Earth Observation in a cost-benefit analysis perspective: Cosmo SkyMed satellites of the Italian Space Agency

Stefano Clò[a], Massimo Florio[b], Valentina Morretta[b], Davide Vurchio[b]

Abstract

Over the past decade, an increasing number of high-resolution satellite images have become available to public administration, policymakers and scientists, boosting the amount of information they can obtain to manage and analyse different issues. Satellites allow observing different natural and socio-economic phenomena that would be very hard and costly to monitor from the ground with the same optimal coverage, accuracy and consistency, providing valuable information both to the private and public sector. These phenomena include global societal challenges, such as climate change and air pollution, as well as local ones such as precision farming, urbanisation and transport infrastructures monitoring. This working paper aims at paving the way to a comprehensive assessment of the socio-economic impact of the Italian Space Agency (ASI) concerning the creation of innovative products and services generated by the Earth Observation (EO)[1]. Although the wide range of potential applications of EO satellite data, little is known about the effective use of Cosmo SkyMed (CSK) data so far. Most of the benefits related to their availability remain potential, unexpressed and undervalued. The analysis also intends to identify the institutional and organisational barriers that limit their full exploitation and formulate sounds policy recommendations to release the untapped potential of the Italian space downstream sector.

Keywords: Earth Observation, Space Economy, Cosmo SkyMed, Italian Space Agency.
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[a] *Department of Economics, Università degli Studi di Firenze*
[b] *Department of Economics, Management, Quantitative Methods, Università degli Studi di Milano*
Contact details: ***stefano.clo@unifi.it, massimo.florio@unimi.it, valentina.morretta@unimi.it, davide.vurchio@unimi.it.***

[1] The present working paper is part of the three years project "Cost-Benefit Analysis of public policy in the space industry" involving ASI and the University of Milan. This project aims at conducting a cost-benefit analysis of ASI and also covers the study of the upstream sector, industrial technological transfer, and university-industry relationship. The working team includes Dr. Paolo Castelnovo, Dr. Stefano Clò, Prof. Carlo Fiorio, Prof. Massimo Florio (Team Leader), Dr. Giancarlo Manzi, Dr. Valentina Morretta, and Dr. Davide Vurchio. Depending on data availability, our analysis can possibly be extended by comparing CSK to Copernicus. We acknowledge Alessandra Tassa (ESRIN - ESA's centre for Earth observation) for sharing information on Copernicus Sentinel. The usual disclaimer applies.

1. Introduction

How is it possible to evaluate the socio-economic impact of science-based infrastructure? Can social cost-benefits methods be applied to investment at the frontier of science (Florio 2019)? In this paper, we discuss the case of Earth Observation (EO) focusing on the last generation of satellites designed, built and managed by government-sponsored space agencies, such as the National Aeronautics and Space Administration (NASA), European Space Agency (ESA) and Italian Space Agency (ASI).

Nowadays, there is an increasing and widespread awareness of the importance of space technologies and how vast can be their impact on contemporary lifestyles, daily habits, and economic activities. Infrastructures and space applications are gaining growing importance in several fields, such as environmental protection, health, energy, agriculture, telecommunications, transports, safety of citizens, and are also pushing the frontier of knowledge and research on different socio-economic aspects. The European Union (EU) guidelines also describe space technologies and programs as a formidable tool to develop knowledge and innovation, promote wellbeing and quality of life, face disasters and critical natural issues (European Commission, 2016).

According to the OECD (2016), the availability of satellite data, combined with advances in computer processing power and analytics, is contributing to the exponential growth of the last segment of the space sector's value chain. This *downstream* sector broadly includes all the products and services that could not exist without the availability of satellites such as GPS enabled devices, satellite communications, weather and EO satellite data, among others. The latter consists in the collection of a wide range of information concerning the planet earth via remote sensing technologies and allows observing, from a privileged perspective, both global and local phenomena that would be very hard to monitor from the ground in the same way. For example, while it is possible to study the process of melting glaciers from the Antarctic ground, EO provides more accurate and comprehensive information on the status and evolution of this issue. In remote areas of developing countries, where there are no adequate infrastructures or in situations of emergencies where infrastructures are damaged or not available, satellite data can provide an alternative and an important integration to the terrestrial network.

In the last decades, both ASI and ESA have invested in the development of dedicated EO satellite constellations, respectively Cosmo SkyMed (CSK - *COnstellation of small Satellites for Mediterranean basin Observation*) and Copernicus. The impact of EO data, with focus on the Copernicus Programme, has been assessed by PricewaterhouseCoopers (European Commission,

2019) that, by analysing ten different value chains[2], shows that investments in the Programme (EUR 8.2 billion from 2008 up to 2020) are forecasted to generate benefits between EUR 16.2 and 21.3 billion[3]. Figures are growing year by year; in 2018, the average penetration of Copernicus data was 20%, and the expected average annual growth rate will be 15% up to 2020.

In Italy, despite the existence of several satellite data applications, no exhaustive assessment of the socio-economic advantages of using EO data has been provided so far. In the framework of a three years project on the cost-benefit analysis of ASI, this paper intends to provide some preliminary indications and evidence about the potential benefits related to the use of CSK data and about the main challenges related to their applications. More specifically, we want to explore what socio-economic benefits are potentially associated with the dissemination of these data, what is the data governance structure and policy adopted by ASI, what barriers are, nowadays, hindering their use and how institutions could eventually overcome the existing barriers.

This working paper is structured as follows: Section 2 provides a brief overview of the practical applications of EO data in different fields with respect to actual and potential benefits that can derive from their utilisation; Section 3 provides a review of the use of EO data in the academic socio-economic literature, how these data have been analyzed so far to study different socio-economic phenomena. Section 4 describes the Italian satellite constellation CSK, its technical properties and governance system, that is how data are managed and made available to the public. Section 5 provides a bibliometric overview to show the increasing role of CSK data in the production of scientific researches; Section 6 introduces a case study on the municipality of Ventimiglia to give a preliminary insight into the potential benefits of the use of CSK data. Finally, Section 7 concludes the working paper and set a future research agenda.

2. Practical applications and socio-economic benefits of EO: a brief overview of case studies from the grey literature

Earth observation can be considered as a critical societal infrastructure; it provides a unique perspective into our world and supports the advancement of civilization by increasing awareness of different environmental, social and economic issues and by supporting concrete actions and policies for a more efficient and sustainable management of global and local resources (Onoda and Young,

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[2] Agriculture, Forestry, Urban Monitoring, Coastal and Marine Exploitation and Preservation , Oil & Gas, Renewable Energies, Air Quality, Insurance for Natural Disasters, Response to Natural Disasters and Security

[3] Such forecast does not include non-monetary benefits. Such economic value includes the added value created in the upstream space industry, the sales of Copernicus-based applications by downstream service suppliers and the exploitation of Copernicus-enabled products by end users of various economic sectors.

2017). In this section, we provide few examples extrapolated from the grey literature on the direct use of EO, its applications in concrete cases and related economic and non-economic benefits for the society.

The advantages related to the practical use and applications of EO are numerous and varied as it allows obtaining high spatial resolution images on the earth, with a wide, frequent and punctual geographical coverage. EO application is not limited to global scale events. For example, a recent report (ESA, EC, NEREUS, 2018) shows 99 cases where Copernicus data have been adopted, at the local level, in different areas such as food and agriculture, forestry and fisheries, biodiversity and environmental protection, climate, water and energy, territorial management and urban planning, civil protection, transports, civil infrastructure and safety, public health, cultural heritage, tourism and leisure.

Onoda and Young (2017) propose a useful classification of the potential applications of EO data, according to the area of interest (terrestrial, maritime, atmospheric) and to the specific purpose of analysis: identify, monitor and assess a particular phenomenon (*inform*), offer support in the management of the phenomenon (*assist*), or provide tools to enforce regulations and discourage illicit behaviour (*comply and intervene*). This classification can be interpreted according to a temporal dimension. For instance, with respect to a specific event and phenomenon (earthquake or landslide), satellite data can be employed i) to provide information before the event takes place (*inform - ex-ante*) to monitor its evolution and preventing potential damages that could raise when the event takes place; ii) to provide information during the event (e.g about its intensity or the areas of interest), to assist intervention and rescue operations (*assist- during*); iii) after the event takes place (*intervene ex-post*), for instance, to assess the extent of damages and provide information during the process of reconstruction. Onoda and Young (2017) recognise that this classification may be partial and may present some overlapping areas: for example, environmental issues related to a system may have repercussions on other systems (impact of a tsunami on the earth's surface), *or ex-ante* information and monitoring activities can be helpful to assist public reliefs or *ex-post* intervention. Nevertheless, we believe that this framework can be useful to provide a general overview of the roles of satellite EO and their practical applications.

Table 1 - Potential fields of application of satellite earth observation data: a taxonomy

Function		Medium		
		Atmospheric	Marine	Terrestrial
Inform	Identify	Existence of the ozone hole	Occurrence of marine dead zones	Forest fires
	Monitor	Greenhouse gas concentration	Sea surface temperature	Pace of Amazon deforestation
	Assess	Recovery of the ozone layer	Rise of sea level Loss of sea ice	Loss of carbon stock
Assist		PM2.5 early warning	Provide early warning of tsunamis	Track pathways of tornadoes
Comply		Identify sources of greenhouse gas (CO_2 and CH_4) emissions	Track Illegal, Unreported, and Unregulated (IUU) fishing	Locate illegal loggers

Source: Onoda and Young (2017)

With respect to the *inform* category, missions such as Envisat, Sentinel-1, Radarsat-2, TerraSAR-X, and CSK are used in combination with ground observations and aerial photography to monitor and detect, marine phenomena such as, for example, dead zones, oil spill and red tides which are algal blooms (phytoplankton) that occur naturally, given certain combinations of environmental conditions, but can exacerbate due to human activities. These phenomena negatively affect water resources; hence satellite data can help to avoid their spread, consequently reducing the costs of ex-post interventions, as it happened in 2006 with the spread of red tide in the Tokyo Bay (Onoda and Young, 2017).

In the atmospheric environment, Dawes et al. (2013) carry out a case study in the US illustrating how satellite data can help to expand the geographical coverage of available information on air quality by integrating surface estimations. In monetary terms, their analysis shows that satellites could provide, for free and in short-time, $PM_{2.5}$ information to 82% of the 18.1 million people currently living in unmonitored areas of Georgia, Colorado and Missouri, against an expense of USD 25.9 million for purchase, installation, and operation of ground infrastructures that would cover only 44% of such unmonitored people taking a period of 5 years. A wide range of nonmonetary values and benefits also emerged from a set of interviews with different stakeholders ranging from a higher consciousness of problems related to industrial development and unregulated activities to better support of public health programmes or more effective health alerts among others. Another practical example of the capability to inform about particular issues related to the status of the atmosphere is provided by Sentinel 5, which can measure ozone concentration and evaluate UV radiation reaching the earth. This information is useful for policy makers and the tourist industry for safe sunbathing as it is estimated that a 10% decreases in ozone could increase both cases of skin cancer by 300.000 and cataracts by 1.75 million (ESA, 2013).[4] In this context, a CBA would possibly compare the cost of the operation with the value of health benefits in terms of quality-adjusted life years (QALY) and the value of the statistical life (VSL).

Other important benefits of EO relate to the effectiveness of providing information during a particular event and *assist* certain interventions and operations. For example, the European Association of Remote Sensing Companies estimated the economic value generated by the use of satellite imagery in supporting navigation in the Baltic Sea. Satellite imageries replace helicopters in helping icebreakers finding the best routes through the ice. These benefits are estimated between EUR 24 million and EUR 116 million per year and include reduced fuel costs of icebreakers, helicopters and ships, reduced operational costs of ships due to arrival delays and savings from reducing collision (insurance and damage). (Sawyer et al. 2015 and Aschbacher, 2017). Another impact analysis presented in (Friedl, 2017) evaluated the benefits of the Volcanic Ash Advisory Center's use of Aura data looking at flight cancellations and revenue losses due to Eyjafjallajökull Vulcan eruption in 2010. The analysis found that during this event, satellite data reduced the probability of an aircraft experiencing a volcanic ash incident by approximately 12%. The use of satellite data saved USD 25–72 million in avoided revenue losses due to unnecessary delays and avoided aircraft damage costs. If the data had been used from the beginning of the incident, an estimated additional USD 132 million in losses and costs might have been avoided.

Ex post, satellite data can be used for regulatory compliance and legal enforcement, for example, to deduce responsibility of natural disasters (KSAT 2016 in Onoda and Young, 2017), deter and prevent illegal deforestation activities (EARSC, 2016), non-authorised water abstractions (Lockwood et al., 2014) illegal irrigation patterns (De Michele 2016; ESA, EC, NEREUS, 2018) and to verify the correct destination of the subsidies granted within the EU Common Agriculture Policy (European Commission, 2018). In the terrestrial environment, Sawyer et al. (2016) examined the impact of satellite imagery on forest management in Sweden which provides 10% of the worlds' sawn timber with an export value of EUR 12 billion. This case study shows how satellites have contributed to the decrease in illegal cutting and lack of immediate re-planting and pre-commercial thinning. The cost of collecting such imageries was EUR 64,000 against a benefit of EUR 16.1 and

[4] Although ozone high up in the stratosphere provides a shield to protect life on Earth, direct contact with ozone is harmful to both plants and animals (including humans). Ground-level, "bad," ozone forms when nitrogen oxide gases from vehicle and industrial emissions react with volatile organic compounds. (https://ozonewatch.gsfc.nasa.gov/facts/SH.html)

21.6 million per annum. Benefits derive from a decreased cost of physical inspections and using aircrafts among others, plus the long-term value increase as a result of higher timber production and enhanced quality. Other non-economic benefits include the creation of an archive of images, improved inter-agency cooperation and wildlife protection. A collaboration between the Brazilian Amazon deforestation authority and the Japan International Cooperation Agency (JICA) also contributed to a reduction of 40% in deforestation thanks to data collected by JAXA ALOS (Onoda and Young, 2017).

Satellite data are also very useful to detect and prevent illegal fishing activities whose black market is estimated to be up to USD 23.5 billion corresponding to 26 million tonnes (FAO, 2019). A possible, conservative, CBA strategy would be to compare the EO with the counterfactual of ground data taking or other monitoring systems. In fact, according to the seminal article of Becker (1968), potential criminals are rational agents who decide whether to make crime or to adopt an illicit behaviour (e.g. illegal deforestation, illegal building or tax evasion) by weighting the potential benefits and costs associated to their actions. While the size of the benefits is usually subjective private information and cannot be affected by the legislator, the size of the economic costs associated to the illegal behaviour is a function of the intensity of the punishment. As a rule of thumb, an increase of the severity of the punishment increases the costs associated with the criminal activity, with an incremental deterring effect. Nevertheless, the punishment intensity needs to be weighted by the probability of detection. If the probability of detection is zero, no matter how high the punishment is, the potential criminal will always commit a crime whenever the associated benefits are positive. The overall cost associated with the criminal activity is therefore given by the intensity of the punishment weighted by the probability of detection (Posner, 1985).

Our research question about the valuation of the socio-economic impact of EO is similar to the Impact Assessment of EO data which is also the core objective of the VALUABLES Consortium[5], a collaboration between Resource for the Future (RFF) and NASA to measure how satellite information can benefit people and environment. In particular, the Consortium aims at measuring the socioeconomic benefits that EO provide, for example, to make decisions to manage water resources, health and air quality, climate change and wildfires. By adopting the Value of Information (VoI) approach, their impact assessments quantify the change between a state in which action is taken based on currently available information and a different state in which action is taken using improved information. For example, in an RFF working paper supported by VALUABLES, Sullivan and Krupnik (2018) explore the possibility that air pollution monitors, adopted by the

[5] https://www.rff.org/valuables/

American National Ambient Air Quality Standards (NAAQS), do not effectively detect the fine particulate matter concentration ($PM_{2.5}$) in compliance with Clean Air Acts. By comparing satellite-based assessments with official attainment designation by terrestrial monitors, they calculated the number of people living in areas not properly classified. They also estimated that if misclassified areas had sped up their $PM_{2.5}$ reductions as those classified as 'nonattainment' by monitors did, 5,452 premature deaths would have been avoided, with a welfare gain of USD 49 billion. Consortium experts also contributed to the article Bernknopf et al. (2018) that quantified the economic value of information deriving from the Gravity Recovery and Climate Experiment (GRACE) satellite mission for drought monitoring. Using satellite data would have changed county eligibility for drought assistance, thus lowering the uncertainty associated with drought understanding.[6]

3. The growing use of satellite data in social sciences

While in the previous section we have briefly reviewed some direct societal benefits, satellites data are also increasingly used in scientific research to investigate and analyse a wide range of issues. This is an indirect benefit, which is more difficult to monetise because its effect will be felt at a later stage. The literature already provides several examples where satellite images have been used to investigate natural phenomena such as sea ice extent (e.g. Spreen and Kern, 2016), large scales ground instabilities and movements (Kalia at al. 2016), differences in crop types (Inglada et al., 2015), post-eruption volcanic ashes (Schmidt et al., 2015), oceans' surface height, temperature and chlorophyll concentration (LeTraon et al., 2015; Von Schuckmann et al., 2016), air pollutant fluxes (Duncan et al., 2014), among others.

Beyond natural issues, satellite data has also boosted the amount of information that social scientists can obtain to study different socio-economic phenomena (Donaldson and Storeygard, 2016). By providing high spatial resolution images on the Earth, with wide frequency and geographical coverage, EO gives the possibility to build innovative datasets at a lower marginal cost compared to terrestrial surveys, which can be used 'ex-post' by social scientists to answer numerous research questions (Donaldson and Storeygard, 2016).

First of all, the increasing availability of satellite data is particularly useful in development economics but also in developed economies at subnational levels, where usually the lack of ground-

[6] The authors examined how GRACE-Data Assimilation may have changed county eligibility for drought assistance under the Livestock Assistance Grant Program (LAGP) even though a quantification of the actual VoI was not possible because of the unavailability of county level data to estimate the effects of drought assistance on local agricultural outcomes.

based data limits the possibility to study different issues. In this respect, Henderson et al. (2012) have demonstrated that satellite night lights data are a useful proxy for GDP growth at temporal and geographic scales for which traditional data are of poor quality or simply unavailable. For instance, Lee (2018) uses data on nightlights to investigate how regional inequality in terms of the spatial distribution of economic activities evolves when a country like North Korea, for which official statistics are almost not existent, become isolated due to sanctions decided by the international community. Storeygard (2016) studies whether Sub-Saharan cities, which are better connected to the main port of their country, grow faster than cities with poorer road connections when the oil price rises. As data on income are poorly available the author uses information on satellite night lights over a period of 30 years as a proxy of GDP growth and find that an oil price increase of the magnitude experienced between 2002 and 2008 induces the income of cities near the main port to increase by 7% relative to otherwise identical cities 500 kilometres farther away.

Secondly, satellite data are also very useful to construct new detailed datasets on specific items that are not available from official statistics, such as indicators of housing quality or built-up land cover. In this respect, social scientists are increasingly supported by experts in machine learning. For example, Marx et al. (2017), by combining a resolution of 0.5 meters satellite images of the Kibera slum in Nairobi between 2009 and 2012 and data collected from a big survey with about 30.000 dwellers, show how ethnic patronage affects both the determination of rental rates and housing quality. The authors find that slum residents pay lower rents and live in higher quality dwellings (measured through the luminosity reflected by corrugated iron roofs) when they have the same ethnicity as the locality chief. These results suggest that ethnic patronage have both distributional effects and consequences on welfare in the residential market of the slum. Vogel et al. (2019) employ satellite data to analyse local economies by defining urban markets with built-up land cover classified from daytime satellite imagery in India. By constructing this innovative dataset with an artificial intelligence algorithm, the authors are able to capture more markets, more urban population and more variation in the spatial distribution of economic activity compared to nighttime light intensity.

Thirdly, satellite data are also useful when available official statistics are not credible. For instance, Clark et al. (2017) use satellite night-time lights as an independent benchmark for comparing various Chinese economic indicators, showing that the rate of Chinese growth is higher than what is reported in the official statistics. Chen et al. (2011) compare aerosol optical depth data from MODIS with the air pollution index of Beijing, which is not always considered reliable as based on official statistics. They show that air quality effectively improved during the preparation of the Olympic games due to the government commitment in taking measures such as traffic controls and introduction of emission standards, among others, for a total cost of USD 10 billion. Just one year after the end of the Olympics, however, such effect weakened by 60%. Results suggest that real environmental improvement depends on the political motivation behind the interventions. Burgess et al. (2012) cannot rely on official statistics to study deforestation in Indonesia. Hence, by combining MODIS data on deforestation with GIS data on administrative districts over the period 2001-2008 they find that, as national logging rules are enforced at the local level, potentially corrupt local bureaucrats and politicians respond to incentives of deforestation consistently with their rent maximization. Jayachandran (2009), by combining daily satellite measures of airborne smoke and dust with info from the 2000 census on "missing children", estimates the impact of air pollution due to illegal forest fires in Indonesia on infant and fetal mortality. The author finds that the spread of pollution of a big illegal fire in 1997 caused 16,400 infant and fetal deaths with a striking difference in the mortality rates between richer and poorer places.

Fourthly, satellite data are also helpful to perform global comparisons among statistics that otherwise would not be comparable. For example Costinot et al. (2012) attempt to quantify the consequences of climate change on agricultural productivity in three different scenario, by using a rich dataset (FAO and GAEZ) which contain data on soil, topography climatic condition to predict the yield, crop by crop, for each of 1.7 million fields covering the surface of the Earth. They find that in the best scenario, climate change amounts to a 0.26% decrease in world GDP with a heterogeneous effect across countries. Hodler and Raschky (2014) look at regional favouritism using a panel of 38,427 subnational regions from 126 countries with observations from 1992 to 2009. By combining satellite data on the intensity of night-time lights from NOAA with resources cited in the codebook of the Archigos database and various Internet sites, the authors mapped 1990-2010 political leaders' birthplaces and found that subnational regions have more intense night-time light when being the birth region of the current political leader. They also show that regional favouritism is most prevalent in countries with weak political institutions and poorly educated citizens.

Lastly, another way in which satellite data are increasingly used in social science is when geography, weather, or other aspects of the earth are used as a source of exogenous variation for estimating the impact of various 'treatments'. (Kudamatsu, 2018). For example, Saiz (2010) uses satellite-data on the use of land provided by the United States Geographic Service (USGS) to show how geography determines housing supply. He constructs a measure of exogenously undevelopable land in cities due to geographical constraints by calculating the area lost to internal water bodies and wetlands and land which exhibits slopes above 15%. He finds that residential development is constrained by the presence of sloped terrain and that land constrained area show inelasticity in housing prices and are more highly regulated. Flückiger et al. (2015) show that negative economic shocks in the fisheries sector are associated with an increase in maritime piracy. They use the variation in the phytoplankton abundance for 109 countries measured by satellite data in the period 2004-2009, as a source of such shocks to avoid endogeneity problems between piracy and fish catches. They find that phytoplankton abundance is positively related to fish catches but negatively associated with the incidence of piracy. Lower abundance of phytoplankton deteriorates economic opportunities in the fishery sector increasing the relative attractiveness of engaging in piracy activity.

4. The Italian Cosmo SkyMed (CSK) satellites constellation

This section provides a brief description of the main technological features, data acquisition and use policy of CSK which is the unit of analysis of our study.[7]

Entirely developed by ASI in cooperation with the Italian Ministry of Defense, CSK satellites expand the number and the quality of existing EO infrastructure and join, in the European context, the heterogeneous fleet of ESA Sentinels satellites.[8] CSK is based on a remote sensing technology[9] and has military and civilian applications. It is composed of four identical satellites orbiting the earth at an altitude of 619 km and with a 97-minute orbital period allowing a high temporal resolution. The system can carry out up to 450 shots of the earth's surface per day, equal to 1,800 radar images, every 24 hours. Over its first ten years of operations, it has snapped more than 1 million radar scenes all over the world, monitoring the earth 24 hours a day, under all weather and visibility conditions. It has contributed to national security, supported people struck by natural disasters like the earthquakes in Aquila in 2009 and Amatrice in 2016, the Nargis cyclone in Burma in 2008 or hurricane Harvey in 2017. It has contributed to monitoring deforestation in Amazonia and has provided data and tools for sustainable farming, surveillance of UNESCO sites, monitoring

[7] Depending on data availability our analysis can be possibly extended to Copernicus.

[8] The Sentinels are a family of EU-owned satellites specifically designed to meet the needs of Copernicus sevices and their users. Copernicus services, which rely on a full, free and open data policy, represent a flagship program of the EU to monitor earth, its environment and ecosystems as well to prepare for crises, security riscks and natural or man-made disasters.

[9] Remote sensing can be either passive or active: while passive instruments detect natural energy that is reflected or emitted from the observed scene, active instruments provide their own energy (electromagnetic radiation) to illuminate the object or scene they observe by sending a pulse of energy from the sensor to the object and then receiving the radiation that is reflected from that object. (https://earthobservatory.nasa.gov/features/RemoteSensing/remote.php) The quality of remote sensor satellites can be evaluated with respect to spatial, temporal, radiometric and spectral resolution.

of the ice caps shrinking in the polar regions and oil spill in the Gulf of Mexico after the explosion of the Deepwater Horizon oil platform in 2010.[10]

The four satellites of CSK are equipped with synthetic aperture radar (SAR) working in the X band and with particularly flexible data acquisition and transmission equipment. The SAR technology can be described as a special camera that, instead of using light, uses a microwave electromagnetic radiation to acquire images of the earth. While the optical sensors represent a natural technological extension of human visual perception, the microwave sensors observe the earth in a completely different way, generating innovative measurements and interpretations. Kirscht and Rinke (1998) describe SAR as a radar that is used to create two-dimensional images or three-dimensional reconstructions of objects, such as landscapes. According to Fornaro (2008), SAR is based on the principle of synthesising a large aperture along the height to provide radar images with 3D resolution. During the last decades, the SAR technique has been increasingly implemented for the analysis of complex scenarios. Various information can be extracted according to the variation of the analysed frequencies. Thanks to its SAR systems, CSK can observe the earth in a practically continuous manner, both day and night and, most importantly, almost independently of atmospheric conditions (Oliver and Quegan 1998; Ramakrishnan et al., 2002). This allows collecting unique cloud-free data that can be examined with interferometric techniques.

CSK allows for very flexible applications because its sensors have been designed to acquire different types of images such as 1) spotlight: the satellites focus on an area of few square km, and it presents a high resolution (1 mt x 1 mt), while the observable surface is only 10 km by 10 km. 2) PING-PONG: an intermediate mode with a resolution of 15 mt x 15 mt with an observable surface with a 30 km side. 3) stripmap: a continuous strip of the land surface is observed. In this mode, the resolution varies from 3 mt x 3 mt to 5 mt x 5 mt and the related observable surface is 40 square km; 4) scanSAR WR (Wide Region): covers a very large area (100 mt x 100 mt) with a discrete resolution (30 mt x 30 mt); 5) scanSAR HR (Huge Region): in this mode the satellites cover a region of 200 km, but the resolution suffers a lot, in fact, does not go beyond 100 mt x 100 mt.

The radar can focus on an area of few square kilometres and observe it with a very high resolution and accuracy, up to a single meter. Alternatively, it can observe a continuous strip of land surface or cover a region of 200 km. In this case, collected data show a lower resolution but cover a wider geographical area. Another advantage is given by the possibility to monitor the same point with a time-lapse shorter than 12 hours, which allows monitoring in a constant way any given area affected by critical events (ASI, 2016). In order to understand the quality of information collectable,

[10] https://directory.eoportal.org/web/eoportal/satellite-missions/c-missions/cosmo-skymed

it is sufficient to consider that, the most popular data used in economic analysis is obtained by Landsat satellites which have a spatial resolution up to 30 mt (15 for panchromatic bands) while the ESA Sentinels have a spatial resolution up to 20 mt for radar imageries and 10 mt for optical ones.

On the basis of specific needs defined by the space program of the Italian government, CSK activated a periodic complete interferometric mapping service of the Italian national territory in the StripMap-HIMAGE acquisition mode. This project, named MAPITALY aims at acquiring consistent time series of images to be used for interferometric investigations to analyse and monitor the evolution of potentially risky natural phenomena (landslides, subsidence, seismic or volcanic phenomena).The CSK satellites constellation system is also often integrated by ground infrastructures, which manage the constellation and grant ad-hoc services to collect, archive and distribute acquired remote sensing data.

With respect to the use data policy,[11] CSK data can be transmitted via two alternative channels. First, whenever data are processed for commercial purposes, or when they are required by foreign institutions, they are managed and provided by the company e-GEOS.[12] This is a company co-owned by ASI (20%) and Telespazio (80%) that offers a portfolio of application services including monitoring for environmental protection, management of natural disasters, specialised defence and intelligence products, oil spill and detection of ships for maritime surveillance, interferometric measures for landslides, analysis of soil subsidence, thematic mapping for agriculture and forestry. e-GEOS sells both the raw satellite data and the information extrapolated from data processing. This represents a crucial point as most of the end-users do not have the skills and capacity to elaborate satellite data internally.[13] In the first 10-years of CSK activities, e-GEOS has delivered more than 117,000 scenes to more than 760 commercial users, in more than 70 countries worldwide. e-GEOS is also managing the network of CSK commercial receiving stations (Ten stations currently located all over the world), called CUT (Commercial User Terminal) that allow downlinking CSK data directly to their antennas for customers' operational needs. (Calabrese et al., 2018)

While commercial requests of CSK satellite data are managed by e-Geos, data requests for national civil institutional purposes are made available directly by ASI. In the latter case, satellite data are granted free of charge, both for national and international institutional users and for international cooperation projects, conditionally on the submission of an official request to the ASI's Earth Observation Unit which then grants a license. This allows ASI to collect information on

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[11] In this analysis, we restrict our attention to the civil use
[12] https://www.e-geos.it/#/
[13] However, entities such as defence ministries of foreign governments or big corporations own internal skills to process raw satellite data independently.

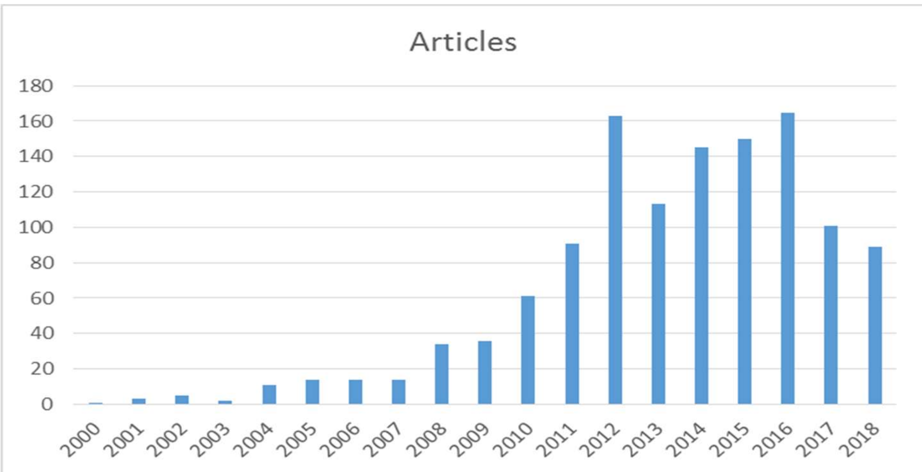
the CSK data users. However, as reported in Tassa (2019), EO data are still too complex and not user-friendly. They need transformation, manipulation and often integration with other types of data in order to provide value-added products and services, particularly in the public sector. The engagement of local institutions in using EO data can be particularly restrained due to several factors such as the lack of awareness of the advantages of using this data, lack of expertise and inertia to innovation (Tassa, 2019).

5. Overview of the scientific publications about CSK

As an empirical strategy to gain more information about the diffusion and utilization of CSK data we explored the number and types of publication related to CSK available on Scopus which is the largest database of peer-reviewed literature including scientific journals, books and conference proceedings.[14] Our preliminary analysis shows that the number of academic publications on this topic is growing year by year and particularly focuses on geoscience and optical engineering. During the period 2000-2018, Scopus reports 1,212 documents related to CSK. These documents have been selected, extrapolated and analysed by typing the keyword "Cosmo SkyMed" into Scopus. 60% of them are classified as conference papers or proceedings, while 36% are research articles. They have been written by 2,318 authors and published into 271 different sources such as journals or books. 25 journals cover 69% of these articles.

The number of publications experienced an increasing trend during the period 2000-2011. As Figure 1 shows, during the years 2012-2016 we registered a peak in publications (163 per year in 2016).

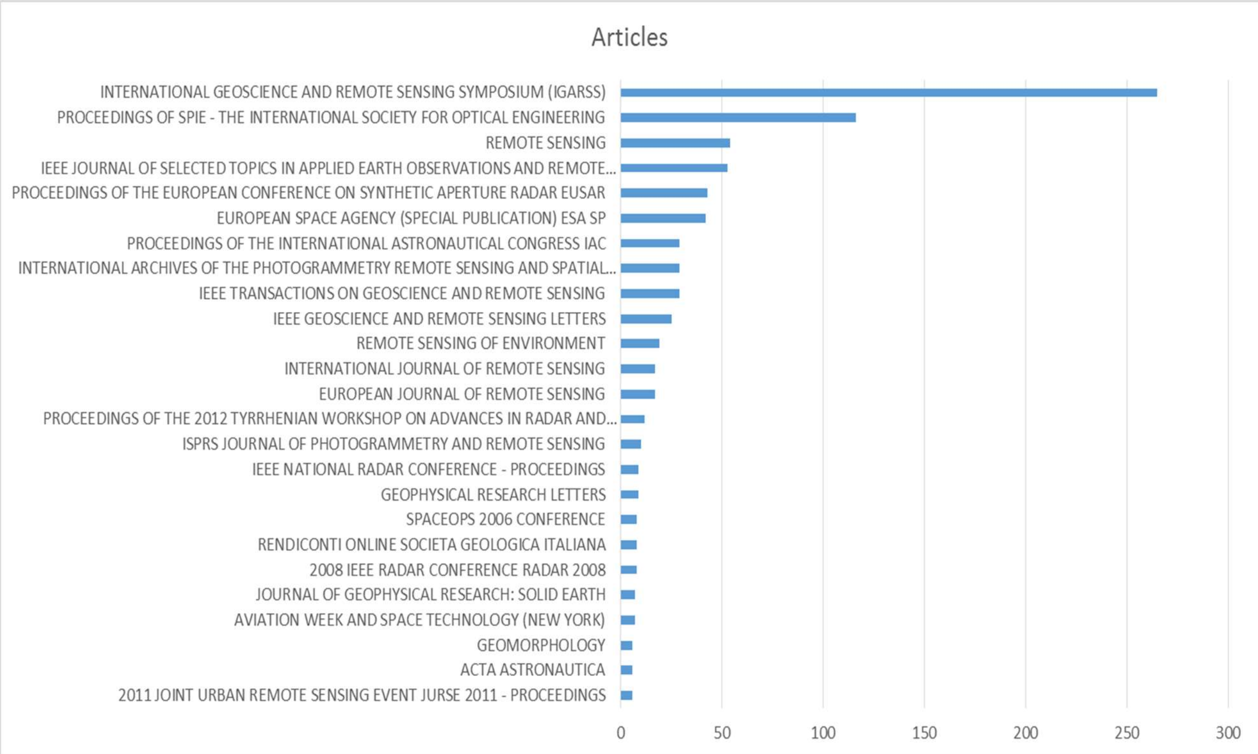
Figure 1 - Temporal distribution of articles related to CSK



[14] https://www.elsevier.com/solutions/scopus

Remote Sensing, which is the top journal in the field of remote sensing (34 h-index), experienced an increasing trend of published papers, from 1 publication in 2011 to 16 publications in 2018. This suggests that CSK data are experiencing an increasing relevance within the scientific community. Interestingly, out of the 271 sources, none of them belongs to the field of social sciences. We deduce that CSK data has so far never been used to develop economic analyses.

Figure 2 - Top 25 journal reporting articles related to CSK: number of articles per journal

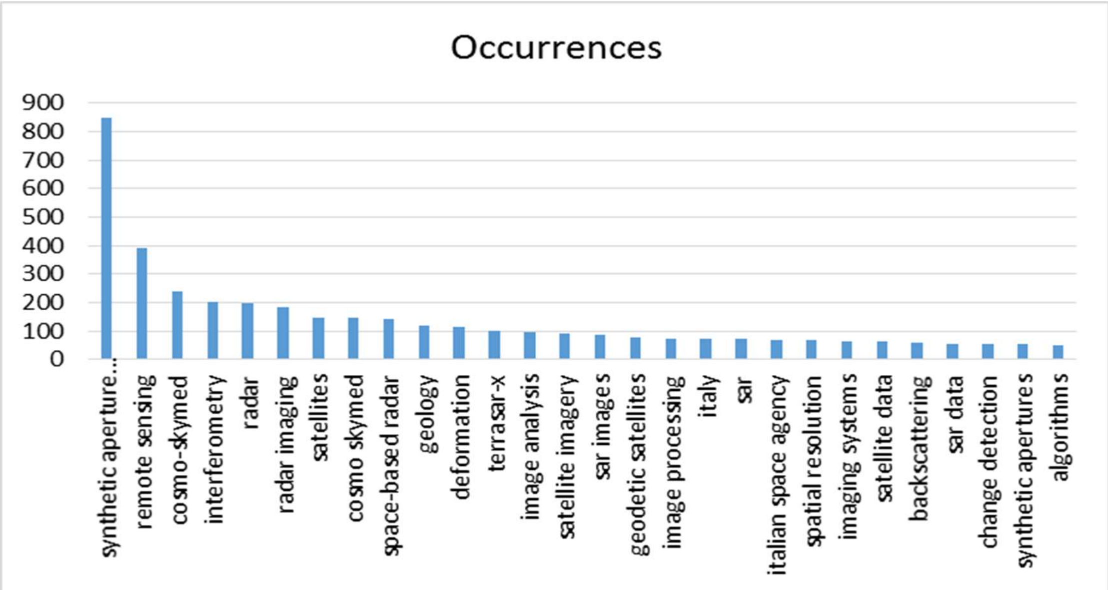


We also looked at the geographical distribution of the authors' affiliations. When we look at the corresponding author's country, the top 20 countries count for 81% of the 1,212 articles. Out of these, 694 publications come from Italy (57% of the entire sample) and, within this sample, 110 articles are the result of collaborations among authors affiliated to multiple countries. The prevalence of Italian publications is evident also by looking at the affiliation of the top 20 authors (not necessarily corresponding authors) in terms of the number of publications. With the exception of one author affiliated to the Luxembourg Institute of Science and Technology (LIST), all the top 20 authors in terms of number of publications come from Italy (and the two top authors are affiliated to ASI).

In spite of being freely available to public institutions and universities, the diffusion of CSK data remains quite limited, probably because the licensing procedure to get access is less friendly than other EO data such as Copernicus data (which can be freely downloaded directly from internet without the need to obtain any access license), or because knowledge about their existence is still limited.

An analysis of the main keywords reveals that, in spite of the concentration of authors in Italy, CSK data have been used to develop analysis all over the world, particularly in Asia and America. Finally, some relevant information can be extrapolated from the textual analysis of the main keywords of these publications. Keywords reported more than 50 times count 70% of the whole sample (5.557 keywords). Both the Co-occurrence network (which provides a graphic visualization of the relation between the main keywords) and their counting show that most of the keywords are technical words referring to the type of data, their sources, and the techniques of analysis (Figure 3).

Figure 3 - Keywords counting



We restrict our analysis on other types of keywords which compose the remaining 30% of the sample. Since various keywords are used to refer to the same concept, we simply group them into the main clusters without counting them and we classify them according to the Onoda and Young (2017) taxonomy. CSK data are mainly applied to natural phenomena which mainly refer to the terrestrial environment, though relevant applications concern the marine environment as well and, to a less extent, the atmospheric one.

Table 2 - Keywords' classification according to the type of environment analyzed

Terrestrial	Marine	Atmosphere
Geology	Hydrology	Wind
Morphology	Oceanography	Climate change
Ground deformations	Floods	Moisture
Volcanic eruption	Surface waters	Hurricanes
Earthquakes	Sea surface	Storms
Landslides	Rain	Clouds
Coast	Water levels-surface	
Soil moisture	Ocean	
Coastal zones	Lakes	
Snow covers	Glaciares	
Soils	Algal bloom	
Glaciers		
Land subsidence		
Arid regions		
Mountainous area		

Other keywords reveal that applications of CSK data refer to human activities and constructions

Table 3 - Keywords related to economic activities

Economic activities	Built environment
Agriculture	Bridges
Groundwater exploration	Buildings
Land use	Cities
Maritime transport	Dams
Military operations	Farms
Public transport	Ferry boats
Railroad transportation	Gas pipelines
Railway transport	Harbor
Road construction	Highways
Urban growth	Historical centres
Urban mapping	Industry
Urban planning	Metropolitan area
Urbanisation	Naval vessels
Water extraction	Oil tanks
Civil engineering	Parks
Archaeology	Railroads
Coal mining	Roads and streets
Crop growth	Roofs
Anthropogenic activity	Submarines
Cultural heritage	Subways
	Urban areas, fabrics, infrastructure, parks

Some keywords clusters suggest that, on top of allowing to monitor natural phenomena or human activities, these data: have been also used to 1) detect illegal activities or to study the impact of human activities on the environment; 2) provide information to develop evaluation processes, quantify damages, assess risks and hazards. 3) provide information to take decisions (protect, prevent, manage, mitigate)

Table 4 - Keywords clusters

Detection/human impact on the environment	Evaluation	Intervention/Management
Damage detection	Damage	Civil protection
Deforestation	Earthquake damage	Disaster management
Fires	Environmental hazards	Disaster prevention
Forest degradation	Environmental risks	Environmental protection
Hazardous materials spills	Environmental Sustainability	Flood protection
Illegal discharges	Fire hazards	Flood risk management
Illegal immigrants	Flood control	Hazard management
Marine oil pollution	Flood hazards	Human resource management
Marine pollution	Food security	Industrial management
Maritime pollution	Land cover classification	Maritime surveillance systems
Noise	Maritime security	Risk management
Oil pollution	National security	Risk mitigation
Oil spill	Natural hazard	Risks management
Oil spill detection	Risk analysis	Water management
Pollutant	Risk assessment	Water resource management
Pollutant materials	Risk management strategies	Crisis prevention
Pollution	Road condition	
Pollution control	Seismic damage assessment	
Pollution effect		
Ship detection		
Ship identifications		
Urban change detection		
Water detection		
Water pollution		

Finally, we mention some keywords which explicitly refer to the economic field: cost-effectiveness, economic activities, economic and social effects, economic development, economic growth, economic opportunities, economics, efficiency measurement, public administration, public policy. The keywords analysis reveals that CSK satellite data provided crucial information for monitoring natural phenomena, such as oil spills into the sea, floods, volcanic activity, earthquakes, landslides, coastal erosion. For example, the continuous availability of precise measurements of vertical or horizontal ground movements can provide information to prevent serious damages. CSK remote sensing data of various serious natural disasters, such as Cyclone Nargis in Burma, the earthquake in China and Hannah and Ike on Haiti, were used by the United Nations and humanitarian organisations involved in aiding the population.[15]

6. CSK data and law enforcement: the Ventimiglia case study

Hereby, we describe a case study to show how CSK data can be used to provide valuable information both in the private and public sector. Jointly with the municipality of Ventimiglia, a town with around 24.000 inhabitants located in the Northwest of Italy (region Liguria), the NeMeA Sistemi, an Italian small business, also based in the Italian region of Liguria, won an ASI open call, reserved to SMEs, start-ups and academic spin-off. The call aimed at creating innovative applications, products and services developed from the elaboration of satellite data and allowed NeMeA Sistemi to get free access to both spotlight and striptmap satellite data on the municipality of Ventimiglia. With such information, NeMeA Sistemi developed digital applications to monitor the coastline and assess its potential erosion, identify riverbed sediment, the existing artefacts on the territory and, after a comparison with cadastral data, identify "Spontaneous Constructions" (illegal buildings).

Our case study focuses on this latter point. The term "spontaneous constructions" refers to unauthorised activities, carried out in a professional and organised manner, aimed at building artefacts of different size on the territory. Illegal edification is a widespread problem throughout the country with serious implications in terms of tax evasion, citizens' security and environmental quality (ISTAT, 2017). Constructions which are not regularly reported in the land registry are not properly accounted for the calculation of national or local taxes (asset-based or urban waste taxes), whose rates are applied to the cadastral volumes. Moreover, unauthorised buildings can be placed in areas which can be either unsafe, due to the exposure to seismic or hydrogeological risks, or protected, due to their landscape, artistic or cultural heritage value.

The digital application developed by NeMeA Sistemi is based on some replicable and scalable algorithms that, by matching satellite and cadastral data, allow identifying, for a given area of interest, all the physical components (artefacts, fences, roofs, excavations for foundations, perimeter walls, roads and access to properties) not registered in the cadaster. The identification of illegal buildings occurs after several steps[16] where data are imported, processed and elaborated by the app.

[15] These and other applications of CSK data are reviewed in the News section of the ASI website, https://www.asi.it/en/news

[16] 1) Import of the updated Cadastral cartography (current + incremental) in the geospatial information systems (GIS) environment. In this first step, land registry data (SIGMATER interchange format) are provided by (and imported from)

In this way, the municipality is equipped with a user-friendly device that allows addressing, efficiently and promptly, further checks by the municipal police personnel and other inspections (domestic water or power connection, urban waste taxes etc.) for the punctual verification of unauthorised buildings.

This case study can be used as a starting point to quantify the socio-economic benefits resulting from the identification of building abuses, also estimating the deterrent effect, stemming from the availability of satellite data, on illegal activities. Concerning the first point, three main benefits can be identified. The first is a potential increase in tax revenues deriving from a higher detection of illegal activities. A second benefit is the potential reduction of monitoring and searching costs deriving from the digitalisation of the inspection procedures. Detecting illegal activities is difficult and costly, especially in light of the scarce resources that institutions can allocate to this activity. The third benefit relates to the increased possibility of identifying human activities taking place in particular areas which can be critical either for their archaeological or landscape value or because of their riskiness. This can allow assessing whether illegal building behaviour causes environmental damage (deterioration of the landscape quality or reduction of the artistic value of cultural heritage areas) or whether it is associated to increased risks and costs related to the safety of citizens. This assessment can be developed by matching the maps reporting the location of illegal buildings with other visual maps showing seismic or hydrogeological risks.

This case study points out another important issue which is related to the effective utilization of CSK data and the identification of barriers that are currently limiting the widespread dissemination of satellite data at the local level. This step is required to identify which policies can be implemented to overcome the existing obstacles and promote a major diffusion in the utilisation of EO data. This is not a secondary issue, as currently most of the potential benefits associated with EO data applications remain largely unexploited because EO data are not sufficiently widespread (in spite of free access policy for local administrations).

Firstly, a taxonomy of these obstacles should be defined, ranging from cognitive obstacles

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the Liguria digital cadastral platform. This process benefits from the use of proprietary NeMeA Systemi (CDU.NET) capable of transferring CML data into MDB GIS compliant formats 2) Import of HD satellite historical data (year 2012) (40 cm on the ground, GeoTiff formats, integrated into GIS); 3) Import of satellite (RADAR / SAR) CSK data (year 2015) and image processing through the use of SNAP_ESA_SAR platform or ERDAS Imagine platform. 4) Import of HD satellite recent data (year 2016) (40 cm on the ground, GeoTiff formats, integrated into GIS): from WorldView 3.8 bands or 4 + pansharpen, orthorectification and output in ECW compressed raster formats.

(data are difficult to be managed), economic obstacles (their elaboration can be expensive), governance and organizational issues. ASI owns and manages directly CSK satellites and the storage of their data, while it is not active in the final segment of the data chain which relates to their elaboration. While e-Geos is entitled to sell elaborated data, ASI makes freely available raw satellite data without providing any related service linked to these data. One could claim that the real value is not in the EO data per se, but in the elaboration of these data and in the various information and services that can be extrapolated from them. Given their complexity, these data maybe be useless (or of little value) to a local entity lacking adequate data mining competences, which are required to interpret these data.

We can claim that, at the moment, there is a decentralized organisational structure (or even a lack of organisation in the data management): each local institution in Italy can freely download and elaborate CSK data, but they do this on a voluntary basis. It is up to the institutions to decide whether to use such data or not. Local public entities (municipalities) usually face financial constraints and lack of adequate scientific skills to elaborate and interpret CSK data. In order to exploit them, they should acquire new competencies, but this implies high replication costs (each municipality should hire data scientists and elaborate algorithms to extrapolate valuable information from the data).

The lack of an adequate organisational framework in the data management and elaboration procedures can result in high costs and barriers that could be reduced through a better organisation of the value chain (for instance by increasing the role of a centralized intermediary body with the duty to elaborate data and provide services). Understanding data governance and policies aimed at overcoming the barriers that currently inhibit the use of these data is a key element to overcome the current obstacles hindering the full exploitation of the EO data. Service providers as NeMeA Sistemi who are able to manipulate the data and extract meaningful information from it and make it fully exploitable by non-expert users, play an essential role in the development of the downstream space sector (Tassa, 2019), particularly in the Italian context.

7. Concluding remarks

An increasing number of products and services, with important socio-economic implications, are deriving from spin-off (or spin-out) initiatives related to the adoption and exploitation of space technologies. While potential benefits stemming from the wide and diverse use of space technologies are identified in the literature, little is known about the use of CSK data in Italy. The impact of ASI's activity on the downstream sector is potentially highly significant, although mainly still unexplored.

In a social cost-benefit analysis perspective, further research is needed to compare, on one side, the intertemporal value of construction and operation costs of CSK (available in the ASI accounting documents with appropriate backwards and forwards estimations) with, on the other side, the stream of socioeconomic benefits produced, against a counterfactual of more traditional ways to monitor earth (such as ground infrastructure, visual inspection, etc.). While this analysis is not yet available, in this paper we have suggested possible research strategies, drawing from international experience, where a number of cases have been considered. Cost-benefit analysis of EO is in its infancy, but this paper suggests that in principle it is feasible.

By relying on Scopus data, our preliminary analysis of academic works using CSK data shows that the number of publications on this topic is growing year by year revealing, at the same time, that CSK data has so far not been used to develop socio-economic analyses. A preliminary analysis of the case study of the Ventimiglia municipality, based on the detection of illegal artefacts, also reveals the potential socio-economic benefits stemming from the use of CSK data, for example, in increasing the amount of tax revenues, reducing monitoring and searching costs, identifying risky human activities and potentially acting as a deterrent for illegal activities.

At the moment, there is a significant discrepancy between the various possible uses of satellite data and their actual use at the national level. This implies that many of the socio-economic benefits related to the availability of CSK data, which have systematically been collected and archived since 2009, remain potential, unexpressed and undervalued. To date, local and central public administrations have not systematically adopted CSK data in management, evaluation and decision-making processes. It is therefore clear that, in the Italian context, there are several technical, legal, organisational or communication barriers that are hindering the full exploitation of information that can be extrapolated from satellite data.

The need of analysing the space downstream sector and the socio-economic impact of EO data plays a key role in the evaluation of national space policies since the real added value of space technologies is not embedded in the creation and collection of satellite data *per se*, rather than in the diffusion of innovative applications able to process these data, extrapolate information that are valuable to final users and make them available in a very short time and at an accessible price (OECD, 2016). Indeed, raw satellite data are complex to be managed, need to be cleaned and processed to extract valuable information to final users. For this purpose, innovative services and applications have been (and many still can be) developed to provide various services that ground infrastructures are unable to offer, if not at prohibitive costs.

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