the assumption alone that they had remained compliant. This was clearly unfair on compliant farmers and landowners who spent time and effort in meeting the CAP requirements asked of them. Now, **thanks to the use of Sentinel data, the likelihood of uncompliant claimants receiving payment has dropped dramatically, thanks to the satellite monitoring system's ability to monitor every single field remotely, encouraging accountability and fairness.** In addition to the transparency of the payment system, **the Sentinel data also helps both the Estonian Government and the European Union enforce and accurately maintain the greening and biodiversity incentives, meaning sustainable practices are being reinforced, natural habitats and biodiversity are being preserved and CO2 sequestration is being aided.**

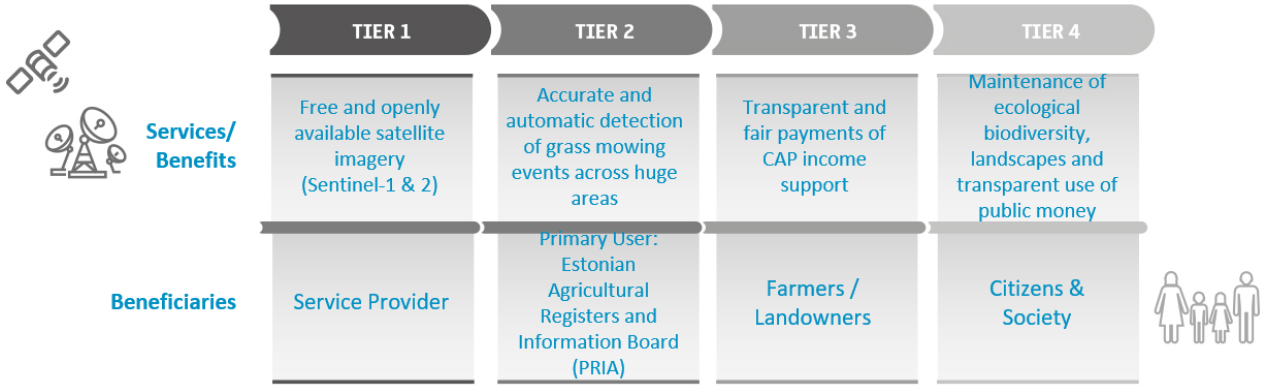


Figure 5-1Value chain: Use of Copernicus-based products by national institutions: monitoring of CAP grassland mowing compliance in Estonia

6 Conclusions

4.1 Benefits from use of Sentinel data to ECA

In conclusion, the use cases are showcases of the role that Copernicus can play in supporting ECA – to different extents, **throughout the whole policy cycle**:

[50] Sentinel-1's interferometric coherence SAR data (both VH and VV polarisation) and Sentinel-2's Normalized Difference Vegetation Index (NDVI) data are displayed. An algorithm then uses these three data sources to calculate the probability of a mowing event having taken place. The user can also click on any of the NDVI points to see the Sentinel-2 image of the field at any stage. The particular deadlines for mowing are also shown, and users have the possibility to activate SMS or email reminders for approaching deadlines they are yet to comply with.

[51] The platform is available at: https://demodev.kappazeta.ee/demo/.

In the **Preparation/Design** of new policies, Sentinel data can be used to identify new policy needs or to evaluate the *status quo*, and to elaborate the technical parameters under which the policy compliance should be evaluated (if this compliance can be monitored through EO).

In the **Implementation** phase, Sentinel data supports ECA in all the constituent processes:

- **Compliance assurance**
  - **Compliance promotion** whereby the EO data are used to showcase success stories and compliance, and also play a deterrent role *vis-á-vis* potential perpetrators.
  - **Compliance monitoring** whereby the EO data are used by the relevant authorities to assess the level of alignment to the prescribed behaviour and/or its breaches.
  - **Follow-up and enforcement** whereby the EO data are used in enforcement-related proceedings (e.g., judiciary or audits).
- **Reporting** whereby streamlined activities (and interoperability of the EO data involved) could facilitate the administrative burden for the duty holders in charge of the reporting, and potentially reduce costs, especially for periodical reporting.

In the **Evaluation phase** (regarding systematic or ad-hoc monitoring of the adequacy of the policy and the efficiency of its implementation), data from EO can be used to unequivocally compare the "before" and "after" of the implementation, and thus capture and trace its stages. This objectivity of EO data, and in particular the full, free and open access granted by Copernicus, contribute to the successful enacting of core principles such as transparency and accountability.

Case study		Use of Copernicus in environmental crime court proceedings	Use of Copernicus in conducted by supreme audit institutions	Use of Copernicus in environmental audits	Member States implementing the Water Framework Directive	Use of Copernicus by EU European Maritime Safety Agency	Use of Copernicus by the environmental measures: dredging in Finland	Member States for monitoring and enforcement of local	Use of Copernicus by EU grassland mowing compliance in Estonia	Use of Copernicus-based products by national institutions: monitoring of CAP
Case type	Operational case				X	X	X	X	X	
	Feasibility assessment	X	X	X	X					
Impact of EO throughout the showcased policy cycle	Preparation/Design									
	Implementation: Compliance promotion									
	Implementation: Compliance monitoring									
	Implementation: Follow-up and enforcement									
	Implementation: Reporting									
	Evaluation									

Very relevant Moderately relevant No relevance

Table 6-1: Overview and mapping of case studies against their relevance for the phases of the policy cycle

4.2 Barriers and opportunities

From a careful analysis of the cases studied and the interviews conducted with environmental compliance stakeholders and Copernicus users, several observations stand out with regards to possible obstacles and opportunities within the use of EO data for environmental compliance assessment:

1. **Awareness of the use of satellite data for environmental purposes is present to a greatly variable extent amongst the interviewed stakeholders.** This is to be expected, as whilst they are among the designated recipients of environmental compliance assurance policies, some are more involved than

others. Notably, several stakeholders are in charge of assisting the European Commission with the implementation of existing EU legislation, programmes and policies related to environmental compliance assessment, through participation in the DG ENV "Environmental Compliance and Governance Forum" (this is the case for environment agencies (NEPA), inspectorates (IMPEL), police officers (EnviCrimeNet), prosecutors (ENPE), and judges (EUFJE)). As we go further from the typical figure of Copernicus core user, the awareness level decreases. Non-core users, designated as "*commercial and private users, the education and research sectors, and not-for-profit organisations*" taking up Copernicus data and services could generate great benefits in terms of overall results for environmental compliance assessment. The challenge – and opportunity – is to identify concrete users and build strategies to engage them. The same barrier is present with regards to each (potential) stakeholder outside of the always expanding, and nonetheless clearly defined, bubble of the Copernicus/Sentinel user community.

2. **The use of satellite imagery in environmental court cases is limited by practical and legal obstacles**. The precision and adequacy of an image (*e.g.,* high enough resolution) need to be sufficiently high for the image to fill its purpose as an evidence**.** Aspects such as verifiability, traceability, and interpretation are always a concern, and insufficient guarantees on any of these could easily degrade the probative value of evidence and negatively impact its admissibility in court. As far as image/data interpretation is concerned, experts can be appointed by the court or by the parties to overcome this barrier. The question of verifiability and traceability, however, requires the implementation of more complex and top-down solutions, such as implementing a certification system in future.

3. **The lack of explicit provisions in EU policies encouraging the use of EO may stand as an obstacle to the use of satellite imagery.** There are cases when, in comparison to current methods, EO could offer equal, or even more precise, extensive, or frequent data (*e.g.* WFD monitoring). Even then, if EO is not formally endorsed within in the provisions as a recommended reference method, the uptake of the method could meet certain barriers (e.g., impossibility to find financing for implementing non-reference methods, even if the cost is potentially lower than the alternative).

   The number and span of similar policies position them beyond the scope of the current work, whilst revealing an opportunity for identifying specific fields for uptake.

4. **The technological specifications of the Sentinels' sensors** strongly impact the use of the data in environmental compliance contexts. There are cases which call for e.g. (very) high resolution optical and hyperspectral imagery, which the Sentinels cannot provide. Solutions to some of these needs are provided either through contributing missions or from non-Copernicus sources. Some sensor-related obstacles are to be revisited by "in-house" solutions in the future, through the selected high-priority candidate missions, seen as suitable candidates to address EU policy and gaps in Copernicus user needs. Finally, it may be possible to extract more value from the existing sensors with the advancement of machine learning and AI technologies for EO.

5. **There are several application areas in the research and development phase which promise to support a range of compliance- or enforcement-related tasks**, such as monitoring marine litter.

Core Copernicus users are as central for its success as the term implies. Nonetheless, in order to draw conclusions representative of the environmental compliance assurance value chain in its entirety, the scope of future studies should further be upscaled to involve more of the less-typical stakeholders from each extremity of the value chain, notably the European Commission itself, and the private sector, as well as other non-core users.