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# The socio-economic value of satellite earth observations: huge, yet to be measured

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## ABSTRACT

Earth-observing satellites provide regular and accurate data that can support evidence-based decisions and public policies in a wide range of domains, potentially bringing huge socio-economic benefits. However, obstacles to effective data exploitation and poor awareness about their impacts risk hindering this potentiality and threaten the investments. Leveraging on the case of the Copernicus Programme, we review the challenges related to the full exploitation of free environmental space data and to the measurement of the related impacts. We then discuss the need for empirical approaches based on value-chain analysis with the objective to stimulate further societal and economic research.

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Socio-economic benefits; satellite-based earth observations; open environmental geospatial data; impact assessment; policy making

## 1. Introduction

Earth observation (EO) satellites provide a privileged viewpoint for watching several geophysical variables, including over areas of the globe that are difficult to access otherwise.<sup>1</sup> The regular and frequent observations of these parameters, on a global scale and in integration with other types of information, contributes to improve the human understanding of many natural processes and can effectively support decision-making at different levels. By providing information about the state of the environment and its changes, EO data can inform the design and development of environmental policies or contribute to shape the environmental dimension of other policies. For instance, they can inform efforts devoted to the preservation of natural resources (e.g. see García et al. 2016; Finer et al. 2018); support emergency management and planning for disaster risk reduction measures (e.g. CEOS 2015a); improve our capacities to efficiently track progress with respect to international agreements and in the achievement of the United Nations Sustainable Development Goals (GEO 2017; CEOS 2018). Although relatively short, the now almost 50-years satellite record allows the determination of consistent trends and scientists are increasingly using them to support the Earth system science that underpins climate policies (IPCC 2013; CEOS 2015b). The systemic and regular nature of the observations can facilitate cross-correlation across different time and geographic scales, providing insights about geographic patterns and their variability. This is extremely relevant when studying occurrences of sociologic and economic relevance, particularly in an era of accelerated urbanisation and climatic changes (see e.g. Nordhaus 2006). Economists

and policy analysts are increasingly having recourse to geospatial datasets to extend their research perspectives, especially where ground data are scarce (see e.g. Donaldson and Storeygard 2016). For example, satellite-derived maps have been used to trace the consequences of some events or policies on given environmental parameters (see e.g. an early example from Pfaff 1999) and the OECD is scrutinizing their use for updating some of its green growth indicators to be used in country reviews and policy analyses (see Haščič and Mackie 2018). By allowing continuous and objective monitoring, EO data can support policies' implementation and enforcement. Their contribution to the detection of illicit behaviours has been highlighted in a number of application areas: for example, they have been credited for contributing to curb the deforestation rates in the Brazilian Amazon forest (e.g. Assunção, Gandour, and Rocha 2015; Finer et al. 2018) and their deterrent effect in protecting the vast EU maritime areas against oil spilling has been recognized by the European Maritime Safety Agency (EMSA<sup>2</sup>). The possibility of using EO to support evidence of environmental compliance is also being increasingly investigated (e.g. see Purdy 2010 and the EnviroLENS project<sup>3</sup>).

The above examples illustrate the potential of EO in supporting different types of applications. However, since the full adoption of geographic information technologies requires awareness and expertise to be developed and can have transformative effects on organisations, their uptake can take several years to materialise – and even more so for the subsequent benefits to emerge. Considering also the timelines typical of large space missions, this implies that long-term visionary strategies are needed to inspire the necessary public investments and the related policies. The capability to predict possible future benefits – and to assess the accrued ones – is crucial to inform such strategies. Space-policy decision-makers and space providers such as the European Space Agency (ESA) are therefore increasingly concerned with finding suitable techniques to measure the actual data exploitation and the related impacts (see e.g. Onoda and Young 2017).

In this paper, the maximisation of the benefits brought by the use of EO data via optimal data exploitation is discussed in Section 2 through the case of the European flagship Programme Copernicus. The genesis of the Programme is briefly recalled, highlighting the legacies, the policies and the technical factors that contributed to mark a quantum leap in EO data uptake. The Programme's state is summarised, with emphasis on the currently known user base of the satellite data. In Section 3, the assessment of the benefits brought by the use of EO data is discussed, with an analysis of the most relevant challenges to be faced. The empirical approaches considered as the most appropriate to tackle them are described and justified. Conclusions and perspectives are proposed in Section 4 to set the frame for research advancements.

## **2. Maximising the benefits of EO data: the case of the copernicus programme**

### ***2.1. From niche high tech to an effective tool for decision making***

The exploitation of satellite-based EO imagery can be rooted to the defense and meteorological sectors back in the 1960s. In recent years its commercial exploitation, especially as support for location-based services, has been exploding: space-based images have become familiar to the wide public (e.g. through Google Maps) and the

demand for very high-resolution optical imagery has grown to a point that it attracted new actors from outside the space sector (e.g. PWC 2016). Still, the range of applications that can be potentially supported is considerably larger. Over the last decades, a number of space missions such as the US Landsat series and the ESA's ERS and Envisat missions have provided a wealth of observations and the corresponding data elaboration techniques have been refined by experts all over the world so that a remarkable confidence has been reached in the estimation of several geophysical parameters. Public programmes (such as e.g. ESA's EO Envelope Programmes) played an essential role in supporting research and innovation in the sector and, through time, paved the way to more mature technologies and services. Pioneering applications gradually reached a considerable maturity, but they were mostly developed within a relatively restricted community of remote sensing specialists and were hardly used to feed regular operational services.<sup>4</sup>

In Europe, the change of pace was driven by a strong political will, as the European Commission (EC) took steps to join forces with ESA. The turning point happened in 1998 with the so-called Baveno Manifesto, a joint declaration emphasizing “*the strategic importance, for Europe, to develop global monitoring capabilities that can inform on a regular basis on the conditions of the environment around the world*”. This declaration set the basis for developing an independent European space capacity through a joint initiative called Global Monitoring for Environment and Security or GMES (EC 2001). Later, with an amendment to the Lisbon Treaty, the principles were set for a European Space Policy of which GMES was a flagship programme (EU 2008). Another major step forward occurred in 2014 when, leveraging the initial developments funded by ESA and by the EU Research Framework Programme, the Programme's operations were finally secured within the EU regular budget under a fully structured governance led by the EC (EU 2014).

GMES, then renamed Copernicus, is a civil user-driven Programme<sup>5</sup> which relies on a set of dedicated space missions called the Sentinels<sup>6</sup> to provide accurate, reliable and easily available data and information in support to environmental monitoring and civil security. The Sentinels follow the legacy of the Envisat and Landsat missions and a brief overview about their characteristics is provided in Table 1. Seven satellites are in orbit at the time of writing. The Programme also includes an in-situ component and six public Services that provide refined information. The current investments (i.e. overall about €8,2Bn from 2008 to 2020 from the EU and ESA) ensure a space capacity lifetime at least until 2030 and discussions are on-going to secure much longer time frames. This long-term sustainability is a key programmatic aspect: uncertain perspectives in the availability of the data have long represented a major drawback preventing investments in EO solutions especially from risk-advert users such as public administrations. A second outstanding feature of the Programme is its open and free data policy (Art. 23 of EU 2014), which is instrumental in boosting the data use: as a comparison, one can see that the adoption of a similar policy for Landsat data in 2008 enhanced the data consumption and contributed to make the mission a worldwide reference (see Wulder et al. 2012). A third notable aspect concerns the Sentinels operational reliability: with pre-defined acquisition plans and systematic processing and dissemination facilities, the mission ground segments ensure a regular, trustable data source for the users.

**Table 1.** Summary overview about Copernicus Sentinels satellites and main applications. Visit <https://sentinels.copernicus.eu> for all information on the missions, the data and the related publications.

	Technology	Launch date(s)	Main applications
Sentinel-1	C-band Synthetic Aperture Radar	S1A: 03/04/2014 S1B: 25/04/2016	Monitoring sea ice, oil spills, marine winds, waves & currents, land-use change, land deformation among others, and to respond to emergencies (e. g. floods)
Sentinel-2	Multispectral optical	S2A: 23/06/2015 S2B: 07/03/2017	Monitoring agriculture, forests, land-use change, land-cover change; mapping biophysical variables such as leaf chlorophyll content, leaf water content, leaf area index; monitoring coastal and inland waters; risk mapping and disaster mapping
Sentinel-3	Multispectral optical/ IR and topography package	S3A: 16/02/2017 S3B: 25/04/2018	Sea-level change & sea-surface temperature mapping, water quality management, sea-ice extent and thickness mapping and numerical ocean prediction; land-cover mapping, vegetation health monitoring; glacier monitoring; water resource monitoring; wildfire detection; numerical weather prediction.
Sentinel-4	Multispectral imaging spectrometer	To be launched	Global information on a multitude of atmospheric trace gases, aerosols and cloud distribution, support monitoring of air quality, stratospheric ozone and solar radiation, and climate monitoring
Sentinel-5/5P	Multispectral imaging spectrometer	S5P: 13/10/2017 S5 to be launched	Global information on a multitude of atmospheric trace gases, aerosols and cloud distributions, support monitoring of air quality, stratospheric ozone and solar radiation, and climate monitoring
Sentinel-6	Topography package	To be launched	Reference, high-precision ocean topography

## 2.2. Maximising the exploitation of copernicus sentinels data in Europe

The Sentinels technical performances, their unprecedented acquisition frequency, their operational reliability, their free and sustained data availability, represent a quantum leap in Earth observations and unlock unprecedented opportunities for data exploitation. But how can Sentinels data be exploited?

Given their complexity, EO data are rarely consumed directly.<sup>7</sup> Most frequently, they are transformed by experts who manipulate them (possibly, in conjunction with other types of information) to provide value-added services or products to be integrated within the services of downstream users. The value-adding providers can be public or private. Public ones mostly consist in environmental agencies or research centres serving other public entities or the citizens. A special case is represented by the Copernicus Services: fully integrated within the Programme, they combine Sentinels data with in-situ observations and other data to provide core refined information and forecasts related to the marine, atmosphere and land environments,<sup>8</sup> climate-related analyses and projections<sup>9</sup> as well as support to security and emergency management.<sup>10</sup> Commercial service providers sell services to both public and private customers: this so-called EO downstream market is extremely heterogeneous and fragmented and, in Europe, corresponds to an estimated 7.800 employees and 510 companies, mostly small and medium sized (EARSC 2017). Service providers play a key role in bridging the complexities of EO data and making them readily exploitable by the larger public and by non-expert users. Even so, the users' engagement may be limited due to a number of factors such as the lack of awareness and expertise, the inertia of decision-support systems to incorporate innovative products and

even some reluctance, from non-space users, to make use of space-based solutions that are sometimes perceived as too “high tech” (see e.g. Secara and Bruston 2016). Institutional users may face additional challenges related to e.g. the lack of off-the-shelf solutions specifically validated for their institutional needs, the lack of trained staff or of funds to organise and incorporate novel technologies within their working practices and the lack of a mandate or political support to do so (see e.g. NEREUS and European Space Agency 2016). Despite these challenges, however, public authorities and international organisations account for the largest customer share (i.e. 55% for the European EO downstream sector according to EARSC 2017).

Because effective institutional data exploitation lies at the core of the Programme, Copernicus integrates – by governance – the main bodies in charge of policies definition and implementation in Europe (see e.g. Art. 30 of EU 2014). The EC, explicitly committed to “*encourage the use of space services, data and applications in EU policies whenever they provide effective solutions*” and to “*make sure that EU legislation is supportive of their uptake*” (EC 2016), put in place a wide and comprehensive strategy encompassing a number of initiatives aimed at facilitating and encouraging the exploitation of Copernicus data and information. These initiatives – undertaken in coordination with ESA, with other entrusted entities and with the governments of the Member States – include e.g. business incubators, master prices, networks and relays, training sessions, data handling tools and, recently, tailored cloud computing services.<sup>11</sup>

The above initiatives are expected to have a multiplier effect in Europe and contribute to a capillary diffusion of Copernicus-derived services through society in the years to come. The capability to monitor such diffusion is vital for the Programme: the increase in the user uptake, the enhancement in market penetration and the benefits provided to European citizens are considered key indicators of its success (Art. 4.3 in EU 2014). In order to grasp them, suitable measurables must be monitored. Readily available ones can be observed at the data access pick-up points: at the main Sentinels data access point managed by ESA, for instance, an ever increasing number of registered users (more than 200,000 at the time of writing) and a steady level of activity have been consistently measured (SERCO 2018). Although these figures already compare with world leading ones and represent over an order of magnitude increase with respect to any precedent in Europe,<sup>12</sup> they must be taken only as a lower bound since they do not include the redistribution performed by institutional (e.g. member states) or commercial (e.g. Google and Amazon) third parties, which is fully allowed under the Copernicus data policy and greatly contributes to enlarge the outreach. Other meaningful, readily available proxies include e.g. the number of relevant peer-reviewed scientific publications, the number of start-ups joining the Copernicus competitions and masters, the number of requests for training received, the number of attendees to the information sessions. These, however, do not provide information about the actual data use and the derived benefits. In this respect, indications can better be gauged from user surveys and crowdsourcing of exemplary use cases (see PWC 2016; 2019). A recent such initiative allowed to record ninety-nine tangible accounts from public authorities across Europe related to areas as disparate as e.g. identification of water leaks or illegal irrigation patterns, optimized maintenance of public utilities in subsidence-prone areas, monitoring of coastal water quality, avalanches forecasting and delineation of post-fire burnt scars in forested areas (NEREUS, European Space Agency and European Commission 2018).

Though not comprehensive, these indicators collectively suggest that the awareness about, and the use of, Sentinels data are growing at an unexpected rate. However, they provide little indication about the value of the benefits derived from such use.

### 3. Assessing the benefits of EO data

#### 3.1. *Rationale, challenges and limitations*

The demonstration of EO-derived benefits is vital to orient investments and to design and prioritize evolutions. As a matter of fact, the valuation of geo-spatial information at large is gaining increasing attention as governments are asked to openly share their data to support economies, improve business effectiveness and enable more efficient administrations (for instance, in the EU, due to the INSPIRE Directive and the Directive on the re-use of Public Sector Information, see Cetl et al. 2017; EC 2018a respectively). Assessments in this respect are mandatory for the Copernicus Programme (see Art. 32 in EU 2014). Since its inception, the Programme has been consistently forecasted to bring end-use benefits that are outstandingly higher than the investments in the infrastructure and that will be largely overriding the direct economic revenues over time (EC 2013; PWC 2017). Interim and ex-post assessments have confirmed these findings to a large extent but highlighted the difficulties to assess the end-use benefits (PWC 2016). The indirect, enduring and sometimes intangible benefits derived from the use of the data are in fact not captured through traditional space sector analyses (mostly focused on space manufacturing, e.g. OECD 2014) and require specific solutions (e.g. OECD 2012 and PWC 2016). Similar considerations apply to the valuation of openly shared public sector information, for which ex-post assessments remain largely anecdotal due to measurement difficulties and to the lack of statistically significant and systematic collection of information (Ubaldi 2013; CapGemini Consulting 2015; EC 2018a).

For evaluating the benefits derived from the use of EO, various methodologies have been applied in the last 20 years: for example, PWC (2016) provide some overview for EO/space data, WMO (2015) for the meteo/hydrological sector and Kruse, Crompvoets, and Pearlmann (2018) for geospatial data at large. Cost-benefit analyses in particular have been widely used, relying on robust and accurate calculations when markets and models exist but often reverting to contingent valuations in absence of established frames. The techniques must be adjusted depending on the thematic areas and/or business models at stake but these can be so numerous and heterogeneous that cost-benefit comparisons are hindered. The absence of “dominant” chains (that, alone, can justify the core of the investments in space) and the scattered nature of the end-use benefits skew the comparison with investments and call for tailored, empirical economic models (e.g. Bernkopf and Shapiro, 2015). Also general equilibrium models have been applied mostly at partial scale and limited to specific sectors (e.g. ConsultingWhere 2010; WMO 2015). In 2010, an attempt to holistically evaluate the societal, economic and environmental impacts of a global Earth observation system of systems eventually highlighted that cross-sectorial impacts should not be neglected (Rydzak, Obersteiner, and Kraxner 2010).

The value of EO data depends, ultimately, on *i*) how far the EO data are actually used to derive value-added information that is exploited by decision makers to take actions and on *ii*) the value of such EO-derived information. Measuring point *i*) is not straightforward: as mentioned previously, EO data are frequently integrated with other types of information

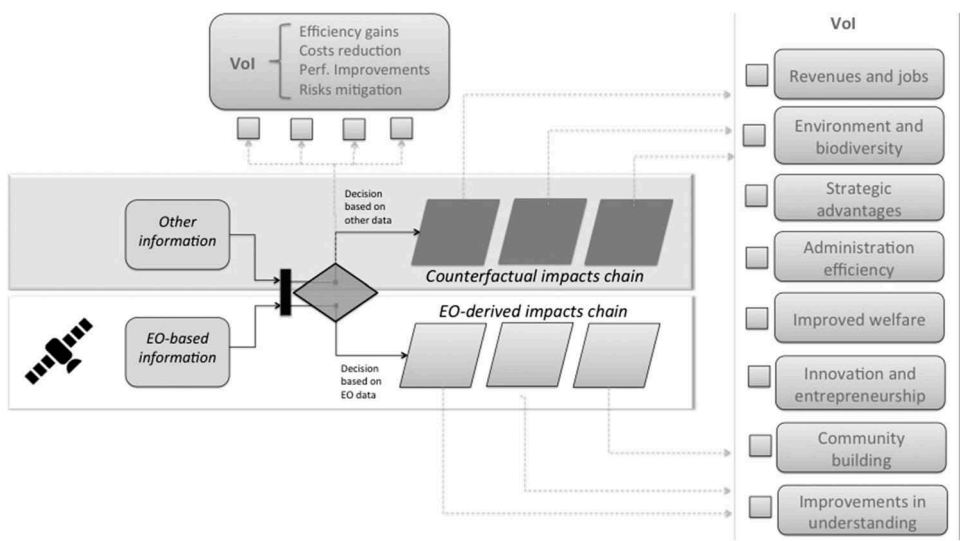


and may be entwined in the derived services or products to the point that the users' awareness may be limited. Moreover, like all digital information under an open and free data policy, they can be used, distributed and shared without any physical tracking and it is therefore impossible to rely upon registries and vendor statistics (that can instead be used in e.g. telecommunications or navigation). The extent of these uncertainties is such that assumptions are heavily leveraged, with limitations and dependencies that are often important. Measuring point *ii*) (a classic Value of Information (VoI) problem) is not simple either, because the value that the users attribute to the EO-derived information is subjective to a significant extent and depends on several parameters such as the cost of the space-based solution, the timeliness of its availability, the existence of viable alternatives, the expected benefits, the risks and potential consequences of a bad decision. These factors are so specific that it is not possible to know the value of the information without considering its use in a given situation context, to such an extent that it is impossible to derive wide-ranging market statistics similar to those available for standardized widely available goods. The reader can consult Macauley (2006) for a primer application of VoI to EO and resources management.

### ***3.2. The advantages of an approach based on value chains***

The most credible way to address the above challenges is by anchoring the data to how they are effectively used in the decision-making and by going as granular as possible when characterizing the contribution of individual EO systems. For this reason, the need is increasingly advocated within the community to narrow and deepen the scope of the analysis to the coherent set of actors that are related by the consequences of using the EO-derived information, in quest for a plausible causal relationship providing evidence that a benefit (or a part of it) is attributable to the use of a given type of data. The problem has been tackled by many authors, although separately and with inconsistent definitions, through the delineation of "chains". The concept develops around a decision taken using EO-derived information and its comparison with a counterfactual situation in which other types of information are used instead (see Figure 1). At the decision point, the counterfactual can be estimated through comparisons with non-EO solutions and this implies that the VoI for the decision maker can often be measured through ex-post analysis of the improved performances (e.g. gains in output or productivity and/or reduced costs as compared to those occurring in absence of EO-derived information), self-assessments from core stakeholders or, where applicable, numerical simulations (e.g. Macauley 2006; Kruse, Crompvoets, and Pearlmann 2018). But with the decision possibly having downstream impacts, the analysis shall be extended throughout the whole downstream "chain of impacts", cumulating the economic values along all the different tiers and carefully avoiding double-counting. For each step along the chain, the most appropriate methods and metrics depend on the type of service at stake, on the stakeholders and on the outcomes to be evaluated but, for Copernicus, these should be in line with the Programme's objectives and include aspects such as e.g. strategic advantages and improvements in understanding about the Earth system and climate change (see an expanded list in Figure 1). For some types of impacts (for example on air, water, soil and habitat), numerical models can be used that are suited to the particular cause-effect relationship being studied (e.g. air dispersion, hydrological or ecological models). Depending on the sector, cascading impact models

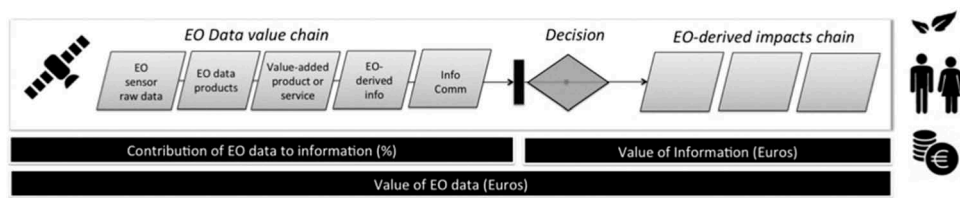




**Figure 1.** Schematic representation of an EO-based data exploitation chain as compared to a counterfactual one, with emphasis on possible metrics of relevance for VoI assessment for the decision maker (top panel) and for the impacts downstream (right panel).

might be already available and could therefore be reused: in those cases, the challenge will be reduced to the estimation of the marginal impact of EO-derived information within the chain.

The VoI does not coincide with the value of EO data, but with a fraction thereof. When the “information” is based only partially on EO data, the relative contribution must be disentangled. This attribution, often far from straightforward, can be best achieved via the identification of the various steps undertaken to transform the *raw satellite data* into *actionable information*, as it is schematically illustrated in Figure 2. This is a classical representation often referred to as the “EO data value chain” and constitutes the digital equivalent of the supply chains for physical goods. The marginal contribution of EO to the information is to be ascertained mainly by the developers of the EO-based solution but might involve different actors because all steps must be considered in the analysis, including e.g. the communication channels towards the person or the pertinent authority in charge of taking the decision. A particularly complex example in this respect is provided by the weather forecasts: these rely on such huge amounts of different kinds of data and sources



**Figure 2.** Schematic representation of an EO data value chain, encompassing all steps necessary to provide EO-derived information to the decision maker. The bottom frames highlights how the contribution of EO must be used for the modulation of the VoI.

that complex sensitivity analyses are required to evaluate the role of single data sources for a given forecast (see an example in Mc Nally, Bonavita, and Thepaut 2013). It is important to notice that precise estimations are not always necessary: as appropriate, one can focus on the enabling value of the source data (i.e. could the solution be developed and/or be viable in absence of EO data?).

“Chains” more or less like the one described above have been variably applied at different levels, from micro to macro-economics. For instance, in the well-developed meteorological context, Perrels, Nurmi, and Nurmi (2012) leveraged a “weather service chains analysis” to model the impact of weather forecasts on Finnish weather-related road accidents while the World Meteorological Organisation emphasized the role of “weather information chains” to explain the value of weather forecasts for the global economy (WMO 2015). “Value chains” were repeatedly used with respect to geo-spatial data (e.g. Genovese, Roche, and Caron 2009; Kruse, Crompvoets, and Pearlmann 2018) and Fritz et al. (2008) introduced “benefit chains” models to describe the relationship between the usage of EO data and the derived incremental costs and benefits for three case studies. For Copernicus, value chains have been used at sectoral level and in “bottom-up” approaches to figure out actual and prospected impacts of the use of the data in Europe. An example of the approach comes from PWC (2016 and 2019), which estimated the value of using Copernicus data by aggregating the results obtained separately for different “sectoral value chains” leveraging the most common types of chains applicable to Sentinel data in eight fields of application (i.e. agriculture, forestry, ocean monitoring, air quality monitoring, renewable energies, oil and gas, urban monitoring and insurances). It is worth noticing here that, after applying a transactional economic impact model to the space manufacturing and downstream service sales, the authors had to revert to a micro-economic diffusion model for the evaluation of the end-user benefits related to the most promising market sectors. From a different perspective, a bottom-up approach was used by the European Association of Remote Sensing Companies (EARSC), under an assignment from ESA, whereby “value chain” analysis was applied to single use cases. One of the case studies concerns the use of Sentinel-2-like data at the Swedish Forest Agency to enforce the local “light touch” forest management policy (Sawyer et al. 2015). Based on ajar assumptions derived from interviews with core stakeholders and analysis of historical data, the authors found that the introduction of EO data around the year 2000 resulted in the drop of illegal timber logging and in efficiency gains for the Agency and was key to reduce transaction costs for the over 300,000 private forest owners, bringing an overall economic benefit to the Swedish economy quantifiable between €16.1m and €21.6m per annum. As a comparison, in its ex-ante assessment for the next Copernicus phase, PWC (2017) projected benefits related to the improvement of yields in the EU forest industry to raise up to between €60.7m and €79.4m in 2035.

The bottom-up methodology developed by Sawyer et al. (2015) offers a particularly robust and effective declination of the extended value chain concept, albeit confined to very specific cases. The authors performed other investigations to assess the impact of Sentinel data in support to winter navigation in the Baltic Sea (with total direct economic benefits for the area estimated to be between €24m and €116m per annum), pipeline monitoring in the Netherlands (between €15.2m and €18.3m per annum), and farm management in Denmark (between €3.8m and €7.9m and up to €23.7- €54.5m in the future when new

machine-learning technology will be applied).<sup>13</sup> Comparing these cases stimulates interesting considerations. First of all, the authors found that although benefits tend to be generally distributed along the chains, they might peak at different tiers depending on the relevant types of business and in many cases they concentrate downstream from the decision point (e.g. at the farmers for the Danish case but down to the local economy in the Gulf of Bothnia for the Baltic case). Secondly, there are profound differences between the parameters driving the most substantial economic gains (e.g. efficiency gains, lowered transaction costs or financial gains), confirming the need to differentiate the models when dealing with different applications and business cases. For the same reason, the possibilities to extrapolate the obtained results to wider frames appear limited and must be screened through a deep understanding of the chains, the underlying markets and, notably, the regulatory conditions. A sufficiently rich set of use cases would therefore be needed, across different applications, scales of assessment and geographic areas, to build a more comprehensive overview and provide useful inputs for wider scope economic modelling.

As a closing remark, it is worth to highlight that the storytelling accompanying the characterization of the chains provides *per se* a convincing narrative capable of creating a common understanding of the links between satellites, citizens and benefits among different communities. It is also evident that, in pursuing a sound account of the data exploitation, the approach provides information useful to improve the services. These aspects make the cascading methodologies especially appreciated by EO data and service providers (such as ESA) in view of leveraging realistic scenarios to design more effective solutions for the future.

#### 4. Conclusions and outlook to the future

In this article we recapitulated the path of satellite-based Earth observations in transitioning from niche, highly specialised technology into a supporting tool for services of general interest, using the example of the EU Copernicus Programme. We argued that the capability to value EO data greatly helps to design effective exploitation strategies and inform space policies. The assessment of the impacts derived from the exploitation of the data is however not straightforward due to a number of difficulties that include e.g. the relatively limited knowledge about the real use of data distributed under an open and free policy, the extreme spread and heterogeneity of the applications that can be supported, and the fact that impacts are closely tied to the specific situation of use. We advocated “chains” or “cascading” methodologies as the most suitable to properly understand and characterize these impacts. The concept is widely used in the digital domain but “data value chain” representations commonly end with the decision point and rarely develop the consequences beyond. This is precisely what needs to be expanded and further developed.

Despite increasing focus, the EO community is not so familiar with general and structured practices for impact assessments. In other contexts, in which they were prescribed by regulation since decades and communities of practice are much wider and actively involved, the discussion is more advanced. For instance, within some EC environmental and strategic impact assessments, “cascading” models are extensively leveraged to take into account the causality premises. An open-minded review of these frames could be undertaken with the objective to identify nomenclatures and methodologies that could inspire and stimulate a community of EO-value practitioners (e.g. toolkits to ease and

stimulate information crowdsourcing). Interesting hints could also come from the “open data” context, whereby the demonstration of the benefits derived from government data touches upon similar challenges.

For what concerns future perspectives, yields from on-going investments can be expected to result in increased market penetration and spread of innovative solutions. In this respect, particular attention should be put on the institutional market, whereby public authorities at national, regional and local level might be increasingly investing in EO-based solutions in support to the implementation and enforcement of environmental policies, especially if their use will be explicitly contemplated by the relevant legislation (see e.g. the proposed Common Agriculture Policy in EC 2018b). The growing awareness at political level might be impactful and the increased evidence brought from the exposure of successful use cases and sharing of best practices might stimulate further uptake. Evolutions in the space infrastructure will bring new possibilities to observe the Earth. For Copernicus, next generations are being discussed between the EC, ESA and their Member States in pursue of an enhanced continuity that could complement the current geophysical observables with others at the forefront of EU environmental policies (e.g. for carbon dioxide monitoring). In the background, the easier and cheaper access to space at international level and the advancement of nano-satellites technologies will contribute to enrich and complement the overall data offer. The general availability of “big data” and of tools for handling them, the increased digitalization of society and its ever growing capacity to consume information through easy-to-use dedicated software applications will undoubtedly contribute to fuel the exploitation of multiple data sources. Meanwhile, sustained research and development activities might result in innovative applications attracting new categories of users. All these occurrences could effectively stimulate the capillary diffusion of existing and new operational EO-based services up to unprecedented levels (see e.g. PWC 2019 for a review of general trends).

In such dynamic and fuzzy contexts, impacts assessments require flexible approaches capable of following the evolutions of the space sector and of the supported markets and of capturing the emerging applications. Estimates will rely on soon-out-of-date assumptions whose rapid evolution might risk to undermine the credibility of the exercise. As a consequence, robust and well-founded analyses shall necessarily leverage on traceable assumptions and on a deep-rooted understanding of the data use, at least for a set of core influential applications. A sound characterization of the use chains provides a clear asset in this respect. The relatively scarce and unconsolidated knowledge available about actual data uses and impacts requires notable amounts of on-the-field investigations to gather sufficient information to feed economic models. ESA supports activities to achieve as credible and comprehensive estimates as possible but this requires a collective effort and a multidisciplinary approach. In particular, increased attention from the data users (in acknowledging the use of the data and transparently contributing to the refinement of the related impact chains) and from economists and environmental experts (in assessing the economic and environmental value of the data) would be needed, to support advances in the exploitation and the development of EO technologies and fully realize their potential benefits for the economy, the environment and society.

## Notes

1. Parameters that can be measured through different remote sensing techniques include e.g. oceanic chlorophyll concentrations, sea ice extent, vegetation indexes for crops and forested areas, terrain and infrastructure instabilities, atmospheric concentrations of various gases such as ozone and sulfur dioxide. The reader can see e.g. Onoda and Young (2017) for a short summary of those of concern for environmental policies.
2. “The deterrent effect of the satellite-based oil spill monitoring service is clear: over most of the past decade the overall trend has been a year-on-year reduction in the number of possible oil spills detected per million sq. km monitored. The increase in awareness of maritime pollution is visible since the beginning of the service; not only maritime laws are stricter, but there is also a significant improvement of national authorities’ action capabilities towards polluters.” Consulted on Feb. 2019.
3. An H2020 project recently started EnviroLENS: Copernicus for environmental law enforcement support .
4. A notable exception in Europe was the EC JRC’s monitoring of agriculture using remote sensing (MARS) which, since 1993, had developed EO capabilities for providing independent and timely information on crop areas and yields in support to EU policies (<https://ec.europa.eu/jrc/en/mars>).
5. [www.copernicus.eu](http://www.copernicus.eu).
6. <https://sentinels.copernicus.eu>.
7. Direct consumption might happen with large entities (public or private) having internal skills and resources or when timeliness/sensitivity needs apply.
8. <https://marine.copernicus.eu>, <https://atmosphere.copernicus.eu> and <http://land.copernicus.eu> .
9. <http://climate.copernicus.eu> .
10. <http://emergency.copernicus.eu> and <https://www.copernicus.eu/en/services/security>.
11. <https://www.copernicus.eu/en/opportunities>.
12. Copernicus has been estimated as one of the largest data provider in the world (PWC (PriceWaterHouseCoopers) 2016).
13. <https://earsc-portal.eu/pages/viewpage.action?pageId=35620366>.

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