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The role of the Sustainable Development Goals for better governance of Carbon Capture and Storage (CCS)

O papel dos Objetivos do Desenvolvimento Sustentável para uma melhor governança da Captura e Armazenamento de Carbono (CCS)

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ABSTRACT: The discussion on the Anthropocene has increased the urgency to promote a sustainable society, considering the planetary boundaries, population growth and resource scarcity. Thus, the United Nations created the 2030 Agenda for Sustainable Development to address this challenge, including 17 Sustainable Development Goals (SDGs) and 169 SDG targets. In this context, the energy sector is one of the main sectors to achieve sustainable development and contribute to climate action using new technologies, such as carbon capture and storage (CCS). However, CCS can positively and negatively impact the planet and hinder or boost the SDGs, depending on how it is governed. Therefore, this article aims to discuss the role of the SDGs to better governance of CCS. To inform this discussion, we first show that 25 SDG targets are impacted positively or negatively by the use of CCS. This implies an urgent need to improve the way this technology is being deployed worldwide. To contribute regarding the governance, we highlight 13 targets that can help guide better use of this technology. This aspect of governance highlights that, to improve, actions must be spread on topics such as strengthening international collaboration, transfer of technology and financial resources, and the organisation of actors (researchers and decision-makers) to work together to achieve sustainable development. Finally, we point out that the sustainable deployment of CCS should be a goal to improve governance. Furthermore, we emphasize that the results of this work might have to be constantly updated, given that current research and technological advances may imply significant changes.

Keywords: carbon capture and storage; sustainable development; 2030 Agenda; governance; sustainable energy.

RESUMO: A discussão sobre o Antropoceno aumentou a urgência em promover uma sociedade sustentável, considerando as fronteiras planetárias, o crescimento populacional e a escassez de recursos. Dessa forma, as Nações Unidas criaram a Agenda 2030 para o Desenvolvimento Sustentável para enfrentar esse desafio, incluindo 17 Objetivos de Desenvolvimento Sustentável (ODS) e suas 169 metas. Nesse contexto, o setor de energia é um dos principais setores para alcançar o desenvolvimento sustentável e contribuir para a ação climática por meio de novas tecnologias como a captura e armazenamento de carbono (CCS). No entanto, o CCS pode impactar positiva e negativamente o planeta e prejudicar ou impulsionar os ODS, dependendo de como é governado. Portanto este artigo tem como objetivo discutir o papel dos ODS para uma melhor governança do CCS. Para fundamentar essa discussão, primeiro mostramos que 25 alvos são impactados positiva ou negativamente pelo uso do CCS. Isso implica a necessidade urgente de melhorar a maneira como essa tecnologia está sendo implantada em todo o mundo. Para contribuir com a governança, destacamos 13 metas que podem ajudar a nortear um melhor uso dessa tecnologia. Esse aspecto da governança destaca que, para melhorar a governança, as ações devem ser difundidas em temas como o fortalecimento da colaboração internacional, a transferência de tecnologia e recursos financeiros e a organização dos atores (pesquisadores e tomadores de decisão) para trabalharem juntos para alcançar o desenvolvimento sustentável. Por fim, destacamos que a implantação sustentável de CCS deve ser uma meta para melhorar a governança. Além disso, ressaltamos que os resultados deste trabalho devem ser constantemente atualizados, dado que a pesquisa atual e o avanço da tecnologia podem implicar significativas mudanças.

Palavras-chave: captura e armazenamento de carbono; desenvolvimento sustentável; Agenda 2030; governança; energia sustentável.

1. Introduction

There is intense debate about a new geological epoch called the Anthropocene, where humanity's dominance has endangered the Earth system and been registered in a stratigraphic record (Crutzen, 2002, 2006; Lewis & Maslin, 2015). The rapid population expansion and exploitation of Earth's resources has intensified faster than the planet can support (O'Neill *et al.*, 2018). The terrestrial system associated with the biophysical processes of the planet, responsible for the safe operating space for humanity, the so-called planetary boundaries, has already begun to be exceeded (O'Neill *et al.*, 2018; Gerten *et al.*, 2020; Lade *et al.*, 2020). The stable environmental state of the Holocene has been displaced outwards by human actions, causing harmful and even catastrophic effects for large parts of the world (Crutzen, 2002; Rockström *et al.*, 2009; Steffen *et al.*, 2011) and calling for urgent action. Therefore, during this human-dominated era, governments worldwide must commit to socio-environmental activities supported by whole-of-society responses to reverse or mitigate the effects caused (UNDP, 2020). For this reason, governments have sought agreements and commitments to deal with this global issue. For example, currently, the Paris Agreement, a legally binding international treaty adopted by 196 Parties in 2015, directs climate action to limit global warming to much less than 2, preferably 1.5 degrees Celsius, compared to pre-industrial levels (UNFCCC, 2015).

Another important and recent commitment to address the diverse global humanitarian issues and safeguard the Earth's life support system was the development of a new global government agenda (Griggs *et al.*, 2013). In September 2015, at the United Nations Conference on Sustainable Development, Agenda 2030 and the Sustainable Development Goals (SDGs) were unanimously approved by the members of the organisation. 17 Sustainable Development Goals (SDGs) associated with 169 targets have been established, demonstrating a greater scale and ambition of the Agenda for current problems. The SDGs are integrated and indivisible, mixing the three dimensions of sustainable development in a balanced way: the economic, social and environmental. It focuses on people, planet and prosperity, aiming not to leave anyone behind, promoting fundamental partnership and peace as the ultimate goal. The 2030 Agenda broadens the debate to address contemporary problems such as energy issues, cities, diverse inequalities and climate change, integrating several goals to cover the Earth's biophysical system and processes (UN, 2015). In this context, countries are committed to meeting the targets and goals set in this Agenda, especially in the energy sector, one of the largest contributors to greenhouse gas emissions and adverse environmental effects on the terrestrial system.

For this reason, new technologies and sources of energy resources have been studied and implemented to mitigate the negative effects of the current energy system. One of them is carbon capture and storage (CCS), which is considered an emerging technology that promises to reduce the emission of carbon dioxide (CO_2) in the atmosphere through capture, transport and geological storage (Bäckstrand *et al.*, 2011; Bui *et al.*, 2018). Consequently, this technology has been touted as essential to achieve the climate objectives of the Paris Agreement and the SDGs as stated by the International Energy Agency (IEA), which estimates that large-scale implementation of CCS could reduce CO_2 emissions by up to 32% by 2050 (IEA, 2017).

CCS can cause both positive and negative impacts on the planet, like any technology developed by humanity. In other words, the implementation of CCS is related to the achievement of the SDGs. To avoid adverse effects and enhance benefits, it is essential to understand the role of this technology within the 2030 Agenda. Several studies have evaluated the risks and benefits of CCS implementation in energy systems (IEA, 2013, 2019; Campbell *et al.*, 2018; Global CCS Institute, 2019; Xu *et al.*, 2021). However, there is a lack of studies that assess the role of CCS global level in contributing to the SDGs. Recently, Mikunda *et al.* (2021) addressed this gap on the 2030 Agenda by analysing the relationship between CCS and the SDGs based on Life Cycle Assessment (LCA) articles. The work shows each positive interaction, highlights the major inhibitors and concludes that CCS is a sustainable option to align climate action and the SDGs. As the attempt by Mikunda *et al.* (2021) was the first to seek these interactions (limited to the scope of LCA studies), a lack of knowledge remains unaddressed, such as the traceable impacts in a broader context.

Moreover, the discussion of the relationship between CCS and SDGs also leads to another implicit gap: what is the role of SDGs in contributing to better CCS deployment and climate governance concerning this technology? The role of SDG and climate governance has been widely debated (Meuleman and Niestroy, 2015; Deacon, 2016; Al-Saidi, 2021; Eskelinen, 2021; Van Zanten & Van Tulder,

2021). Wurzel *et al.* (2019) point out that climate governance involves international, supranational, transnational, national, and subnational levels. Furthermore, Schulz *et al.* (2020) stress the need to govern emerging technologies to achieve the SDGs. Thus, aiming to address this gap, the present work focuses on understanding the connection between the 2030 Agenda and the governance of CCS. Following what was stated by Allen *et al.* (2018), we first assess the interactions, synergies and trade-offs between the 2030 Agenda and CCS. This initial assessment is broader and does not limit one methodology (e.g. LCA) and guides our discussion on what needs to be introduced and discussed in CCS governance in future years to establish a sustainable deployment of this technology.

The article is divided into four sections in addition to this introduction. The following section describes the methodology applied and outlines the main limitations of the research framework. The third section presents the synergies and trade-offs between CCS and the 2030 Agenda and subsides the discussion on CCS governance in the fourth section. Finally, the last section offers the conclusion and recommendations of this work.

2. Methodology

2.1. Research framework

The research framework is shown in Figure 1 and is subdivided into three main steps and provides a qualitative analysis consolidated by a literature review. The steps are:

1) Individual questionnaire,

2) Elicitation of experts based on consensus, and

3) Experiment-driven literature search.

The approach is based on previous work conducted by Fuso Nerini *et al.* (2018), Fuso Nerini *et al.* (2019) and Vinuesa *et al.* (2020), in which all 169 SDG targets are analysed. The framework aims to answer how the relationship between the SDGs and the implementation of the CCS. Following on from Allen *et al.* (2018), it is necessary to first assess the interlinkages, trade-offs, and synergies to construct effective governance. Thus, our research framework is based on two guiding questions to understand how the 2030 Agenda can improve CCS governance. These are A) "Will the CCS impact the achievement of this Target?" and/or B) "Will this target impact the deployment of the CCS?". Details about each methodological step are provided below.

2.2. Steps 1 and 2: questionnaire and elicitation of experts based on consensus

The research team carried out stages 1 and 2 together, comprising authors with expertise in geology, environmental engineering, energy transition, technology and meteorology. In stage 1, they answered the questions A) "Does CCS impact on the achievement of this SDG target?" and B) "Does this target impact on CCS deployment?" individually and for each of the 169 SDG targets. In addition to both questions, an assessment was also made on whether the impact was positive or negative.

Following step 2, the expert research team discussed the results during meetings to construct a consensus. The methodology is known as consen-

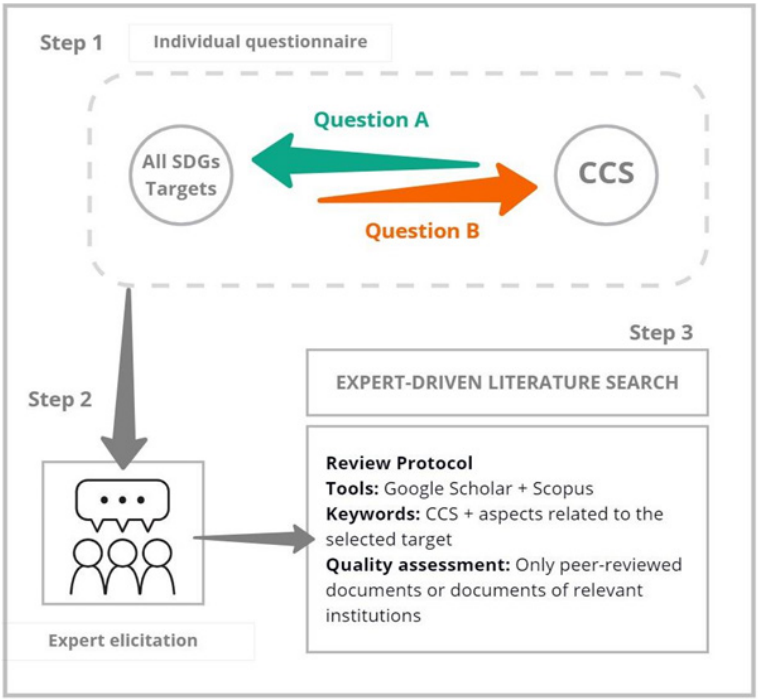

FIGURE 1 – Research framework.

sus-based expert elicitation and is a useful tool for exploring problems using researchers, policymakers, and other actors with primary expertise (Morgan, 2014; Butler *et al.*, 2015). The subjective bias is decreased by building a diverse team of expert in the area and applying a structured protocol. This technique has provided analysis in different areas such as health (e.g., Papavasiliou *et al.* (2014)), energy (e.g., Schmidt *et al.* (2017)), and natural sciences (e.g., Nevalainen *et al.* (2018)), and recently it has also been used in sustainable development studies, especially to link a specific topic to the 2030 Agenda (Fuso Nerini *et al.*, 2018; 2019; Vinuesa *et al.*, 2020). As in other studies (Fuso Nerini *et al.*, 2018; 2019; Vinuesa *et al.*, 2020), the 2030 Agenda has guided the concept of sustainable development.

2.3. Experiment-driven literature search

To consolidate the results of the two questions, we performed an expert-driven literature search. In other words, at least two academic texts were selected to justify each of the chosen targets (Step 3). The academic text could be peer-reviewed articles and grey literature from important institutions (e.g., UN). As search tools, we used Scopus and Google Scholar, applying as keywords the combination of terms that indicate the aspect assessed (e.g., public perception) with CCS or its variants (e.g., CCUS or

CO_2 storage). Steps 1 and 2 were repeated to ensure consistency of the final list of selected SDG targets. The process resulted in the selection of 57 articles, widely spread among different topics within the CCS debate. Unlike previous works, our analysis approaches a broad perspective on the complexity of this technology. It discusses a wider scope of the literature review and embraces the opposite relationship, i.e., how the SDGs can govern the implementation of the CCS.

The results were presented after dividing the SDGs into environmental, economic and social aspects, which are fundamental pillars of sustainable development (Strange & Bayley, 2008; Baker, 2015; Vinuesa *et al.*, 2020). This division gives a broad understanding of the relationship.

2.4. Limitations of the research framework

The use of consensus-based expert elicitation relies heavily on the expertise of the research team. Therefore, it is reasonable that the authors might not have considered several interlinkages between CCS and SDGs. Another relevant point is that ensuring the consistency and quality of the literature corpus to support the consensus-based expert elicitation implies not to cover other relevant literature that may indicate different linkages. In other words, recent content published in scientific events, institutional reports, and media sources could also have been used as indicators. They could highlight essential ongoing issues and solutions more readily than peer-reviewed articles. Finally, the interconnection between technology and the SDGs is not well established in the literature (Mikunda *et al.*, 2021). Consequently, different points of view and discrepant results can be expected. Moreover, several methodologies should be stimulated to show how different perspectives bring new insights.

3. Results and discussion

Next, question A is discussed for each of the core aspects of sustainable development (environmental, social and economic) in Section 3.1. For this question, Figures 2-4 show the impact (positive or negative) on each chosen target. In the Section 3.2, Figure 5 summarises the results for question B, which addresses the governance aspect.

3.1. Synergies and trade-offs between CCS and Sustainable Development Goals

The discussion on the role of the 2030 Agenda in CCS governance must be grounded first in how the use of CCS impacts the SDGs. Thus, we found that 25 SDGs targets (15%) present synergies and trade-offs between CCS and sustainable development. These targets span many of the 17 SDGs and therefore, comprise diverse topics. CCS has a positive impact on 18 targets, while 15 are negatively impacted. 8 of the selected targets have both synergies and trade-offs. The existence of targets that can be both a synergy and a trade-off shows how ambivalent capture and storage technologies can be in sustainable development.

The crucial role in climate action of CCS reflects in its contribution to sustainable development, as pointed out by the International Energy Agency (IEA) on its mitigating use (IEA, 2017). However, this technology can also play a role in climate resilience actions. Only a few studies link

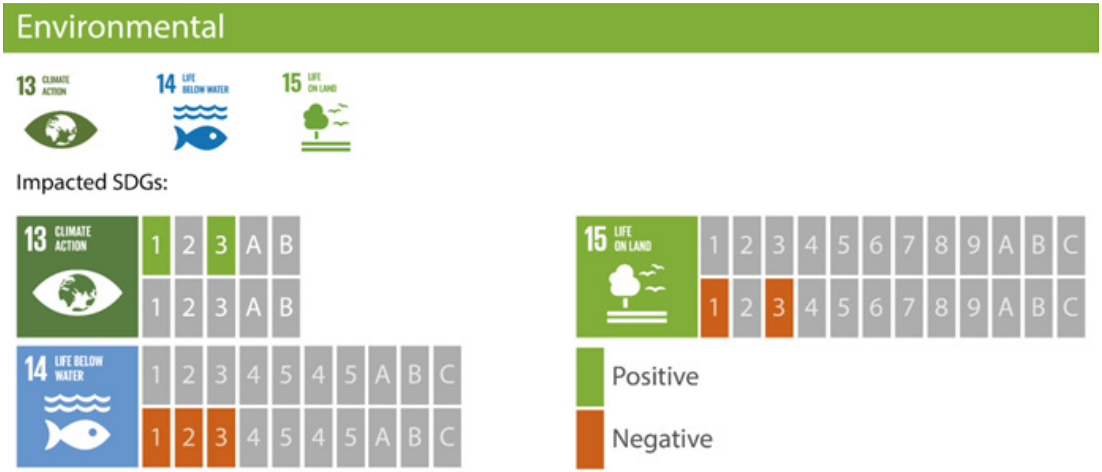

FIGURE 2 – SDGs linked to the environmental aspect (SDGs 13, 14 and 15) and impacted SDG targets.
SOURCE: Elaborated by authors using SDGs data (UN, 2015).

the concept of climate change resilience with CCS, such as Grafakos & Flamos (2017) and Wang *et al.* (2017), which can be defined as "a measure to evaluate the trade-off performance of available energy technologies embedeed in various energy systems" (Wang *et al.* 2017, p. 3220). Therefore, CCS can positively advance the achievement of target 13.1. Nevertheless, another contribution to climate action is disseminated through education programs as an essential solution to empower citizens. These programmes show the benefits of CCS and create a better public perception of this type of technology (Target 13.3) (Bloxsome *et al.*, 2017; Karimi & Toikka, 2018). One of the most notable educational programs on CCS is the Commonwealth Scientific and Industrial Research Organisation's Sustainable Futures – CarbonKids – an education program that aims to educate primary and secondary school children about climate change and its challenges.

While CCS contributes to climate action on the environmental aspect, other important trade--offs must be considered. SDGs 14 and 15 seek to better manage aquatic and terrestrial resources, respectively, and are negatively impacted by CCS deployment. The environmental issues related to CCS are well documented in the literature. There are concerns about the risks of adverse impacts on soil, vegetation, groundwater quality, aquifers, ocean acidification, reefs, benthic biodiversity, microbial ecosystems, marine biota, among others (Barros *et al.*, 2012; Halsband & Kurihara, 2013; Lessin *et al.*, 2016; Gao *et al.*, 2019; Blackford *et al.*, 2020). Regarding aquatic ecosystems, offshore CCS technology presents different challenges from those found in onshore CCS. Human life is not directly affected in these cases, but indirect impacts can be the result of CCS leaks, for instance, which can promote ocean acidification (Targets 14.3) (Molari *et al.*, 2019; Blackford *et al.*, 2020; Roberts & Stalker, 2020), marine pollution (Target 14.1) (Molari *et al.*,

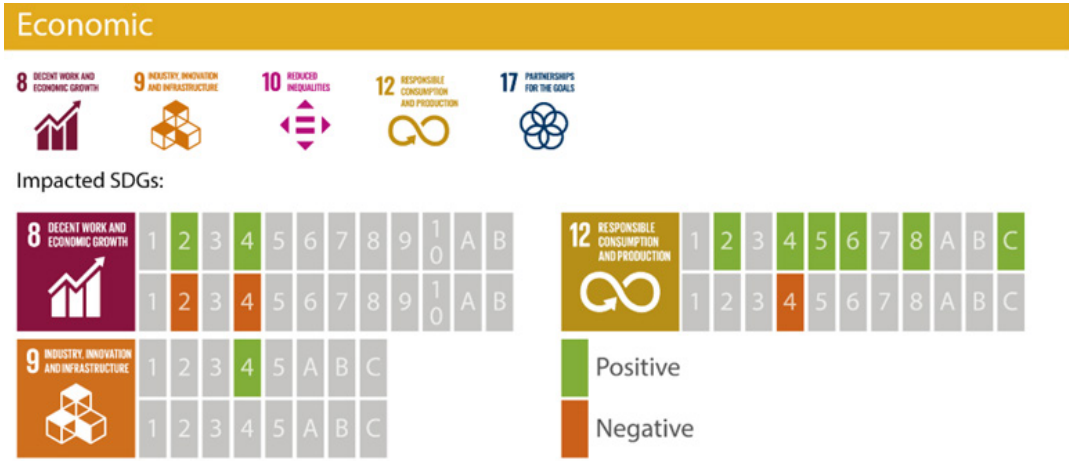

FIGURE 3 – SDGs linked to the economic aspect (SDGs 8, 9, 10, 12 and 17) and impacted SDG targets.
SOURCE: Elaborated by authors using SDGs data (UN, 2015).

2019; Blackford *et al.*, 2020; Roberts & Stalker, 2020), and damage to ocean fauna and flora (Target 14.2) (Molari *et al.*, 2019; Blackford *et al.*, 2020; Roberts & Stalker, 2020). It should be noted that, to ensure the environmental integrity of the site, a prior study of the reservoir's behaviour for the new pressure conditions and constant monitoring is required, which reduces the risk of accidents. These environmental risks to the ocean should be analysed through the perspective of the benefits of using CCS, since the reduction of GHG emissions also contributes to the preservation of marine life. On the land side, environmental degradation by CCS spreads across all sectoral chains, i.e., in both capture and storage processes (Targets 15.1 and 15.3) (Fogarty, 2010; Stauffer *et al.*, 2011). The study of a CCS project that does not consider the possible environmental impacts associated with the activity would be incomplete. Questions risks are distributed over the different phases of the project, making it possible to analyse them from each part of the chain. Life cycle assessment is a useful tool to investigate the environmental consequences associated with the development of CCS projects.

The different techniques that result in the separation of stored CO_2 have a greater or lesser degree of development, and the presence of a capture facility is necessary. CO_2 emissions are expected to occur, directly or indirectly, and it is also essential to consider the costs of this activity (IEA, 2007). The transport of CO_2 alone results in a different compression of CO_2 due to the energy use associated with pumping procedures, among others (IEA, 2007). Regarding storage, it is impossible to consider the risks associated with CO_2 storage without considering the risks of leakage (Commonwealth Parliament of Australia, 2007).

CCS deployment largely contributes to the financial aspect of sustainable development. Among the chosen objectives, only 3 have negative trade-offs. Essentially, CCS deployment means a technological upgrade for current energy systems seeking

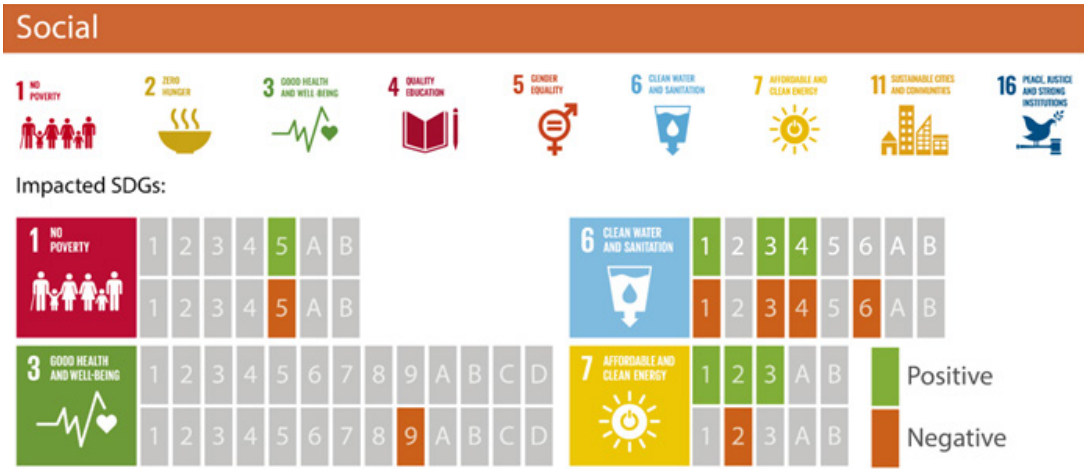

FIGURE 4 – SDGs linked to the social aspect (SDGs 1, 2, 3, 4, 5, 6, 7, 11 and 16) and impacted SDG targets.
SOURCE: Elaborated by authors using SDGs data (UN, 2015).

cleaner energy generation (Target 9.4) (Praetorius & Schumacher, 2009; Szulczewski *et al.*, 2012; Bui *et al.*, 2018; Roussanaly, 2019). The role of reducing CO_2 emissions (Target 8.2) (Gibbins & Chalmers, 2008; Selosse & Ricci, 2017), promoting better use of fossil fuel resources (Targets 8.4 and 12.2) (Stauffer *et al.*, 2011; Lund & Mathiesen, 2012; Wennersten *et al.*, 2015; Jin *et al.*, 2017), improving the management of hazardous chemicals and wastes in the sector such as agriculture and mining (Targets 12.4 and 12.5) (Bobicki *et al.*, 2012; Theo *et al.*, 2016; Mascarenhas *et al.*, 2020; De Almeida *et al.*, 2021) are reflected in higher level of sustainable economic production, as energy is an essential resource for economic growth. However, the effective achievement of these goals requires strong governance. Otherwise, the environmental impacts of CCS deployment will outweigh the financial benefits (Targets 8.4 and 12.4) (Stauffer *et al.*, 2011; Bobicki *et al.*, 2012; Wennersten *et al.*, 2015; Benoit *et al.*, 2018). All these practices must be reinforced by scientific communication, ensuring awareness about CCS use, impacts and benefits to the economy and the global climate crisis (Targets 12.8) (Ostfeld & Reiner, 2020; Vasilev *et al.*., 2020).

The social aspect encompasses 9 SDGs in general; however, only four relate to CCS deployment, and most of the targets chosen present negative impacts. Following the classification of (Vinuesa *et al.*, 2020), SDG 6 contributes to the social aspect of the 2030 Agenda, even though it strongly relates to environmental concerns. The addition of CCS to power plants increases plant and water life cycle use, depending on the level of CO_2 capture. CCS requires a lot of water as it is a resource intensive technology and can exacerbate water resource crises. The impact of this use depends on the overall management of environmental, economic and social aspects. An inappropriate approach will harm aquifers by inserting undesirable and hazardous chemicals (Targets 6.6) (Wang & Jaffe, 2004; Carroll *et al.*, 2009) and will reflect negatively on

water availability and quality and increase water vulnerability (Targets 6.1, 6.3, and 6.4) (Fogarty, 2010; Byers *et al.*, 2016; Kang *et al.*, 2017; Lu *et al.*, 2018; Yang *et al.*, 2020). However, best practices in wastewater use, mainly for industrial purposes, show efficient water use and an important decrease in water consumption (Targets 6.1, 6.3, and 6.4) (Fogarty, 2010; Byers *et al.*, 2016; Kang *et al.*, 2017; Lu *et al.*, 2018; Yang *et al.*, 2020).

As an emerging energy technology, CCS is intrinsically and positively linked to the SDG 7. Prospects show that energy-related CO_2 emissions will increase in the coming decades, compromising climate action and enhancing exposure to extreme weather events. In this context, the growth of fossil fuel use is a huge threat, but its total discontinuation can also be harmful, especially for society and the economy. The use or not of this source of energy generation, in addition to the concerns about climate change, encompasses how to ensure universal access to affordable, reliable and modern energy services (Targets 7.1). Therefore, the deployment of CCS is innovative to provide energy security through fossil fuel-based generation while reducing CO_2 emissions (Montañés *et al.*, 2016). It is noteworthy how crucial this technology is in areas without abundant renewable resources, especially in developing countries where energy demand growth is expected to be steeper than in developed countries (Heuberger *et al.*, 2017). However, CCS deployment cannot be an enabler of the indiscriminate use of fossil fuels, which does not allow for a substantial increase in the share of renewable energy in the global energy matrix (Target 7.2) (Lipponen *et al.*, 2017; Miranda-Barbosa *et al.*, 2017; Hanak & Manovic, 2020). This commitment depends on governance: if well implemented and managed, CCS has the potential to effectively contribute to an energy secure world that largely relies on renewable sources and even improves energy efficiency (Targets 7.3) (Liu & Gallagher, 2010; Saygin *et al.*, 2013).

Due to COVID-19, global poverty may be aggravated (Patel *et al.,* 2020; Bargain & Aminjonov, 2021; Whitehead *et al.,* 2021). In this scenario, CCS can be ambiguous regarding the vulnerability of the poorest population (Target 1.5). On the other hand, this technology can boost economic growth and job creation, helping in poverty reduction (Beck *et al.*, 2011). In addition, CCS has major negative impacts on the environment (as presented in the previous subsection) and human health, such as suffocation of humans, cardiorespiratory disease, and even death due to continuous air pollution (Fogarty, 2010). These negative impacts were also spread in target 3.9. As mentioned earlier, CCS projects, if not well managed, are threats to water reservoirs and soil pollution, contamination, and degradation (Fogarty, 2010; Ma *et al.*, 2020).

3.2. Governing CCS for sustainable development

Assessing the impact of CCS on selected objectives, especially the negative ones, highlights the importance of governance regarding sustainable development. Recently, governance has been largely discussed as essential for the implementation of sustainable development measures (De Guimarães *et al.*, 2020; Omri & Ben Mabrouk, 2020; Vazquez-Brust *et al.*, 2020; Li & Puppim de Oliveira, 2021). The discussion covers topics such as governance challenges (Bowen *et al.*, 2017; Stafford-Smith *et al.*, 2017; Allen *et al.*, 2018) and the role of the

institutions to guide the implementation of the SDGs at different levels (Biermann *et al.*, 2017; Fenton & Gustafsson, 2017; Gustafsson & Ivner, 2018; Chimhowu *et al.*, 2019). Besides the intense academic production, international organisations and networks have been publishing guidelines for sustainable development actions. Some examples encompass the Organization for Economic Cooperation and Development (OECD) (OECD, 2016), the Sustainable Development Solutions Network (SDSN) (SDSN, 2015) and the United Nations Development Group (UNDG) (UNDG, 2017). However, this attempt to improve governance towards sustainable development does not imply a consensus on the concept of governance (Joshi *et al.*, 2015). The United Nations, for instance, understands governance as a multi-level system consistent with human rights, international norms and standards (UN, 2012). Hyden *et al.* (2004) complement the concept by including the formal and informal rules created and regulating the public domain. This multi-level approach contributes to horizontal networks spanning public, private and non-profit organisations (Bingham *et al.*, 2005; Weiss, 2000). Even the 2030 Agenda underscores the multi-level approach in targets 17.16 and 17.17.

Understanding governance as a multi-level process is useful for applying the concept to guide CCS implementation in line with the current sustainable development agenda. There are two notable points about governance that should be considered to seek better implementation of CCS. The first point addresses the need to internalise the measures, indicators, and regulations for the SDGs at national and even more micro scales where necessary (Gupta & Nilsson, 2017). This context-driven application is fundamental for any technology and for those that may cause more environmental damage, such as CCS. The second point is more critical and highlights one presented by the 2030 Agenda: that no country in the world has to pursue a more sustainable path, even those identified as developed (Gupta & Nilsson, 2017). This essential characteristic indicates that sustainability must be understood as a global challenge. In the context of CCS, this implies strengthening better practices in developed countries, which currently concentrate on this technology, and promoting the implementation in developing countries. Finally, effective governance should assess the interlinkages, trade-offs, and synergies between the objectives (Allen *et al.*, 2018).

The answer to the third section correlates mainly with the third point and provides insights to discuss CCS governance. Therefore, looking for this important aspect of the SDGs governing CCS, we found 13 targets that can help and guide its deployment goals, focusing on SDGs 7, 8, 9, 12, 13, and mainly on SDG 17 and focus on partnership (Targets 7.a, 8.4, 12.6, 17.6, 17.9, 17.7, and 17.16), financial resources mobilisation (Target 13.a), technology transfer (Target 17.6), infrastructure creation (Target 7.b), scientific advancement (Targets 9.5, 9.b, 12.a, and 17.6), and governance (Targets 17.14 and 17.16), putting extra effort into boosting this technology in developing countries. Figure 5 summarises these findings.

The global status of CCS points to the existence of a small number of facilities and uneven development and application of this technology (Global CCS Institute, 2019). The first aspect enhances how lessons learned must be shared internationally to accelerate the deployment of safe, large-scale and

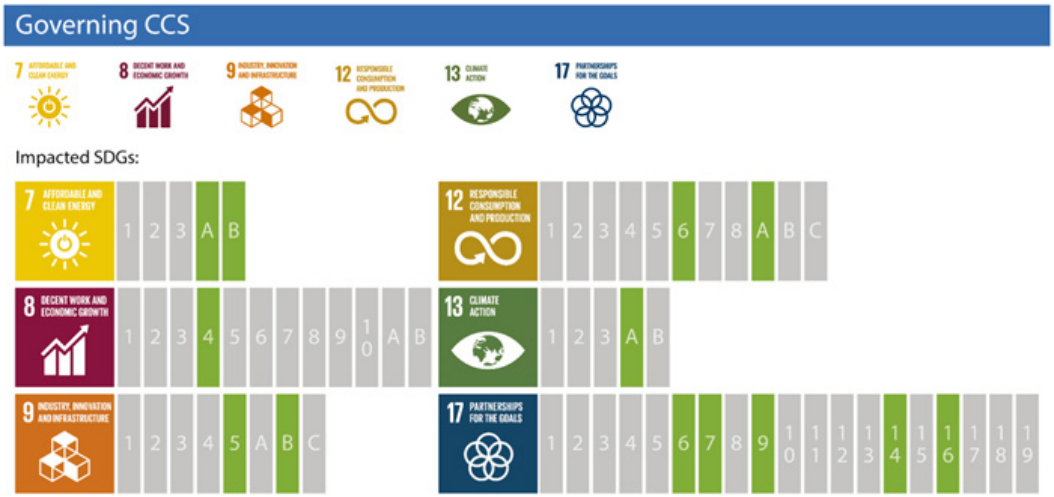

FIGURE 5 – A detailed assessment of the SDGs that impact CCS deployment.
SOURCE: Elaborated by authors using SDGs data (UN, 2015).

commercially viable CCS projects (Target 7.a) (Gastine *et al.*, 2017; Czernichowski-Lauriol *et al.*, 2018). The second aspect is the way in which these facilities spread around the world and are concentrate in developed countries, which are the biggest emitters of CO_2, dominate the technology and scientific knowledge of CCS, and have already created specific regulations for CCS.

For instance, in countries and areas such as the United States, European Union, Australia, Canada, and Norway, the regulatory system is already established and has been an example to construct structures in other countries (Câmara *et al.*, 2011; Ishii & Langhelle, 2011; Torvanger, 2013). This point is embraced by targets 13.2 and 12.c and points to the importance of internalisation of CCS measures in the national and regional context (Van Egmond & Hekkert, 2015; Fan *et al.*, 2018; Fu *et al.*, 2020; Silva *et al.*, 2020). It is, therefore, reasonable to put pressure on these countries to lead the way towards large-scale global use of CCS (Target 8.4) (Wennersten et al., 2015). Developed countries must act by supporting the CCS infrastructure in developing countries (Target 7.b) (Liu & Liang, 2011; Shirmohammadi *et al.*, 2020) that consider regional specificities (Target 9.b) (Rai *et al.*, 2010; Kern *et al.*, 2016) and national energy, climate planning and regulation (Target 17.9) (Wennersten *et al.*, 2015; Czernichowski-Lauriol *et al.*, 2018). The sharing of technology and knowledge are other necessities for CCS deployment in developing countries (Target 17.7) (Wennersten *et al.*, 2015; Czernichowski-Lauriol *et al.*, 2018) but need to be applied together with improving local science, technology and innovation (Targets 9.5, 9.b, 12.a and 17.6). To promote these actions, developed countries must mobilize financial resources (Target 13.a) (Klimenko *et al.*, 2019). Furthermore, all countries interested in CCS should pursue strong and sustainable policies to promote the use of CCS

(Target 17.14), seek a multi-stakeholder partnership (Target 17.16), including the private sector (Target 12.6), and discourage inefficient use of fossil fuels (Target 12.6).

4. Conclusion

Our analysis maps the relationships between CCS and the development goals of the 2030 Agenda. We showed that 22% of the SDGs are linked to CCS (positively or negatively) or are an enabling factor for better CCS governance. Most critical trade-offs between this technology and the Agenda focus on environmental and social goals. Overall, the issues in any aspects analysed call attention to the urgent need to improve governance. In other words, while we understand the broader impacts of CCS that could undermine the sustainable development agenda, we argue that this is only the first step. For this reason, we stress the role of the 2030 Agenda in guiding the deployment of CCS. Related to this topic, we found that 8% of the 2030 Agenda can help policymakers and researchers identify and create better pathways to minimise negative interactions and enhance positive ones. We illuminate points for the two main actors - researchers and policymakers - to improve CCS knowledge, governance, and deployment.

The **research community** should enhance transdisciplinary studies on CCS. It is essential to improve the debate in all fields, discuss technical characteristics and environmental and social impacts, and minimise these important trade-offs. Furthermore, there is an urgent need to establish more international collaboration on CCS, transferring know-how from developed countries to developing ones and boosting local research to address context-oriented national and regional issues. Examples of broad global initiatives to promote CCS research include the UK CCS Research Centre (UKCCSRC, 2021), the Norwegian CCS Research Centre (NCCS, 2021) and the Brazil Gas Research Centre (RCGI, 2021). Another challenge facing researchers is the creation of a robust database on CCS projects, initiatives and knowledge. To improve CCS deployment, it is fundamental to democratise access to these data, and make it understandable to decision-makers and all stakeholders. Researchers should also work to communicate key concepts and findings and educate the general public about CCS.

Public and private sector **decision-makers** must act together to advance CCS deployment worldwide. First and foremost, there is an urgent need to break down the barriers between sectors and the siloed perspective on CCS to guarantee sustainable deployment. This holistic perspective has been largely discussed across all areas that seek to approach the 2030 Agenda (Fuso Nerini *et al.*, 2018, 2019; Vinuesa *et al.*, 2020). In the public sector, this implies better coordination between institutions and diminishing conflicting interests. In addition, national governments should internalise measures and regulations capable of guiding the use of CCS, increasing financial investment in research and development (R&D), and seeking domestic and foreign partnerships. The private sector plays an important role in funding projects and making this technology application possible. For instance, in many countries, Shell invests in many projects and R&D. Finally, another way to help the decision-making process is to establish global institutions to bring together the main actors. This is currently the role of the Global CCS Institute, the largest inter-

national think tank on CCS. This institute is based in Melbourne, Australia, and aims to be a source of research, data and information on all aspects of CCS to accelerate its deployment globally (Global CCS Institute, 2021).

Finally, CCS can have both positive and negative impacts on the planet. However, it is possible to seek a sustainable deployment of this technology by mapping synergies, trade-offs and the 2030 Agenda as a guide for governance. In the context of CCS, we have shown that efficient governance should encompass several aspects, such as a holistic approach and a strong global partnership among all stakeholders. The research community plays a key role in this governance by providing the necessary scientific knowledge to the act of stakeholders and a transdisciplinary approach. Therefore, our main contribution has been to present a broader perspective of the links between CCS and SDG and discuss its implications for governance. Finally, this research does not claim to be a final result. Rather, we argue that there is a need to constantly review impacts in light of ongoing academic and technological advances to promote a sustainable deployment of CCS across the world.

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