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Earth Observation and Sustainable Development Goals: a scoping review

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Abstract

Purpose:
Earth Observation (EO) is a set of technologies (based on remote sensing) that turns data (satellite imagery) into actionable knowledge, as forecasting weather, monitoring natural disasters and the health of ecosystems. EO supports stakeholders to capture important aspects of sustainable development and in particular the Sustainable Development Goals (SDGs). Despite the key relationship between EO and SDGs, such a link has not been thoroughly investigated in an systematic way by the managerial literature, also due to the novelty of the topic, that began to be studied only recently. Accordingly, our paper aims to fill such a gap.

Methodology:
The authors used a scoping review with the aim to analyse the main trends of the topic, the SDGs covering within the EO processes, and the empirical indicators obtained from EO for the SDGs. A sample of 79 papers has been included in the analysis,

Findings:
We find out different thematic areas. The first one aims at understanding how EO can be useful for the sustainability issues (environmental, economic and social ones), in terms of urbanization trends, land consumption and earth monitoring. The second area describes the impact of SDGs on policy-making through the policy-science interface strengths and weaknesses. The third area analyses needs of change management practices for integrating the EO inputs into the value chain.

Research limitations/implications:
Our limitations are mainly related to the procedure we follow for analyzing the data, as the exclusion criteria that might have limited the consistency of our findings. Then, findings are, for the most, basically depending on the authors' background and the interpretivist approach for analyzing the papers' content.

Originality/Value:
Given the few papers analyzing the managerial contribution of EO on SDGs, this review represents a first, original attempt to know more about this topic It provides insights into the potential benefits of EO in terms of integration also with other complementary aspects, as the policy makers interface and change practices. We believe that this original literature review

can provide scientists, policy-makers, business and researchers better awareness and understanding about limits and potentiality of EO technology and its impact on SDGs.

Keywords: Earth Observation, Sustainable Development Goals, Remote Sensing, Scoping Review

Paper type: Literature review.

Introduction

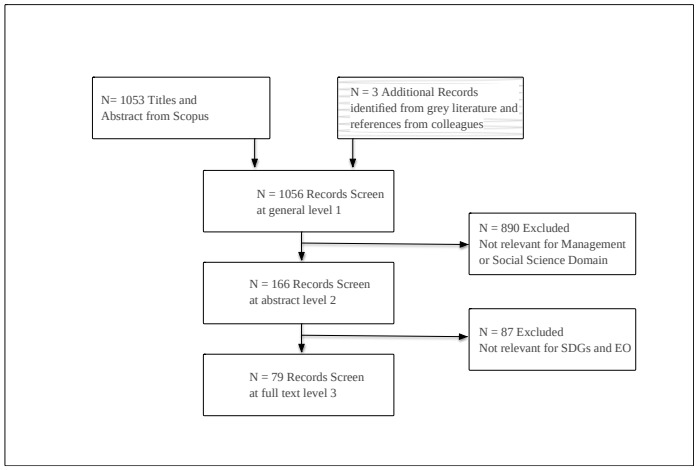
Earth Observation (EO) plays an important role in the development of digital and green services across a wide range of industries (ESA, 2020). EO is defined as a set of processes and technologies to monitor natural and human-made phenomena across the earth. In particular, Earth observation is the gathering of information about physical, chemical, and biological systems of the Planet. EO includes remote sensing technologies, such as satellites images, unmanned aerial vehicles or drones, underwater sensing, and aerial surveys. It also includes other in-situ technology such as floating buoys for monitoring ocean currents, temperature, and salinity; terrestrial air quality and rainwater sensors; sonar and radar for estimating fish and bird populations; and GPS technology. Remote sensing is arguably the most important and widely accessible Earth observation technology, and it is synonymous with EO for many users. EO has enormous potential for organizations (both private and public organizations) to improve ecosystem-based decision-making. It relies on satellite big data, for generate knowledge and applications for citizens, government, and industry at relatively low cost or even free.
EO value chain starts from the input of the scientific and R&D needs, as well as government policies and the needs of individual agencies and create value for end users (governments, academia, industry, science and even the general public as customers for EO products). EO application (i.e. forecasting weather, monitoring natural disasters and the health of ecosystems) helps stakeholders to capture important aspects of sustainable development and in particular the Sustainable Development Goals (SDGs) (Andries et al. 2022), ratified on 2015, mandatory for the committed countries as part of a global plan to end poverty, promote prosperity and people's well-being and protect the environment.
EO data support the SDGs achievement due to their socioeconomic nature and to the conception and formulation of the SDGs indicators.
Despite the key relationship between EO and SDGs, such a relationship have not been thoroughly investigated in an organic way by the literature. The reason is related the novelty of the topic, that began to be studied only recently (after the 2015, see table below), and, regarding EO, it has been deepened mainly from a technical perspective more than from a managerial one.
Accordingly, our paper aims at understanding how the managerial literature has approached the topic of EO in relation to the SDGs. Our objective is to understand the impact of Earth Observation on SDGs, and more specifically, our RQ is the following: "in what way, and how, does the EO impact on SDGs?"
Increasingly, we want to analyze more the impact of EO on SDGs by understanding the main issues of the EO and impacts on SDGs. In the next sections, after describing the research method we discuss the main findings, implications and conclusion.

Research Method. The scoping review approach

Our paper draws from the relationship between EO and SDGs. We adopt different techniques, including bibliometric methods and scoping review of published articles and their citations to

assess their influence.
We adopt a scoping review method, increasingly utilised in the social sciences and evidence-based policy-making (Moher et al., 2015). Scoping review typically aims to present a broad overview of the evidence pertaining to a topic, irrespective of study quality, and are useful when examining areas that are emerging, to clarify key concepts and identify gaps and to examine the extent, nature, and range of research activity on a particular topic or question; summarise and disseminate research findings; and, identify gaps in the existing research and does not make any assessment of the quality of the research.
Scoping review is more exploratory than the systematic review, and typically addresses a broad question, associated to an exploratory overview of the topic to assess the available evidence, and to highlight gaps about an area that has not yet been deeply reviewed (Moher et al., 2015). Given the relatively newness of the topic, and the consequent exploratory nature of the research question, we apply the following methodological framework (Levac et al., 2010) (Fig. 1).

Figure 1 – Scoping Review framework



We firstly identified the relevant EO literature by using Scopus database, which is widely recognized as a world-leading database (Paschou et al., 2020) and locating research papers accordingly to our research question. We use two sets of keywords related to the concepts of Earth Observation and Sustainability to search for relevant articles. The first set of keywords was related to the EO ("Earth observation" or EO or "Satellit* data" or "Remote Sensing" or "Satellites Data Analytics"). The second set of keywords was based on the sustainability concepts by using the general combination of keywords "SDGs"or "Sustainable Development Goals", as a proxy for sustainable development related topics. We received also other sources on the topic from experts. Initially a total of **1056** studies were identified from the database.
Next, we refined the database by using the selection criteria of inclusion-exclusion, in particular, given the research topic based on SDGs, we covered studies conducted from 2017 to 2022. We excluded not peer-reviewed journal articles, only written in English language. Then we selected the most appropriate journals for the topic: Business, Management and Accounting, and Social science. We accepted only journal articles and duplications of articles were checked through. After removing the publications that did not meet the inclusion criteria, a total of 166 remained for 'EO and SDGs". All these journal articles were quality assessed by analyzing the abstracts, in order to identify relevant papers to analyze, synthesize and present the interpretations on the theme investigated.
At the end of this stage we carried out 79 articles.

Results

The descriptive studies of EO on SDGs

In this stage a careful evaluation of each full journal article was caried out for the 7 finalized articles to ensure we capture only the paper based on the core topic of Earth Observation and SDGs. All 79 journal articles were identified relevant to analyze, synthesize and present the interpretations on the paper topic. The papers selected are descriptively analysed in this section with respect to the year of publication, journal, and impact factor according to Scopus database.

Figure 2 – Time distribution of the selected papers (Note: TP = total articles, ATC/P = average global citation per document, ATC/Y = average global citation per year)

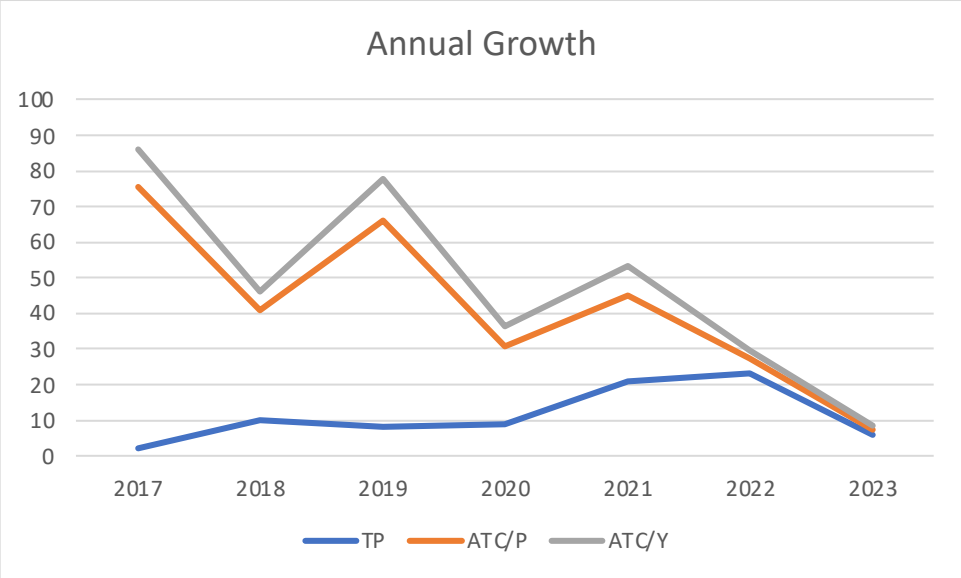


Figure 2 depicts the time distribution of the papers analysed, all published between 2017 and 2022. More specifically, 75 articles (i.e., 85% of the 79 scrutinised papers) were published between 2019 and 2022, pointing to an increased scholarly interest in the earth observation and sustainability analysis. The journals were also classified according to Scopus database subject area (Table 1).

Table 1 – Scopus database subject area classification

Journal	Records	%	IF
Sustainability	17	21,52%	3.889
ISPRS International Journal of Geo-Information	8	10,13%	3.099
Environmental Science and Policy	7	8,86%	6.424
Geo-Spatial Information Science	5	6,33%	4.278
Land Use Policy	4	5,06%	6.189
Journal of Cleaner Production	3	3,80%	11.072
Space Policy	3	3,80%	1.609
Others	32	40,51%	-
Total	**79**	-	-

The journal impact factor (IF) was retrieved from the Clarivate Analytics database (2023) and Journals Website. The 79 articles in our database appeared in a total of 39 journals. Only 7 of

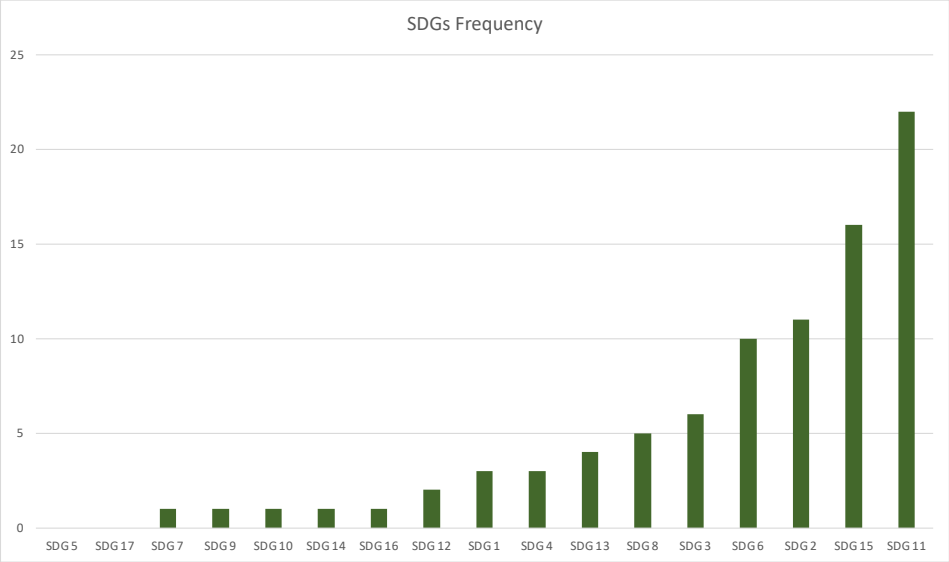
these journals published on the topic three papers or more, showing a high degree of fragmentation of the literature.

Finding 1. The increasing interest for EO and SDGs is very recent but shows a fast-growing trend, with the knowledge stocks fragmented and distributed among different journals, such as space policies, land use, cleaner production and environment. Moreover, few, specialized managerial journals face the topic.

The EO importance for sustainability

Our results highlight an explosion within the topic indagated in the number of articles produced since 2017. In general, studies describe how EO has been used for analyzing SDGs, with different frequency (Fig. 3).

Figure 3 - Frequency of SDGs indagated



The importance of EO for SDGs is documented by different papers that show EO-based information and services could support monitoring and management tasks for SDGs (Wu et al., 2020).

SDGs and EO: singular vs multiple targets

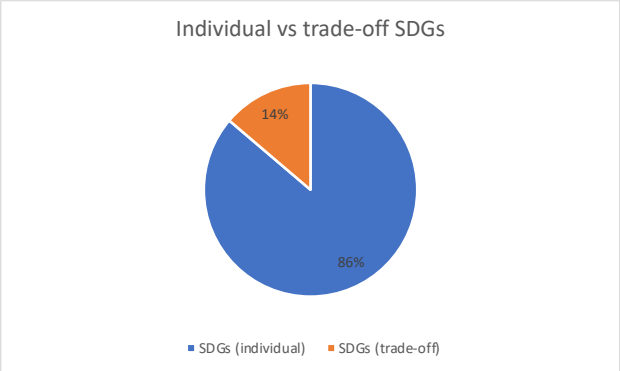
By analyzing these articles, we identify an attention to the contribution of SDGs through EO in order to improve the sustainability in several dimensions, from make cities more sustainable (i.e. urban growth trends in South Africa), to the analysis of the different dimensions of inhabited spaces (from schools to slums overcrowding) to the links between spaces dimensions and trends of poverty (SDG 11) to the soil transformation (Andries et al., 2022; Boyd et al., 2021; Fraisl et al., 2022; Gómez et al., 2021; Mudau et al., 2020). For example, a study explores the impact of EO for urban health decision-makers to build a better urban sustainable

development assessment framework and references for the sustainable development in cities, in China and even the world (Mao et al., 2018).
Other papers analyse the soil status (degradation, consumption, distribution and efficiency) (Acheampong, 2022; Estoque et al., 2021) and how remote sensing data can support soil quality and provide insight in predicting the impact of agricultural practices and optimise their application (Iodice et al., 2021).
Again, other studies are focused on the soil stability monitoring for managing its effects (Honeck et al., 2018; Moltchanova et al., 2011) through analysing the stability of the earth, for example, in relation to earthquakes (Koren & Rus, 2019) for better systematic understanding the response actions to earthquake or climate and ultimately improve their efficiency.

The importance of analyzing SDGs as trade-off

According to the papers analyzed, SDGs should be considered not only individually but also as a combination of goals. SDGs could produce synergies, when SDGs targets in the same area are enhanced simultaneously, as when fish populations (SDG target 14.2) and improve reef quality for tourism (SDG target 8.9) are impacted by sustainable management of coral reefs (through the material, energy, and information flows from human subsystem to natural subsystem). SDGs can also interact in opposite directions, leading to a trade-off (targets of one or multiple SDGs are enhanced at the cost of hampering other targets or SDGs). Studies highlight how the land-use planning decision on urban expansion may, in fact, considers the need for more housing (SDG 11.1) alongside the economic and employment benefits of new industrial zones (SDG 8) and the environmental health benefits for urban citizens of relocating polluting industries (SDG 3) against the need to preserve agricultural land for the sake of food security (SDG 2) (Dolley et al., 2020).

Table 3 – Individual SDGs versus trade-off analysis



Also another study shows the complex interplay and conflicts among SDGs: “policies that can assist in preserving the terrestrial ecosystem of Semarang (SDG 15) while creating a sustainable city (SDG 11, SDG 9) and providing sufficient work for individuals (SDG 1) in a growing economy (SDG 8) while simultaneously maintaining a sufficient food supply (SDG 2)” (Kelly-Fair et al., 2022).
For the most literature has analyzed papers by focusing on single SDGs more than in combination (Table 3).

Finding 2: From a managerial perspective, the EO process supports the analysis of individual SDGs more frequently for SDGs 2, 11 and 15. For the most SDGs, EO has been used to analyze SDGs individually more than collectively and on trade-off analysis.

The frameworks for systematizing EO

A second area of studies on EO and SDGs relates to the previous one, and it is related to the use of official frameworks for understanding how EO contributes, directly and/or indirectly, to the monitoring of the SDGs (Table 4).

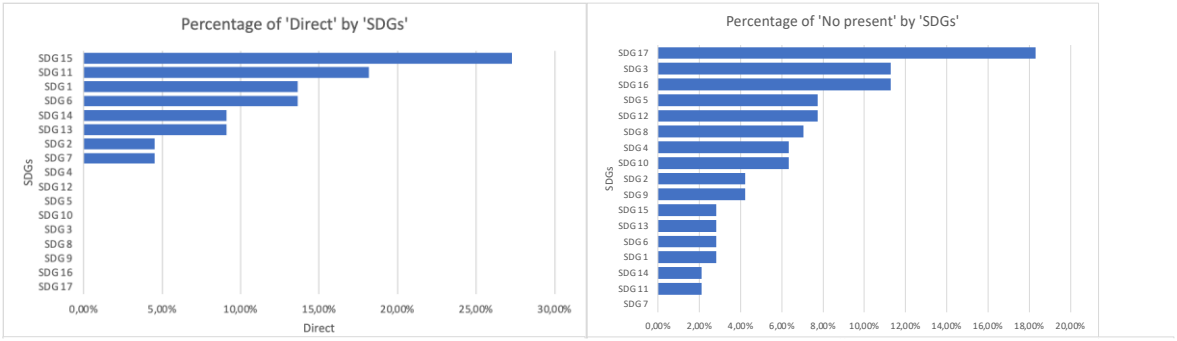
Table 4 – Frameworks for EO

EO framework	Papers	%	% on total
EO4SDG	6	33,33%	
MMF	5	27,78%	
Compendium	4	22,22%	
Satellite EO in support of the Sustainable Development	3	16,67%	
	18	100,00%	22,78%

We find out a mix of theoretical and grey literature frameworks that aims to analyze the use of EO for SDGs. The report "Satellite Earth Observation in support of the Sustainable Development" (ESA, 2018) analyzes the statistics around the custodianship (UN bodies and other international organisations), by highlighting the importance of EO for SDG 6 (clean water and sanitation), SDG 11 (sustainable cities), SDG 14 (life below water) and SDG 15 (life on land), involving the provision of information related to land cover, land productivity, ground biomass, soil content, water extent or quality characteristics, as well as air quality and pollution parameters. Another report, EO4SDGs initiative (EO4SDG, 2020), demonstrates how earth observations and other data (both spatial and no spatial) contribute in novel and practical ways to support sustainable development efforts and the SDGs with a classification based on three tiers (from I to III according to conceptual clarity, established methodologies, standards availability). Accordingly, 127 indicators were collocated on tier I, 99 indicators were collocated on tier II, zero indicators were collocated on tier III. In the compendium of Earth Observation (ESA, 2020) contributions to the SDG targets and indicators, it has been used a system of red, (Observation currently has no contribution to the methodology, i.e. all other SDG Indicators amber (SDG Indicators for which Earth Observations has not been currently identified as a source of information but where there is potential to do so with further methodological development) and green colors (SDG Indicators for which Earth Observations have or have not been currently identified as a source of information but would make a definite contribution to their methodological development with relative ease). The ESA Compendium presents case studies of using EO satellite-derived data for a total of 34 indicators which were assessed against a framework that discriminates the indicators into two categories; 17 indicators can be directly measured and 17 indicators indirectly informed by EO data across 29 targets and 11 goals.
Finally, Andries et al. (2022) propose the MMF (2.0), as an evolution of the theoretical framework called MMF for the potential role of EO to measure each SDG indicator. Such a framework estimates that 22 indicators are strongly supported by EO (SDG 15,11,1,6,14,13,2,7).
139 indicators had no evidence that EO data could be used for their support. 67 indicators rely on weak and partial support from EO, from which the possibility of use no-spatial data aim to facilitate the share and integration of multi-source (spatial and no spatial) data inside a framework with a number of technological components, policies and standards. EO data.

However, this is a rapidly evolving field in which future approaches to using EO data for social indicators may be developed.

Figure 4 - Percentage of SDGs that could be directly observed and not observed through EO



Finding 3: from a managerial perspective, EO is useful for monitoring directly or indirectly SDGs. However, more evidence are needed for understanding how EO can contribute to not yet covered SGDs.

The impact of SDGs on policies

Another topic we discover by analyzing the literature was about the evolving role that EO technology has for policy-makers. EO allows policy-makers to making decisions for stakeholders in terms of sustainable development (Mazzetti et al., 2022).
Studies agree that EO creates value by assisting policy makers on understanding the stakeholders needs about environmental decision (about land, urban development and others field) (Anderson et al., 2017).
For example, EO data can be used to identify areas of deforestation, which can then be used to target conservation efforts. EO data can also be used to track the movement of pollutants, which can help to identify sources of pollution and develop mitigation strategies (Ghosh et al., 2020).
However, EO data needs for the functional analysis (understanding EO functionality for integrate knowledge, procedures and uses) necessary together with the identification of the emergent aspects of the values systems. The use of EO data works to know the environment, but also to design and deploy EO technologies, specifically to monitor human impacts on the environment (i.e. oceans), and foretell possible consequences. EO should be integrated with the analysis of the social value systems, attitude and behaviour changes, by focusing on the overlapping issues of society, technology and the environment (Pirrone et al., 2022).
Policy-science interface among different stakeholders with different views, values and attitudes (Mazzetti et al., 2022) calls for appropriate dialogue and integration of EO to policy-making, a reflection and critical process (Adamo & Willis, 2022) for the resolution of connected and conflicting environmental problems (Singha & Swain, 2022).
However, dialogue and integration depend on the technical and socio-political barriers that may exist. The dialogue should increase awareness among those being mapped about the value and impacts of the data used to design EO products, a dialogue that transitions those being mapped from data subjects to potential data citizens. More so, this dialogue on how and whether to be mapped can be impeded by technical and socio-political barriers and the representational power of EO products (Gómez et al., 2021).

Moreover, exceedingly complex undertakings and even when mechanisms exist to inform decision-making, the science is often poorly elaborated (Adamo et al., 2022), monitoring is mismatched with policy and implementation, and the need for social innovation and stakeholder engagement in support of decision-making is inadequately addressed. From a managerial point of view, the EO process supports SDG-oriented policies. However, to make this process more consistent, a greater capacity for science-policy dialogue is needed (facilitated by the concept of *interoperability*).

Finding 4: from a managerial point of view, the EO process, to be effective, needs for more integration between technology and organization.

EO and Change practices on management

The impact on change practices is another important streamline of the analysis. Knowing SDGs through EO implies the needs for changing practice in industries as EO is important for helping the decision-makers to adopt decisions that should change sustainable development practices (Mazzetti et al., 2016).
A study found that productivity indicator (i.e. NDVI) were able to identify increases productivity in the locations where the sustainable land management practices are implemented in comparison to control sites (Gonzalez-Roglich et al., 2019). Another study focuses on three management practices, by showing that depending on the goal, not only the indicators required change, but also the management practices or approach required to reach those goals (Blatchford et al., 2018). From the SDGs target and goals coherent policy design and implementation should follow changes in farming and industries practices to address sustainability problems and sustain the wellbeing and livelihoods.
Therefore, the remote sensing approaches and methods to provide information about SDGs and track their progresses requires change on management practices (i.e. agricultural irrigation status, rotation and planting date) (Dolley et al., 2020). However, the intention to change practices should be confirmed by tangible benefits (i.e. of farmers, regarding EO data evolution, need to see the economic benefit both in terms of performance and economic impact).

Finding 5: from a managerial point of view, the EO process supports the change of practices oriented towards the SDGs. However, to make this process more concrete, a greater description with case studies of how the change process can take place is needed.

Discussion and implications

Although the publication rate on EO topic has been evolving rapidly in the last years, findings show that the field under research, from a managerial perspective, still presents interesting gaps and trends to be analyzed. Therefore, the subsequent paragraph presents promising paths for future research.

EO and SDGs: the importance of trade-offs

When it comes to EO, we claim the importance of analyzing SDGs trade-off as it represents the most difficult and under-investigated process for sustainable development (Boar et al., 2021). Despite literature suggests that SDGs are conflicting in nature, it is not still clear how EO could help to reduce SDGs trade-off and improve their synergies. Our analysis suggests that only a small percentage of papers consider EO impact on trade-off analysis despite we found papers that suggest the need to reconcile the trade-offs and consider the interactions

among SDGs (Dolley et al., 2020; C. Singha & Swain, 2022; M. Singha et al., 2021). Therefore, future research should focus on analysis dedicated on the understanding of EO contribution to solve the different SDGs trade-off.

The importance of policy

SDGs oriented policies are the central output for the EO process. EO play a fundamental role for supporting policy-making. From this point of view, the communication interface between science (based on the development of EO technology and processes) and policy (based on the EO and non EO data) is relevant (Lehmann et al., 2022).

The science-policy interface is the "*social processes which encompass relations between scientists and other actors in the policy process, and which allow for exchanges, co-evolution, and joint construction of knowledge with the aim of enriching decision-making*" (Mazzetti et al., 2022; van den Hove, 2007), and basically allows to provide knowledge from data by experts (scientists, data providers companies) to users (local communities, stakeholders and, policymakers). The dialogue among scientists and decision-makers with different views, values, and attitudes, calls for an alignment between industry activities and government incentives (Kerstens et al., 2017). However, such a dialogue is sometimes challenging as raw earth observation data are not readily usable for the policy actors, requiring a value adding industry – that transforms raw data to information. The technical open issues requires effort and collaboration within the actors of the value chain to gain the necessary market pull needs with the technology push and link downstream with upstream (Kerstens et al., 2017).

Literature, although it has been highlighted the importance of EO as a critical policy tool, has not analyzed sufficiently how to make the dialogue science-policy effective and fluent (Mazzetti et al., 2022). This gap should be analyzed in future research on EO.

Change on sustainable practices

From a managerial point of view, very little attention has been paid to how changes are processed regarding the EO technology adoption.

We found that only few articles use case study methodology and collect retrospective data to depict the impact of change and digital transformation on end-users, in particular, how practices change due to policies about EO.

What lacks in literature are longitudinal case studies able to inform practice on limits and opportunities of change regarding the EO. In this perspective, scholars might consider for future research case study approach for longer periods of analysis and observe the sequential relationships of events the influence the change management EO related practices on companies. Sustainability transition doesn't require only technological solutions; the challenges of such a transition will be enacted through change management practices. This will be facilitated by the technology mediation, dissemination and discussion of environmental data and applications (Adamo & Willis, 2022).

Conclusion

This scoping review identified significant gaps and trends for EO in managerial literature. Despite we identify different trends that literature could deepen and explore further in the future, we also highlight some limitations in our analysis. The first limitation is related to the procedure we follow for analyzing the papers and particularly to the exclusion criteria. Including papers only in the English language and excluding publications (as conference papers) might have limited the consistency of our findings. We believe also that due to the journal type and specific disciplines selected for refining the sample analyzed, some papers that are related to the research focus but have been published in other Journals or domain could be excluded. Finally, findings are, for the most, basically depending on the authors' background

and the interpretivist approach for analyzing the papers' content. However, we think that our findings are reliable due to the scoping literature review approach. We believe that this original literature review can provide scientists, policy-makers, business and researchers better awareness and understanding about limits and potentiality of EO technology and its impact on SDGs.

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