CCU technologies as a tool to achieve Scope and ESG goals

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Abstract. The work examines current methods for the development and study of environmental, social, and governance aspects (ESG factors) in connection with international and governmental measures for sustainable development. It covers the UN Sustainable Development Goals and the Paris Agreement, which incentivize the consideration of ESG factors, as well as the impact of ESG on the industry and investors, particularly in the oil and gas sector. The authors delve into CO₂ utilization technologies (CCS, CCUS, CCU) and the challenges of their implementation in various sectors. The role of oil and gas companies in sustainable development through the implementation of CCU technologies is analyzed; methods for capturing, transporting, and utilizing CO₂ are discussed, along with technologies for producing chemicals from CO₂ and their efficiency. The influence of CCU technologies on Scope 1, 2, 3 emissions, defining greenhouse gas emissions, is also examined. The challenges of transitioning to sustainable development and the importance of implementing CCU projects to enhance the ESG-rating of companies are highlighted. Sound implementation of CCU projects can determine successful industrial development, especially in the oil and gas sector, by reducing carbon dioxide emissions and creating competitive products.

1 Introduction

Expansion and deepening of analysis related to environmental, social, and governance (ESG) criteria are being observed worldwide. This process is intensified by active international efforts and governmental support for sustainable development. The adoption of the United Nations Sustainable Development Goals, the Paris Agreement, and the strengthening of national policies on climate, social, and environmental standards serve as important stimuli for increased attention to ESG factors [1-2]. As a result of these processes, industry representatives and investors are increasingly striving to enhance information disclosure levels and improve metrics relevant to ESG across a wide range.

The set of principles known as ESG relates to sustainable practices in commercial activities. It guides companies in matters of environmental responsibility, social impact, and corporate governance [2].

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Environmental principles highlight the importance of minimizing the company's ecological footprint and reducing any harm caused to the environment. By adopting sustainable practices and embracing renewable resources, companies demonstrate their commitment to preserving the planet for future generations.

Social principles, on the other hand, revolve around the company's interactions and relationships with various stakeholders. This includes employees, suppliers, customers, partners, and consumers. To adhere to the standards of ESG, businesses must prioritize the well-being of their employees, ensure gender equality, and actively invest in social initiatives that benefit the communities they operate in.

Lastly, management principles are essential for ensuring effective and ethical corporate governance. This involves maintaining transparency in reporting, establishing fair management salaries, fostering a healthy workplace environment, nurturing positive relationships with shareholders, and implementing robust anti-corruption measures. Overall, ESG serves as a comprehensive framework that promotes responsible and sustainable business practices. By embracing these principles, companies can make a positive impact on society, the environment, and their own long-term success.

ESG principles not only act as a set of guidelines for a company's operations but also serve as criteria for investors when considering potential investments [3]. In the coming years, global funds will no longer invest in companies that fail to adhere to sustainable development principles [4]. These principles, particularly the ESG environmental principles, highlight the importance of companies transforming their management strategies to achieve carbon neutrality. Consequently, energy sector companies are actively engaging in projects that aim to reduce greenhouse gas emissions, acquire renewable energy sources, and implement energy- and resource-efficient technologies in their core product production processes.

The oil and gas sector stands out as one of the most environmentally harmful industries operating within the industrial sector. Consequently, oil companies have expressed significant concern regarding ESG initiatives. It is widely recognized that the fuel and energy industry must prioritize the mitigation of carbon dioxide emissions and the active adoption of sustainable climate strategies. However, compliance with ESG environmental standards for companies in the oil and gas sector often becomes a difficult task, as it requires the implementation of new environmental projects, transformation of existing technologies into more environmentally friendly ones [1, 5-6].

Carbon dioxide utilization technologies can make a key contribution to the energy sector enterprises in achieving the above-mentioned goals.

There are the following ways to reduce carbon dioxide emissions [7]:

- CCS (carbon capture and storage) technologies - capture, transportation and burial of carbon dioxide in geologic sequestration.
- CCUS (carbon capture, utilization and storage) technologies differ from CCS in that at the final stage CO2 is injected into oil fields to enhance oil recovery.
- CCU (carbon capture and utilization) technologies, in which carbon dioxide is a raw material for its subsequent transformation into various carbon-containing compounds.

The method of carbon dioxide utilization implemented by the company must be economical, environmentally friendly and sustainable in the long term. Today, CO2 utilization technologies are not limited to underground storage and have expanded to the use of carbon dioxide in oil production and the production of useful chemicals from CO2.

Despite the various advantages of chemical utilization of carbon with the production of new substances compared to underground storage, CCU technologies are rather difficult to implement primarily due to high energy costs. It is known that technologies of chemical utilization of carbon dioxide require large investments in comparison with more traditional CCS and CCUS technologies. The main advantage of CCU technologies is that carbon
dioxide utilization is usually a cost-effective project, as the result of such technologies is a new product that can become a raw material for new industries or a ready for sale material. Obviously, the main disadvantage of CCU technologies is the smaller volumes of carbon dioxide that can be utilized. Consequently, for companies with significant emissions (oil, metallurgical, energy industries) CCU technologies can be considered only as an additional method of CO₂ utilization, the main part of emissions will have to be injected into the reservoir either for long-term disposal or for enhanced oil recovery [8-10].

To successfully apply CCU technologies, companies must address three challenges:

- The CO₂ capture process – the most capital and energy intensive step.
- Transportation to the CO₂ conversion plant.
- Realization of the chemical CO₂ conversion process.

Given problem rescripts to be solved, this comprehensive article delves into the analysis of prevailing concerns and future possibilities regarding the advancement of chemical carbon dioxide utilization technologies. It astutely examines the profound impact that CCU technologies have on key indicators of Scope 1, 2, and 3.

2 Carbon dioxide capture

In 2023, the number of large-scale geological storage facilities reached fifty-five. Today, the total capacity of carbon capture and storage projects, either under construction or already operational, is about 40 million tons per year. The CO₂ capture process involves extracting carbon dioxide from industrial emissions, compressing it, transporting it, and injecting it into geological formations for underground storage.

The main goal of carbon capture is to create a concentrated stream of CO₂ under high pressure that can be easily transported to the storage site. This technological process is the most costly part of the CO₂ storage chain, accounting for up to 60-70% of the overall project cost. Since capture technologies vary significantly depending on the industry where they are applied, more common sectors, like the power sector (coal and gas-fired power plants), are often chosen for analyzing the techno-economic aspects of projects. The three main technological methods for carbon dioxide capture in major industries are pre-combustion, post-combustion, and oxyfuel combustion [11-13].

To separate CO₂ from flue gases after combustion ("post-combustion"), capture systems are employed, utilizing mechanical separators and liquid solvents based on amines, primarily monoethanolamine. Amine scrubbers form a stable chemical bond with CO₂ during the reaction with flue gas. Subsequently, these bonds are broken upon heating, allowing the release of a concentrated stream of CO₂ for further transportation to a reservoir. Amines undergo a regeneration process and are reintroduced into the production cycle for reuse. In the production of food-grade carbon dioxide, the technology of chemical absorption is widely used, typically applied when concentrating CO₂ in flue gas up to 15%. Despite being well-researched and prevalent, the primary drawbacks of this technology include significant energy losses and considerable resource costs during the capture phase. This method is frequently employed in natural gas combined cycle power plants and in power plants operating on coal dust [13].

During the pre-combustion capture process, the initial fuel is converted into "synthesis gas," primarily composed of carbon monoxide (CO), hydrogen (H₂), and water vapor (H₂O). After purification to remove unwanted contaminants, a gas mixture of carbon dioxide (CO₂) and hydrogen (H₂) is formed, which is further subjected to separation. In such energy systems, the combustion end product is water vapor, unlike post-combustion capture where gas stream separation relies on chemical reactions. In the pre-combustion capture procedure, physical absorption is utilized, leveraging the ease of separation due to hydrogen's low density compared to other gases. Hydrogen, obtained during the process
and known as "blue hydrogen," is used as an energy carrier for production cycles and generating environmentally friendly energy. Physical absorption, requiring energy inversely proportional to the CO₂ content, is efficient at high concentrations (over 15%).

Carbon capture and storage technologies involve a process where the primary fuel is burned in pure oxygen instead of air, resulting in flue gas predominantly containing carbon dioxide (about 80% by volume) and water vapor. The next step involves cooling and compressing the gas to remove water vapor. However, before burning the fuel, it is necessary to separate oxygen from the air, and after combustion, additional cleaning of the flue gas from impurities and gases such as nitrogen is required to prevent potential contamination before the carbon dioxide is sent for storage [14].

In addition to the technologies described earlier, which have been adopted from other industrial sectors and have shown promising results in pilot projects, there are also other innovative approaches to carbon capture. These methods include the use of membranes, the application of flexible metal-organic frameworks, as well as technologies such as chemical looping combustion (CLC) and direct air capture (DAC), which are currently in the laboratory testing stage.

3 CO₂ Transport

Unless the plants are situated next to chemical plants, the captured CO₂ needs to be transported from the point of capture to the plant location for additional chemical conversion. Global CO₂ pipeline network spans approximately 6,500 kilometers and, as of 2013, includes pipes with a diameter that can reach 921 millimeters. This extensive pipeline complex annually transports about 180 million tons of carbon dioxide [15].

The technology for transporting carbon dioxide is largely similar to natural gas transportation systems, except that due to the presence of CO₂, pipes are subject to enhanced corrosion. Nonetheless, pipeline transportation remains the predominant method used for these purposes. Various measures are taken to reduce the negative impact of carbon dioxide. Firstly, the gas is dehydrated before transportation. Protection against corrosion caused by carbon dioxide is ensured by using specialized steel during the construction of transport pipelines that are resistant to such exposure. Additionally, pipeline sections located before dehydration units receive additional corrosion protection by coating them with an alloy that prevents corrosion. These measures help safeguard the pipeline from corrosion-related issues.

To improve the transportation process of carbon dioxide, it is compressed to high pressures exceeding 8 MPa. This helps transform the gas into a more economical and easily transportable form. Additionally, this pressure prevents the two-phase flow of the gas and increases its density, thus facilitating transportation in gaseous form.

However, there is another way to transport CO₂ in a liquid state, which can be achieved through the use of road, rail, or maritime transport [16-17]. In certain circumstances, such as long-term or maritime transport needs, transporting liquid carbon dioxide via ships may be more preferable and economically feasible.

Currently, tankers mainly used for transporting liquefied propane and butane have the capability to also deliver carbon dioxide. Typically, marine CO₂ transport is carried out at a pressure of 0.7 MPa, although demand for such transport remains low. Road and railway tankers operating at a pressure of 2 MPa and a temperature of around -20°C are also used for CO₂ transportation. Nevertheless, these methods are more expensive for long-term CO₂ transport compared to pipelines or maritime vessels, making them less economically viable.

Considering that carbon dioxide is heavier than air and tends to accumulate in lower areas, posing a significant health and safety risk, awareness of this risk is crucial. High concentrations of this gas can be extremely dangerous. Furthermore, the danger increases
when there is potential interaction with impurities such as hydrogen sulfide (H₂S) or sulfur dioxide (SO₂), intensifying the risks. Leaks, pipe wear, valve system malfunctions, and connections further amplify these risks, making these aspects crucial to consider during the transportation and storage of carbon dioxide.

### 4 Production of chemicals from carbon dioxide

To date, there is a wide variety of useful uses of carbon dioxide (Figure 1). CCU technologies find application in cement production, carbon dioxide mineralization, polycarbonate and plastic production (Figure 2) [18]. Through CO₂ capture and utilization, various chemicals such as methanol, urea, formic acid, salicylic acid, organic carbonates such as acyclic carbonate, cyclic carbonates, fine chemicals such as biotin, etc. can be produced. Urea is considered as a major agricultural fertilizer with the largest market volume among other chemicals [19-23]. Urea is also used in other applications including some pharmaceuticals, fine and inorganic chemicals, and polymer synthesis [23].

Fig. 1. Directions of useful utilization of CO₂ [19].

Carbon dioxide can also be a fuel source to produce fuels such as methane, methanol and syngas [23]. Methane dry reforming and hydrogenation are considered as the main pathways for converting CO₂ into fuels. Dry reforming of methane is an endothermic reaction that involves using CO₂ instead of steam to react with methane and produce synthesis gas.

CO₂ hydrogenation competes with the traditional process of producing methanol from fossil fuels. However, the fossil fuel-derived hydrogen used in the methanol hydrogenation process poses additional environmental constraints because the hydrogen production process releases additional CO₂ into the atmosphere. Consequently, new methods and processes are needed for environmentally friendly hydrogen production from renewable energy sources [24].
Mineralization is another important area of Carbon Capture and Utilization (CCU) technology. It involves the reaction of carbon dioxide with natural minerals or solid wastes containing metal ions to form carbonates. In this process, CO₂ can react with minerals such as serpentine, olivine, wollastonite, or metal ions present in wastewater or solid waste materials like fly ash. The result of these reactions is the formation of stable carbonates. Mineralization also occurs naturally through a process known as natural weathering. Metal oxides, such as magnesium and calcium, react with atmospheric CO₂ over long periods, forming carbonates. However, the reaction process is slow [21]. Mineralization reactions are also an important process in carbon dioxide disposal. Precipitation of secondary carbonates at contact of carbon dioxide with formation water and rock minerals allows long-term burial of carbon dioxide in the form of stable carbonates [22].

The advantages of mineral carbonization are less stringent requirements for the purity of carbon dioxide than for the production of other chemicals. Impurities such as NOₓ and SOₓ present in CO₂ obtained from industrial sources do not affect the carbonization reaction. Consequently, obtaining high purity CO₂, in this case is not required, resulting in lower energy consumption [23].

One of the applications of mineral carbonates is the construction industry, where carbonate blocks are used instead of Portland cement-based concrete blocks. In addition to natural mineral rocks, wastes from the steel or cement industries (i.e., rich in calcium and magnesium oxides) can also be used as a source of cations for carbonate formation in the presence of CO₂ [25].

Biological carbon dioxide utilization is another CCU pathway with great CO₂ storage potential. This pathway involves the uptake of CO₂ by algae and other plant crops through the process of photosynthesis. Microalgae is a type of microscopic algae that grows in aquatic environments and is used in a variety of applications, from biofuel production to animal feed. This type of algae can grow in freshwater and seawater, and some can also be grown in wastewater. Through the process of photosynthesis, microalgae use light to convert CO₂ into organic carbon needed to produce cellular compounds. Microalgae are an advantageous way to reduce CO₂ emissions due to their rapid growth rate in the presence of high CO₂ concentrations, which allows them to fix CO₂ about 50 times more than land-grown crops [25].
Thus, it can be concluded that the technologies for obtaining various chemicals on the basis of CCU technology are quite diverse and have significant advantages over traditional technologies of underground storage of CO₂ and its injection to enhance oil recovery.

5 Impact of CCU technologies on Scope 1, 2, 3 indicators

One of the main parameters for assessing the impact of technologies on emission reductions is the assessment of changes in Scope indicators.

Scope 1, 2, and 3 refer to different sources and types of greenhouse gas emissions (Figure 3) [26].

Scope 1: This scope covers all direct greenhouse gas emissions that originate from sources owned and controlled by the company. It includes emissions from industrial processes, fuel combustion, and other company operations. Examples of gases emitted within this scope include carbon dioxide, methane (CH₄), and other relevant gases.

Scope 2: This scope encompasses indirect greenhouse gas emissions associated with the energy consumed by the company. It includes emissions from the generation of electricity supplied to the company. This scope accounts for CO₂ and other gases released during electricity generation.

Scope 3: This scope includes all other indirect greenhouse gas emissions that arise as a result of the company's operations but are not directly related to its internal activities. These emissions may stem from the supply chain, use of products or services, transportation, waste, and other contributing factors. It is important to consider these emissions to gain a comprehensive understanding of the company's overall greenhouse gas footprint.

In a typical Carbon Capture and Utilization (CCU) technology, the following steps are involved:

- **Carbon dioxide capture**: The first step involves capturing carbon dioxide from an industrial emissions source. This can be done using various methods such as absorption, adsorption, or membrane separation.

- **Transportation**: Once captured, the carbon dioxide needs to be transported to the location where the chemical production units are located. This can be done either through pipelines or ground transportation methods.

- **Chemical production**: At the chemical production units, the captured carbon dioxide is used as a feedstock for chemical reactions. Through these reactions, chemicals and materials are produced. This step involves the utilization of the captured carbon dioxide to create valuable products.

Carbon dioxide capture from the source of emissions of companies will have a significant positive impact on the change of indicators for Scope 1. At the same time, transportation steps and direct implementation of the chemical reaction itself may lead to an increase in Scope 2 and 3 emissions.

In this regard, the use of renewable energy sources and the implementation of pipeline transportation can positively affect the change in Scope 2 and 3.
6 Conclusion

ESG-friendly sustainability will remain highly relevant for oil and gas companies due to the growing pressure to drastically reduce pollution and protect the environment. Industrial companies have great prospects for becoming leaders in this area. Today, many large oil and gas companies realize the importance of compliance with sustainability goals and are actively developing ESG-friendly strategies.

CO₂ utilization technologies are key projects that can significantly affect the ESG rating of industrial companies. In turn, it is the ESG rating of the company that will become one of the main criteria for investing in projects offered by companies in the near future. Consequently, the key factor for the successful development of industrial companies is the implementation of projects and technologies for reducing carbon dioxide emissions.

Among the known technologies of carbon dioxide utilization, the most commonly applied methods involve underground storage in aquifers or injection into oil reservoirs for enhanced oil recovery (EOR). However, underground storage of CO₂ is not considered economically viable due to various factors. Additionally, when CO₂ is used for EOR, a significant portion of the injected gas is produced back with the extracted oil. In light of these challenges, technologies focused on utilizing carbon dioxide for the production of various chemical compounds offer a promising solution. CCU projects that involve the production of competitive chemical products and materials can be economically viable and even profitable. While CCU projects may require more investment initially, they allow for the utilization of significantly less carbon dioxide compared to underground storage methods. By turning carbon dioxide into valuable chemical products and materials, CCU projects not only contribute to reducing greenhouse gas emissions but also offer the potential for financial returns. This makes them an attractive alternative to traditional carbon storage methods.
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