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Use of Satellite Data for Energy and Raw Materials Applications and their Impact on SDG Indicators

Tesi di Laurea Magistrale in
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Abstract

The rapid growth of Earth Observation industry caused in the past years a massive increment in the number of commercial satellites launches. Furthermore the market nowadays is conditioned by a strong increase in the demand of satellite information, which is leading to a strong redundancy in the available data, as private agencies are pushed mainly by their economic interests. The following analysis tries to build an analytical framework to better organise the demand and the supply taking into consideration only the energy and natural resources market defined by EARSC. Firstly it has been necessary to define an updated EO satellites database, specifying the type of sensors on board and identifying for each payload the revisit time. The types of instruments considered are only the SAR sensors for the active ones, while for the passive ones the panchromatic, multispectral and hyperspectral cameras have been considered. Once completed the database, the analysis switched its focus on the definition of energy market applications. First of all it is important to divide the market into three different sectors: renewable energy, oil and gas and raw materials. The three sectors, despite having common interests, are nowadays approaching in a completely different way the increasing exploitation of remote sensing information, and for this reason it is fundamental to assign to each of them different applications. Moreover, through the introduction of some variables, it has been possible to directly connect the specific sector applications to the satellites in the database, using the definition of the constraints associated to their sensors and revisit time. At this point it is possible to find rapidly and easily all the active satellites able to grant the support to every specific application defined in the analysis. Lastly a study of the Sustainable Development Goals indicators defined by UN has been conducted: starting from the identification of the indicators which could be supported by the energy market, and then ending with the definition of an analytical approach to compute in a quantitative way the potential impact of the EO applications on the indicators.

Keywords: earth observation, EARSC, energy, sustainability, SDG indicatos, space economy

Abstract in lingua italiana

Il veloce sviluppo dell'industria di *Earth Observation* all'interno del settore spaziale è stato causa, negli ultimi anni, di un massiccio incremento nel numero dei lanci di satelliti commerciali adibiti a questo scopo. Il mercato recente, oltretutto, è condizionato da un forte aumento della domanda di informazioni satellitari, che ha portato a una forte ridondanza dal punto di vista di dati disponibili, essendo le aziende private spinte principalmente da interessi economici. La seguente analisi cerca di trovare un metodo di ottimizzazione per fare ordine tra domanda e offerta, prendendo in considerazione solamente il mercato dell'energia e risorse naturali definito dall' EARSC. Per prima cosa un database aggiornato comprendente satelliti EO è stato definito, valutando la tipologia di sensori a bordo dei payload e definendo il revisit time di ciascuno. Le tipologie di strumenti considerate sono solamente sensori SAR tra quelli attivi, e camere pancromatiche, multispettrali e iperspettrali per quelli passivi. Una volta completato il database, l'analisi è passata sulla definizione delle applicazioni collegate al mercato energetico. Innanzitutto è importante suddividere il mercato in tre settori differenti tra loro: energia rinnovabile, petrolio con gas naturale e infine materie prime. I tre settori, sebbene abbiano interessi comuni, attualmente si approcciano in maniera molto differente allo sfruttamento delle informazioni provenienti da satelliti, ed è stato per questo motivo fondamentale assegnare a ciascuno differenti applicazioni. Attraverso l'introduzione di alcune variabili inoltre, è stato possibile legare direttamente le specifiche applicazioni ai satelliti presenti nel database, sfruttando la definizione di vari vincoli legati a specifiche dei sensori e revisit time. A questo punto è quindi possibile trovare in modo rapido tutti i satelliti attivi in grado di supportare ogni specifica applicazione definita nell'analisi. Infine uno studio degli indicatori appartenenti ai *Sustainable Development Goals* definiti dall'ONU è stato svolto: inizialmente gli indicatori idealmente supportabili dalle applicazioni del mercato energetico sono stati identificati, e in seguito la definizione di un approccio per misurare in modo quantitativo l'impatto delle applicazioni derivanti da dati EO sugli indicatori è stata introdotta.

Parole chiave: osservazione della terra, EARSC, energia, sostenibilità, indicatori SDG, space economy

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1 | Introduction to Space Economy

1.1. History Overview

The remote sensing era started in 1957 with the launch by USSR of the Sputnik-1. This satellite was obviously very rudimentary: the batteries lasted only a week, and it burned out in the atmosphere just a couple of months after the launch, but it was able to transmit radio signals to the ground on its 96 minutes orbital period around Earth[44].

Though the launch of the satellite itself had no practical use at the time, thanks to it the first cycle of space development began[35]. The first cycle [1957-1972] is characterized by the so called "Space Race" between USA and USSR: the two governments were moved by the wish to demonstrate their military supremacy, through technology and industry, during the Cold War. In order to accomplish that, the push was focused mainly on the technologies necessary to support human exploration of space, and military surveillance with secret intelligence. As a matter of fact, right after Sputnik-1, Sputnik-2 was launched, with the first living being on it, and in January 1958 also the first US satellite was launched, named Explorer-1.

The second cycle of space development went from 1973 to 1986 and saw the birth of other space agencies in the world, among which the Chinese, Japanese and European ones are the most significant. ESA is between these the most relevant, since it can also be consider one of the first examples of political collaboration between different governments, with the aim to achieve common goals. This period is also characterized by the first generation of space stations, named Skylab and Salyut, alongside with a massive improvement of the space military applications, such as the GPS. Another important achievement of this cycle is the beginning of the civilian and commercial applications, with the example of the Landsat series, the first satellites with multispectral sensors aboard, able to depict large areas of ground surface in several bands of electromagnetic spectrum.

The third cycle [1987-2002] coincide with a strong development of the space role in the civilian and military applications, alongside with the start of the cooperation between the most important agencies, after the fall of the Soviet Union in the 1991. This stronger cooperation led to the second generation of space stations, which took his peak with the project of the International Space Station, launched at the end of the century, and still active nowadays.

The use of information coming from satellites in the commercial activities is always increasing even in cycle 4, which is considered to go from 2003 to 2018. This time lapse is a perfect indicator of the development of applications in various fields: thanks to the advent of digitalisation there was a rise in downstream activities, also caused by the generation of small satellites as new space systems, which led also to a more global market consisting of a lot of different space programmes.

Nowadays the fifth cycle has begun, with the main goal of granting the easiness of access to space for everyone, going from Earth observation, to global navigation systems. A full analysis on this new phase of Space Economy is found in 1.2.

1.2. Space Economy Today

Space Economy is the full range of activities, and the use of resources that create benefits to human beings, in the course of exploring, understanding and utilising space[19]. Therefore it includes all the public and private actors developing space-related products and services, but also all the scientific researches generated by such activities.

Despite the exponential growth of this sector through the years, space is not recognized as a category in the international standards of industrial classification, and this cause the lack of data comparability between national space statistics. This fragmented data structure makes the evaluation of socio-economics impact impossible.

The Organization for Economic Co-operation and Development (OECD) anyway, thanks also to the involvement of ESA member states, paved the way for the definition of three space segments, defining the perimeters of space activities and products[18]:

- Upstream: it includes space manufacturing, research and ground systems. It provides raw data coming from satellites.
- Downstream: it includes services related to the satellite technology and operations for terrestrial use, it elaborates and processes data coming from the upstream segment.
- Space-Related Users: it is the part of Space Economy which is more distant to the direct space applications, it includes all the products which use satellites technologies, but do not depend directly on them. It includes a variety of sectors such as

energy, agriculture and defence.

Figure 1.1: Space Economy Scheme

It is important to understand that though also the private market in space has grown in the past years, the governments still play a major role in the space activities[42], and for this reason it is fundamental to understand their vision of space as an instrument to support public policy objectives. These public objectives include for the most part defence and security, national sovereignty and economic development. This kind of view has an influence also on the newborn private activities, where the 61% uses the EO data for defence, and another 19% is divided between infrastructures and natural resources[9].

1.3. Copernicus Programme

Important topics as environment and sustainability have been included in governments objectives only in the last few years: the Copernicus programme represents the main example. It is a programme focused on Earth Observation, designed by ESA and opened in 2014 with the launch of Sentinel-1 satellite. It is composed nowadays by more than ten satellites, with this number which is intended to grow. The satellites of the fleet have different kind of sensors on board and at the same time they are on different orbits: this is fundamental in order to have different types of images and data. They are equipped with both optical sensors and synthetic aperture radar (SAR), and are able to give information about some major environmental topics, with the focus on six macro fields of application[20]:

- Atmospheric monitoring
- Marine environment monitoring
- Land monitoring
- Climate change
- Emergency management

- Security

The amount of information is massive, it is intended to become the third largest data provider in the world, and the first largest if only free of charge data are considered; in this way the European Agency aims to provide new operational services, but especially to boost the creation of new business opportunities. Furthermore this kind of investment made by the European Union, consisting in 4 billion between 2014 and 2020, is expected to result in the creation of more than 48000 jobs in the space field, focused to identify and respond to global phenomena, such as climate change[38].

1.4. Brief Focus on Downstream Segment

The role of downstream actors is fundamental in the Earth Observation market, their duty is to keep contact between the upstream segment and the end users. It occupies everything that goes from the acquisition of raw data coming from satellites, and the final use by the companies, which usually are not space related. It needs to give value to the high amount of information coming from space infrastructures, elaborating and filtering data, sometimes even using the help of in-situ exploration, in order to give back valuable and ready to use information.

The downstream segment is evolving exponentially through the recent years, with an increase in employment numbers which is very close to 20%[14] through the 12 month of 2020. This phenomenon is attributed to two different causes: the parallel expansion of the upstream segment, with the enormous growth in the number of launches, and the fundamental advancements of the digital technologies. Focusing on the latter, the main limit of the expansion of Space Economy in the past years was the fact that, even if the amount of data coming from satellites was high enough, softwares for the handling and the processing of imagery were very expensive and complex. As of today instead it is possible to find basic softwares which are cheap, or even free, and a lot more user-friendly. This is valid anyway only for basic versions, as more advanced programs require usually costly license.

This improvement of the technologies summed to the higher availability of the data has a direct effect on the creation of new start-ups: the information and the resources can be obtained with less investments and this created an exponential growth of small companies. According to EARSC the 84% of the start-ups created in 2019 have less than 10 employees each[14].

This turn could result also in the democratization of the access to the space sector, thanks to scalable and innovative business models. The market anyway is still bonded to the amount of funding that the start-ups receive, since it is necessary to the acceleration of services commercialization. Europe, thanks also to the impact of Copernicus programme, and North America represent nowadays the major hotspots for new space innovation companies, having 74% of start-ups concentrated in these two regions, followed by Asia, South America and Oceania which do not arrive to the 10%[36].

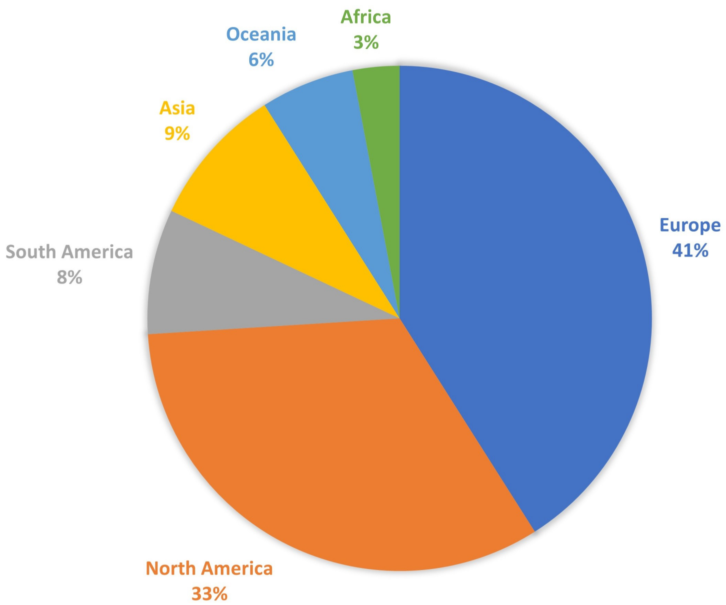


Figure 1.2: Start-up distribution by continents

This can be attributable to the minor investments presents in these regions, but it cannot be the only reason, since the investments in Europe are a lot less than in Asia, and are just a little more than the Oceania ones. The cause of the disparity can stand in the low trust of the investors in the emerging space technologies. The lower confidence in these kind of technologies is considered a problem also for the European companies: though the market is growing, it is harder for them to grow at the beginning of their activities, and this may boost the tendency to concentrate innovation and relocate in the US borders.

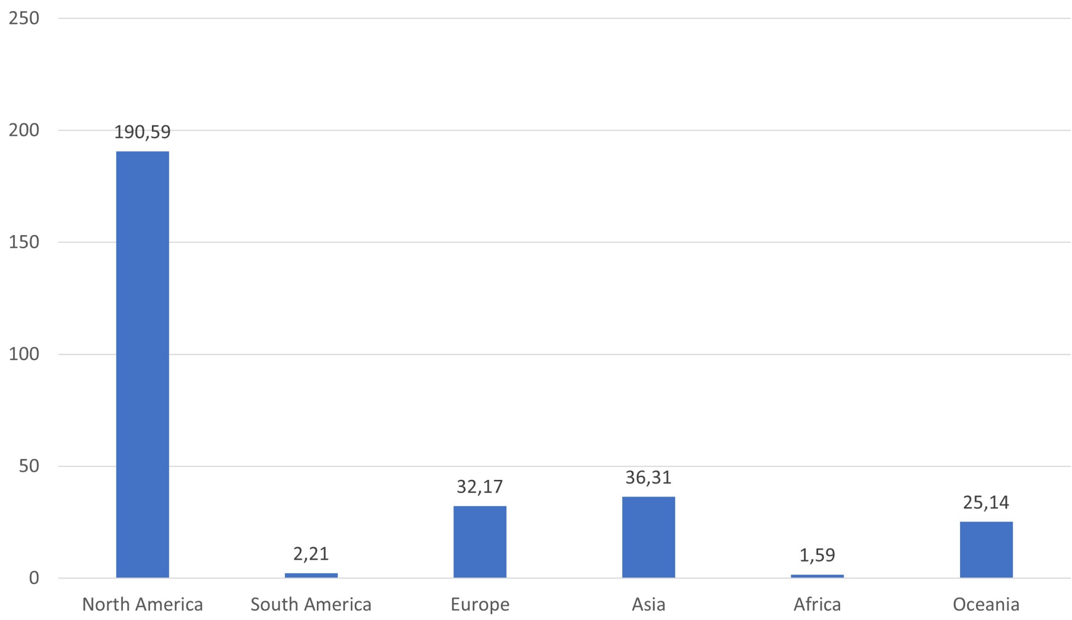


Figure 1.3: Total investments in new start-ups by continents [M$]

Many of these new companies are fully aware of the importance that their services could have, more than a half of the start-ups evaluated by EARSC claim to be delivering services which can help with SDG's indicators. This could act as a magnet for future investments in the space related field.

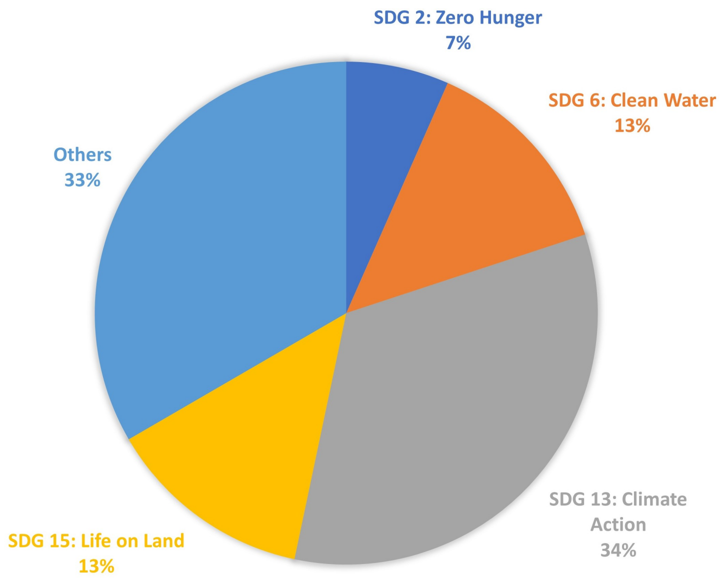


Figure 1.4: SDGs for which the service are delivered

1.5. Sustainable Development Goals

Since the last decade of the XX century the United Nation Organization started working on plans of action regarding mostly environmental and social themes, with the *Agenda 21* in 1992 and the *Millenium Development Goals* in 2000 the focus was already on creating international partnerships with the aim to improve the quality of all human lives, reduce extreme poverty and protect the environment[47].

In September 2015 then the UN heads and representatives compiled the 2030 Agenda for Sustainable Development, based on 17 key goals centred around economic, social and environmental topics: the Sustainable Development Goals (SDGs). The call for a global partnership to take the challenge on these themes is more and more urgent, and the Agenda provides a shared project for prosperity for all people and planet. The main objective is the ending of poverty and all other deprivations and in order to achieve these targets, the goals put in the foreground the importance of the education, health and economic growth, all while tackling climate change.

Figure 1.5: Sustainable Development Goals[11]

The 17 SDGs are very ambitious and are studied to be achieved by the year 2030. As seen in figure 1.5, they are quite general in their definition, and it is difficult to find a quick correlation with actual applications, therefore each one of them is associated to a set of targets, in total 169, which represent a particular field of applications. To track the progress towards goals and targets, also a global Indicator framework composed by 232 specific indicators has been defined.

The role of Earth Observation in the achievement of the goals has been considered a fundamental tool since the beginning of the project, so that some partnerships were created in order to monitor its contribution. The Committee on Earth Observation Satellites (CEOS) and the Group of Earth Observation (GEO) constantly work with governments to develop partnership for the implementation of the SDGs.

The observation and evaluation of Indicators advancement requires multiple types of data, the space data can be essential to have a diversification from the traditional administrative one, and can grant continuous and qualitative information of remote places[25]. There are other features of satellite data that result to be optimal: the consistency of data grants a standardisation in the measurements, useful to compare information coming from different parts of the world; the scaling is also very useful, satellites can provide data from a regional, national, or even global point of view.

1.6. Thesis Contribution

The main aim of the thesis is to build an analytical framework able to assess the direct contribution of Earth Observation data coming from satellites into the Sustainable Development Goals indicators.

The process will not directly correlate indicators and satellites, but it will need intermediate steps: the introduction of applications and variables is fundamental to try to create a strong bond between the first and the last steps of the sequence. The applications considered in the analysis are the ones related only to the *Energy and Raw Materials* market defined by the EARSC Market Taxonomy[12].

Figure 1.6: Optimal sequence result of the thesis

Though the ideal process should start from SDG indicators and arrive at last at the identification of the useful sensors, evaluating the satellites useful to exploit the requirements of the indicator, it is impossible to make the analysis starting from the definition of indicators. For this reason the study makes the inverse process: it starts by completing the EO satellite database adding for each one of the satellites the sensor's characteristics, later it highlights the *Energy and Raw Materials Market* applications with their respective variables and lastly it arrives at the quantification of their contributions on indicators.

2 | Satellite Database

2.1. Upstream Segment

During the recent years the number of satellites launched has seen an important increase, going from two hundreds of 2013, to the almost five hundreds launched only in 2019. The primary cause of this growth is attributable to the trend of launching more small satellites with respect to the big ones which were preferred before. As a matter of fact, while the launches of extra heavy payloads have remained constant through the years, the so-called Smallsats (satellites having a mass which is less than 600 kg) went from 130 launches in 2013, to the 389 of 2019[6].

The tendency consists in preferring bigger constellations of smallsats in LEO compared to bigger satellites orbiting at higher altitudes. This is caused by the fact that constellations are becoming so dense, that they can be able to provide continuous coverage, which is the strong point of GEO satellites, but at the same time they can provide a global coverage and higher accuracy with respect to the big satellites in the higher orbits.

The enormous increase in the number of launches is also related to the different actors at stake: the growth of the downstream segment reflects itself also on the upstream one, more private companies are entering the space sector granting commercial services to downstream clients. Between all the five hundreds launches in 2019, 62% have commercial purposes.

The communication domain is right now dominating the services market: its satellites belong to both commercial and military spheres. It is expanding in terms of navigation, with the expansion and the differentiation of the GNSS constellations, with every nation trying to produce its own system, and also in terms of private Satcoms infrastructure such as SpaceX, OneWeb and Amazon, which count now more than 900 satellites in orbit[42].

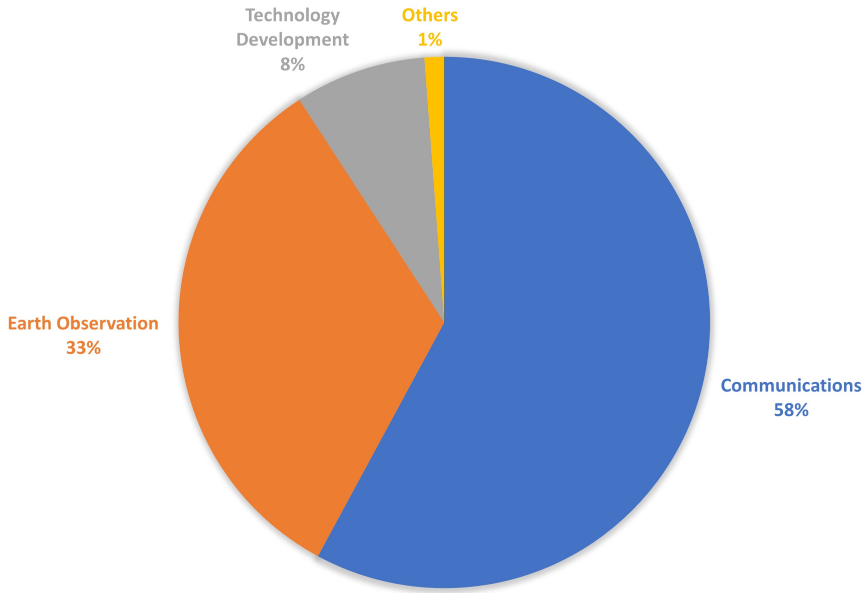


Figure 2.1: Satellites launched in 2019 by purpose

The following analysis anyway will consider only Earth Observation satellites.

2.2. Sensors Categorization

The Earth Observation satellites are just a part of the larger group of the Remote Sensing satellites. As a matter of fact, remote sensing is defined as the science of obtaining information by a device which is not in contact with the object.

The first distinction made in the analysis for the sensors on board of the satellites is between active and passive sensors:

- The passive sensors are for the most part cameras. They are called passive because they collect the natural light emitted from the sun and reflected by the surface that is framed. They represent the majority of the sensors in the space field, and typically they work in the visible, near-infrared and infrared wavelengths of the electromagnetic spectrum.
- The active sensors instead have the source of radiation which is built-in the system. The two most used systems are Synthetic Aperture Radars (SAR) and Laser Image Detection and Ranging (LIDAR), LIDAR systems use signals in the visible spectrum, which have shorter wavelengths compared to SAR, whose waves belong to the radio frequencies. Though LIDAR sensors have higher sensibility, and are

also sensible to different chemicals, SAR ones are able to grant images with any meteorological condition, having the capacity to penetrate the atmosphere and the clouds. Both systems collect information by measuring the phase and amplitude of the return wave backscattered from the ground. During the following analysis the LIDAR systems will not be considered as their technology is innovative and presents just few examples so far in the space sector.

The active sensors have some major advantages compared to the active ones: the passive instruments are dependent on the atmospheric conditions and on the time of the day, since visible waves can be perturbed by clouds and different luminosity gives different optical results.

Despite these pros, the active sensors are less used in the space field with respect to the passive instruments. The latter are indeed more basic and less difficult to design, while the former, besides the complexity in the interpretation of the data, also require a greater energy expense from the payload point of view.

2.3. Performance Parameters

In this section the most important performance parameters of the instruments will be discussed. At first, also some considerations on the orbital characteristics of the satellites will be made, since all the parameters depend also on the altitude, inclination and period of the orbit itself.

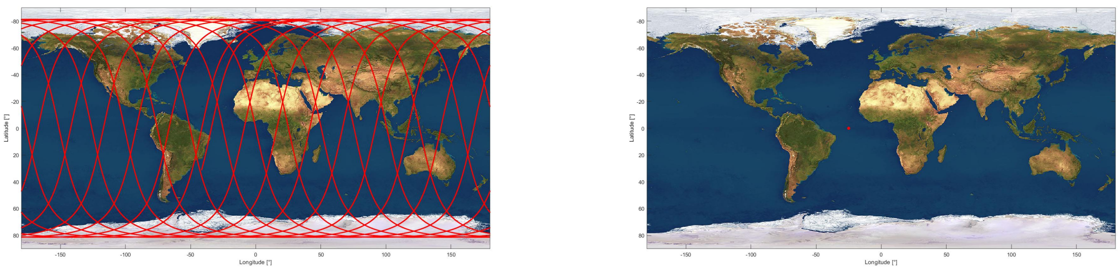
2.3.1. Orbits

The orbit of a satellite is defined as its path around the Earth. The selection of orbits for EO satellites is made also considering the sensor that the satellite will carry, and the type of information that will be gathered. The parameters relevant to imagery are:

- Orbit altitude: it affects mostly the resolution of the images, as lower altitudes correspond to higher spatial resolution. The coverage is also dependent on this parameter.
- Orbit inclination angle: it is the angle between the equatorial plane and the orbital plane. It affects the ground coverage of the satellite.
- Orbital period: it is the time the satellite takes to complete a single orbit. It mostly affects the temporal resolution and the quality of images. If the exposition time is too long, an higher ground velocity of the satellite can result in making blurred

images.

The Earth Observation satellites database is composed mostly by two completely different orbit: the Geostationary orbit is an equatorial orbit with a high altitude (almost 36000 km); the spatial resolution of the images will be poor, but it is able to grant a continuous coverage on the framed zone, since its orbital period is exactly the same as the rotational period of the Earth. Another type of orbit, which is establishing itself in the recent period with the growth of the small satellites and constellations, is the Sun Synchronous orbit. The SSO is part of the LEO orbits, their altitude is low so that the satellites can grant high spatial resolution and their inclination is usually very high, so that they can track high latitude zones on Earth. The ground coverage results to be very poor, causing an high temporal resolution. The characteristic which differentiates the SSO from other LEO orbits is the fact that they grant the passage of the satellite on the same zone, always at the same local time, offering comparable images.



(a) Sentinel 2a (SSO) ground track

(b) GEO-Kompsat 2a (GEO) ground track

Figure 2.2: Comparison between the ground tracks of a SSO and a GEO orbit over one day, considering no perturbations

2.3.2. Spatial Resolution

The spatial resolution of an instrument is the size of a pixel. It represents a fundamental feature of the sensor, since it determines the minimum detectable feature of a terrain. As seen before it depends also on the altitude of the orbit, but mostly it is a feature of the acquisition system. For the following dissertation, despite having for most of the sensors the exact value of resolution in meters, the choice has been to divide the sensors into 4 different categories in order to grant a more reasonable analysis[39].

Category		**Resolution [m]**
VH	Very high resolution	<1
H	High resolution	<10
M	Medium resolution	<30
L	Low resolution	>30

Table 2.1: Categories of spatial resolution

2.3.3. Spectral Resolution

The spectral resolution is another necessary parameter of the sensors to be evaluated. It is a property of the passive instruments only, that will be divided accordingly, while the active ones (SAR) will not follow this split. It is defined as the width of the electromagnetic bands collected, so it regards the distinguishable electromagnetic wavelengths.

The division has been made following the number of bands detectable, and their bandwidth: 3 major categories of sensors can be found:

- Panchromatic sensors: they collect images using the entire visible spectrum, the result is a greyscale image. The final image usually has an higher spatial resolution with respect to the other sensors, since brightness changes can be collected at a smaller scale.
- Multispectral sensors: they are able to collect different bands for each pixel. The number of available bands is usually between 3 and 15[7], not only in the visible, but also in the IR regions.
- Hyperspectral sensors: they are similar to the multispectral sensors, with the difference that they have a higher number of smaller width bands (more than 15), with whom it is easier to gather information about different substances on the ground.

Usually the images coming from different types of sensors can be combined to grant more useful results, the panchromatic and multispectral sensor for example can be used together in order to obtain a result with a higher spatial resolution coming from the former, and the useful information about the terrain coming from the latter.

In the analysis another kind of passive sensor not belonging to the visible region will also be considered: the thermal infrared sensors. These instruments use infrared energy as heat for detection, they are really sensible to the wavelength and they usually find their application in the measures of temperature from remote.

2.3.4. Revisit Time

The last needed parameter to be considered for the analysis is the temporal resolution, expressed here as revisit time. The revisit time describes how often a point on the ground is photographed. It depends mostly on the orbital period of the satellite, but also some other parameters can have an impact on it, such as the swath width of the sensor and the latitude of the point on Earth.

Differently from the spatial and spectral resolution, the revisit times of the satellites is hard to find in the technical data sheets of the sensors. The cause is to find, as seen before, in the different types of information that the calculation requires. To solve this issue and obtain coherent values for all the satellites present in the database, the choice has been to implement an algorithm based on repeating ground tracks[30].

The algorithm is applicable only to the Sun-Synchronous orbits, since it is necessary that the nodal period of the orbit is exactly one day. Moreover, it measures the mean revisit time of a satellite at the equator. The value considered at the equator is suitable for the analysis because the revisit time at zero latitude has the highest possible value between all latitudes, so in this case it represents the worst possible scenario.

Variable	**Unit of Measurement**
Orbital period	[s]
Orbit inclination	[rad]
Instrument swath width	[km]

Table 2.2: Revisit time algorithm inputs

The computation considered takes as input characteristics of both the satellite's orbit, with the orbital period and the orbit inclination, and the sensor's characteristics with the swath width. The result is obtained using the Bezout equation, passing through the repeating factor calculated on the orbit, the fundamental interval (interval on the equator between two successive ground tracks) and the minimum interval (interval on the equator between two ground tracks after a repeat cycle).

Variable	**Unit of Measurement**
Revisit time	[s]

Table 2.3: Revisit time algorithm output

2.4. Final Database

The analysis started finding a suitable database for the EO upstream sector. The choice was to use the pre-existent database formulated by UCS[46], which is updated to the operative satellites operating in 2021. The total number of satellites considered is 521, of which 448 are passive and only 73 are active.

The UCS database gives information only on the orbits, on the operators and launches. Later on, an important step was to complete the database with the characteristics necessary for the development of the analysis, so the performance parameters previously discussed of the sensors on board of the satellites were found. For most of the sensors the technical data were available on the JACIE database[28], while for the remaining ones, the parameters were retrieved on the data sheets of the single companies or agencies.

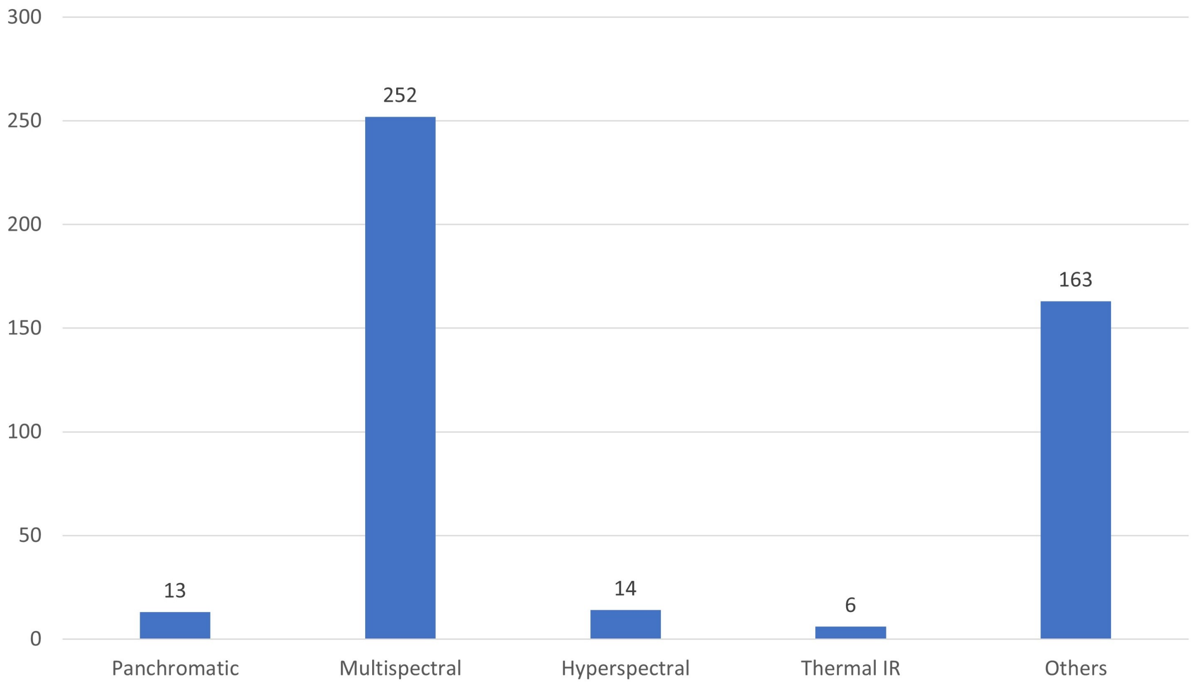


Figure 2.3: Division of passive sensors satellites according to their spectral resolution

The graph 2.3 underlines the major development of the multispectral sensors above all the others. As a matter of fact they are the most useful from a remote sensing point of view, since their data can be used for a lot more applications compared to the other types of sensors. Anyway, it has to be said that this number is tainted by the Planet Labs constellation, which counts more than 200 satellites.

The *Others* category includes all the satellites which mount more than one sensor. The number is not irrelevant, as some are studied to satisfy specific applications which require different types of data. Most of the hybrid satellites, 96 in total, carry the combination of panchromatic and multispectral sensors.

Between the 521 depicted above, only the satellites with all the parameters needed for the analysis available are present, there are indeed some other active payloads in orbit, mostly military, for which it was impossible to find all the indispensable features. The values of spatial resolution, spectral resolution and swath width are the only ones about the sensors which are considered essential for the continuation.

The analysis includes all types of satellites, regardless of their official users.

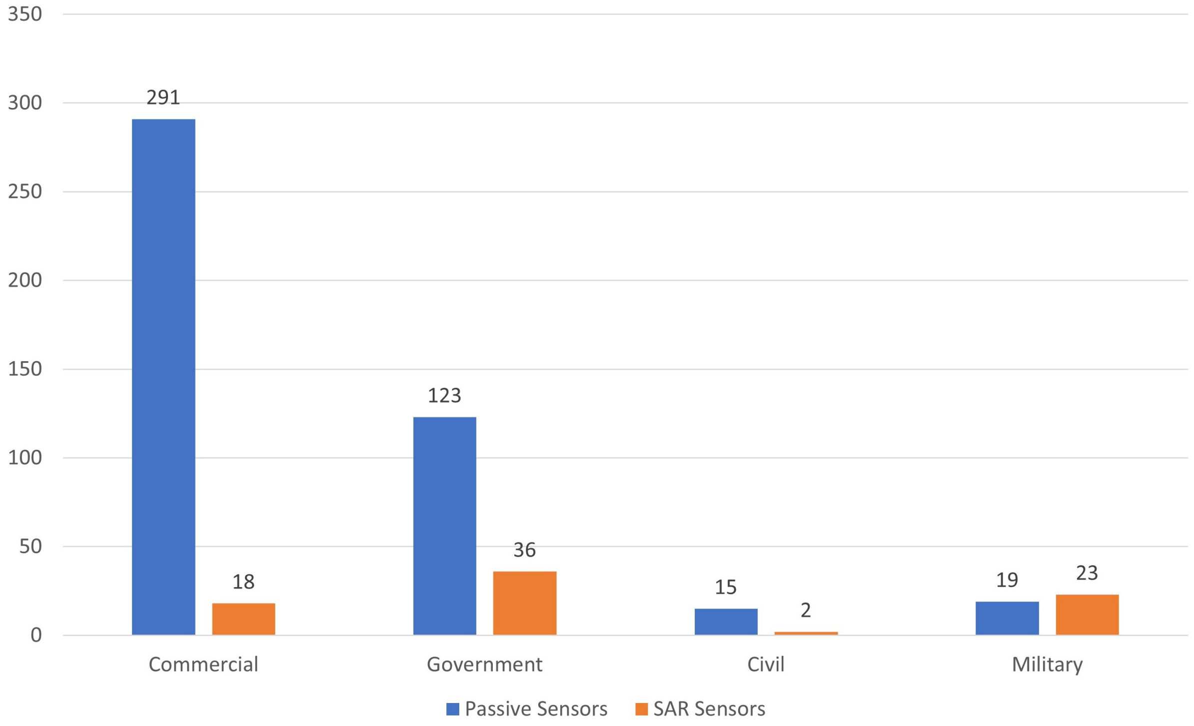


Figure 2.4: Total EO satellites divided by *Users*

As seen in the graph 2.4, the number of commercial satellites is far higher than the others for what concerns the Earth Observation. The military ones should be a lot more than the 48 considered, but it was more difficult to find all the information needed, in most cases indeed, mostly for non-European agencies, the data about the performance parameters of sensors are maintained secret.

Further analysing the graph, another point can be made: the number of commercial active satellite not only does not follow the trend of the passive ones, but it is even less than both government and military ones. The reason can be seen, as stated in 2.2, in the reluctance of companies to invest higher amounts of money into a more complex and expensive technology with respect to the passive instruments, which are already well advanced.

3 | Market Definition

3.1. EARSC Taxonomy

Remote sensing satellites find potential applications in a lot of different fields, going from the monitoring of target zones to the prevention of natural disasters and the study of natural resources. First of all it is fundamental to give a precise and common classification of the sectors in which information coming from the satellites can be used. The choice has been to use the *Market User Taxonomy* stipulated by EARSC and updated at 2020[12], in other words, their process of naming, classifying and categorizing EO services and products has been applied.

The European Association for Remote Sensing Companies (EARSC) is a network of european companies operating in the downstream sector, used as reference to study the impact of the diffusion of EO data on companies applications. In 2021 the total number of companies included in the member list is 142[13], with this number that is intended to grow.

Taxonomy is based on a hierarchical classification approach, in this work the base choice has been to consider just the two higher orders: the most general classification for the services will be called *Market*, while the second order groups will be the *Sectors*.

The structure of Taxonomy is based on two different approaches related to two different points of view: the Thematic approach reflects the technician view on the services, while the Market one reflects the customer view. The difference between the two approaches is just in the description and in the terminologies assignment of the same EO services: as the thematic approach appoints the products from a "provider" point of view, the market one is based on the "user" perspective, highlighting and gathering together real-life applications more than scientific similarities.

Market Taxonomy	Thematic Taxonomy
Managing living resources	Atmosphere climate
Energy and mineral resources	Disaster and geohazard
Infrastructure and transport	Land
Financial and digital services	Built environment
Urban development	Marine and Maritime
Administration, defence and security	Security
Environment and climate	

Table 3.1: EARSC 1^{st} level division

As seen in the table, market approach takes into consideration one more market with respect to the thematic one. Firstly the selection of just one between the two approaches has to be made: the thematic point of view is more easily relatable to the satellites characteristics, since it divides the services according to the scientific approach of the providers, but the choice for this work has been to consider more in detail the market approach. There will be indeed the necessity to relate the potential applications of the EO products to the SDGs, and with a user-friendly approach the evaluation will be focused on the effective services that could be useful to the society. An introductory explanation of the markets is at this point fundamental in order to better understand the division and the successive subdivision in sectors:

- Managing living resources: users refer to human activities exploiting natural organic resources.
- Energy and natural resources: users deal with the harvesting of energy from renewable resources and extractive industries.
- Infrastructure and transport: users apply to all manufacturing and physical supply both in land and in marine domain.
- Financial and digital services: users cover a broad area of activity that touches many other sectors such as insurance and media.
- Urban development: users perform tasks at local and regional scales on mapping land use and monitoring urbanization.
- Administration, defence and security: users work in the field of military and social protection, they collect and analyse information to provide intelligence and safety.

- Environment and climate: users take advantage of EO to increase the environmental impact on policy making decisions.

3.2. Sectors

Once the macro markets have been selected, the next step has been to assign to each of them more specific categories indicating groups of business activities that have similar characteristics.

Even for this second step the choice has been to exploit the *EARSC Taxonomy* division, in order to complete the study with a scientific method taken from literature and not arbitrarily. Taxonomy is defined by EARSC through three successive steps:

- Definition: bibliography research and review of existing taxonomy.
- Results: discussion with relevant stakeholders, usually EO service providers, on the offers on the market, and try to have accurate description of services.
- Uptake: study of the applicability of the results to all the stakeholders and to other communities.

In this way the categorization of the products can be considered exhaustive, therefore the second level division has been applied and the new groups called *Sectors* have been found. To each Market is corresponding a different number of sectors, with a total amount of 24, divided as follows in this paragraph.

3.2.1. Managing living resources

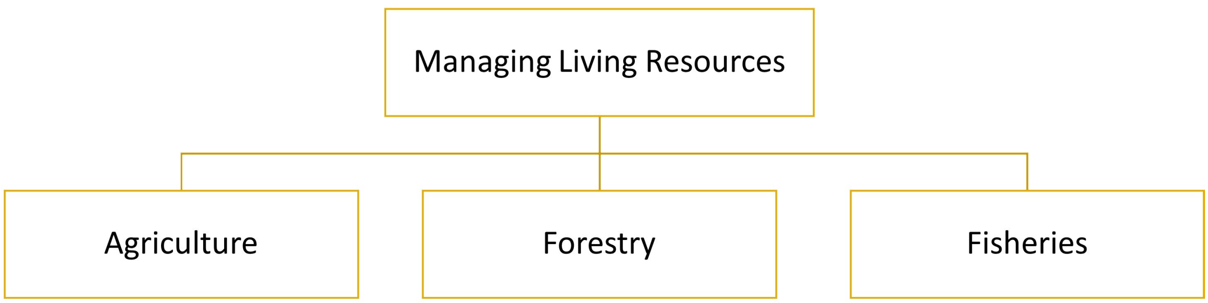


Figure 3.1: Living Resources partition

3.2.2. Energy and natural resources

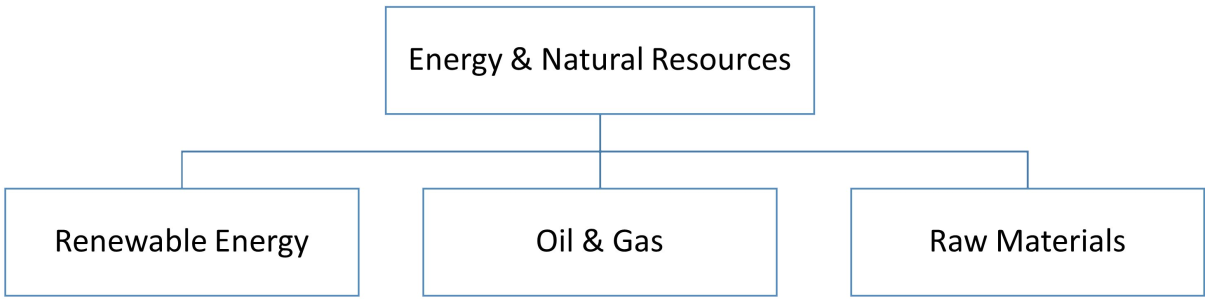


Figure 3.2: Energy and natural resources partition

3.2.3. Infrastructure and transport

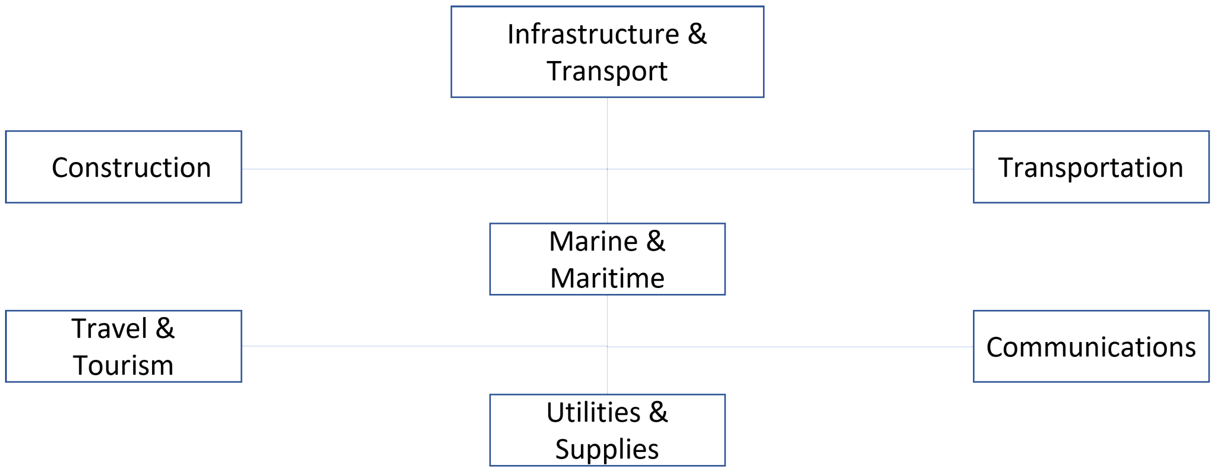


Figure 3.3: Infrastructure and transport partition

3.2.4. Financial and digital services

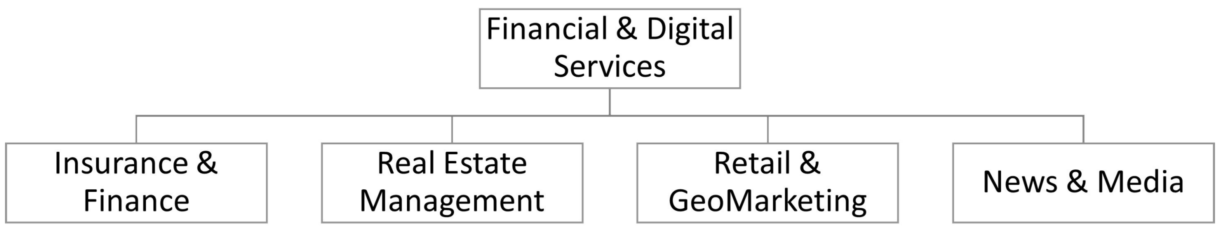


Figure 3.4: Financial and digital services partition

3.2.5. Urban Development

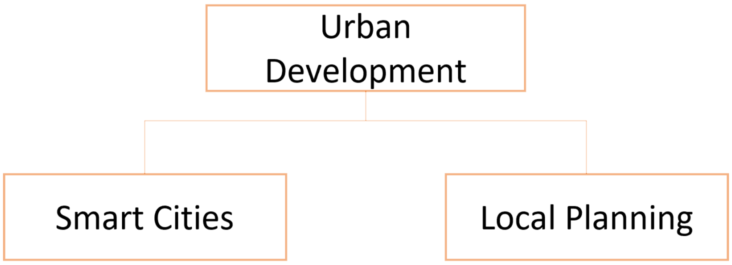


Figure 3.5: Urban development partition

3.2.6. Administration, defence and security

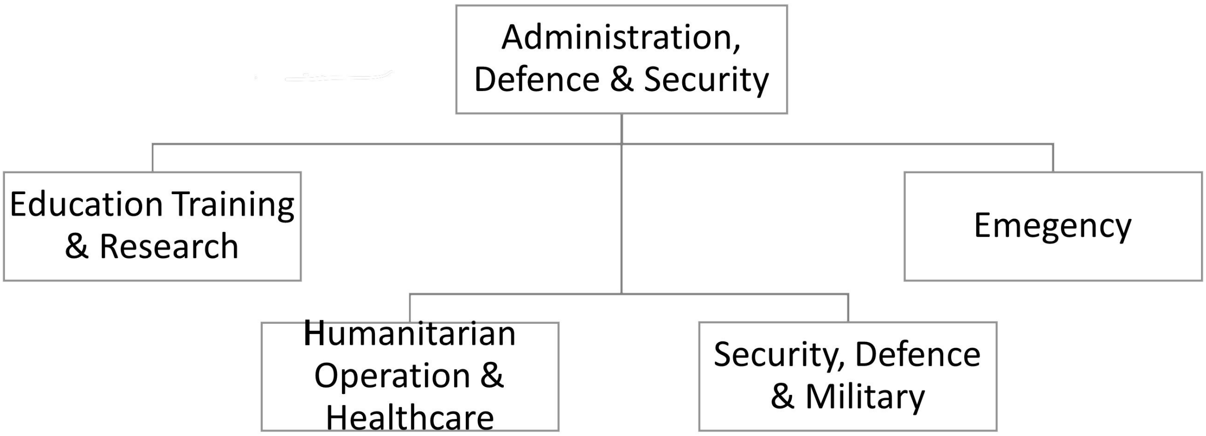


Figure 3.6: Administration, defence and security partition

3.2.7. Environment and climate

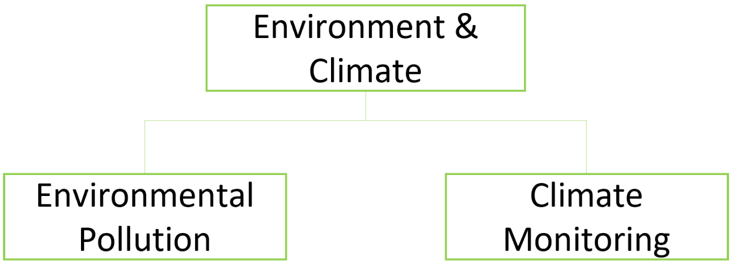


Figure 3.7: Environment and climate partition

3.3. Market selection

The objective of the thesis is to focus on just one of the macro-markets depicted above. As a matter of fact the presented study is just the beginning of a long discussion regarding these topics, and it will need further analysis with future works to be completed.

The choice has been to proceed with the group of energy and mineral resources: this group indeed represents a very actual topic nowadays, since energy use is a big problem in terms of environmental sustainability being still primarily based on fossil fuels, to the point that it accounts for about 60% of the total global greenhouse gas emission.[34]

EO can be a fundamental carrier of the green transitioning in the energy field, thanks to its potentially continuous information regarding different services such as meteorology for power output estimations of power plants, hazards such as oil slicks or simply a detailed classification of land use and pollution, with the monitoring access of different types of energy resources. Furthermore, it could also help to grant universal access of energy even in remote zones where on field surveys would be impossible or too expensive.

Regarding the energy sector, Europe has been an early mover in the exploitation of EO resources, as a proof the fact that in 2019 5 out of the top-10 companies in the sector are European can be underlined. This is related to the focus that EU has given to sustainability related to the sector, which usually has a bad reputation for what concerns environmental impact and emissions. The European Green Deal, proposed by the European Commission, is the driving force of this change: it aims to let Europe climate neutral by 2050, and to lower the greenhouse gases emission of 55% with respect to the 1990, by 2030.

For what concerns the renawable energy sector, the analysis obtained from Earth Observation data can be an important feature to help planning the selection of the site, and then the monitoring of renewable energies plants. It has been used for example to analyse wind data and select the optimal collocation of off-shore wind turbines, for which EU has right now the 70% of the world's capacity, and it will be for sure used in the next decades to exploit other green energy sources[41]. Regarding the raw materials instead, EO can have an important role for all the phases of the mining cycle, from exploration, discovery and development, to production.

The revenues in the energy sector related to the sales of EO data are destined to increase moderately but constantly in the future years, passing from the 300 million euros in 2021, to more than 400 millions in 2031.

In the next chapter there will be a focus on the specific applications regarding renewable energy, oil and gas and raw materials.

4 | Applications and Variables

The aim of the analysis is to find an easy path to pass from the SDGs indicators to the satellites that could contribute to achieve their related targets. The choice is to privilege the less number possible of passages, in order to avoid repetitions that could occur, and to make the study as objective as possible. It is impossible, anyway, to directly correlate the indicators to the satellites, so the definition of two intermediate steps must be made: applications and variables.

The selection of both steps gives value to all the analysis, so it is necessary to name them in a proper way: the applications are quite general, but directly related to the three sectors of renewable energy, oil and gas and raw materials, and it is easier to find a correlation with targets and indicators. The variables indeed are more attributable to the characteristics of sensors satellites and they do not belong to fixed categories.

These two different steps then can be connected as each application is composed by a different number of variables with which it can be quantified.

4.1. Applications

The selection of applications was done through a sort of a trial-and-error process, considering at the end only the result which granted more generality and less subjectivity. The selected applications have to be directly correlated to the sectors in which they are used. As a matter of fact they can be defined as the concrete ways to enhance the use of Earth Observation satellites into a specific sector.

The first idea was to find directly the in-use applications starting from the satellites characteristics and actual employment by the different agencies. This option was immediately rejected since it does not respect the parameter of generality of applications. In this way, indeed, the total characterization of the applications was too dependant on the information coming from the upstream sector agencies rather than from the requirements coming from the downstream sector.

The second idea consisted in considering the applications starting from an hard core given by two different databases adopted by EUSPA[41] and Copernicus[39]. Their two analysis have some different aspects but at the same time have an important feature in common: they both start from a user perspective, considering both recent developments and future market evolution.

This approach has been considered effective enough, so it was only adjusted for the requests of the analysis, underlining the necessities for each sector.

Totally the applications considered are 20, some are from the cited reports, and the others have been added later to complete the analysis for the sectors.

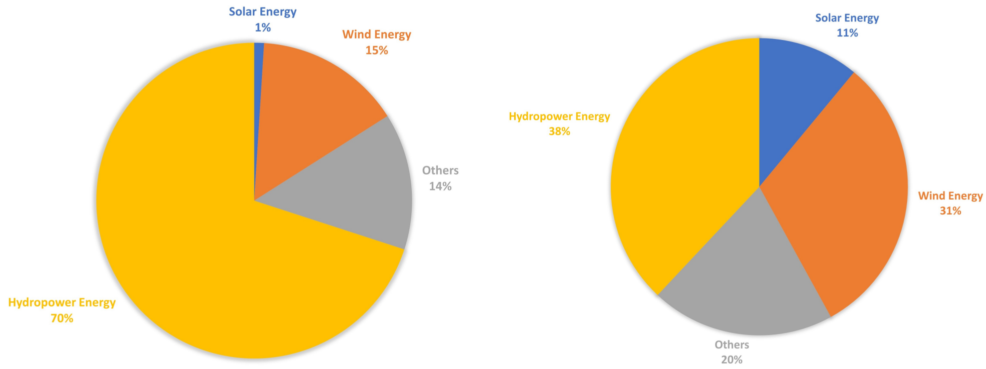
Sector	Number of Applications
Renewable Energy	8
Oil & Gas	6
Raw Materials	6

Table 4.1: Number of applications divided by sectors

4.1.1. Renewable Energy

The use of renewable energy is set to constantly increase during the years, for this reason the use of Earth Observation data can assume important economic benefits also for the providers of the services. Despite the economic growth, an even bigger and more significant result could be achieved from an environmental point of view, enhanced by data services.

Renewable energy encompasses a lot of different types of energy, usually the most considered ones are: solar, wind, geothermal, hydropower, wave, tidal, biomass. The following analysis anyway puts its focus only on the most developed ones: solar, wind and hydropower. All of three sources have faced an important cost reduction in the past years, but the two who were mostly touched are solar source with photovoltaic infrastructure and wind source with offshore plants. This cost reduction resulted in a huge increase in the use of these two renewable energy sources compared to the others, as seen in graph 4.1



(a) Renewable energy division in 2005 (b) Renewable energy division in 2015

Figure 4.1: Comparison between the exploitation of different renewable energy sources between 2005 and 2015

The applications considered belonging to the renewable energy sector are mostly related to site selection and efficiency monitoring. The use of Earth Observation data could be a useful tool to grant the access to energy and electricity to people from developed countries in a more sustainable way, but it can be even more important in the developing countries, where there are still entire cities without advanced electricity grids which can sustain the demand of all citizens. Most of these places are located in remote areas of their countries, making it difficult to find connections and study proper solutions; the remote sensing data can be a necessity in these zones to develop plans avoiding the difficulty of in-situ measurements, which can often be very expensive. The EO information then can also be used to monitor the production of the plants, making it easier and faster to solve possible problem which can occur. One of the major costs related to renewable energy power plants is indeed the maintenance activities: remote sensing data can also be a tool to help avoiding failures, by anticipating damages on infrastructures or adverse meteorologic conditions.

Starting from the solar power source, as already seen in the paragraph, there are two major applications to be considered. Site selection is a fundamental requirement for the solar power plants, it can be useful not only for remote places with a lack of measurements, but also to evaluate possible issues in urbanized areas, where shadows caused by buildings can result in less efficiency. The site selection requires data about both solar irradiance in the studied zone and also models about climatic conditions and possible extreme weather events. The other application considered is the power output monitoring, it is fundamental in order to constantly evaluate the efficiency of the power plants and detect any issue related to them. In this case the climatic conditions are not important, but in addition to the solar irradiance, it is necessary to be evaluate issues on the photovoltaic panels such as dust presence or broken components.

Solar Energy Source
Solar power output estimations
Solar power output monitoring

Table 4.2: EO applications for solar energy source

Considering the wind power source, the most relevant applications remain the site selection and production monitoring, and equal to the solar energy, the study of the primary resource, the wind in this case, is fundamental. The wind analysis can be achieved from a remote sensing evaluation, granting also a more complete result with respect to in-situ analysis, considering it at a global scale. For what concerns the efficiency of production, it is important to make a distinction between the meteorologic conditions, able to give information of an entire zone (for example an entire offshore power plant), and a more accurate wind analysis, usually done with the highest resolution possible, in order to evaluate the wind around a precise wind turbine, estimate its output and study if there are some issues that occurred. In addition to the solar power source then, for the wind plants it is useful to also calculate the impact that the massive turbines have on the local environment, both for onshore and offshore power plants. These giant infrastructures indeed could result in some variations in the local conditions, causing problems to the ecosystems, and also affecting the air quality.

Wind Energy Source
Wind resource assessment
Wind plants monitoring
Wind plants impact on local environment

Table 4.3: EO applications for wind energy source

For what concerns the hydropower energy, the three applications are similar to the wind energy ones. Remote sensing information can be useful to map hydroelectric sources, evaluating meteorological data, water flow models and land cover. At the same time these types of data can be used later by managers of the dams, to have fundamental information about the status of the dams themselves, to prevent hazards due to extreme weather conditions and to organize the activities based on lithology and the distribution of snow. As for the wind energy, frequent feedback on the environmental impact of the power plants is fundamental, even more so given the locations of the dams, which are usually in mountain locations which can be considered very fragile from vegetation and climate points of view.

Hydropower Energy Source
Hydroelectric sources map
Hydroelectric plants monitoring
Effects of hydropower plants on ecosystems

Table 4.4: EO applications for hydropower energy source

4.1.2. Oil and Gas

The oil and gas sector is experiencing a challenging period, the demand of resources is still very significant, but at the same time the investments in the exploration, due also to the global momentum to a carbon-neutral world, is constantly decreasing, causing a decline in the new discoveries and a consequent risk of supply shortage for the next years.

The sector is more commercially oriented with respect to the others, and it includes mostly private companies, but their investments in new technologies, such as the ones related to Earth Observation, are still little nowadays. This poor trust in innovation is caused by the difficult period that the industry is experiencing since the 2014, when the price of oil fell sharply, but it depends also on the risk averse of most companies, which are very traditional, when it comes to new products.

The remote sensing data anyway could be an important added value for the industry, providing significant information mostly on exploration and monitoring. For what concerns exploration, for example, Earth Observation data allow to study large scale areas both onshore and offshore. If the exploration and the detection of oil seeps with in-situ activities require high investments and time, satellites information can grant more accurate maps in a minor amount of time. The monitoring is another fundamental aspect of the industry: the work sites and plants have to be constantly controlled in order to avoid environmental disasters which could affect the ecosystem and worker's health. Remote sensing can be exploited to point out problems related to oil spills or generally water or land pollution, and at the same time it can prevent disasters caused by extreme climatic conditions, such as flooding and storms.

As for the renewable energy sector, here it is even more important to quantify the impact of the industry on the local environment. The satellite data let to understand, through information about ecosystems, pollution, air quality and vegetation indexes the impact of dredging operations to extract oil, and the effects of gas hollows, which are the natural containers of extracted gas. In addition, there can also be applications related to the detection of illegal activities of dredging in remote zones, where otherwise they would be impossible to track.

Oil & gas applications
Early identification of hydrocarbon basins
Monitoring oil system plants
Prevention of disaster risks
Monitoring effects of gas hollows
Assess environmental impact of dredging operations
Detect illegal dredging activities

Table 4.5: EO applications for oil & gas sector

4.1.3. Raw Materials

Concerning raw materials, the past years have seen an increasing interest in innovations in the supply chain, led by sustainability ambitions. As a matter of fact key raw materials are fundamental to achieve the goal of building a greener future. For this reason, some alliances were recently made, mostly in the European Union with the creation of the European Raw Materials Alliance (ERMA)[21], which has the aim to bolster the creation of environmentally sustainable innovations and infrastructure, and at the same time support raw materials industry capabilities, from the extraction to the recycle. The promotion of innovation conducted by ERMA goes at the same pace with the possible applications provided by remote sensing satellites, which in this sector regard mostly the identification of sites and materials, the safe operation of mining activities and the environmental monitoring of their footprint.

In the analysis a total of six general applications have been defined for the raw materials, starting from the identification of sites, satellites data could be useful to characterize the geological properties of the surface and identify subterranean minerals in large areas, comparing them to the topographical maps in order to find the best locations for the industry. Thereafter the remote data can be used to monitor the mining operations of an entire site, and at the same time it can be useful to grant the safety of the workers, underlining slope instabilities and monitoring the ground motion in order to exclude dangerous conditions. As said previously in the paragraph, it is important to monitor also the environmental impact of the mining activities: it is not only important to evaluate the air quality, water and vegetation pollution around the sites, but also to assess the damage that the activities can make on the surface concerning the geological properties and vegetation indexes. The last application considered for the raw materials sector, is related to the detection of illegal activities. It can be very useful for the most part in very remote zones, where otherwise they would be very difficult to track down.

Raw materials applications
Select mining locations with optimal conditions
Monitor mining operations
Grant safety of the workers
Assess surface damage due to mining activities
Mining environmental impact assessment
Detect illegal mining activities

Table 4.6: EO applications for raw materials sector

4.2. Variables

Contrarily to the applications, the variables in the analysis are not bonded to the different sectors of the energy market, but can be correlated with different applications across the sectors. It is fundamental to include this additional step in the study, since the applications, as seen in 4.1 are quite general and it is difficult to relate them directly to the performance indicators of the sensors on board of the satellites. The variables here considered instead are specific elements which can be measured directly from satellite information. It is necessary to underline the fact that all the following variables require different levels of data processing, while some of them are even the result of an integration of more sub-variables. The sub-variables anyway will not be specified in the analysis, as the ones considered for the same variable are usually calculated starting from the same data set and therefore do not add any constraint to the requirements of the sensor.

During this paragraph a little focus on each variable will be made, specifying the most used methods based on remote sensing which are nowadays employed. To each variable it will be assigned the performance parameters of the one or more sensors which are involved in the calculation, so the type of sensors, the spatial and spectral resolution will be specified.

Along with the sensor's characteristics, also an example of a satellite currently used for the calculation of the variable will be specified, completed with the number of active satellites having instruments able to record that type of data. The constellations having all the same kind of instrument in this statistics will be counted as one satellite.

4.2.1. Solar irradiance

The solar irradiance is a fundamental parameter to quantify the production of energy coming from solar source. This variable must take into account the influence of the clouds on the total radiation of the sun over a specific zone. The clouds indeed can block the solar radiation and critically reduce the production of the photovoltaic solar panels. The most used instruments to compute this parameter are nowadays ground-based sky cameras, but there is the improvement of new techniques, based on satellite images, which can grant better performances and more accurate estimations[10]. An important data provider for these techniques is the MODIS instrument, aboard on Terra and Aqua satellites, an hyperspectral instrument with a spatial resolution of 250 meters.

Sensor	Spatial resolution	Satellites example	N° Satellites
Hyperspectral	Low	MODIS instrument	8

Table 4.7: Solar irradiance sensor specifics

4.2.2. Meteorologic conditions

The monitoring of the meteorological conditions is significant for a lot of different applications across all the markets. It can be used for example to assess the climatic conditions over a certain period in specific zones and at the same time it is necessary in some situations to prevent catastrophic events and dangerous situations. The meteorologic conditions are typically measured with Geostationary satellites, which grant a continuous coverage and therefore can be applied for both rapid and distant measurements. The resolution of images is very low, even in the order of kilometers.

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	Low	GOES	30

Table 4.8: Meteorologic conditions sensor specifics

4.2.3. Dust presence on panels

The presence of dust above the surface of solar panels can affect the overall efficiency of power output of the solar power plants. For this reason it is important to monitor this aspect especially in arid zones and in places where sandstorms could occur. The information coming from Earth Observation satellites is relevant, and could easily replace the in-situ measurements in the near future. The measurement must consider two different kinds of images: firstly, it is important to observe the pattern of sand accumulation in the target area, the resolution can be low (in the order of hundreds of meters), but an instrument with a thermal infrared band is necessary. Secondly, high resolution images from multispectral sensors are required in order to validate quantitatively the sand indices for each panel[43].

Sensor	Spatial resolution	Satellites example	N° Satellites
TIR + Multispectral	Low TIR + High MS	Landsat-8 + Dove	8 + 47

Table 4.9: Dust presence evaluation sensor specifics

4.2.4. Wind analysis

Remote sensing analysis allows the mapping of wind energy resources, both onshore and offshore. Though its application can be considered redundant onshore, due to the ground analysis that could be easily done, the rapid growth of the offshore wind plants, where it is less immediate to obtain in-situ surveys, is a perfect opportunity to the increase of the EO technology[27]. The analysis of the wind is done through SAR instruments with very high spatial resolution, in most of the cases indeed it is important to detect information about wind direction and velocity directly on specific turbines, considering also the differences between the upstream and downstream flows. These high precision computations are used mostly for the wind plants, while for the other sectors, where it is almost useless to make an analysis this precise, information about the wind is usually derived from the evaluation of the meteorological conditions with low resolutions[5].

Sensor	Spatial resolution	Satellites example	N° Satellites
SAR	Very high	ERS-2	16

Table 4.10: Wind analysis sensor specifics

4.2.5. Monitor ocean current movements

The role of the ocean is influential in many different sectors and applications, from tourism industry to transportation, risk prevention and a lot of other economic activities. The importance of its monitoring has never been underestimated, for this reason there are a lot of different ways, already used, to acquire data from remote sensing observations. During the following analysis only the two most used methods, one passive and one active, will be considered. The passive instruments most used are the thermal infrared[1], which provide low resolution images, while the active instruments have the advantage to grant higher spatial resolutions[2].

Sensor	Spatial resolution	Satellites example	N° Satellites
Thermal Infrared	Low	Landsat-8	8
SAR	Medium	Sentinel-1	17

Table 4.11: Monitoring ocean currents sensor specifics

4.2.6. Monitor air quality

The evaluation of air pollution is a fundamental asset for what concerns the impact of all the energy sources on the environment. However air quality does not regard only the pollution, but it is equally important to monitor the different levels of chemical components. The most useful molecules to keep track of are CH4, CO2, NO2, SO2 and particulate matter[22]. For the aim of this study, it was impossible to consider the different requirements of each of the molecules, therefore the constraints considered are only an estimate of the PM requirements, considered the most relatable to the sectors.

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	Medium	Landsat-5	18

Table 4.12: Monitoring air quality sensor specifics

4.2.7. Identify discreet lithology

The regional lithology mapping is in most areas of the world very costly and challenging, due to vastness and poor accessibility. The variable is mostly used for what concerns the assessment of hydropower resources but can also be employed to avoid hazards such as floodings and surface instabilities. Therefore, it is important to find a way to evaluate the lithological conditions of specific areas properly and continuously over time. Remote sensing imagery represents the perfect solutions mostly adapted to remote and inaccessible zones: studies integrating data coming from Sentinel-2a, which provides imagery with high spectral resolution, and Digital Elevation Models (DEM) give nowadays the best results in terms of evaluation of the variable[8].

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	High	Sentinel-2a	47

Table 4.13: Lithology identification sensor specifics

4.2.8. Water depth

Water depth evaluation is related to bathymetry, which is the science of determining the topography of the seafloor. Bathymetry is used for a lot of different applications among all the markets, going from the biological oceanography to the beach erosion and sea level rise evaluations. Concerning the energy market, bathymetry covers a major role in planning near-shore work activities, such as dredging operation and oil drilling. The water depth measurements were made using costly and inefficient methods, so the advent of EO imagery has represented a significative turn in this specific field. There are several ways to compute water depth from remote sensing satellites, both from active and passive instruments. Usually the passive instruments are used to compute the depth near to the coast, as they are able to grant exact information up to 20 meters of depth[37]. For measurements of over 20 meters instead, the use of active instruments is preferable.

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	High	WorldView-2	47
SAR	High		23

Table 4.14: Water depth measurement sensor specifics

4.2.9. Water pollution

Another fundamental parameter to keep under control is water pollution, especially around big engineering sites such as those related to the energy market. In this analysis water pollution will be associated to the integration between the chlorophyll concentration and ocean colour. Some other causes, more specifically related to the evaluated sectors, as the oil spills and seeps, will be later analysed more in detail and singularly. For what concerns the chlorophyll concentration, it is an essential indicator to monitor carbon cycles and food chains, while the ocean colours evaluation is used to detect the water constituents. Both the components can be evaluated with multispectral imagers with low resolution[1].

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	Low	MODIS Instrument	30

Table 4.15: Water pollution measurement sensor specifics

4.2.10. NDVI

The Normalized Difference Vegetation Index is the most widely used and studied vegetation index and it permits to evaluate and monitor vegetation covers over specific areas. The changes in vegetation are important indicators of environmental change, for this reason there are in literature a lot of different indexes to consider. For the intent of this analysis anyway, the choice has been to consider only the NDVI, the most used since its development in 1970[29]. NDVI is currently analysed mostly around mineral extraction zones, but can result to be useful in every other sector here considered, as a direct feedback from the environmental impact assessment on the local vegetation. In order to study NDVI the use of hyperspectral sensors with high spectral resolution give better results with respect to multispectral instruments[32].

Sensor	Spatial resolution	Satellites example	N° Satellites
Hyperspectral	Medium		4

Table 4.16: NDVI measurement sensor specifics

4.2.11. Detection of oil spills

Oil spills in the ocean are considered massive environmental problems that can endanger the sea ecosystems. With the expansion of oil and gas sector, the incidents related to the spills have significantly increased, endangering marine life, with consequences also on human life. Firstly, it is important to detect rapidly the problems that caused the spills, which can derive from ships incidents, underwater pipelines or issues with oil rigs[1]. Later on reliable information about the location and extent are fundamental to mitigate risks and damages. Remote sensing satellites can be an efficient tool, providing multitemporal images at high spatial resolution. The detection of oil spills can be carried out from both active and passive instruments, and both are able to outperform the classical machine learning algorithm[2].

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	High	Kompsat-2	47
SAR	High	Sentinel-1	23

Table 4.17: Oil spills detection sensor specifics

4.2.12. Detection of oil seeps

Oil seepage is a completely different phenomenon with respect to oil spills. The seeps are defined as *migration pathway along which petroleum is flowing, driven by buoyancy from a sub-surface origin*[31], practically they offer clues to detect the presence of oil and gas reservoirs under the sea, just studying these small natural effects on the surface of the oceans. The detection of the seeps on the surface is not difficult with the recent remote sensing technologies, and it can be done with active or passive instruments. From the passive point of view, it is easier to employ TIR sensors, able to easily distinguish oil from water; usually TIR data is coupled with multispectral data in the ultraviolet region, in order to avoid errors which could be caused by cold water. SAR sensors instead have the advantage to be independent of weather conditions, but at the same time are less effective than TIR sensors.

Sensor	**Spatial resolution**	**Satellites example**	**N° Satellites**
TIR + Multispectral	Low	Landsat	8 + 30
SAR	Medium	RadarSat	17

Table 4.18: Oil seeps detection sensor specifics

4.2.13. Topographical maps

Topographic data provide information about the elevation of the surface of the Earth. There are different types of topographical maps, but in this analysis only the Digital Elevation Models (DEM) will be considered, since they are the most useful for the energy applications. DEMs are representations of the surface of the Earth, where each pixel contains an elevation value. They are useful for a lot of applications, mostly oil and mining sectors, as they let the viewers to distinguish every terrain characteristic. It is possible to obtain topographical maps with different spatial resolution, depending on the size of the land covered[45]. The energy applications require regional topographic data, which underline the characteristics of small regions with the possible highest spatial resolution. The best instruments to obtain this kind of information are active SARs.

Sensor	**Spatial resolution**	**Satellites example**	**N° Satellites**
SAR	Very high	ifSAR	16

Table 4.19: Topographic maps sensor specifics

4.2.14. Land pollution

Land pollution evaluation is related directly to the environmental impact of human activities. It assesses changes in terrestrial ecosystems and biodiversity. This variable is similar to the NDV Index explained in 4.2.10, but it is more complete as it does not regard only vegetation. In order to grant suitable remote sensing images, hyperspectral imagers are required, with high spectral resolution useful to distinguish the terrain features, but also an high spatial resolution is fundamental[48].

Sensor	Spatial resolution	Satellites example	N° Satellites
Hyperspectral	High	FTHSI	3

Table 4.20: Land pollution evaluation sensor specifics

4.2.15. Flooding maps

The mapping of flooding is used mainly to rapidly react in case of emergency, but it could be useful even in other situations: flooding indeed can have critical mid-term consequences, and it is necessary to detect any changes and understand possible emerging problems. Therefore remote sensing could be fundamental tool not only in the quick response to a disaster, but also in preventing any possible problems that could arise in dangerous zones. The computation requires multispectral images with high resolution to grant exhaustive information[15].

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	High	Sentinel-2	47

Table 4.21: Flooding maps evaluation sensor specifics

4.2.16. Assess offshore or coastal activities

The assessment of coastal and offshore activities is directly related to the detection of illegal dredging activities. In most cases the oil rigs are located in remote zones around the Earth, and for this reason it is almost impossible to evaluate externally the actions of the private companies. Illegal dredging can have significant impacts on local ecosystems since it usually does not respect the environmental policies and laws. Remote sensing is very useful in this contest: it is necessary for the detection of illegal activities to provide images with the highest temporal resolution possible, privileging a lower revisit time over an higher spatial resolution.

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	Low	Landsat	30

Table 4.22: Coastal activity assessment sensor specifics

4.2.17. Identification of slope instability

Analysis of slope stability is carried out to minimise the occurrence of landslides and slope failures. It is important to conduct this analysis in the selection of the optimal mining locations, and at the same time it must be continuously conducted throughout all the life of mining works, in order to grant the minimum safety conditions for the workers, and at the same time assess the environmental impact of the activities. The analysis to be performed requires some different factors which can be provided by EO satellites, the most important are soil cohesion and moisture, friction angle and soil unit weight. The computation of the factors is quite different between them, so there is the necessity of the integration of both active and passive instruments, even with medium resolution[26].

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral + SAR	Medium	Landsat + RadarSat	18 + 17

Table 4.23: Slope instability identification sensor specifics

4.2.18. Monitor ground motion effects

The monitoring of land movement is purely associated to the monitoring and risk prevention applications between all the three sectors. It could be caused by human activities or could be the result of natural phenomena, and can create disastrous hazards in particular zones, which can impact local infrastructures and human activities, with enormous cost in terms of human lives, environment and economy[16]. Earth Observation satellites can become an important tool to assess risks in remote zones with low costs. The most used instruments to retrieve measurements are active SAR, but they are usually supported by multispectral imagers, even with lower resolution, which have the aim to identify areas affected by distorsions in SAR data[24].

Sensor	Spatial resolution	Satellites example	N° Satellites
MS + SAR	Low MS + Medium SAR	Sentinel-1	30 + 17

Table 4.24: Ground motion monitoring sensor specifics

4.2.19. Assess and monitoring of mining activities

Satellite imagery can have a fundamental role in detecting illicit and unregulated mining. Differently from the case of illegal dredging seen in 4.2.16, where low spatial resolution of data is enough, the features of illegal mining are small scale, requiring higher resolutions. The information extracted from the analysis typically concern the location and extent of illicit mining and the characterization of sites that may represent potential hazards. Nowadays the computations are done with high or very high resolution SAR sensors[17].

Sensor	Spatial resolution	Satellites example	N° Satellites
SAR	High / Very high	TerraSAR	25

Table 4.25: Mining activities monitoring sensor specifics

4.2.20. Characterisation of surface geological properties

The study of surface geological properties is necessary to find the suitable locations for mining activities. The characterization requires high spatial resolution imagery, as the terrain must be studied in detail. The use of EO satellites anyway compliments the use of traditional methods rather than replaces them: aerial photography is still necessary to acquire more specific data. Remote sensing data considered to exploit this variable must come from multispectral imagers with high spatial resolution.

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	High	WorldView	47

Table 4.26: Surface geological properties characterisation sensor specifics

4.2.21. Tailings dam monitoring

Tailing dams are the storage of the toxic mine waste and effluent. The monitoring of tailings dam is required for every mining activity, since failure in storage could cause significant local ecosystem damages, water contamination, and dangerous situations for the workers caused by inundation of the downstream area[40]. It is also important to specify that the failure rate of tailings dam is unfortunately very high, therefore a continuous and efficient observation must be conducted in every site. Remote sensing has the potential to reduce the risks, with very high spatial resolution active instruments, it is possible to carry out an efficient and detailed monitoring[23].

Sensor	Spatial resolution	Satellites example	N° Satellites
SAR	Very high	TerraSar	16

Table 4.27: Tailings dam monitoring sensor specifics

4.2.22. Classification of land use

Information about land use is important for all the sectors in the energy market, as it entails the evaluation of possible strategies for land planning and management. Satellite remote data can have a greater degree of confidence compared with traditional ground-based estimates. Nowadays the most used instruments to manage this task are passive multispectral sensors, even if in some zones, mostly near to the equator, the data must be properly filtered to avoid errors related to cloud presence and other atmospheric perturbations[33].

Sensor	Spatial resolution	Satellites example	N° Satellites
Multispectral	Medium	Sentinel-2	18

Table 4.28: Land use classification sensor specifics

4.3. Variables to Applications Connection

Once both the applications and the variables have been defined, the aim of the analysis is to link them up. As already written at the beginning of this chapter, for each application exists a different number of variables, with its related sensor performances constraints. Therefore, it is impossible for a single satellite to satisfy every request of an application, since it is uncommon for a single satellite to mount more than 2 or 3 different sensors. The study could be useful anyway to assess the status of the Earth Observation data available into the energy market.

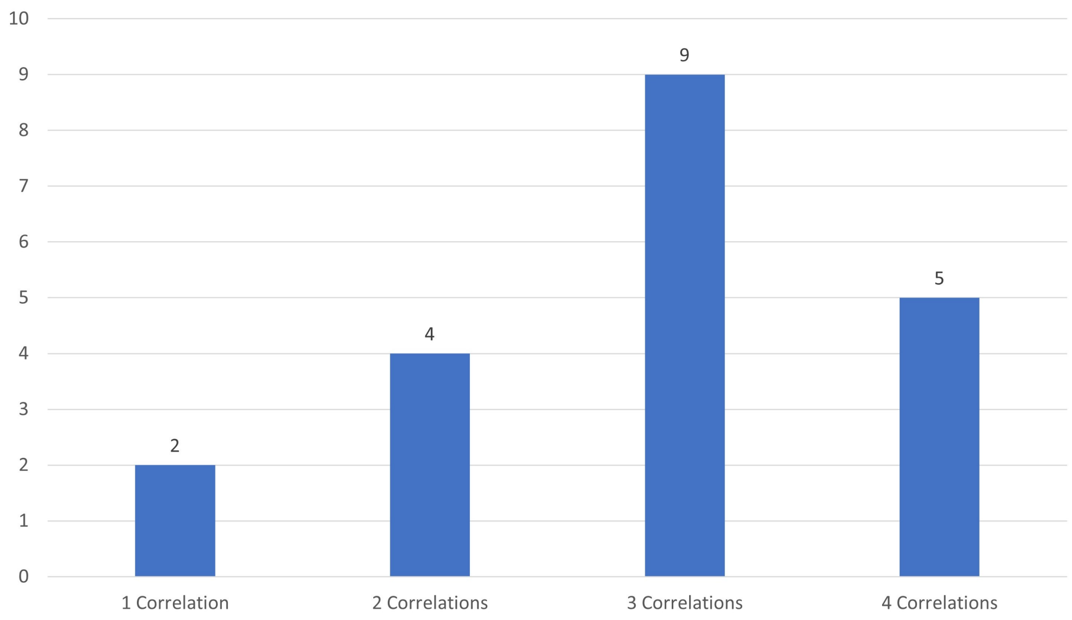


Figure 4.2: Applications divided by the number of variables associated

The last fundamental constraint that was not associated to the variables is the revisit time. It was assigned indeed directly to the applications: the reason behind this choice is the fact that it is necessary to obtain the raw data coming from satellites sensors depending on the requirements of the applications, so in which way the data must be elaborated. It is impossible to assign the revisit time directly to the variables, since it could vary depending on the different use or elaboration of the data provided. Data coming from the satellites, which meet the requirements of the variables according to the instruments aboard, must then fulfill also the constraint on the revisit time: in this way not every satellite which grant the evaluation of some variables, will be considered for the exploitation of the final application.

The measures of revisit time assigned to the applications have been estimated from the literature, and successively approximated in the different categories presented in table 4.29.

Category	**Revisit time [h]**
Hourly	<12
Daily	<48
Weekly	<150
Monthly	>150

Table 4.29: Revisit time approximations

All the relations between each application to its respective variables is described in the tables in A, divided for the 3 sectors. The final column has been added to specify the required revisit time.

5 | Identification of Energy related SDG Indicators

The last step of the analysis is the research of correlations between Energy and Raw Materials sector applications and the targets and indicators associated to the 17 Sustainable Development Goals. The overview on the SDGs is found in 1.5, the focus at this point is indeed just to consider specifically only direct and evident correlations from applications to indicators and exclude all the others. As a matter of fact, starting directly from SDG indicators, evaluating the connection between them and general Earth Observation information, and from this result later considering only the applications related to the energy market, was a difficult and misleading process, as it would have privileged some links and exclude others.

Therefore, the choice adopted in this case was to assign to each application of the framework already found, the SDG indicators directly related to it. The passage between applications to indicators is the core of the entire analysis, and its approach will be studied more in detail in 6.

The results of this approach find only 6 of the 17 Sustainable Development Goals having indicators directly relatable to the applications of the energy market. Each one of them has a different number of indicators, as specified in 5.1

SDG	3	7	12	13	14	15
Indicators	3.9.3	7.2.1	12.2.1	13.1.3	14.1.1	15.1.2
		7.3.1	12.a.1		14.3.1	15.4.1
		7.b.1	12.c.1			

Table 5.1: List of indicators used divided by SDG

SDG	Indicator	Definition
3	3.9.3	Mortality rate attributed to unintentional poisoning
7	7.2.1	Renewable energy share in the total final energy consumption
	7.3.1	Energy intensity measured in terms of primary energy
	7.b.1	Installed renewable energy-generating capacity in developing countries
12	12.2.1	Material footprint, material footprint per capita, and material footprint per GDP
	12.a.1	Installed renewable energy-generating capacity in developing countries
	12.c.1	Amount of fossil-fuel subsidies (production and consumption)
13	13.1.3	Proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies
14	14.1.1	(a) Index of coastal eutrophication; and (b) plastic debris density
	14.3.1	Average marine acidity (pH)
15	15.1.2	Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
	15.4.1	Coverage by protected areas of important sites for mountain biodiversity

Table 5.2: Definition of indicators used into the analysis

The focus of the applications previously considered is mainly targeted on the energy efficiency and sustainability of the human actions and infrastructures of the energy market. For this reason the two most important goals to be considered, which are also the ones which find the most number of correlations with the applications, are the 7 and 12 goals. They regard respectively the access to affordable and modern energy for all, and the sustainability of consumption and production patterns. The other goals considered instead, are mainly focused on the human environment, lad and water ecosystems in a more general way, and basically find matching parts basically only due to the multidisciplinary of some of the applications considered for the energy market.

Another important specification to be made is the fact that each application is not bonded to a single goal, but can have an impact on a different number of indicators, even if they belong to different goals. The figure 5.1 specifies the number of applications distinguished by the different correlations which they can have.

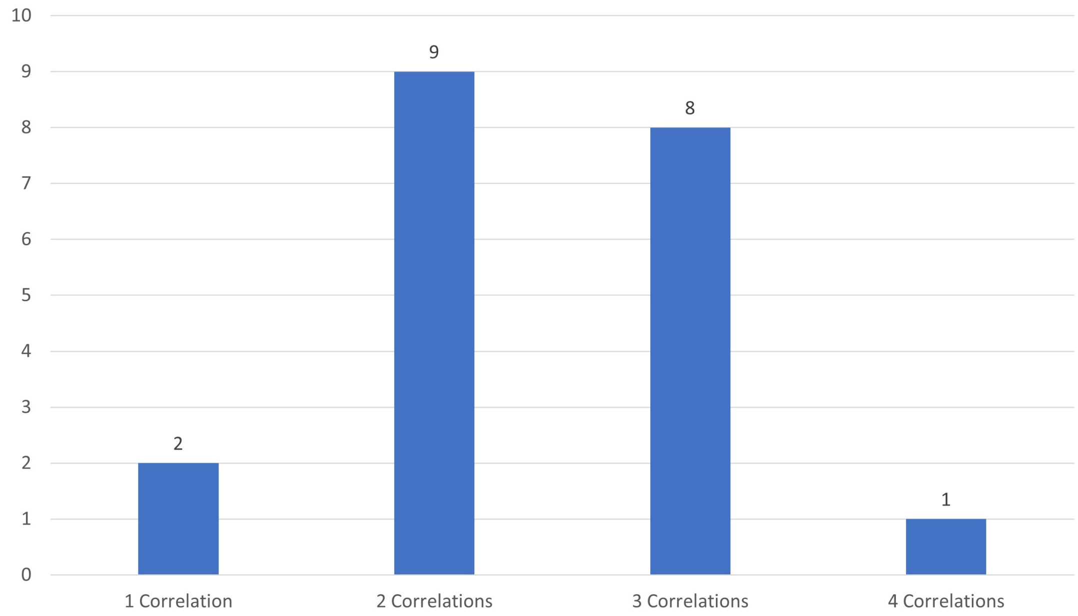


Figure 5.1: Applications divided by the number of indicators associated

At the same time it is necessary to specify the inverse passage: figure 5.2 specifies the number of different applications having an impact on each indicator.

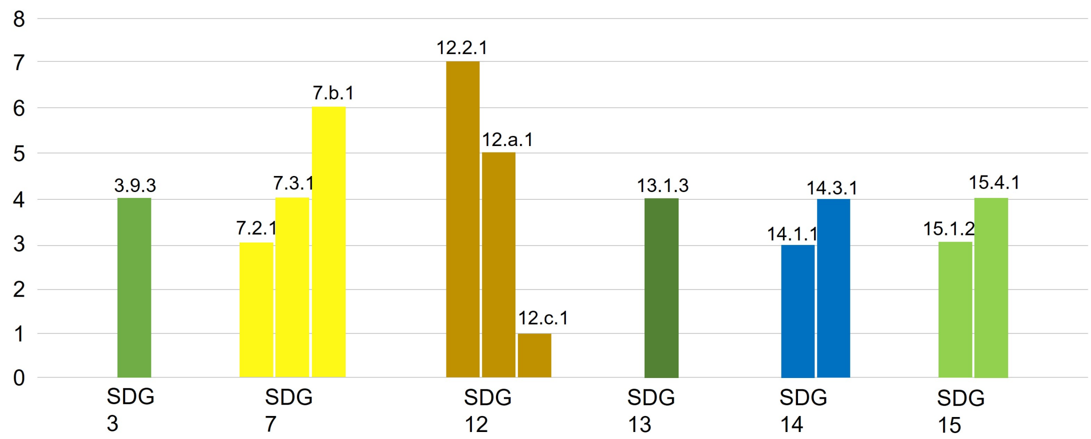


Figure 5.2: Number of applications related to each SDG indicator

The collection of the indicators found before is deeply dependent on the applications considered in the analysis, for this reason potential future Earth Observation applications could result in the expansion of the indicators database to be considered regarding the energy and raw materials market.

6 | Quantification of Indicators and Applications link

After the identification of the link between SDG indicators and energy applications, it is useful to assign a numerical value to this bond, in order to quantify the impact of each application on the specific indicator. The quantification of the links has been considered an important step for the analysis, as it directly specifies an appropriate degree of importance in the SDGs of each application, and it could also open new analysis in the future for a quantitative relation directly between EO satellites and the goals.

During the study anyway the focus was not on the type of analysis to be made at this point, which will be useful to be elaborated accordingly some other time, so the process was made starting from the pre-existing concept of Maturity Matrix Framework (MMF), proposed by an article of the Sustainability journal[4]. The original framework makes an analysis on the usefulness of the entire Earth Observation field on the SDG indicators, for this reason, it has been necessary to adapt it for the case at issue, where the study of the relations is more specific and regards only energy applications.

6.1. Original MMF

The first version of the Maturity Matrix Framework assesses the potentiality of Earth Observation data to populate the SDG indicators. The research is the first to systemically review the scope of using EO satellites into the SDGs. This framework is based entirely on the literature analysis conducted by the authors, which studied almost one hundred documents related to both fields, and later designed the first version of the MMF[3]. The matrix assigns a score from 0 (no potential) to 10 (strong potential) to each SDG indicator, according to two fundamental premises. The first premise is based on the technical methods of processing EO data, and the need of combining it with non-EO information; the second premise instead indicates the level of completeness offered by EO data to satisfy the requirements of the indicator.

The second MMF, which is the one considered for the analysis, is more advanced than the previous version: as a matter of fact, it starts from a more solid base than before, taking into consideration also consultations and interviews had with some EO and indicators experts. In this way, also the rapid developments of both markets are considered, and the framework appears more robust, transparent and comprehensive.

Through the suggestions of the experts, which highlighted the most important missing elements from the first MMF, the second version of MMF was elaborated: the two premises already present were maintained unchanged, as experts affirmed their importance, while the addition of other four premises completed the analysis. The total six premises considered at the end are:

- Uncertainty assessment
- Directness
- Completeness
- Requirement for non-EO information
- Practicability
- Cost effectiveness analysis

The result then did not consider the summation as before, but the mean of all six premises.

The analysis of the present work, however, needs to consider a different version of MMF, since the requirements are not the same of the article described. In order to find a potential quantitative correlation between indicators and precise EO applications, some premises have to be discarded as they would not have sense in this particular case.

6.2. Adapted MMF

The MMF, as seen before, represents a robust framework to link indicators and EO satellite data, for this reason the fundament of the analysis can be considered as well solid. The problem however arises from the adaptation into this specific case study: the matrix indeed has to be modified in order to let it fit into the specific case of applications, and no more considering the entire EO data. Though it could be used for all markets, and not just for the energy one, the new adapted matrix is innovative and has no feedback from literature, for this reason it is important to specify that it is used in this work just to start to give numerical values to the correlations, and it will for sure need further analysis and hypothesis.

Between the six premises listed in 6.1, only three were considered: directness, completeness and requirement for non-EO information. Uncertainty assessment was excluded from the analysis as it would need a process of validation, impossible to find at this stage, in order to find an accurate value to assign to the indicator-application relation. Practicability would be useless to consider in this case, since it addresses the practical feasibility of a technique, and its maturity in terms of TRL: all the methods considered in 4.2 associated to the variables are already exploited, so all the Technology Readiness Levels would result to be maximum. The last premise was discarded for a similar cause to the uncertainty assessment, the analysis of cost-effectiveness would need a much deeper study only to evaluate all possible applied methods and in-situ processes, and it would have been impossible to evaluate a suitable value for all cases.

The three remaining premises are defined as:

- Directness refers to whether the EO application can support the indicator directly or indirectly. Usually indirect or proxy measures from the application are associated with empirical methods that could find some important parameters for the computation of the indicator.
- Completeness is the only premise which is unchanged with respect to the first MMF, it assesses the extent to which the application information can be used to populate the indicator. Some indicators indeed can be divided into sub-indicators, as the calculation of them can contain more than one variable.
- Requirement for non-EO information is similar to the completeness premise, but instead of focusing just on the application data, it analyses the necessity of exploitation of non-EO information in order to complete the requirements of the indicator. The score in this case is associated to the level of importance of non-EO data which are used.

All the premises give a score to the correlation from 1 to 5, if for the primary scope of the MMF it would be possible to obtain indicators completely related to EO data, in the case of specific applications it is impossible to grant such result, for this reason the values will be much lower.

	A: Directness	B: Completeness	C: Requirement for non-EO information
Score			
1	Application does not support indicator	Application does not support indicator	Indicator measured by non-EO data
2	Application provides information towards indirec approach	Application supports minor part of indicator	Application supplements primary analysis based on non-EO data
3	Applications measures a proxy indicator	Application supports moderate part of the indicator	Application and non-EO data are interconnected
4	Application measures high quality proxy indicator	Application supports main part of indicator	Application data used directly, non-EO used only for modeling
5	Application can directly measure the indicator	Application supports completely the indicator	Application data used directly

Table 6.1: Description of MMF Premises score

When all the correlations have their score according to 6.1, a simple arithmetic mean between them is computed in order to find the final Maturity Matrix Score of the link between indicator and application:

$$MMS = \frac{PremiseA + PremiseB + PremiseC}{3} \tag{6.1}$$

6.3. Results

The total number of correlations considered between SDG indicators and applications in 48, and their total mean is just higher than 2,5.

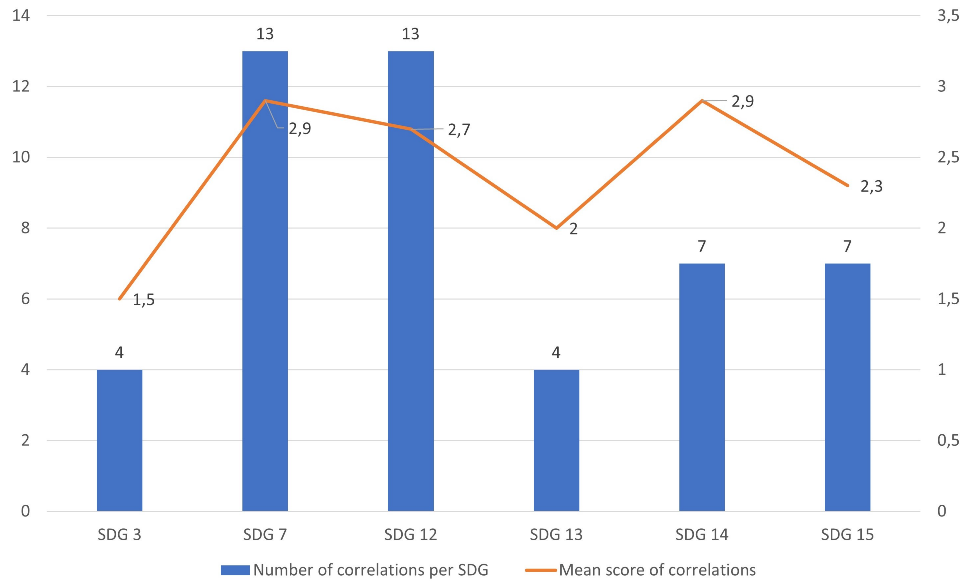


Figure 6.1: Number of correlations and mean score divided for SDG

As already stated in 5, the highest impact of energy applications into the indicators is found in the SDGs 7 and 12: the previous image underlines this concept, the two goals count the highest number of correlations with applications, and these have an higher mean score with respect to the others. Another fundamental goal for this type of market is SDG 14: who is defined as "*Conserve and sustainably use the oceans, seas and marine resources for sustainable development*", despite having less correlations, the applications could cover an important role for the indicators, with the score which almost arrives at 3. The other 3 goals instead, find relatively low score and correlations with the current energy applications, but it is anyway important to consider them in the analysis, as they could enhance future developments.

The complete list of links between all the indicators with the applications, including their relative score based on Maturity Matrix Framework can be found in B

7 | Ideal Process Example

One of the most important features of the described process is its ability to be read starting from any step the viewer decides to. Even though it is studied to start from SDG indicators to arrive to the satellites database, it is also possible to acquire information only on applications, variables and their relations with sensors orbiting with active satellites. The inverse process anyway, that is going from the satellites to the indicators, is quite difficult to exploit due to the high number of correlations and will need in future some improvements.

At this point of the analysis it is almost useless to try to assess points to improve in the satellites database starting from the indicators. The reason is based on the definition of the different steps of the correlation: the applications are indeed found starting from existing satellites, so there will not be blank spaces in the database related to some variables or applications. However the presented study can be used as an initial framework to find smart and rapid correlations between markets which are nowadays still considered very distant.

An example of the ideal process is described in this chapter: taking a random SDG indicator from the previously described ones, all the steps associated to it will be unrolled using the relative tables present in A and B, until the selection of a proper list of satellites related to it will be done.

The start of the process is from the indicator 12.a.1, which states: *Installed renewable energy-generating capacity in developing countries*. From the definition it is possible to assign to it all the applications involved having an impact on the specific indicators, along with the actual score given by the Maturity Matrix Framework.

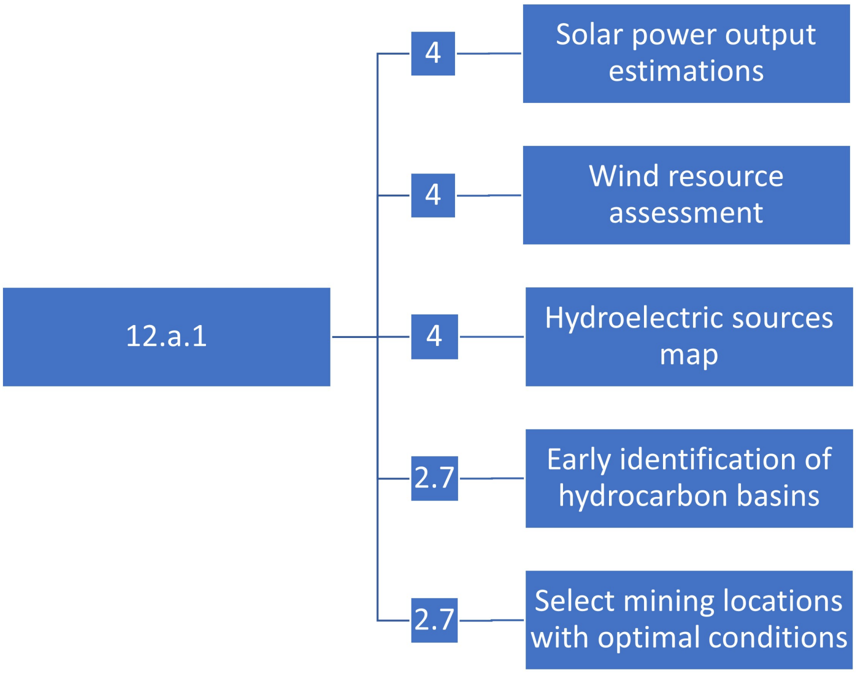


Figure 7.1: Applications related to 12.a.1 indicator with the relative MMF score

Each of the five application is composed by the definition of a different number of variables, which represent a fundamental step into the analysis. Therefore it is necessary to specify them.

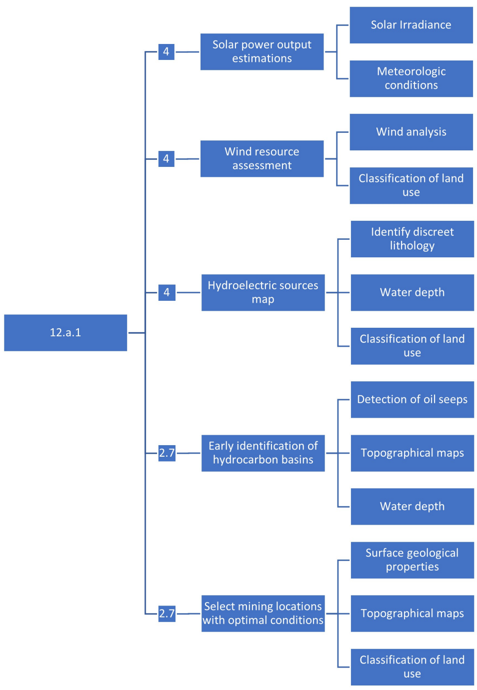


Figure 7.2: Variables related to 12.a.1 applications

It is interesting to underline the fact that some of the variables associated to different applications are the same. In most cases indeed a single variable could enhance the EO data use in different sectors. The constraints in terms of sensors are the same, while the only difference stands in the temporal resolution: the requirements of revisit time depends only on the application.

Taking now only the *Wind resource assessment* application, it is possible to find the list of satellites which respect all the constraints associated to sensors and revisit time. The number of satellites present in the list will not coincide with the total number found in 4.2 tables, as a matter of fact those numbers were related only to sensors requirements, while the following numbers will take into consideration also the required revisit time.

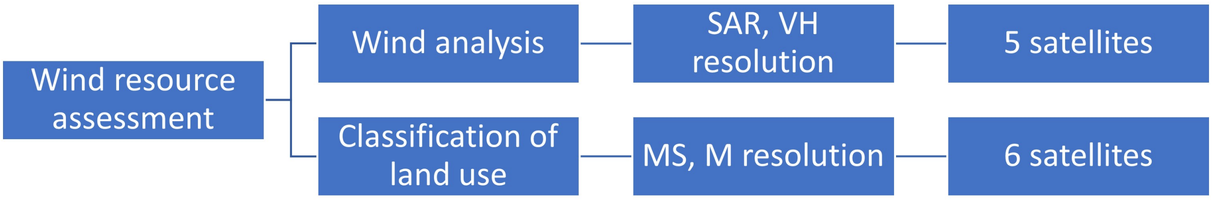


Figure 7.3: Number of satellites associated to *Wind resource assessment* application

The number of satellites in 7.3 includes mainly constellations of satellites more than single ones, as the revisit time is very high required for the application is very high.

8 | Conclusions

The final framework developed with the work of this thesis can be considered as a first model of characterization of the Earth Observation satellites footprint on the 2030 UN Sustainable Development Goals. It is impossible to link directly the satellites, here are considered both constellations and individual payloads, to the indicators, so a study involving different markets is necessary. The energy market is, between the seven considered adopted by EARSC, one of the most active, but yet only the Renewable energy sector already exploits effectively EO information. Raw materials and oil and gas sectors are less developed from this point of view, and this is caused mostly by the private nature of their companies, which ensure their reluctance on innovative products. Therefore, the bond which the analysis tries to create between satellites and SDG indicators can boost both the level of trust of companies, and at the same time enhance the number of investments related to Earth Observation related to this specific market.

However the analysis to be complete will have to include all seven sectors of EARSC Market Taxonomy, in this way the applications can become simply the mean to build a general framework: this could help on one hand the investors going from the indicators and reaching the satellites which grant the best option in terms of data provided, and on the other hand the space agencies which can start from here to evaluate what types of sensors are the most used in the different markets, and then recognize every kind of lack in the type or quality of information that they are able to grant.

The presented model anyway represents an innovative analysis without any base or feedback coming from science literature and therefore, it is filled with some weak points.

One of the most delicate steps is for sure the introduction of the Maturity Matrix Framework, though the original matrix has been approved by a vast team of experts, the adapted solution has been used in the analysis just to find a concrete and numerical final result. In the future it will be necessary to revise this passage and create a proper matrix framework in order to quantify accurately the footprint of applications on SDG indicators. As seen during the treatise, despite having some differences in the results, all the values are similar and close to the medium point, which can be considered as index of low accuracy.

A solid MMF could allow also to assign an hypothetical numerical value to all the EO satellites, based on all the applications which they are able to provide, and summing the score of each application with the corresponding SDG indicator.

Another important step which will have to be reviewed is the one related to the applications in the different markets. Even though the hints for the creation of the database of energy market applications arrived from important articles from EUSPA[41] and Copernicus[39], the analysis comprehends only present and already exploited applications, without considering future changes. However, changes in the applications field are not easy to track down, as they could come from different aspects and innovations of the sequence: the space market is always expanding in every step of the chain, and new innovations in steps such as data integration and elaboration, or in the specifics of the sensors could revolutionize the entire market.

As of now, the framework cannot be used to evaluate possible gap in the satellite database starting from the variables, since all the variable constraints are assigned starting from present examples of satellites. The argument anyway can assume relevance if the list will be filled with new innovative applications and variables: in this way it will be easier to directly find blank spaces in the satellites database.

One last important criticism to be underlined is the fact that most of the applications considered in the analysis still require some feedback coming from in-situ information in order to be approved and to be complete, so future developments must for sure involve new techniques of data analysis and integration.

The presented work nowadays still cannot be used to find accurate indexes or any type of results associated to the footprint, but it only tries to introduce a new type of framework for an expanding market like the Earth Observation one. It can indeed represent a solid base that will allow to study more in detail EO applications, and their influence on the Sustainable Development Goals. It will also help customers to select the right products to buy in terms of satellites data, and at the same time it will be an important input for satellites agencies to increase cooperation between different systems, and avoid redundant constellations.

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A | Appendix A

Application	Variables	Revisit time
Solar power output estimations	Solar irradiance Meteorologic conditions	Hourly
Solar power output monitoring	Solar irradiance Dust presence on panels	Daily
Wind power assessment	Wind analysis Classification of land use	Hourly
Wind plants monitoring	Wind analysis Monitor ocean currents Meteorologic conditions	Daily
Turbines impact on local meteorology	Meteorologic conditions Wind analysis Air quality	Monthly
Hydroelectric sources map	Identify discreet lithology Water depth Classification of land use	Weekly
Hydroelectric plants monitoring	Identify discreet lithology Water depth Meteorologic conditions Monitor ground motion effects	Daily
Effects of hydropower plants on local ecosystem	Identify discreet lithology NDVI Water pollution Meteorologic conditions	Monthly

Table A.1: Variables associated to each renewable energy sector application

Application	**Variables**	**Revisit time**
Early identification of hydrocarbon basins	Detection of oil seeps Topographical maps Water depth Classification of land use	Weekly
Monitoring of oil system plants	Water pollution Detection of oil spills Land pollution	Daily
Prevention of disaster risks	Flooding maps Monitor ocean currents Meteorologic conditions Monitor ground motion	Daily
Monitoring effects of gas hollows	Land pollution Monitor air quality NDVI	Weekly
Assess environmental impact of dredging operations	Land pollution Water pollution	Monthly
Detect illegal dredging activities	Assess Coastal activities	Hourly

Table A.2: Variables associated to each oil & gas sector application

Application	Variables	Revisit time
Select mining locations with optimal conditions	Characterisation of surface properties Topographical maps Clasification of land use	Monthly
Monitor mining operations	Identification of slope instability Asses mining activites Monitor ground motion	Daily
Grant safety of the workers	Identification of slope instability Monitor air quality Monitor ground motion	Daily
Assess surface damage due to mining activities	Characterisation of surface properties Identification of slope instability NDVI	
Mining environmental impact assessment	Water pollution Air quality NDVI Tailings dam monitoring	Weekly
Detect illegal mining activites	Assess mining activities	Hourly

Table A.3: Variables associated to each raw materials sector application

B | Appendix B

Indicator	Applications	Maturity Matrix Score
3.9.3	Monitor gas hollows effect	1.7
	Dredging Operations impact	1.3
	Mining environmental impact	1.7
	Grant safety to workers	1.3
7.2.1	Solar power output estimations	2.3
	Wind resource assessment	2.3
	Hydroelectric sources map	2.3
7.3.1	Solar power output monitoring	2.7
	Wind plants monitoring	2.7
	Hydroelectric plants monitoring	2.7
	Identification of hydrocarbon basins	1.7
7.b.1	Solar power output estimations	3.3
	Solar power output monitoring	3.7
	Wind resource assessment	3.3
	Wind plants monitoring	3.7
	Hydroelectric sources map	3.3
	Hydroelectric plants monitoring	3.7
12.2.1	Turbines impact on local meteo	2
	Effect of hydropower plants on ecosystems	2
	Monitor gas hollow effects	1.7
	Dredging operations impact	2.3
	Surface damage due to mining	2
	Mining environmental impact	2.3
	Mining locations with optimal conditions	1.3

Indicator	Applications	Maturity Matrix Score
12.a.1	Solar power output estimations	4
	Wind resource assessment	4
	Hydroelectric sources map	4
	Identification of hydrocarbon basins	2.7
	Mining locations with optimal conditions	2.7
12.c.1	Monitoring oil system plants	3.7
13.1.3	Monitoring oil system plants	1.7
	Prevention disaster risks	2.3
	Monitoring plants operational life	1.7
	Grant safety of workers	2.3
14.1.1	Monitoring oil system plants	3
	Prevention disaster risks	2.3
	Monitoring plants operational life	2.7
14.3.1	Effect of hydropower plants on ecosystems	3.3
	Dredging operations impact	3.3
	Detect illegal mining activities	2.7
	Mining environmental impact	3.3
15.1.2	Dredging operations impact	2.7
	Detect illegal dredging activities	2
	Detect illegal mining activities	2
15.4.1	Effect of hydropower plants on ecosystems	2.7
	Detect illegal dredging activities	2
	Detect illegal mining activities	2
	Surface damage due to mining	2.7

Table B.1: Applications associated to each indicator and their relative score

List of Symbols

Acronym	Description
CEOS	Committee on Earth Observation Satellites
DEM	Digital Elevation Model
EARSC	European Association of Remote Sensing Companies
EO	Earth Observation
ERMA	European Raw Materials Alliance
ESA	European Space Agency
EU	European Union
EUSPA	EU Agency for the Space Programme
GEO	Group of Earth Observation
GNSS	Global Navigation Satellite Systems
HS	Hyperspectral
LEO	Low Earth Orbit
LIDAR	Laser Image Detection And Ranging
MMF	Maturity Matrix Framework
MMS	Maturity Matrix Score
MS	MultiSpectral
NDVI	Normalized Difference Vegetation Index
SDG	Sustainable Development Goals
OECD	Organization for Economic Co-operation and Development
SAR	Synthetic Aperture Radar
SSO	Sun Synchronous Orbit

Acronym	Description
TIR	Thermal Infrared
UN	United Nations
USA	United States of America
USSR	Union of Soviet Socialist Republics

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