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Review Article

The role of CCUS technologies in electricity generation: A comparative analysis of Türkiye and the World

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ABSTRACT

The share of renewable energy sources in electricity generation is increasing day by day. However, being an intermittent resource, it is not enough to completely end the use of fossil fuels. In the current situation, the use of fossil fuels continues, but the amount of carbon they release into the air during combustion is at a point that cannot be ignored, and carbon capture, storage and transportation technologies gain importance at this stage. In this study, examples of Carbon Capture, Utilization, and Storage (CCUS) technologies used in the electricity generation sector in the world and in Türkiye are examined. The CCUS techniques used in the plants and the working principle of these techniques are mentioned. The efficiency of the plants before and after CCUS is analyzed according to the fuels used. The situation in Türkiye and the world is analyzed technically, economically and politically and the potentials are evaluated. According to the data obtained, it is seen that the use of amine-based carbon capture technology (monoethanolamine (MEA)) is more appropriate in the electricity generation sector. Carbon capture from flue gas after combustion has been found to slightly reduce the total system efficiency. As a result, in addition to the few examples in the world, the applications in Türkiye are at the pilot stage and it is seen that there is already a high potential for carbon capture when the installed natural gas and coal plants are considered.

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INTRODUCTION

Electricity generation, as a key pillar of modern economies, is one of the main contributors to global carbon dioxide (CO_2) emissions, primarily due to its heavy reliance on fossil fuels. Approximately 40 % of global CO_2 emissions stem from fossil fuel combustion in power plants [1]. While renewable energy investments have grown, fossil fuels still maintain a significant share in both global and national energy portfolios, including Türkiye. For instance, in 2024, coal and natural gas accounted for over 50% of Türkiye's electricity generation.

The deployment of smart electricity grid technologies has the potential to reduce these emissions. Carbon Capture, Utilization, and Storage (CCUS) technologies play a

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critical role to reduce these emissions. CCUS applications in the electricity sector include the processes of capturing, transporting and safely storing emissions at source. The electricity generation sector plays a critical role in terms of energy supply security, economic growth and technological transformation both on a global scale and in Türkiye.

At global and national level, the electricity generation sector has a strategic importance in terms of energy security and economic development. Increasing investments in renewable energy sources contribute to diversifying the energy portfolio and reducing external dependence. However, the still significant share of fossil fuels requires careful and balanced management of the energy transition process. This information provides a basic framework for understanding the current state and future potential of the electricity generation sector. Keeping abreast of developments in the sector is important for the effectiveness and sustainability of energy policies. In 2024, data released by the Turkish Ministry of Energy and Natural Resources indicated that electricity generation in Türkiye was composed of 35.2% coal, 18.9% natural gas, 21.5% hydraulic energy, 10.5% wind, 7.5% solar, 3.2% geothermal, and 3.2% other sources.

While the transition to renewables is accelerating, fossil fuels still dominate electricity generation in many countries, making emission mitigation technologies like CCUS essential for reaching climate The Paris Agreement aims to limit the increase in global average temperature to well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C [2]. Achieving this goal requires global carbon emissions to reach net zero by 2050. However, given the current energy infrastructure and the continued reliance on high-carbon industrial processes, renewable energy and energy efficiency technologies alone appear insufficient to meet this target. In this context, carbon capture, utilisation and storage (CCUS) technologies play a crucial role, particularly in emission-intensive sectors such as electricity generation.

To achieve net-zero targets, substantial reductions in emissions from the energy sector and energy-intensive industries such as cement, iron and steel, and chemicals are essential. CCUS stands out as one of the few available solutions capable of directly capturing and reducing emissions from these sectors [3]. According to the International Energy Agency's (IEA) Net Zero by 2050 Roadmap, CCUS technologies are expected to account for approximately 15% of the total global CO_2 emission reductions required by mid-century, equivalent to about 7.6 billion tonnes annually. Furthermore, CCUS is seen as a key enabler in low-carbon hydrogen production, particularly in the form of "blue hydrogen" derived from natural gas [4].

The growing adoption of advanced carbon pricing mechanisms, such as the EU Emissions Trading System, is enhancing the economic viability of CCUS projects. However, in countries like Türkiye, where such mechanisms are not yet fully implemented, government incentives are critical to accelerate the deployment of these technologies.

Highlights

- The article analyzes the integration of Carbon Capture, Utilization, and Storage (CCUS) technologies within the iron and steel industry, addressing its role as a critical sector for global CO2 emission reduction.
- It provides a comprehensive assessment of various capture methods—pre-combustion, post-combustion, and oxy-fuel—comparing their technical efficiencies and economic feasibility for large-scale steel production.
- The study outlines necessary regulatory frameworks, infrastructure requirements, and strategic recommendations to overcome implementation barriers and achieve net-zero targets in the industry.

This study aims to examine the current status, challenges, and future potential of CCUS technologies in the electricity generation sector through a comparative analysis of Türkiye and global practices**.** The goal is to contribute to policy and investment strategies that align with both national energy security and international climate commitments.

LITERATURE REVIEW

Decarbonization of high-emitting sectors, such as the electricity generation sector, is vital in the fight against climate change. Around 40% of carbon dioxide (CO_2) emissions worldwide come from electricity generation, and this proportion is even higher in countries where fossil fuel-based systems such as coal and natural gas are predominant. In this context, carbon capture and storage (CCS) technologies offer a transition strategy that makes it possible to achieve climate goals without threatening security of energy supply by both continuing to use existing infrastructure and reducing carbon emissions. The main carbon capture technologies used in electricity generation include absorption, adsorption, membrane separation and cryogenic separation. These technologies can be applied at different stages such as pre-combustion, post-combustion and oxy-fuel, and are particularly preferred due to their high efficiency and ability to be integrated into existing infrastructure. Internationally, CCS investments have gained great momentum.

According to the Global CCS Institute (2024), there are 50 active plants and 44 new plants under construction worldwide, bringing the total number of plants to 628, an increase of 60% in one year. This growth is the result of government-backed policies, carbon pricing mechanisms and financial incentives. CCS technologies are generally classified into three main categories: post-combustion, pre-combustion and oxy-fuel combustion [5]. In addition, advanced and experimental technologies such as direct air capture (DAC), bioenergy carbon capture and storage (BECCS), and chemical loop capture (CLC) are gaining importance, especially for negative emissions targets [6-7]. CCS technologies in the electricity sector are categorized under four main headings to reduce CO_2 emissions: absorption, adsorption, membrane separation and cryogenic processes. Post-combustion capture technologies in particular stand out in terms of retrofit applicability to existing coal and natural gas power plants. Pre-combustion capture is mostly preferred in integrated gasification systems. Carbon mitigation strategies include the use of renewable energy, energy efficiency, carbon-free transportation and afforestation activities. In addition, innovative models for carbon management (e.g. Carbon Transport & Storage-as-a-Service - T&SaaS) facilitate access to CCS for small producers. Next-generation technologies such as BECCS (carbon capture and storage with bioenergy) and direct air capture (DAC) are increasing the solution capacity in the sector, especially for negative emission targets. The allocation of large-scale budgets for these technologies under the European Union's Horizon Europe program is also a critical incentive for investments.

Table 1 provides a comparative summary of literature studies on Carbon Capture and Storage (CCS) systems applied across various sectors, highlighting key aspects such as capture method, facility type, storage option, and annual CO_2 capture capacity, along with technical and economic evaluation approaches.

CARBON CAPTURE TECHNOLOGIES IN THE ELECTRICITY GENERATION SECTOR

Fossil fuel-based electricity generation remains one of the leading contributors to global carbon emissions. Accordingly, carbon capture technologies that aim to mitigate CO_2 emissions from power generation facilities have become a critical focus within the energy sector. As shown in Figure 1, carbon capture methods are broadly categorized into three main approaches: pre-combustion, post-combustion, and oxy-fuel combustion systems [8]. In addition to these conventional methods, advanced carbon management strategies such as Direct Air Capture (DAC), Bioenergy with Carbon Capture and Storage (BECCS), carbonate mineralization, carbon utilization, and geological storage have also been evaluated in recent studies as complementary or alternative solutions [5-7].

Conventional CO_2 Capture Methods

Pre-combustion capture

Pre-combustion carbon capture, particularly applied in Integrated Gasification Combined Cycle (IGCC) power plants, is based on the gasification of fossil fuels [8].The main advantage of this method lies in converting the fuel into synthesis gas (syngas) prior to combustion, which allows for more efficient separation of carbon dioxide from the system. In the process illustrated in Figure 2, in the initial stage, pure

Table 1. Studies reviewed

Pub. date	Authors	Facilty type	Review method		Capture method			Storage type	Captured CO_2 (tCO_2/yr)
			Tech.	Econ.	PCC	PrCC	OFC		
2021	Beiron, J. et al.	Energy Production	x	-	x	-	-	-	150K
2021	Reyes-Lúa, A. et al.	Oil Refinery	x	-	x	-	-	Geological Storage	0.48~1.44 M
2018	Sawada, Y. et al.	Hydrogen Production	x	-	x	-	-	Geological Storage	100K
2018	Zhang et al.	Energy Production	x	x	x	-	-	Geological Storage	8.44M
2016	Cormos, C.C	Energy Production	x	x	-	-	x	-	-
2016	Hetland, J. et al.	Energy Production	x	-	x	-	-	Geological Storage	-
2016	Yuan Wang	Energy Production	x	x	x	-	-	Geological Storage	-
2015	Rubin, S.E. et al.	Energy Production	x	x	x	x	x	Geological Storage	4.56M
2001	Byre, C. et al.	Energy Production	x	x	x	-	-	Geological Storage	-

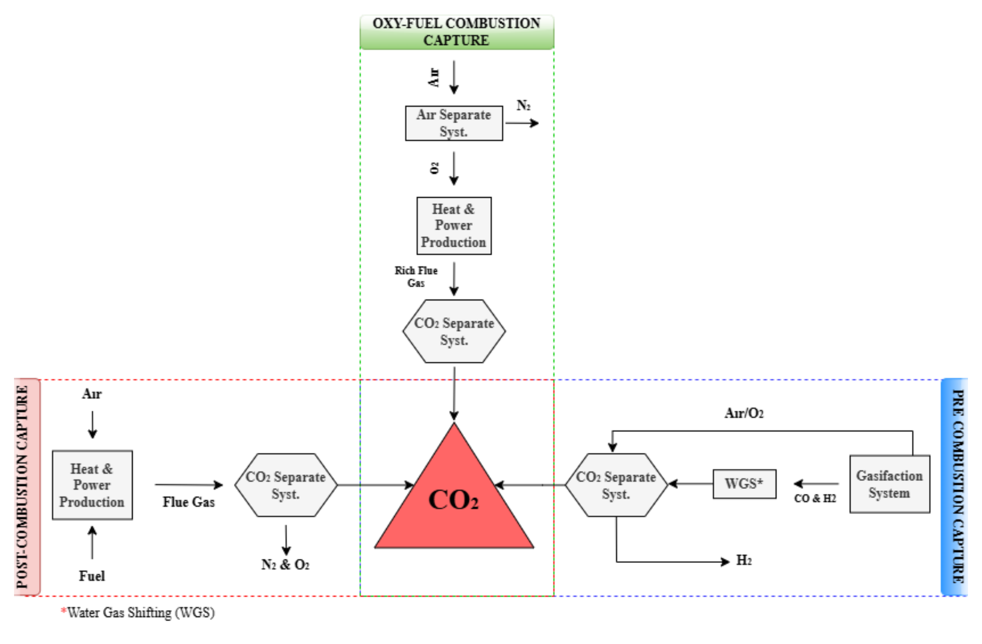

Figure 1. Convantional carbon capture methods.

oxygen or oxygen-enriched air obtained from the air separation unit is fed into the gasification reactor, where it reacts with fossil fuel. This reaction results in a syngas primarily composed of carbon monoxide (CO), hydrogen (H_2), and water vapor (H_2O). The resulting gas is then cleaned via a cyclone unit to remove ash, soot, and other particulates. Subsequently, the CO and H_2O components in the syngas undergo a chemical reaction within a Water-Gas Shift (WGS) reactor, producing additional hydrogen (H_2) and carbon dioxide (CO_2). .This method offers high efficiency and energy recovery but is primarily feasible for newly constructed facilities [9]. Retrofitting costs and infrastructure requirements limit its integration into existing plants.

The chemical reactions that occur during this process are presented in Equations (1) and (2)

Water-Gas Shift Reaction:

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{1}$$

Partial Oxidation and Gasification of Carbon:

$$2C + O_2 + H_2O \rightarrow H_2 + CO + CO_2 \tag{2}$$

Oxy-fuel combustion

Oxy-fuel combustion technology involves burning fuel with pure oxygen instead of atmospheric air, resulting in a flue gas stream primarily composed of CO_2 and water vapor, significantly reducing nitrogen content and thereby simplifying CO_2 separation [10]. In this process, high-purity oxygen is first produced via an air separation unit (ASU) and subsequently reacts with the fuel in a controlled combustion environment. The resulting flue gas is then cooled and condensed to remove water vapor, leaving behind a CO_2-rich stream that can be captured at high purity [11].

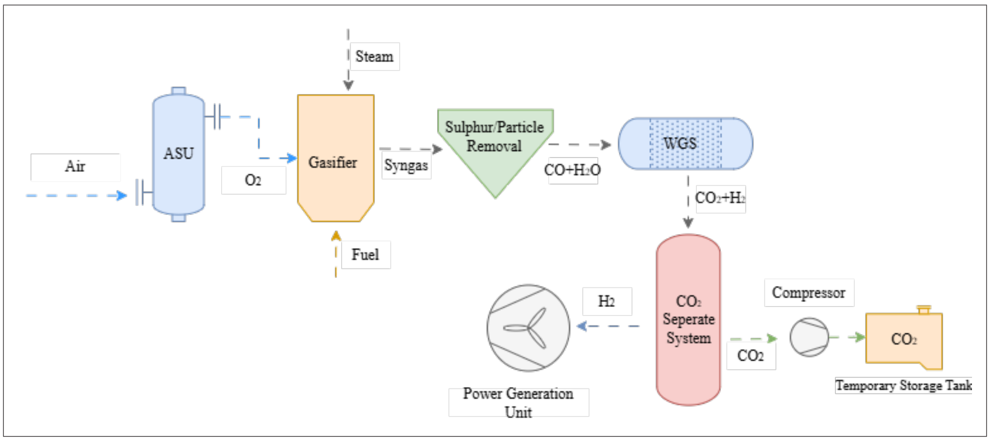

Figure 2. Pre-combustion capture method.

While this method facilitates the direct compression and storage of CO_2, it is also associated with significant energy consumption, primarily due to the operation of the ASU and the compression units such as pumps and compressors. Although integrated system designs in the literature indicate potential improvements in boiler efficiency, studies report an overall net efficiency penalty of up to 10% and a possible increase in electricity generation costs by as much as 70% compared to conventional systems [12]. Consequently, oxy-fuel combustion remains largely limited to specific coal- and natural gas-fired power plants, and is currently implemented at pilot or small-scale facilities, as identified in recent literature surveys.

Post-combustion capture

Post-combustion carbon capture is one of the most widely deployed technologies in fossil-fuel-based power generation facilities, aiming to prevent the release of CO_2 into the atmosphere by separating it from the flue gas after combustion [13]. In this method, the flue gas is contacted with chemical solvents that selectively interact with CO_2 in absorption columns prior to atmospheric release. Among the most commonly used solvents are amine-based compounds such as monoethanolamine (MEA), methyldiethanolamine (MDEA), piperazine, and AMP, which react with CO_2 to form carbamate-type intermediate compounds via covalent bonding [13-14].

In this study, a process example based on an MEA solution system is considered [8]. In the first stage of the process, the flue gas is cooled to approximately 40 °C to reach the absorption temperature. The cooled gas is then fed from the bottom of the absorption column with the help of a fan, while the amine solution is introduced from the top in a counter-current flow. As a result of the reaction between CO_2 and the amine, carbamate is formed (Equation 3):

$$2R{-}NH_2 + CO_2 \rightarrow R{-}NH_3^+ + R{-}NH{-}COO^- \tag{3}$$

The saturated solution is subsequently transferred to a stripping column operating at 100–120 °C, where the CO_2 is released from the solvent by the application of heat, and the amine solution is regenerated for reuse in the system (Equation 4):

$$R{-}NH{-}COO^- + R{-}NH_3^+ + \text{heat} \rightarrow CO_2 + 2R{-}NH_2 \tag{4}$$

Following regeneration, the recovered CO_2 is cooled to 40–45 °C, compressed to approximately 20 bar, and liquefied for temporary storage or transportation [15]. The efficiency and viability of this method depend on several factors, including solvent stability, the impurity level of the flue gas composition, and the overall energy requirement of the process. In cases where the flue gas contains high concentrations of SO_2, integration of a desulfurization unit is generally required to prevent amine degradation [16]. In retrofit projects, post-combustion carbon capture is considered one of the most commercially feasible options [17]. Its ability to be retrofitted into existing power plants makes it the most widely adopted carbon capture technique. The Boundary Dam project in Canada and the Petra Nova project in the United States serve as examples of large-scale implementations [18].

Next-generation carbon capture technologies (overview)

In recent years, alongside conventional methods such as pre-combustion, post-combustion, and oxy-fuel capture,

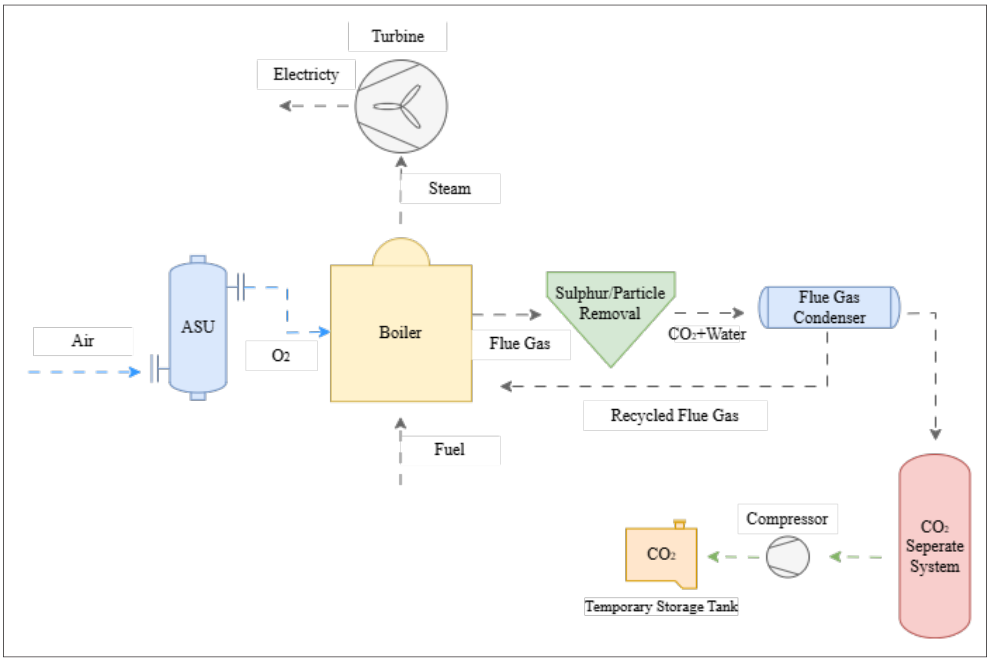

Figure 3. Oxy-fuel combustion capture method.

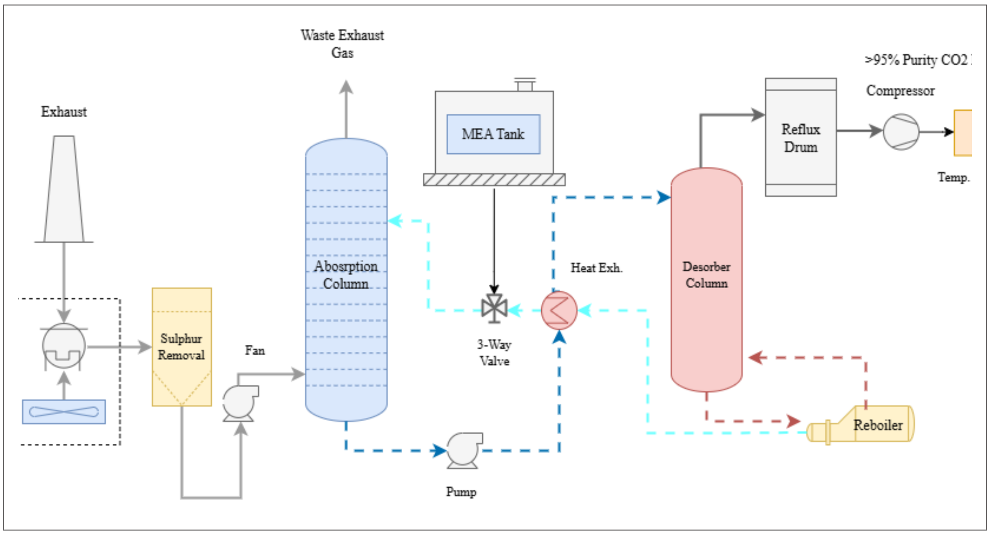

Figure 4. Flow chart of chemical absorption.

a range of next-generation carbon capture technologies have emerged. These approaches aim to address the energy and cost limitations of traditional systems, while offering enhanced flexibility and environmental compatibility. Although most are still at early development stages, their conceptual potential is noteworthy.

Chemical Looping Combustion (CLC)

CLC is an emerging combustion technology that enables inherent CO_2 separation by using solid oxygen carriers, thereby eliminating nitrogen from the flue gas. This results in a stream composed primarily of CO_2 and H_2O, simplifying downstream capture. While CLC offers thermodynamic advantages and high theoretical capture efficiency, it currently remains at the pilot scale due to technical and economic challenges [18-19]. These techniques remain in the research and development phase (Technology Readiness Level (TRL) 5–6) but hold promise for long-term carbon sequestration. Mineralization and geological storage offer significant opportunities for permanent carbon storage [20].

Membrane-Based CO_2 Separation

Membrane-based systems use semi-permeable materials to selectively separate CO_2 from flue gas without chemical solvents. These systems reduce environmental impact and maintenance costs; however, low gas pressures in power plants necessitate additional compression, increasing energy demand and limiting large-scale applicability [20-21].

Cryogenic CO_2 Capture

Cryogenic technologies separate CO_2 by cooling gas streams to very low temperatures, exploiting phase changes to isolate high-purity CO_2. Although suitable for streams with high CO_2 concentrations, their high energy consumption limits their feasibility in conventional flue gases from power plants [18-22].

Direct Air Capture (DAC)

DAC targets the separation of low-concentration CO_2 directly from the atmosphere using solid adsorbents or liquid solvents [6]; Despite its high energy consumption (5–11 GJ/ton CO_2), its ability to operate independently of emission sources is a key advantage. The Orca facility, operated by Climeworks in Switzerland, represents one of the first commercial DAC applications [23].

Bioenergy with Carbon Capture and Storage (BECCS)

BECCS combines CO_2 capture from biomass combustion with geological storage, enabling negative emissions [24]. It is one of the few technologies capable of removing carbon from the atmosphere. The Drax Power Station in the United Kingdom is a leading example of BECCS implementation [25].

Carbon Transport, Storage and Utilization

After the carbon capture stage, CO_2 must be conditioned for transport to suitable storage sites. Typically, the captured gas is converted into a supercritical phase, achieving a liquid-like density that facilitates both transportation and storage [8]. For large-scale CO_2 sources, pipeline transport is the most cost-effective and widely used method. Cryogenic tankers and ships are generally reserved for smaller volumes or geographically isolated storage locations. Transport costs typically account for 10–30% of the total CCS system costs, though this can be significantly reduced by repurposing existing natural gas infrastructure [18] For short pipelines (approximately 50–200 km), transportation costs average between \$1–5 per ton of CO_2 per 100 km [4]. Once delivered, CO_2 is primarily injected in supercritical form into geological formations such as depleted oil and gas reservoirs, deep saline aquifers, or unmineable coal seams [8]. The cost of storage depends on site-specific characteristics, but typically ranges from \$1 to \$15 per ton of CO_2. CO_2 is injected into geological formations, such as saline aquifers or depleted reservoirs, for permanent isolation [18]. The Gorgon Project in Australia exemplifies large-scale geological storage, injecting millions of tons of CO_2 annually as part of one of the world's largest CCS initiatives (Chevron Australia, 2024). As an alternative to geological storage, mineral carbonation offers a pathway for permanent sequestration by reacting CO_2 with naturally occurring rock minerals. The CarbFix project in Iceland is a notable demonstration of this approach, where CO_2 is mineralized by reacting with basalt formations, resulting in stable carbonate compounds [26]. In addition to storage, CO_2 utilization has gained attention as a complementary strategy for climate mitigation. Captured carbon can be converted into synthetic fuels or chemical products, such as through Fischer–Tropsch synthesis. The Norsk e-Fuel project in Norway exemplifies this pathway by integrating Direct Air Capture (DAC) with fuel production to create sustainable aviation fuel, showcasing a practical and value-added use of captured CO_2 [27].

International Projects

As of 2024, approximately 50 operational Carbon Capture and Storage (CCS) facilities worldwide successfully capture millions of tons of CO_2 annually [18]. However, economic feasibility, high initial costs, and scalability issues remain ongoing challenges (Table 2).

Table 2. Summary of CCUS Technologies International Projects

Project Name	Start/Features	CO_2 Capture (Annual)	Technology	Integration	Storage& Use	TRL Level
Boundary Dam (Canada)	First integrated CCS facility leading CCUS innovation	~1M	Amine-based solvents with post-combustion capture	Coal-fired power plant	Enhanced Oil Recovery (EOR)	9
Petra Nova (USA)	One of the largest carbon capture projects in the US	~1.4M	Amine-based solvents with post-combustion capture	Coal-fired power plant	EOR	9
Drax BECCS (UK)	Major negative emissions project aims for atmospheric CO_2 removal	Not specified	BECCS technology capturing CO_2 from biomass combustion	Biomass power plant	Geological Storage	7-8
Sleipner (Norway)	First offshore carbon storage project active since 1996	~1M	CO_2 separation using amine solutions, pressurized, and offshore injection	Natural gas processing	Subsea Formation Injection	9
Net Zero Teesside (UK)	Large-scale industrial CCS project in UK	Not specified	Post-combustion technology for CO_2 separation	New natural gas-fired power plant	Geological Storage	6-7
Taizhou BECCS (China)	Generating energy from agricultural waste while capturing carbon	Not specified	Biomass combustion and BECCS technology for CO_2 capture	Energy production	Geological Storage	6-8

Carbon Capture, Utilization, and Storage (CCUS) Projects and Implementations in Türkiye

As of 2024, Türkiye's electricity production totals 348.9 TWh, with 35.2% from coal and 18.9% from natural gas. The energy sector accounts for 71.3% of total emissions. Türkiye has set a 41% emission reduction target for 2030 and a net-zero goal for 2053. However, 54.1% of electricity generation remains fossil fuel-based (Table 3).

Carbon capture technologies are advancing globally, offering significant emission reduction potential [5]. In Türkiye, widespread adoption requires identifying geological storage potential, establishing carbon pricing, enhancing public-private collaborations, and increasing public awareness [28]. High costs, limited technical capacity, and regulatory uncertainties remain critical barriers.

RESULTS AND DISCUSSION

Carbon Capture and Storage (CCS) technologies have gained significant momentum globally, particularly in countries such as the United States, Canada, and Norway, where supportive regulatory frameworks and financial incentives have enabled large-scale implementation. These countries benefit from mature infrastructure and institutional capacity, allowing CCS to effectively reduce emissions from fossil fuel-based power generation. In contrast, CCS development in Türkiye remains at an early stage, largely limited to research, feasibility studies, and small-scale pilot projects. Although Türkiye's centralized energy infrastructure and emission profile are technically compatible with CCS, the lack of a comprehensive national strategy and regulatory framework

Table 3. Carbon Capture, Utilization, and Storage (CCUS) Projects and Implementations in Türkiye

No	Project Name	Entity	Features	Technology/ Methods	Integration	Status	TRL Level
1	TUBITAK ACT3	TUBITAK	One of Türkiye's most comprehensive R&D projects on carbon capture and storage technologies aims to reduce carbon emissions from electricity generation.	Post-combustion and pre-combustion carbon capture methods	Electricity generation	Lab and Pilot Studies	4-5
2	SOCAR NEFERTITI Project	SOCAR Türkiye	Aims to convert CO_2 into chemical products using solar energy-supported photocatalytic systems	Solar energy-supported CO_2 conversion	Indirectly related to electricity generation	R&D Phase	3-4
3	EUAS Hybrid Systems	EUAS	Reducing emissions from coal-fired thermal power plants using with Hybrid Membrane-Adsorbent CO_2 Capture System	Membrane and adsorbent technologies for CO_2 separation	Coal-fired thermal power plants	Pilot Studies	4-5
4	REC Türkiye	REC Türkiye	Mapping Türkiye's geological carbon storage potential and developing data-driven strategies for CO_2 storage from electricity generation.	Infrastructure analysis for CO_2 transportation and underground injection	Electricity generation	Analysis Phase	3-4

poses a major barrier to deployment. Furthermore, high investment costs and limited public awareness exacerbate the challenges of adoption. [29–33]. Nevertheless, CCS presents a strategic opportunity for Türkiye to meet its 2053 net-zero emissions target and participate in global carbon markets. Aligning with international climate finance mechanisms, such as the EU Green Deal and Horizon Europe, could enhance Türkiye's capacity to scale CCS technologies. Addressing regulatory, technical, and social acceptance issues will be crucial for narrowing the gap between Türkiye and leading countries in CCS deployment (Table 4).

To articulate CCUS (Carbon Capture, Utilization, and Storage) technology in economic terms, the economic feasibility of Carbon Capture and Storage (CCS) fundamen-

Table 4. Opportunities and challenges of CCUS technologies in power generation: A SWOT perspective (IEA – International Energy Agency - IEA)

SWOT Analysis of CCS Technologies in the Electricity Sector	
Strengths	***Weaknesses***
Enables up to 90% reduction in CO_2 emissions	High investment and operational costs
Can be integrated into existing fossil fuel infrastructure	Efficiency loss due to additional energy consumption
Applicable in high-emission sectors	Uncertainties regarding long-term storage security
Opportunities	***Threats***
Creates new job opportunities	Public acceptance issues (NIMBY effect)
Contributes to carbon markets	Insufficient legal regulations and investment uncertainties
Technology transfer and cross-border collaborations are developing	Risk of CO_2 leakage and potential environmental impacts

Table 5. Cost overview [29]

No	Progress	Method	Average Cost (US$/t$CO_2$)
1	Capture	Chemical Absorption	50–90
2	Capture	Physical Absorption	40–70
3	Capture	Cryogenic	>100
4	Transportation (Ship)	Medium Pressure (10k t)	~41
5	Transportation (Ship)	Medium Pressure (50k t)	~28
6	Transportation (Ship)	Low Pressure (50k t)	~18
7	Transportation – (Pipeline)	Intensive Phase (130-150 bar, 250 km)	25–50
8	Storage (Geological)	Saline Aquifer / Reservoir	5–20
9	Storage (Storage Tank)	Medium Pressure Tank	25–35
10	Storage (Storage Tank)	Low Pressure Tank	10–20

Table 6. CO_2 Capture method and efficiency [4-18-30]

CO_2 Capture Method	CO_2 Capture Efficiency (%)	Energy Consumption (MJ/kg CO_2)	Cost ($/ton CO_2)
Post-combustion	85–90	2–4	50–80
Pre-combustion	90–95	1.5–3	40–60
Oxy-fuel combustion	90–95	3–5	60–100

tally depends on the aggregated costs of its three principal components: capture, transportation, and storage. These components collectively determine the overall economic viability and scalability of the technology. Based on the literature review and related analyses, the average unit costs of CO_2 capture, transportation, and storage vary depending on the method and operational conditions, and these ranges are summarized in Table 5. These costs vary depending on the technology type, process configuration, and project scale. Among capture technologies, post-combustion MEA-based systems typically range from 50–90 USD/tCO_2, primarily due to high energy consumption and solvent losses [33]. Pre-combustion systems, which rely on gasification and subsequent chemical conversion, tend to be more complex and costly, averaging 60–100 USD/tCO_2 [34]. Oxy-fuel combustion, by using pure oxygen instead of air, simplifies CO_2 separation but requires capital-intensive infrastructure such as air separation units (ASUs), resulting in costs between 40–80 USD/tCO_2.Transport costs, influenced by distance, pressure, and mode (pipeline or ship), range from 18 to 50 USD/tCO_2, while geological storage in saline aquifers or depleted reservoirs typically adds 5–20 USD/tCO_2. An overview of these cost ranges is provided in Table 5, based on international benchmarks [8-18-29].

These findings emphasize the importance of selecting appropriate CCS technologies and integrating them effectively into energy systems. In the case of Türkiye, where fossil fuels still account for a large portion of electricity generation, the targeted deployment of CCS—particularly in emission-intensive sectors and coal-dominated regions—could significantly contribute to long-term climate targets [31]. However, this requires not only technological readiness but also supportive regulatory frameworks, investment incentives, and infrastructure planning to ensure large-scale implementation.

According to the data, Post-Combustion management can be integrated more easily than other methods.

CONCLUSION

In conclusion, the electricity generation sector is very important for the use of CCUS technologies as it is the sector with the highest carbon emissions. In the power generation sector, carbon capture technologies that are easy to integrate later should be used due to the old installation of fossil fuel plants. Post Combustion method leads to exergy losses as it partially prevents the utilization of waste heat in flue gases. When all methods are evaluated in terms of capture efficiency, economic feasibility, ease of integration and energy losses, it is understood that the Post-Combustion method with amine-based chemicals (MEA) is the most suitable capture technology for the power generation sector.

Although numerous examples of carbon capture exist globally, Türkiye currently lacks any fully commercialized carbon capture initiatives. However, Türkiye has significant potential with its existing large-scale fossil fuel-based facilities. In terms of carbon storage, the oil and gas reserves in Türkiye are highly suitable for injecting carbon dioxide. There are examples of these reserves in the Southeast, Black Sea and Thrace regions. Storage is also actively practiced in Türkiye with the Batı Raman field in Batman.

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