Open Journal of Energy Efficiency, 2024, 13, 25-37
https://www.scirp.org/journal/ojee
ISSN Online: 2169-2645
ISSN Print: 2169-2637

Carbon Capture Technologies in OAPEC Member Countries and the Circular Carbon Economy: A Roadmap to Zero Emissions by 2050

Salem Baidas

Sematco Soil and Engineering Material Testing Co., Kuwait City, Kuwait
Email: Salem.baidas@sematco.net

How to cite this paper: Baidas, S. (2024) Carbon Capture Technologies in OAPEC Member Countries and the Circular Carbon Economy: A Roadmap to Zero Emissions by 2050. *Open Journal of Energy Efficiency*, **13**, 25-37.
https://doi.org/10.4236/ojee.2024.132002

Received: April 16, 2024
Accepted: June 16, 2024
Published: June 19, 2024

Abstract

Several Organization of Arab Petroleum Exporting Countries (OAPEC) member states (OMSs) have updated their nationally determined contributions (NDCs) with the aim of achieving zero carbon emissions by 2050. Carbon neutrality requires shifting from a linear carbon economy (LCE) to a circular carbon economy (CCE). Carbon capture and storage (CCS) technologies, including reduction, recycle, reuse, removal, and storage technologies, represent an important strategy for achieving such a shift. Herein, we investigate the effects of CCS technology adoption in six OMSs—namely the Kingdom of Saudi Arabia (KSA), Qatar, the United Arab Emirates (UAE), Kuwait, Algeria, and Iraq—by examining their Circular Carbon Economy Index (CCEI) scores, which reflect compliance with CCE-transition policies. Total CCEI, current performance CCEI dimension, and future enabler CCEI dimensions scores were compared among the aforementioned six OMSs and relative to Norway, which was used as a global-high CCEI reference standard. Specifically, CCEI general scope and CCEI oil scope dimension scores were compared. The KSA, Qatar, the UAE, and Kuwait had higher CCEI scores than Algeria and Iraq, reflecting their greater adoption of CCE-transition policies and greater emission-reducing modernization investments. The current performance CCEI scores of Algeria and Iraq appear to be buttressed to some extent by their greater natural carbon sink resources. Based on the findings, we recommend specific actions for OMSs to enhance their CCE transitions and mitigate the negative impacts associated with the associated investments, including: taking rapid practical steps to eliminate carbon oil industry emissions; detailed CCS planning by national oil companies; international cooperation and coordination; and increased investment in domestic CCS utiliza-

tion infrastructure.

Keywords

OAPEC, Petroleum, Fossil Fuels, Carbon Capture and Storage, Circular Carbon Economy

1. Introduction

Since the industrial revolution, human activity has been releasing greenhouse gases, such as carbon dioxide (CO_2) and methane, into the Earth's atmosphere [1]. In addition, industrial activity has added ozone to the troposphere, and continues to release chlorofluorocarbons and nitrogen dioxide [2]. CO_2 emissions, which accounted for as much as 82% of the total greenhouse gas emission from some countries in 2017, are the primary driver of global climate change [3].

Fossil fuel combustion produces air, water, and soil pollution and has been linked to climate change and solid waste disposal issues [2]. The combustion of carbon in fossil fuels releases a number of gases, the most concerning of which is the greenhouse gas CO_2 due to its negative environmental effects, including its substantive global warming effects. Carbon emissions trap solar energy in the atmosphere, which raises global temperatures and intensifies the occurrence of storms, fires, droughts, and heat waves [4]. They affect human health directly by contributing to respiratory pathology [5]. About 75% of the increase in atmospheric CO_2 over the past 20 years was due to burning fossil fuel [6], and fossil fuels accounted for 85.2% of the total global energy supply in 2008 [7]. In 2008, there was 30 billion metric tons (CO_2 equivalent) of carbon emissions from the fossil fuel sector, a 40% increase from 1990 [8].

1.1. Organization of Arab Petroleum Exporting Countries (OAPEC)

OAPEC, whose headquarters are in Kuwait, was founded in January 1968 to promote international economic cooperation in the fossil fuel industry. The OAPEC member states (OMSs) are Algeria, Bahrain, Egypt, Iraq, Kuwait, Libya, Qatar, the Kingdom of Saudi Arabia (KSA), Syria, Tunisia, and the United Arab Emirates (UAE) [9]. OAPEC seeks to achieve the following goals for its member states: embrace close national ties, preserve common interests, unify efforts to maintain profitable flow of petroleum to markets, establish a suitable climate for industry, develop oil-economic policies and legal mechanisms, and promote the exchange of technology and information [9]. OMSs have a total land area of 8.19 million km^2 and a total population of 276.16 million. These figures represent 5.4% of the habitable area in the world and 3.6% of the world population. The economic output of OAPEC is 2,110.92 billion US dollars per year, or approximately 2.5% of the global economy. The most recent reported value of all exported goods was 492.13 billion US dollars per year [9].

1.2. Gulf Cooperation Council (GCC)

The GCC is a political and economic alliance of six countries in the Persian Gulf region whose economies are heavily reliant on large domestic oil and gas resources, namely the KSA, Kuwait, the UAE, Qatar, Bahrain, and Oman. It was established in Riyadh, KSA in 1981 [10].

1.3. Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC)

The IPCC was established in 1988 to gather scientific, technical, and socioeconomic information on climate change [11]. In 1992, the IPCC played a decisive role in establishing the UNFCCC, which produced a foundational treaty for dealing with climate change [8]. The UNFCCC recommendations were first operationalized in the Kyoto protocol, which was adopted by the UNFCCC in December of 1997 [12]. The Kyoto protocol has been ratified by 192 member nations of the United Nations. The Kyoto protocol called for a 5% reduction in carbon emissions from developed countries relative to 1990 levels over the period 2008-2012 [13]; it outlined obligations for all committing parties as well as responsibilities of developed countries towards developing countries [14].

During its 2010 negotiations at the Conference of the Parties (COP) that led to the Paris Agreement, the UNFCCC recommended reducing carbon emissions with the goal of limiting the global temperature rise to 1.65˚C (<2˚C) relative to preindustrial levels [15]. To meet this goal, the UNFCCC affirmed that greenhouse gas emissions should not exceed 450 ppm (CO_2 equivalent) and aimed to reduce global emissions by 50% - 85%, relative to 2010 levels, by 2050. This agreement was adopted by 196 UNFCCC parties at COP21 in Paris in December of 2015 and it became active in November of 2016 [15]. This agreement serves as a motivation for the development of carbon capture in the oil industry, which remains the world's main source of energy and produces the largest portion of carbon emissions. As an Example, in 2008, the fossil fuel sector emitted 30 billion metric tons (CO_2 equivalent) of carbon emissions, a 40% increase from 1990 [8]. Notably, in 2021, several OMSs updated their National Determined Contributions (NDCs) for emissions with the aim of reaching carbon neutrality by 2050 [16].

2. Carbon Capture and Storage (CCS)

Carbon neutrality requires transitioning to a circular carbon economy (CCE). In a traditional linear carbon economy (LCE), emissions are managed after they are produced. In a CCE, to avoid releasing carbon emissions into the atmosphere entirely, CCS technologies—including carbon reduction, recycling, reuse, removal, and storage—are applied [17] [18] [19]. To this end, carbon flows in refining processes are tracked with a cradle-to-cradle approach, looping carbon flow from refinery outputs to manufacture inputs and, ideally, transforming carbon from a waste product to a raw material for the manufacture of new products [17] [18] [20]. In a CCE, carbon waste that cannot be looped must be stored safely in tanks or geographical formations to prevent it from reaching the atmosphere [21]. CCE characteristics are compared to LCE characteristics in **Figure 1**.

This study provides a conceptual explanation of CCE, an overview of the efforts of OMSs to implement CCEs based on the 2021 CCE index report produced by researchers at King Abdulla Petroleum Studies and Research Center (KAPSARC) [22], and the potential for OMSs to reach carbon neutrality by 2050.

3. CCE History

Willem McDonough formulated the concept of a CCE in 2016 based on circular economy models for industrial manufacturing processes with the aim of increasing revenue while minimizing waste and reducing raw material input needs [23]. The circular economy principles were adapted such that the focus on money flows to control costs shifted to a focus on energy flows to control carbon emissions [23]. In a circular economy, waste is returned to the economy or used more efficiently, thereby benefiting the environment and improving the efficiency of natural resource use [24] [25]. CCE development can encourage innovations to make use of captured carbon. Indeed, Germany is already pursuing efforts to produce marketable chemicals from captured carbon [22].

The KSA, which assumed the G20 presidency in December of 2019, has embraced the CCE concept and the G20 leaders are in unanimous agreement regarding a comprehensive framework to achieve sharp reductions in carbon emissions [22]. The ultimate goal of the framework is to achieve zero carbon emissions by 2050, thereby contributing to environmental sustainability and the delimiting of climate change [15]. The framework calls for the development of a quantitative tool for conducting comparative evaluations of the energy management and emission technology employment of countries and international groups, including elaboration of the strengths and weaknesses of each and gaps between NDC goals and local strategies [26]. The framework lays out the following objectives and guidance:

- Explore carbon neutrality pathways by studying all available reduction technologies and determining those best suited for local circumstances.

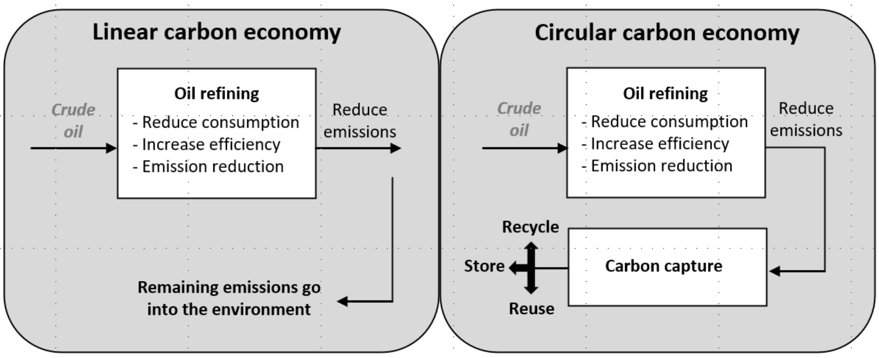

Figure 1. Linear carbon economy (LCE) versus circular carbon economy (CCE).

- Plan for gradual transformation into a CCE, allowing slow progress in the initial stages.
- Seek financial support from governmental and international bodies to support costly CCS integration with emission reduction technologies.
- Identify obstacles to reaching zero carbon emissions.
- Track the gap between current emissions and zero emissions to find appropriate technologies for implementation and to identify enabling factors.

3.1. Circular Carbon Economy Index (CCEI)

Meeting the aforementioned framework's call for a quantitative tool, the CCEI is a tool that can yield data to be used by climate policy regulators in their efforts to assess emission reduction performance and quantify transition progress towards a CCE [22]. The CCEI is a unified measure with two multi-element dimensions (current performance and future enabler); it is based on standardized values and it was developed by researchers at KAPSARC [22]. The CCEI is intended to enable policy analysts to compare results between countries quantitatively and over time. CCEI data can be used to help countries distinguish productive from lagging programs, thereby enabling them to focus on addressing weaknesses. Given the global nature of climate change, it is hoped that countries with high CCEI scores will use their expertise to improve the performance of low-scoring countries.

Ultimately, continuous improvement of CCEI values can lead to an oil industry without carbon emissions. KAPSARC urges oil industry-heavy economies to pursue full CCE transformation. Doing so will requires the infrastructure of a new carbon-based industrial sector to be fully developed, including production, transportation, storage, recycling, shipping, exportation, and marketing [22]. As summarized in **Table 1**, KAPSARC has published CCEI elements for CCEs generally with an additional set of indicators specific to oil producing countries.

Table 1. Overview of CCEI elements (source: KAPSARC, March 2021 [22]).

CCE elements (general scope)		Additional oil scope elements	
Current performance	**Future enabler**	**Current performance**	**Future enabler**
Energy efficiency	Policies and regulations	Carbon density during oil refining	Quality of resource management
Renewables	Technological advancement	Burn density during oil refining	Environmental and social risks
Electrification	Finance and Investment	Methane density during fossil fuel production	Transparency of sustainability data
Nuclear	Work environment and energy security	Carbon density for added manufacturing value	Carbon capture and storage capability
Alternative fuels	Social and economic context	Added value for chemical manufacturing	Level of commitment to achieve zero carbon emissions by 2050
Natural carbon sinks	-	-	-
Carbon capture and storage	-	-	-
Green hydrogen	-	-	-

3.2. Improve CCEI Performance to Reach NDC Goals

Several OMSs, including Kuwait, KSA, UAE, Qatar, and Bahrain, updated their NDCs in 2021. Both Bahrain and KSA developed strategies for achieving a full CCE. To achieve a full transformation into a CCE, other OMS need to identify appropriate technologies and enabling factors for which CCEI evaluations can be invaluable.

4. Results and Discussion

4.1. General-Scope CCEI Values for 2021

KAPSARC collated 2021 CCEI scores for 30 countries (G20 plus other oil producers). Data from six OMSs, namely the KSA, Qatar, the UAE, Kuwait, Algeria, and Iraq, were available for analysis in the present study [22]. The highest CCEI scoring country in the world, Norway, was also included for comparison. Total and dimension general-scope CCEI scores for these seven countries are reported in **Figure 2**.

4.1.1. General-Scope CCEI: Current Performance Dimension

Because the GCC countries of Kuwait, the KSA, Qatar, the UAE, and Bahrain have started implementing CCS projects, as well as renewables and green hydrogen projects, it was expected that GCC countries would have better CCEI current performance dimension scores than Iraq and Algeria. Although Iraq and Algeria had lower overall 2021 CCEI scores than the other counties, the difference was less than two-fold in magnitude (**Figure 2**). Moreover, Kuwait's current performance was similar to Algeria's, while Iraq's was similar to those of Qatar and the UAE. The abundance of vegetation cover in Iraq and Algeria could be providing natural carbon sinks, thereby improving their current performance results. All six OMSs' CCEI scores were far below those of Norway

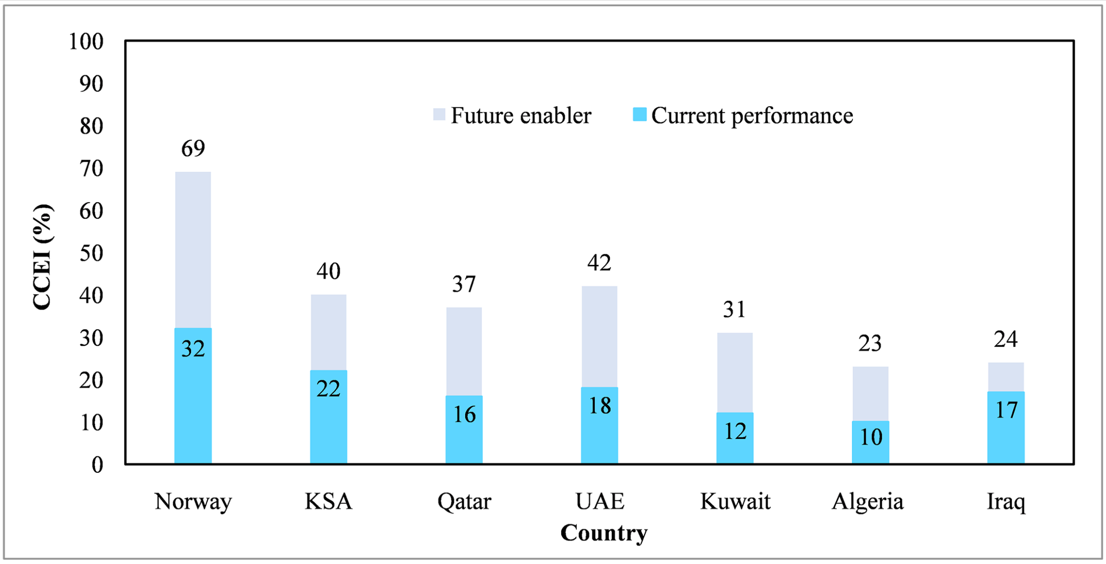

Figure 2. General-scope CCEI results for 2021. Source: KAPSARC, March 2021 [12].

(and other developed countries) [27]. OMSs should seek assistance from countries with high CCEI scores, particularly those with strengths in the elements where they have weaknesses, to improve their performance.

4.1.2. General-Scope CCEI: Future Enablers Dimension

The GCC countries of Kuwait, the KSA, Qatar, and the UAE had similar future enabler scores and contributing elements (Table 1). Iraq and Algeria had lower CCEI (general scope) future enabler dimension scores than GCC countries. This separation can be attributed to relatively weak policies and regulations, obstacles to technological development, and a lack of a stable investment environment in Iraq and Algeria. GCC countries can assist Iraq and Algeria by sharing technologies, providing support for political stability, and contributing to their finance and investment sectors. Meanwhile, all six OMSs had markedly lower CCEI future enabler dimension scores than Norway had in 2021 (Figure 2) and therefore should seek assistance from developed countries; each should identify the particular enabler elements in need of improvement domestically.

4.1.3. Dimensional Distinctions among Countries

Among OMSs, the KSA had the highest CCEI current performance dimension score for 2021, while the UAE had the highest future enabler dimension score. The KSA and the UAE could potentially improve their scores through mutual cooperation. Kuwait may seek guidance from the KSA, Qatar, and the UAE to improve their current performance. GCC countries should assist Algeria with their weakest elements to help improve their current performance metrics. Areas in need of improvement for OMSs include: policies to support projects; energy efficiency and consumption technologies; CCS, renewables, electrification, and alternative fuels; scientific research and exchange of expertise to share appropriate technologies for local conditions; development of conditions conducive to CCE transformation; finance and investment sector strength; creation of industries that can utilize the captured carbon; and creation of CCS infrastructure.

4.2. Oil-Scope CCEI for 2021

The 2021 CCEI report prepared by KAPSARC contained data from 19 oil producing countries. Oil-scope CCEI data from six OMSs (the KSA, Qatar, the UAE, Kuwait, Algeria, and Iraq) and Norway (highest score of all countries) were included in this study (Figure 3).

4.2.1. Oil-Scope CCEI: Current Performance Dimension

The four GCC countries (the KSA, Qatar, the UAE, and Kuwait) had higher oil-scope CCEI current performance dimension scores than Algeria and Iraq, with the KSA's score coming within a few points of Norway's score (Figure 3). The GCC countries showed good performance with respect to the oil-scope CCEI current performance elements (Table 1), indicating that they can indeed achieve carbon neutrality and a complete transformation into a CCE. The relatively poorer performance in this dimension for Algeria and Iraq can be attributed to their use of old refinery equipment and ongoing deficiencies in their modern emission-reduction, consumption-reduction, and energy efficiency technologies. GCC countries should thus cooperate with Algeria and Iraq to help them modernize their oil refineries. All oil producing countries should continue to develop resources that will enable them to adapt to progressively stricter environmental policies.

4.2.2. Oil-Scope CCEI: Future Enablers Dimension

As shown in Figure 3, the four GCC countries of the KSA, Qatar, the UAE, and Kuwait had notably higher oil-scope CCEI future enabler dimension scores than Algeria and Iraq, but remained far behind Norway (>20-point deficit). Norway excels in the elements of: resource management quality; environmental and social risks; corporate sustainability data transparency; governmental commitment in reaching zero carbon emissions by 2050; and CCS capabilities. OMSs should seek assistance from developed countries such as Norway in these areas according to each of their specific deficits.

4.3. Comparison of General-Scope versus Oil-Scope CCEI Results

4.3.1. Current Performance Dimension

With respect to current performance, oil-scope elements represented relative strengths for the four GCC countries compared to the general-scope elements (Figure 4). The strong oil-scope CCEI current performance dimension scores for the GCC support the feasibility of GCC countries' achieving carbon neutrality and transformation to CCEs. They can continue to improve by developing their fossil fuel industries to conform to environmental legislation without abandoning their fossil fuel resources entirely. With an approach of technological innovation, the fossil fuel industry can continue to be economically sustaining

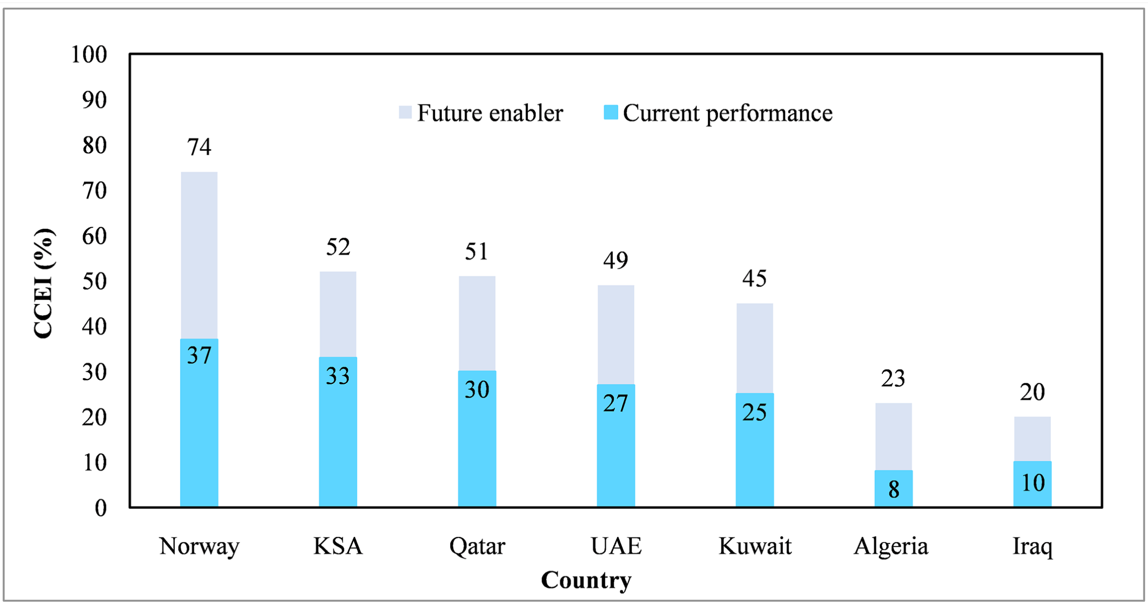

Figure 3. Oil-scope CCEI results for 2021. Source: KAPSARC, March 2021 [12].

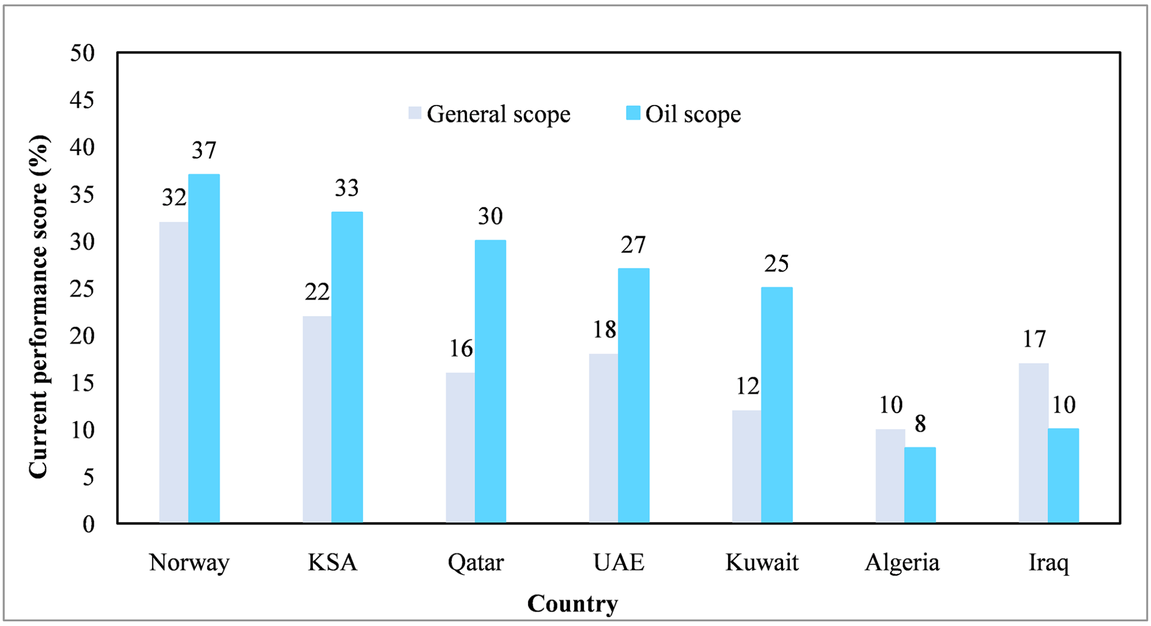

Figure 4. Comparison of general-scope CCEI and oil-scope CCEI current performance dimension scores. Source: KAPSARC, March 2021 [22].

for OMSs into the future while zero emissions are reached, potentially before 2050 [3] [28]. Conversely, oil-scope CCEI elements were weaker than general-scope CCEI elements for Iraq and Algeria (Figure 4), reflecting a lack of CCS technologies, LCE continuation in the oil industry, not having taken serious steps to transform into CCEs, weak oil industry modernization policies, and not applying technologies to reduce energy consumption and maximize energy efficiency in refineries. GCC countries can assist Iraq and Algeria in these areas to improve their oil-scope CCEI current performance dimension scores.

4.3.2. Future Enablers' Dimension

With respect to the future enablers' dimension, oil-scope elements again represented relative strengths for the four GCC countries compared to the general-scope elements (Figure 5). Compared to Norway, there remains substantial additional potential for further reducing oil industry emissions in OMSs, particularly in the areas of CCE transition and CCS technology integration. Iraq and Algeria's oil-scope CCEI future enablers dimension scores were notably depressed relative to those of their neighboring OMSs, suggesting they have yet to take decisive actions toward reaching zero emissions and that they remain in the early stages of transitioning to CCEs.

4.4. Country-Specific CCE Transition Agendas

In this section, a summary of OMS projects, technologies, and strategies to meet NDCs based on KAPSARC's 2021 data is provided. The KSA is working to increase their natural gas electricity generation to 50% of electricity production by 2030 through several ambitious projects, including: achieving 650 tons/day of

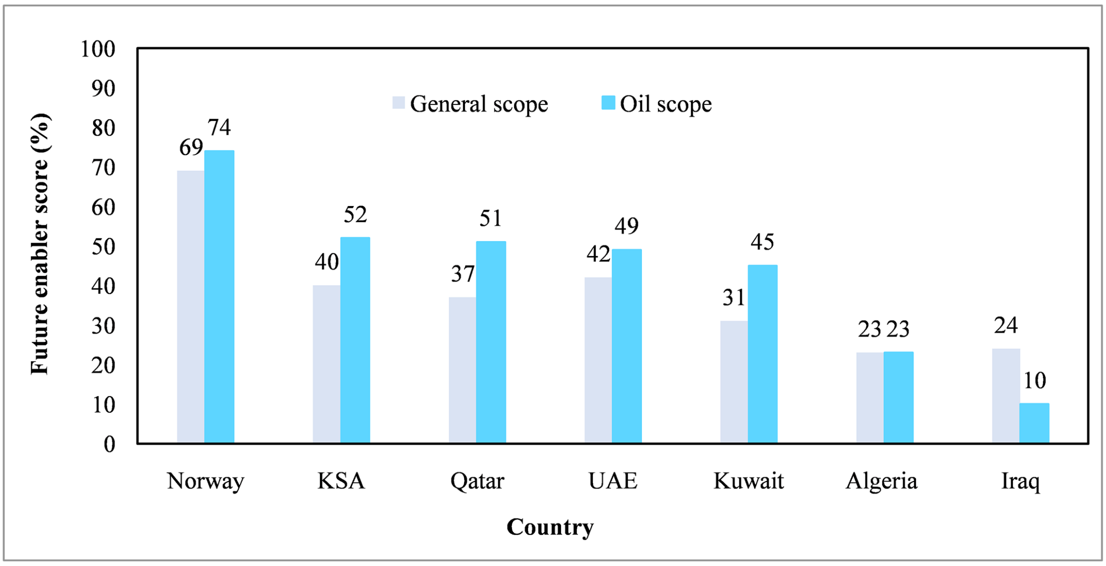

Figure 5. Comparison of general-scope and oil-scope CCEI future enabler scores. Source: KAPSARC, March 2021 [22].

green hydrogen production from natural gas; CCS projects; transformation of the Yanbu and Jbeel areas into global centers for CCS; developments estimated to enable the production of 1.2 million tons/year green ammonia by 2025; and initiation of blue hydrogen production [28]. The KSA is working to reduce their CO_2 emissions to 278 million tons by 2030 and to zero by 2060 [28]. Meanwhile, the UAE is pursuing foreign investment and government financing in support of their goals to reduce energy consumption to 40% of 2010 levels by 2050, expand CCS projects, and reduce carbon emissions to 23.5% of 2010 levels by 2030 and to zero by 2050. Qatar is implementing well-established sustainability practices and CCS projects in the liquefied gas sector, and is aiming to reduce its carbon emissions to 25% of 2010 levels by 2030. Kuwait is implementing energy consumption reduction and efficiency improving policies, including increasing their liquefied gas share to 70% of their total energy consumption as of 2022 and initiating CCS projects to reduce carbon emissions (reduced to 216 kilotons CO_2 equivalent by 2022), with the goals of reducing their carbon emissions to 7.4% of 2010 levels by 2035 and to zero 2050 [28].

5. Recommendations

The author of this paper urge OMSs to take practical and rapid steps to reduce their carbon emissions by: 1) Increasing the efficiency of energy production and consumption processes; 2) Increasing the use of electric vehicles and hydrogen fuel cells; 3) Shifting to renewables, including green hydrogen production from renewables; 4) Using more low-carbon-content fossil fuels, such as natural gas instead of coal; 5) Planting trees to serve as a vegetative carbon sinks; 6) Adopting CCS technologies [29] in the oil industry. CCS will be critical for achieving carbon neutrality. Thus, it is imperative that national oil companies in OMSs produce more detailed CCS implementation plans. CCS innovations can increase income and grow labor markets while helping countries abide by environmental regulations, meet NDCs, and reduce the environmental and health impacts of carbon emissions.

All OMSs should be working to transform into CCEs with the aim of reaching carbon neutrality by 2050. The KSA is well positioned to be a regional leader with respect to sharing its CCE expertise. It is feasible that OMSs can achieve zero emissions by 2050 if they support climate change responsive policies. To enable progress to be tracked, all OMSs need to submit CCEI data in the future. Moreover, cooperation among OMSs and assistance from developed countries with high CCEI scores can serve to optimize future CCEI outcomes for OMSs.

6. Conclusion

Attaining the Paris Agreement NDCs and achieving zero carbon emissions by 2050 will require OMSs to abandon LCEs and embrace CCEs. CCS technologies and energy efficiency technological innovation are critical to OMSs' abilities to reduce their carbon emissions and, concomitantly, reduce carbon emission-associated health and environmental impacts. Challenges associated with adopting CCS technologies include increased oil production costs and the reluctance of oil consuming countries to share the additional cost. Conversely, improved energy performance would enhance the competitiveness of countries in the oil market and increase their revenues. OMSs should cooperate and coordinate their problem-solving efforts to attain a sustainable balance between economic growth and environmental burdens, to stabilize fossil fuel supplies, and to bolster their positions in the global energy market.

Acknowledgments

The author thanks KAPSARC (KSA) for providing CCE data. This manuscript was edited by Ann Power Smith, PhD, a professional scientific editor at Write Science Right.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] [EPA] US Environmental Protection Agency (2021) "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2018" Annex 2 (Methodology for Estimating CO_2 Emissions from Fossil Fuel Combustion), Table A-28 for C Coefficient and Table A-38 for Heat Content. EPA, Washington DC, U.S. EPA #430-R-20-002. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2018

[2] Sadatshojaie, A. and Rahimpour, M.R. (2020) CO_2 Emission and Air Pollution (Volatile Organic Compounds, etc.)-Related Problems Causing Climate Change. In:

Figoli, A., Li, Y.D. and Basile, A., Eds., *Current Trends and Future Developments on* (*Bio*-) *Membranes*: *Membranes in Environmental Applications*, Elsevier, Amsterdam, 1-30. https://doi.org/10.1016/B978-0-12-816778-6.00001-1

[3] Department of Energy and Climate Protection, Ministry of the Environment of the Czech Republic (MoE) (2017) Climate Protection Policy of the Czech Republic: Executive summary. MoE, Prague. https://unfccc.int/files/na/application/pdf/cze_climate_protection_policy_summary.pdf

[4] Yoro, K.O. and Daramola, M.O. (2020) CO_2 Emission Sources, Greenhouse Gases, and the Global Warming Effect. In: Rahimpour, M.R., Farsi, M. and Makarem, M.A., Eds., *Advances in Carbon Capture*, Woodhead Publishing, Cambridge, 3-28. https://doi.org/10.1016/B978-0-12-819657-1.00001-3

[5] Xu, R., Yu, P., Abramson, M.J., *et al.* (2023) Wildfires, Global Climate Change, and Human Health. *The New England Journal of Medicine*, **383**, 2173-2181. https://doi.org/10.1056/NEJMsr2028985

[6] Kanoğlu, M., Çengel, Y. and Cimbala, J. (2020) Fundamentals and Applications of Renewable Energy. McGraw-Hill Education, New York.

[7] [EIA] US Energy Information Agency (2011) Annual Energy Outlook. https://www.eia.gov/todayinenergy/detail.php?id=1110

[8] Allison, I., Bindoff, N.L., Bindschadler, R.A., *et al.* (2009) The Copenhagen Diagnosis: Updating the World on the Latest Climate Science. The University of New South Wales Climate Change Research Centre (CCRC), Sydney, 60 p. https://www.lpl.arizona.edu/sites/default/files/resources/globalwarming/Copenhagen_Diagnosis_HIGH.pdf

[9] Johra, N. (2010) Strategies for Producing Clean Fuel in Syrian Refining Sector. *OAPEC/NOGA Conference*, Bahrain, 25-27 October 2010, 119 p.

[10] Galeeva, D. (2018) The Gulf Cooperation Council (GCC): A Comprehensive View. Al-Mesbar Center, Dubai. https://mesbar.org/the-gulf-cooperation-council-gcc-a-comprehensive-view/

[11] [IPCC] Intergovernmental Panel on Climate Change (2020) Oceans and Cryosphere under a Changing Climate: Special Report of the Intergovernmental Panel on Climate Change. Summary for Policy Makers. IPCC. (In Arabic) https://www.ipcc.ch/site/assets/uploads/sites/3/2020/07/SROCC_SPM_ar.pdf

[12] IPCC (2007) Summary for Policymakers. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate.

[13] IPCC (2011) Summary for Policymakers. In: Edenhofer, O., Pichs Madruga, R., Sokona, Y., Seyboth, K., Matschoss, P., *et al.*, Eds., *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, Cambridge University Press, Cambridge, 183 p.

[14] IPCC (2006) IPCC Guidelines for National Greenhouse Gas Inventories. Volume 2 Energy. IPCC, Geneva.

[15] United Nations Climate Action. https://www.un.org/en/climatechange/net-zero-coalition

[16] [UNFCCC] United Nations Framework Convention on Climate Change, Secretariat (2021) Nationally Determined Contributions under the Paris Agreement: Synthesis Report by the Secretariat. FCCC/PA/CMA/2021/8, Document 306848. https://unfccc.int/sites/default/files/resource/cma2021_08E.pdf

[17] Saputra, R., Khalid, M., Walvekar, R., *et al.* (2022) Chapter 15. Circular Carbon Economy. In: Khalid, M., *et al.*, Eds., *Emerging Carbon Capture Technologies*, Elsevier, Amsterdam, 427-462. https://doi.org/10.1016/B978-0-323-89782-2.00010-7

[18] Jung, J., Jeong, Y., Lim, Y., *et al.* (2013) Advanced CO_2 Capture Process Using MEA Scrubbing: Configuration of a Split Flow and Phase Separation Heat Exchanger. *Energy Procedia*, **37**, 1778-1784. https://doi.org/10.1016/j.egypro.2013.06.054

[19] Lake, L.W., Mohammad, L. and Bryant, S.L. (2018) Chapter 2. CO_2 Enhanced Oil Recovery Experience and Its Messages for CO_2 Storage, Science of Carbon Storage in Deep Saline Formations. In: Newell, P. and Ilgen, A.G., Eds., *Science of Carbon Storage in Deep Saline Formations*: *Process Coupling across Time and Spatial Scales* Elsevier, Amsterdam, 15-31. https://doi.org/10.1016/B978-0-12-812752-0.00002-2

[20] Lee, R.P., Keller, F. and Meyer, B. (2017) A Concept to Support the Transformation from a Linear to Circular Carbon Economy: Net Zero Emissions, Resource Efficiency and Conservation through a Coupling of the Energy, Chemical and Waste Management Sectors. *Clean Energy*, **1**, 102-113. https://doi.org/10.1093/ce/zkx004

[21] Madejski, P., Chmiel, K., Subramanian, N., *et al.* (2022) Methods and Techniques for CO_2 Capture: Review of Potential Solutions and Applications in Modern Energy Technologies. *Energies*, **15**, Article No. 887. https://doi.org/10.3390/en15030887

[22] Luomi, M., Yilmaz, F., Al Shehri, N., *et al.* (2021) The Circular Carbon Economy Index-Methodological Approach and Conceptual Frameworks. Methodology Papers (King Abdullah Petroleum Studies and Research Center), ks-2021-mp01. https://ideas.repec.org/p/prc/mpaper/ks--2021-mp01.html https://doi.org/10.30573/KS--2021-MP01

[23] McDonough, W. (2016) Carbon Is Not the Enemy. *Nature*, **539**, 349-351. https://doi.org/10.1038/539349a

[24] Luomi, M., Alshehri, T. and Howarth, N. (2021) Measuring to Manage: The Case for Improving CO_2 Monitoring and Reporting in Saudi Arabia. KAPSARC. https://www.kapsarc.org/research/publications/measuring-to-manage-the-case-for-improving-co2-monitoring-and-reporting-in-saudi-arabia/#

[25] [UNCTAD] United Nations Conference on Trade and Development (2018) Circular Economy: The New Normal? Policy Brief, No. 61 (May). https://unctad.org/system/files/official-document/presspb2017d10_en.pdf

[26] Yusuf, N. and Lytras, M.D. (2023) Competitive Sustainability of Saudi Companies through Digitalization and the Circular Carbon Economy Model: A Bold Contribution to the Vision 2030 Agenda in Saudi Arabia. *Sustainability*, **15**, Article No. 2616. https://doi.org/10.3390/su15032616

[27] Calzado Catalá, F., Flores de la Fuente, R., Gardzinski, W., *et al.* (2013) Oil Refining in the EU in 2020, with Perspectives to 2030. CONCAWE, Brussels. https://www.concawe.eu/wp-content/uploads/2017/01/rpt_13-1r-2013-01142-01-e.pdf

[28] Surampalli, R.Y., Zhang, T.C., Tyagi, R.D., *et al.* (2015) Carbon Capture and Storage: Physical, Chemical, and Biological Methods. American Society of Civil Engineers (ASCE), Reston, 538 p.

[29] Kuwait Petroleum Corporation. KPC 2050 Energy Transition Strategy. https://www.kpc.com.kw/uploads/SustainabiltyReport/KPC_2050_Energy_Transition_en.pdf