

# Saudi Arabia's Net-Zero World Narrative

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# At a Glance

- › Given the expected eventual decline in global oil demand and prices, Saudi Arabia's efforts to diversify its economy away from oil are inextricably linked to its climate policy. Successful efforts in climate change mitigation could prolong Saudi Arabia's political and economic influence granting policymakers the power to shape the energy transition in such a way as to ensure a greater long-term role for cleaner hydrocarbons, simultaneously positioning the country as a leader in sustainable development. Effective climate action is urgently required as the Gulf region is among the world's most vulnerable to the impacts of climate change, including rising temperatures, water scarcity, and extreme weather events.
- › In its pursuit of net-zero over the coming decades, Saudi Arabia is promoting its own narrative: a narrative of transitioning to a net-zero world, which is portrayed as a more just approach than one that advocates for a rapid transition away from fossil fuels as the only solution.
- › This study takes stock of Saudi Arabia's net-zero ambitions in terms of its formulation, the status of its implementation and whether the narrative is a viable alternative to one that "merely" advocates the removal of state support for fossil fuels and the pricing of emissions. The study argues that there is a substantial gap between the Kingdom's ambitions and implementation and questions some of the practical complexities of the overarching Circular Carbon Economy (CCE) approach. Simultaneously, the study acknowledges that the CCE approach offers collaboration opportunities needed for achieving the required economies of scale in renewables, hydrogen, and carbon capture utilisation and storage (CCUS). In this regard, the study points towards the fact that the EU and its member states are starting to develop policies and capacities that allow for deeper and wider avenues of cooperation with Saudi Arabia and its net-zero world narrative.

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# Introduction: Saudi Arabia's Net-Zero World Narrative

Alarmingly, Saudi Arabia (or “the Kingdom”) is experiencing a more accelerated warming trend than the global average. While the world has warmed by an average of 1.1°C since the pre-industrial era (1850–1900), warming in the Arabian Peninsula has already surpassed 1.5°C and is on the verge of exceeding 2°C (McCabe et al. 2023). For each degree of global warming, the corresponding increase in regional temperatures is significantly more pronounced for the Arabian Peninsula. As evidenced by the rapid degradation of its marine and terrestrial ecosystems, suffering the burden of pollution and overexploitation of resources, the Kingdom’s environmental parameters are already “at the verge of liveability” and an unmitigated climate crisis will “have profound implications on the future viability of a sustainable and healthy society, and will likely manifest an existential crisis to Saudi Arabia” (McCabe et al. 2023).

Whether in Germany, Saudi Arabia or almost any country in the world, achieving net-zero will entail a radical transformation of the energy system from one that is dominated by fossil fuels to one that is based on renewable sources, such as solar, wind, and hydrogen. It will also require enhancing energy efficiency, electrifying end-use sectors (such as transport and industry), reducing non-CO<sub>2</sub> emissions (such as methane and nitrous oxide), and increasing carbon sinks (such as afforestation and soil carbon sequestration) (Maalouf 2024).

The gargantuan task of decarbonising Saudi Arabia is evident in a few simple statistics.

In 2022, the country ranked 48<sup>th</sup> in the world by population and 17<sup>th</sup> by economic activity while consuming more oil than any country outside the United States, China, and India (Energy Institute 2024; United Nations 2024; World Bank n.d.). In 2022, it ranked 8<sup>th</sup> among the world’s top ten CO<sub>2</sub>-emitters (in absolute terms) and 2<sup>nd</sup> among them in terms of CO<sub>2</sub> per capita footprint (Figure 1).



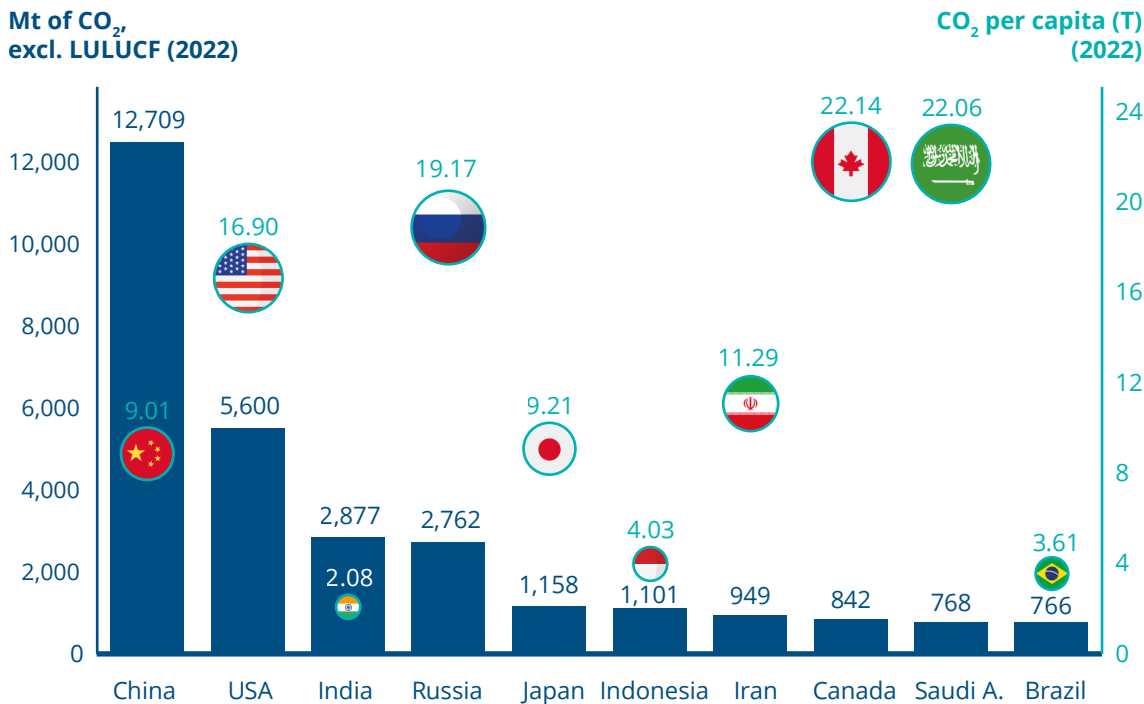


Figure 1: Top 10 countries (2022) global CO<sub>2</sub> emissions (Mt) from all sectors and excluding land use, land-use change, and forestry – LULUCF (bars, left y-axis) and CO<sub>2</sub> (t) per capita (flag icons, right y-axis). Source: Climate Trace (n.d.).

Although Saudi Arabia has among the world’s highest emissions per capita, mainly driven by the energy sector, the country has the second lowest emissions globally per unit produced, with the reduction in flaring intensity helping it reduce upstream carbon intensity despite higher oil production (IMF 2023).

As one of the world’s leading global oil producers, the Kingdom “fully recognises its share of responsibility in advancing the fight against the climate crisis” (SPA 2021a). In 2021, the country told the world that its goal is to “reach net zero carbon emissions by 2060” under the precondition that this goal “will not have an adverse financial or economic impact on oil exporters” (SPA 2021b). In 2020, Saudi Aramco, the world’s largest integrated energy and chemicals company and a substantial contributor to direct and indirect atmospheric emissions, announced it would decarbonise its own operations by 2050. By 2030 already, the Saudi government promises to be a “model for the production of all energy sources and the best in terms of energy efficiency” (SPA 2021b).

In its pursuit of net-zero over the coming decades, Saudi Arabia is promoting its own narrative of a just world. This narrative envisions cost-competitive oil production with a low-carbon intensity from the Gulf region continuing to provide stability over the coming decades as the world gradually shifts to a Circular Carbon Economy (CCE). The CCE is presented as a management system aimed at minimising, reusing, and storing carbon, viewing it as a tradable commodity rather than a negative externality. During this shift, hydrocarbon exporters like the Kingdom aim to successfully diversify their economies while wholeheartedly embracing renewables, implementing energy efficiency measures and converting their natural resources into valuable products such as low-carbon hydrogen. The Kingdom’s policymakers argue that this narrative of transitioning to a net-zero world is more holistic and just than one that simply advocates a rapid transition away from fossil fuels as the only solution (Luomi 2022).

This study analyses and describes the main features of Saudi Arabia's net-zero world narrative. It also argues that although the Kingdom has taken some steps in implementing its narrative, there is a substantial "ambition-to-action" gap in terms of practical implementation and effective results.

The main questions this study answers are the following:

- I) How is climate change impacting Saudi Arabia and the Gulf region?**
- II) How and where has the Kingdom articulated initiatives in support of its net-zero narrative?**
- III) In terms of ambition-to-action, what is the status of Saudi Arabia's net-zero narrative?**
- IV) How and where can Europe and Saudi Arabia collaborate effectively in implementing an inclusive net-zero action plan?**

# Climate Change in the Gulf: Historical Trends and Projections

The six countries of the Gulf Cooperation Council (GCC), i.e., the Kingdom of Bahrain, the State of Kuwait, the Sultanate of Oman, the State of Qatar, the Kingdom of Saudi Arabia, and the United Arab Emirates (UAE) are among the world's most vulnerable to the impacts of climate change, such as rising temperatures, water scarcity and extreme weather events. In April 2024, for example, a record of 254 millimetres (10 inches) of rainfall was recorded in Al Ain, UAE, a city bordering Oman. This was the largest amount ever in a 24-hour period since records began in 1949 (Cornwell 2024). After Dubai experienced the heaviest downpours in the UAE in 75 years, the city announced that it will spend 30 billion dirhams (8.2 billion USD) to enhance its rainwater drainage system (Reuters 2024).

An in-depth analysis of historical data regarding precipitation and temperature in the Gulf is, therefore, relevant, not only for the development of policies linked with future planning for the water and agriculture sectors, but also to preserve national heritage sites, promote the tourism industry, and provide disaster resilience (Almazroui 2020a).

While there are differences in methodology, data coverage, and periods, this section highlights a consensus in the literature regarding observed temperature and precipitation trends from the World Bank Climate Change Knowledge Portal (CCKP) and the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR). Despite some variation, all observations indicate increasing extremes in these two critical climate variables across the Arabian Peninsula, which is an alarming trend for sectors such as water resources, agricultural production, public health, and infrastructure.

Recent analyses of these essential climate variables in the GCC include data obtained from dozens of stations across the Arabian Peninsula (AP) and within a data period from 1943 to 2008. Although the data coverage is low density (i.e. 24 stations) and covers a relatively short period, the majority of stations in the AP reported statistically significant increasing trends over the AP as a whole regarding mean annual temperature. The highest trends in this regard took place in the central and eastern/southeastern parts of the AP (AlSarmi and Washington 2011; 2014). In conjunction, the yearly number of very warm days (> 40°C) and very warm nights (> 25°C) has increased significantly.

Historical data from the World Bank CCKP for the GCC over a more extended period (1901–2020) correlates with findings for the AP as a whole (World Bank 2021).<sup>1</sup> Figure 2a shows a statistically significant upward trend line (p-value <0,0001) in the average annual temperature between May

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1 CCKP historical data comes from observational data produced by the Climate Research Unit (CRU) of the University of East Anglia. The CRU historical dataset is derived from observational data and provides quality-controlled temperature and rainfall values from thousands of weather stations worldwide. Globally observational datasets from the CRU are widely accepted as reference for the baseline in climate research. The historical trend information presented in the CCKP uses CRU data to quantify changes in mean annual temperature and mean annual precipitation, for the period 1901 to 2020. To test the ability of the models to represent the historical climate, simulations of that historical past (for the same period as the data available for CRU) are compared against CRU data. To evaluate projected temperature and precipitation, the model's representation of the seasonal cycle (monthly values for key variables) is additionally evaluated with respect to historic values. The same thresholds and assumptions to categorise the observed changes have been used as for the projected changes.



and September; the bold bright line shows the Gulf as a whole, while the lines in the background designate the six countries separately.<sup>2</sup>

**Avg. temperature (celsius)**

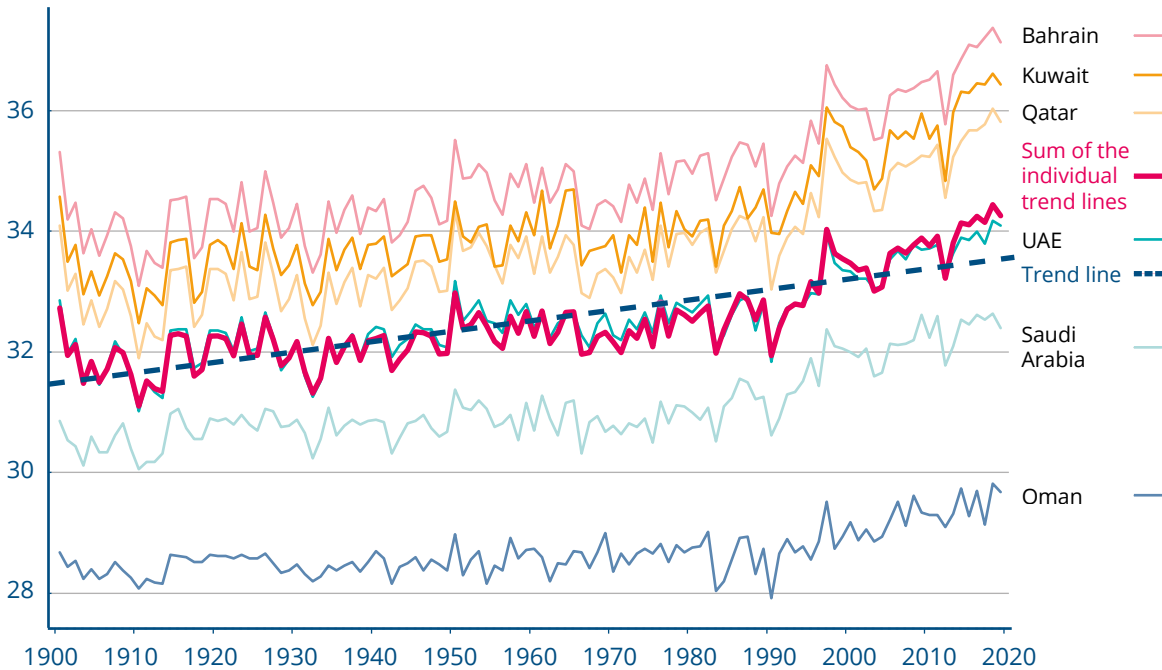


Figure 2a: Average annual Gulf summer temperature (May–September 1901–2020). Source: World Bank. CCKP (2021). Note: The thick, centred line depicts the sum of the individual trend lines.

<sup>2</sup> Statistical significance is a determination that a relationship between two or more variables is caused by something other than chance. Statistical hypothesis testing provides a p-value (“probability value”). This value is a measure of the probability that an observed difference could have occurred just by random chance. The lower the p-value, the greater the statistical significance of the observed difference. A p-value of 5% or lower is considered here to be statistically significant. With a p-value of 5% comes a confidence level of 95%, i.e. it’s always the inverse of the p-value. The confidence level expresses how sure we are that, if we were to repeat our data analysis, we would get the same averages.

Figure 2b shows that measuring for the last four decades (1980–2020), the upward, red-thick-dotted trend line (p-value <0,0001) across the axes is steeper than in Figure 2a. This trend means an accelerated rise in the annual summer temperature across the Gulf as a whole, as well as in individual countries during this period.

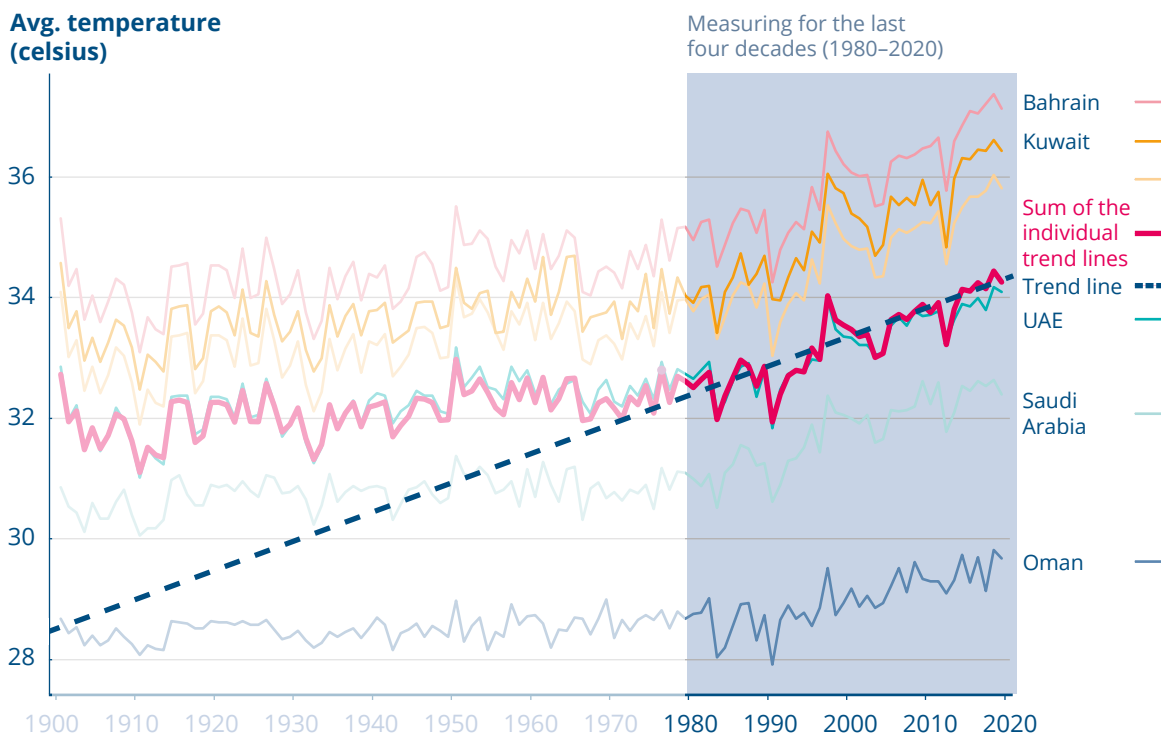


Figure 2b: Average annual GCC summer temperature (May–September 1980–2020). Source: World Bank Group CCKP (2021). Note: The thick, centred line depicts the sum of the individual trend lines.

While increasing summer temperatures are a growing concern across the Gulf, decreasing, more irregular, and extreme precipitation also plays into regional resiliency. The rainy seasons on the AP fall into two broad categories. The wintry type of rainfall, which extends from October to April, constitutes rain covering most of the AP. The summer season, which extends from May to September, is the season in which rain covers the mountains in the north and south of Oman, and in the south-west of Saudi Arabia.

Recent studies on historical rainfall trends and extremes in individual Gulf countries like Saudi Arabia, for example, measure daily rainfall data obtained from 25 meteorological stations across the country for 42 years in the period from 1978–2019 (Almazroui 2020a). This detailed analysis reveals a decreasing trend in annual and wet seasonal rainfalls over Saudi Arabia during the study period, and simultaneously an increasing frequency of extreme rainfall events. This is described in terms of “an alarming situation for the country’s water resources, agricultural production, and socioeconomic needs” (ibid.). This analysis calls for further investigation to understand the impacts of climate change on Saudi Arabia and the other GCC countries.

Regarding future projections across the AP, applying the regional climate modelling approach to dynamically downscale three general circulation models, RICCAR provides data on the essential climate variables. These include the mean change in the number of days warmer than 35°C and the mean change in the number of days above 20mm precipitation. Figure 3a indicates a substantial increase in the number of hot days; under a Representative Concentration Pathway (RCP) of 4.5. This is felt most intensely in Oman; under a RCP8.5, the GCC is set to exceed the 35°C threshold

towards the end of the century (Annex 1).<sup>3</sup> A recent contribution to the literature that uses similar greenhouse gas (GHG) scenarios, yet with a different control period (1976–2005) and projection focus (2006–2009), argues that the number of hot days ( $\geq 40^\circ\text{C}$ ) shows an increasing trend for all capitals and that daily maximum temperature during the summer months could exceed  $50^\circ\text{C}$  for almost all cities in the GCC (Almazroui 2020b).<sup>4</sup> Projections for precipitation in Figure 3b indicate an overall decrease across the GCC in the number of days of 20mm, except for some coastal areas of Oman.<sup>5</sup>

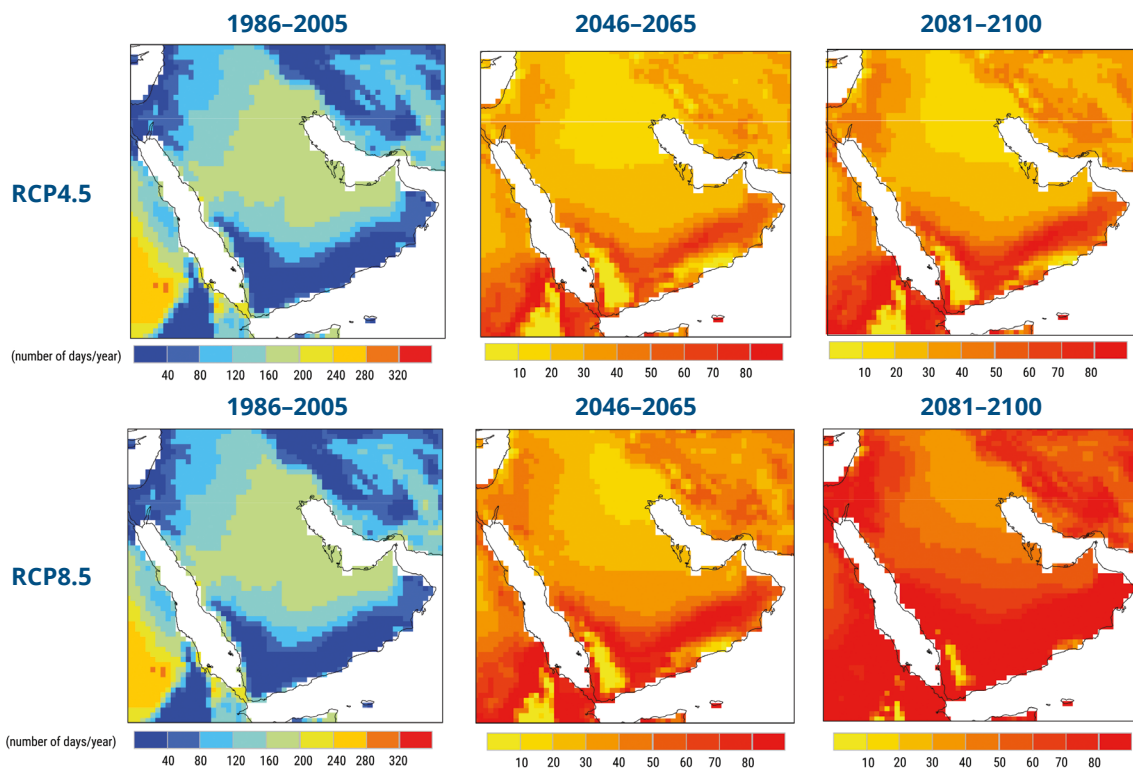


Figure 3a: Mean change in the number of hot days ( $35 > ^\circ\text{C}$ ) for mid- and end-century for RCP4.5 and RCP8.5 projections (2046–2100) compared to reference period (1986–2005). Source: RICCAR (2017).

Note: The two future periods (2046–2065 and 2081–2100) represent a change in values relative to the reference period. The reference period shows the absolute number of days and the two future periods show the change in number of days.

<sup>3</sup> The emissions scenario used to generate RCP8.5 has come under criticism by a number of researchers for its assumptions around high future emissions and a dramatic expansion of coal use (Hausfather and Peters 2020; Ritchie and Dowlatabadi 2017).

<sup>4</sup> This study uses an ensemble of three dynamically downscaled global climate models (ECHAM, GFDL, and HadGEM) available from the Coupled Model Intercomparison Project Phase 5 (CMIP5).

<sup>5</sup> The data is based on 50-km grid and represents an average from three downscaled models (CNRM-CM5, EC-EARTH, and GFDL-ESM2M).

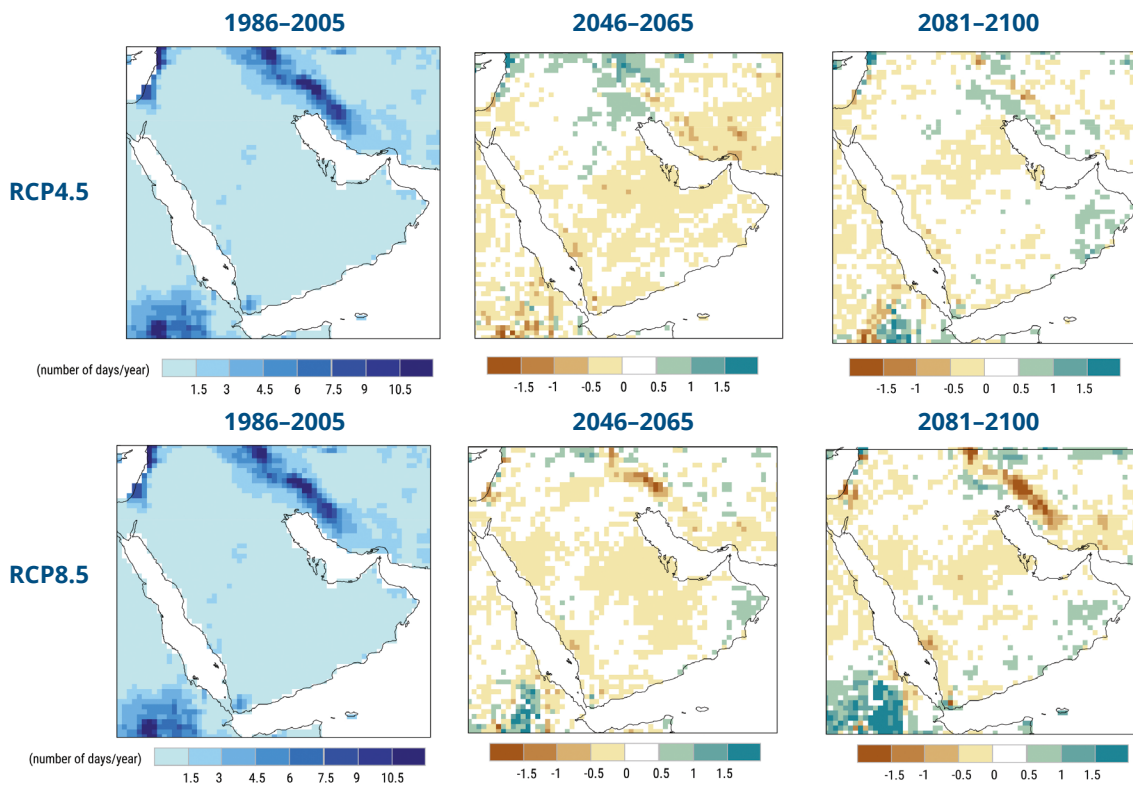


Figure 3b: Mean change in the number of 20mm precipitation days (20mm) for mid- and end-century for RCP4.5 and RCP8.5 projections (2046-2100) compared to reference period (1986-2005). Source: RICCAR (2017). Note: The two future periods (2046-2065 and 2081-2100) represent a change in values relative to the reference period. The reference period shows the absolute number of days and the two future periods show the change in number of days.

The 2023 Climate Futures Report “Saudi Arabia in a 3-Degrees Warmer World” forecasts some of the potential consequences arising from this possible climate trajectory by the end of the century and discusses how to avoid some of the potential climate outcomes that such a future might impose (McCabe et al. 2023). Furthermore, this study encourages “informed decision-making processes, [to] drive the adoption of adaptive and climate resilient strategies and facilitate needed efforts in sustainable development” (ibid.). Finally, the variation in climate outcomes projected from different climate models and scenarios “underscores the importance of [Saudi] decisions and actions today in shaping [its] climate future” (ibid.).

# The World's Central Oil Banker and the Energy Transition

As the largest economy in the MENA region, Saudi Arabia wields significant political and economic influence.<sup>6</sup> Figure 4 shows the Kingdom's economic powerhouse status and the fact that its gross domestic product (GDP) reached over one trillion USD for the first time in 2022 (thereby accounting for more than a quarter of the MENA total).

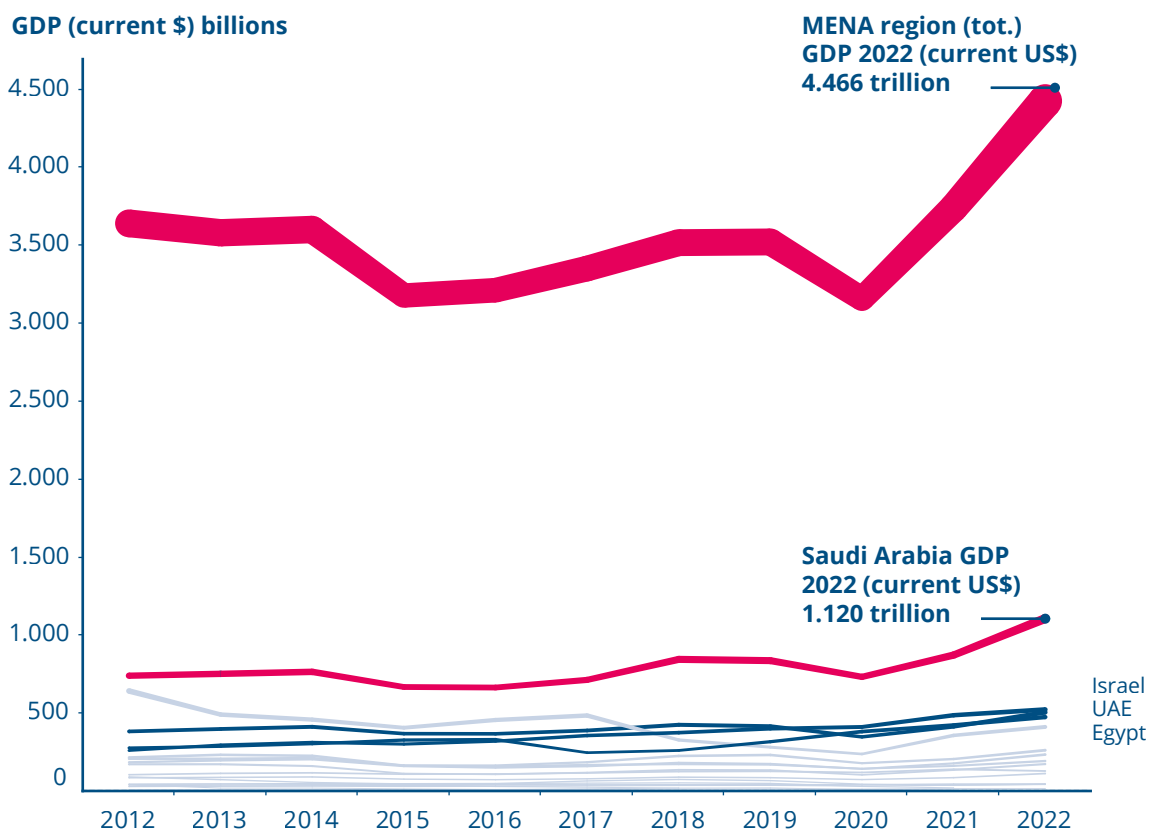


Figure 4: GDP (current USD) MENA (2012–2022). Source: World Bank Group (n.d.ii).

Saudi Arabia is perhaps the world's purest example of a petrostate (Krane 2019). In 2020, Saudi Arabia held 17.2% of the world's proven oil reserves, second only to Venezuela (17.5%) and is by far the largest producer within the Organisation of Petroleum Exporting Countries (OPEC) (Energy Institute 2024). Oil accounts for about 40% of real GDP in the last few years while oil revenues averaged 75% of total budget revenues since 2010, although with large variations related to global oil boom and bust cycles (IMF 2022). The Kingdom is among the top three petroleum producers in the world and the biggest exporter of crude oil (Figure 5).

<sup>6</sup> The World Bank defines the MENA region as consisting of the following 21 countries: Algeria, Bahrain, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Malta, Morocco, Oman, Qatar, Saudi Arabia, Syria, Tunisia, United Arab Emirates (UAE), West Bank and Gaza, and Yemen.

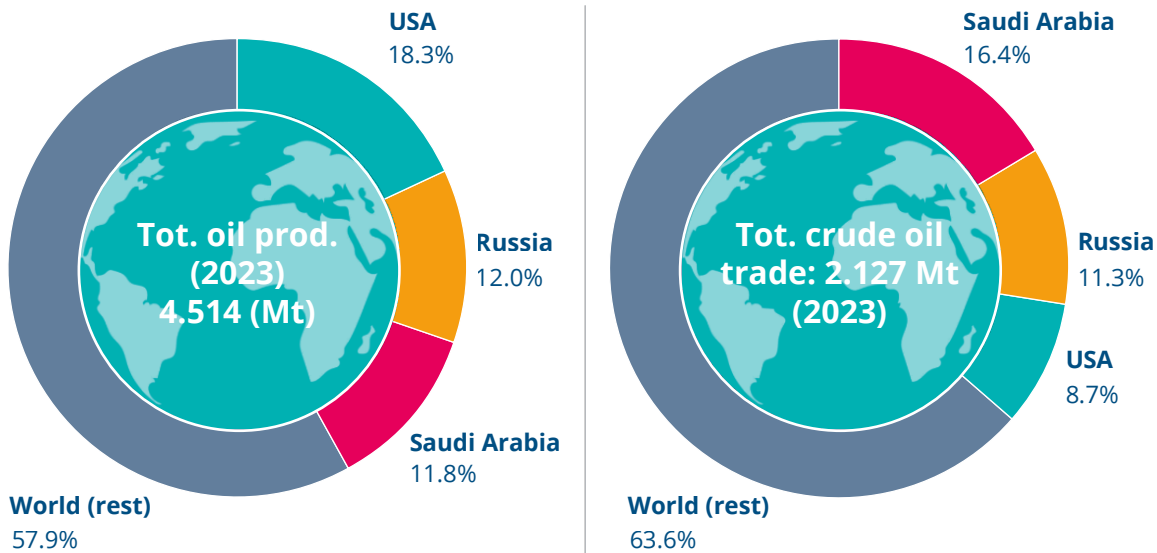


Figure 5: Global crude oil production and trade (2023). Source: Energy Institute (2024).

The main destinations for its crude petroleum exports are non-EU countries, including China (27.8% in 2021), Japan (15.9%), South Korea (13.5%), India (11.5%), and the US (5.64%). In 2021, the EU accounted for approximately 7.8% of Saudi Arabia's crude exports (Delivorias and De Martini 2023).<sup>7</sup> Since Russia's war against Ukraine in February 2022, however, GCC exports of oil products to Europe have been on the rise, reaching a record level of near one million barrels a day in April 2023, with the growth dominated by refineries in Saudi Arabia, Kuwait, and Oman (Fattouh 2024).

As the world's largest crude oil exporter and sole swing producer, the Kingdom's decisions on oil production levels in OPEC have global repercussions, affecting energy prices and economic stability in the region and beyond. The country's oil wealth has fuelled its economic development for decades, enabling it to invest heavily in infrastructure projects, social programmes, and the development of other industries. Through its sovereign wealth fund, the Public Investment Fund (PIF), Saudi Arabia has become a major global investor in diverse sectors, including technology, energy, infrastructure, and entertainment. Additionally, Saudi Arabia provides financial aid and loans to other countries in the MENA region, further enhancing its political and economic influence.

Saudi Arabia is starting the energy transition from a strong position due to the low cost and relatively low CO<sub>2</sub> intensity of its oil production (Aramco 2023). Among the top 30 oil and gas producers globally, Saudi Arabia has the third-lowest flaring intensity rate per barrel of oil produced after Norway and the Netherlands (KAPSARC n.d.). It also has the fourth-lowest levels of fugitive methane emission intensity (CCE Index 2023). These attributes allow Saudi's national oil champion Aramco to present itself as the optimal choice to serve a climate-stressed market, even one in decline (Krane 2021).

The Kingdom also has advantages when it comes to decarbonisation, i.e., a relevant knowledge base, ideal geology, and renewables-rich geography. As exemplified by the 2023 Climate Futures Report, the Kingdom's front-line exposure to climate change is drawing increasing domestic research scrutiny and political attention. Wealth is another advantage. Cyclical windfalls provide

<sup>7</sup> The main destinations of Saudi petroleum exports in Europe were the Netherlands (5.7%), Spain (2.3%), France (2.2%), Italy (1.9%), and Germany (1.1%).



investment capital. Investments in future-oriented sectors represent an ideal way to share oil rents with coming generations (Krane 2022).

The Kingdom is an absolute monarchy, meaning there is no legislature or veto-wielders who can block the ruler's directives while reducing the government's need to tailor policy to short-term election cycles. These factors allow policymaking on a long-term horizon ideal for responding to climate change (ibid.). A disadvantage of the Saudi absolutist monarchical rule is that decrees or pronouncements made by an unelected sovereign are less credible and durable than those made under a democratic system (ibid.). This lack of institutional oversight means that absolute rulers can discard past priorities and even make strategic U-turns (Rundell 2020). It is therefore difficult to oblige absolute rulers to adhere to decisions if rewards from deviation outweigh those from compliance. Therefore, credibility is an important consideration when evaluating present day pronouncements about a decades-long process of emissions elimination, even more so when these pronouncements are not accompanied by a clear implementation plan.

Undeniably, Saudi Arabia faces energy transition risks as the world strives to shift towards net-zero emissions over the coming decades. One such risk is economical given the increasing challenge by alternative fuels and technologies like Power-to-X products (ammonia, methanol, Fischer Tropsch), EV batteries and fuel cells to the conventional transportation fuel market.

But even in a world that is serious about decarbonisation, uses for oil will almost certainly remain. And even in a transition scenario where all countries implement their Nationally Determined Contributions (NDC) fully, the impact on the Kingdom's economy is expected to be limited since oil prices are not projected to significantly reduce (IMF 2023). In combination with the growing expertise of countries like China in the electric vehicles space, which is Saudi Arabia's largest oil customer, the energy transition offers opportunities to extend major existing trade relationships (Saxena et al. 2024). This opportunity is exemplified by the plethora of investments in electric vehicles and technology agreements that was signed during the 10th Arab China Business Conference in Riyadh in 2023 (Arab News 2023).

# Saudi Arabia’s Net-Zero Narrative: Priorities, Initiatives, and Targets

The Saudi Green Initiative (SGI) is one of the key pillars of Saudi Arabia’s Vision 2030, i.e. the government’s strategic framework introduced in 2016 to reduce the country’s dependence on oil and diversify its economy by developing various sectors (e.g. health, recreation, and tourism). Under the umbrella of the SGI, Saudi Arabia announced its pledge to achieve net-zero emissions by 2060 in the lead-up to COP26 in 2021. As a central instrument for realising a substantial emissions reduction by 2030 and net-zero by 2060, the SGI aims to catalyse and implement a sustainable long-term climate action plan for the Kingdom through more than eighty initiatives that are carried out by public and private stakeholders in what is described as a “whole-of-society action” (SGI n.d.).

Table 1 presents a selection of the initiatives under the three main pillars of the SGI: Reducing emissions, greening Saudi Arabia, and protecting land and sea.

SGI target	Result in year (2030)	Initiatives (selected) & completion year	Emissions reduction / offset (CO <sub>2e</sub> )
<b>Reducing emissions</b>	Reducing carbon emissions by 278 mtpa	<ul style="list-style-type: none"> <li>› Enhance Energy Efficiency Program (2025).*</li> <li>› Domestic energy mix: 50% renewable energy for electricity generation &amp; 50% nat. gas (2030).</li> <li>› Developing a carbon capture and usage programme to produce chemicals and synthetic fuels (2030).**</li> <li>› Produce 4 mt of clean H<sub>2</sub> per year (2030).</li> </ul>	<ul style="list-style-type: none"> <li>› 175 mtpa</li> <li>› 27 mtpa</li> </ul>
<b>Greening Saudi Arabia</b>	<i>(interim)</i> ***: Plant 600 million trees across Saudi Arabia	<ul style="list-style-type: none"> <li>› Plant 100 million mangrove trees (2030)</li> <li>› Sustainable forest management and devel.</li> <li>› Plant 4 million lemon trees with treated wastewater (2025).</li> <li>› Plant 45 million agricultural trees in mountain terraces (2025).</li> <li>› Regreen NEOM with 100 million native trees (2030).</li> </ul>	<ul style="list-style-type: none"> <li>› offset 45 mt (by 2030)</li> <li>› 24 mt</li> <li>› <i>not mentioned</i></li> <li>› <i>not mentioned</i></li> <li>› <i>not mentioned</i></li> </ul>

<b>Protecting land and sea</b>	Raise protected areas to >30% of terrestrial and marine areas	<ul style="list-style-type: none"> <li>› Desert Preservation Initiative (2025).</li> <li>› Designate 10 biodiversity protection areas of 977 sq. km<sup>2</sup> (2025).</li> <li>› Sustainable management and conservation of coastal area environments (2025).</li> </ul>	
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*Table 1: Saudi Green Initiative. Source: Saudi Green Initiative (2024). \*) Implement new energy efficiency standards across power generation, water desalination, and electricity transmission and distribution. \*\*) Harnessing novel technologies to convert captured CO<sub>2</sub> into 12 tons per day of small-scale green methanol. \*\*\*) a 10 billion trees target (equivalent to rehabilitating 74 million hectares of land) is mentioned but without a target year. Only the interim target contains a target year.*

As part of the SGI, and as a signatory to the Paris Agreement (2015), the Kingdom updated its climate pledge, with the ambition to reduce, avoid, and remove 278 million tons of CO<sub>2</sub>eq annually by 2030 (Kingdom of Saudi Arabia 2021). Next to implementing the actions, projects, and plans mentioned in Table 1, their NDC also highlights the Kingdom’s participation in major international initiatives that are working to address emissions, including the Middle East Green Initiative, Global Methane Initiative, Mission Innovation, the Clean Energy Ministerial, the Net-Zero Producers Forum (launched in April 2021) and the Global Methane Pledge (announced in September 2021) (Kingdom of Saudi Arabia 2021).

The Circular Carbon Economy (CCE) approach is the central tool of the Saudi NDC (Figure 6). The CCE builds on the idea of the circular economy but, instead of material flows, focuses on energy and CO<sub>2</sub> or GHG emissions (KAPSARC 2020). The CCE consists of 4Rs:

- › **Reducing** carbon through low-carbon fuels, electrification, and renewables, and improving energy and process efficiencies.
- › **Reusing** carbon as an input to create feedstocks, fuel, and for enhanced oil recovery.
- › **Recycling** emissions or products containing GHGs into similar or different products with different chemical characteristics.
- › **Removing** carbon by carbon dioxide removal (CDR) technologies and measures to offset residual emissions.

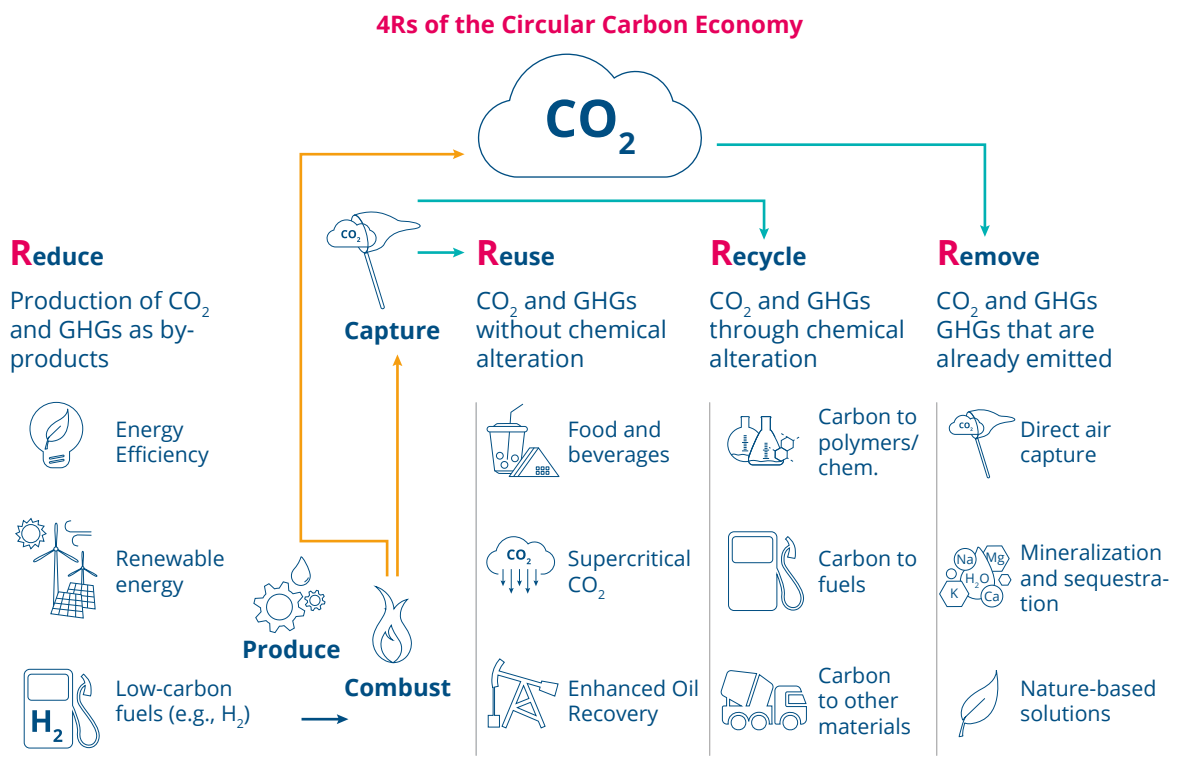


Figure 6: 4Rs of the Circular Carbon Economy (CCE). Source: Adapted from Al-Ghareeb (2022).

To achieve a CCE and net-zero emissions, the Kingdom argues that no technology option should be excluded. Emissions should be reduced, recycled, reused, and removed in the most efficient way in each individual country. With an emphasis on cost-effectiveness, the CCE is open to all mitigation options tailor-made for each specific country, including renewable energy, energy efficiency, green hydrogen, and CCUS. The underlying aim of the CCE is to reframe the discourse on GHG emissions from being viewed solely as negative externalities to commodified goods.

Next to the CCE, the Saudi NDC mentions other pillars of the Saudi net-zero narrative. To advance the uptake of CCUS technologies and scale up their deployment, the Kingdom plans to transform several industrial cities along the Red Sea coast into global hubs for CCUS. During the launch of the Saudi Green Initiative at COP 27 (2022), Saudi Energy Minister Prince Abdulaziz announced the goal to achieve 44 million tonnes per annum (mtpa) of CCUS by 2035, supported by Aramco, which raised its carbon capture and storage (CCS) target from 11 to 14 mtpa by 2035 (Arab News 2022; Aramco 2023).

All Saudi climate ambitions exist beneath the overarching statement in the NDC that they are contingent on long-term economic growth and diversification of the Kingdom's sources of national income. This is to be achieved by increasing the number of sectors which participate in the economy but remains dependent nonetheless on a robust contribution from hydrocarbon export revenues (Kingdom of Saudi Arabia 2021).<sup>8</sup>

<sup>8</sup> Among these "other sectors", the NDC mentions manufacturing industries, energy-related derivatives, mining, tourism, logistics, and information technology industries.

# Saudi Arabia's Net-Zero Challenges, Gaps, and Counterarguments

Saudi Arabia has implemented a wide range of climate change policy instruments to date. Examples include energy pricing reforms in 2016 and 2018, energy efficiency in manufacturing processes, loan programmes for distributed solar electricity generation, and fuel and vehicle price-related policies in the transport sector (Belaïd and Aldubyan 2022; Gasim et al. 2023; NKC 2023; Shannak et al. 2022; Sheldon and Dua 2021).

In an international context, the CCE Index is an annual publication providing an overall score that incorporates measures for eight primary climate change mitigation technologies and policy measures currently in implementation in countries worldwide (Table 2).

CCE performance score	CCE enablers score
Energy efficiency	Policies and regulation
Renewable energy	Technology knowledge and innovation
Electrification	Finance and investment
Nuclear energy	Business environment
Fuel switching	System resilience
Natural sinks	CCE Performance & Enablers scores = <b>Tot. CCE Index score (scale: 0-100)<sup>9</sup></b>
CCUS	
Hydrogen	

Table 2: 2023 CCE Index indicator framework. Source: Luomi et al. (2023).

In the 2023 CCE Index, the top three countries were Norway, the United Kingdom, and the Netherlands (KAPSARC n.d.). Among the total 64 countries covered by the index, Saudi Arabia ranked 20<sup>th</sup> in 2023, i.e. up from its 22<sup>nd</sup> position in the 2022 and showing clear strengths and weaknesses across its performance and enablers scores (Luomi et al. 2023).<sup>10</sup>

The Kingdom has made some progress in implementing emissions reduction policies and technologies, providing tools that allow for the measuring of developments in key parts of its net-zero narrative. However, significant challenges, gaps, and counterarguments remain.

<sup>9</sup> The 2023 edition of the CCE Index comprises a total of 38 indicators. Eight indicators measure performance, and 30 measure enabling factors. Separate scores are first calculated for the performance and enablers scores, which are then aggregated to form the total CCE Index score.

<sup>10</sup> The CCE Index covers 64 major economies across all world regions, accounting for approximately 90% of the global economy and CO<sub>2</sub> emissions.

## i. Janus-Faced Climate Action

Saudi Arabia's current climate policies and commitments for 2030 are rated as "critically insufficient" as these are not consistent with limiting warming to 1.5°C (Climate Action Tracker 2023). The NDC aims to reduce, avoid, and remove GHG emissions with the goal set at 278 million tons of CO<sub>2</sub>eq annually by 2030 compared to a business-as-usual (BAU) scenario (and with 2019 as a reference year). However, the NDC does not specify where overall emissions would stand in 2030 under this scenario. Without this, it is not possible to know what absolute emission levels the NDC targets for 2030 (NKC 2023). Also, the more oil is allocated to domestic consumption the higher the emissions baseline will be; moreover, exported hydrocarbons will not contribute to the Kingdom's GHG emissions (NKC 2023; Kingdom of Saudi Arabia 2021).

The 2030 emissions reduction target mentioned in the Saudi NDC is explicitly based on a scenario with substantial fossil fuel exports and includes an "opt-out clause" in case the economic and social consequences of international climate change policies place a disproportionate or abnormal burden on the country's economy (Kingdom of Saudi Arabia 2021).

Saudi Arabia also has a track record of obstructing international climate negotiations by opposing references to the 1.5°C warming limit, and of engaging in efforts to remove language on fossil fuel subsidies while hosting the G20, (Michaelson and Greenfield 2022; Farand 2020). Only in exchange for political support from the EU for its CCE approach did the Saudi presidency reinstate language at the last minute on the G20's recurring commitment since 2009 on phasing out fossil fuel subsidies (Lo 2020).

## ii. Circular Carbon Economy Complexities

Regarding the cornerstone of the Saudi net-zero narrative, a National CCE Program has been announced but not yet released (NKC 2023). It had already been pointed out in 2022 that a clearly defined CCE taxonomy, and its consistent use in a national programme can provide the required conceptual clarity, and function as a blueprint for other countries regarding its practical implementation (Al Shehri et al. 2022). Besides the absence of a CO<sub>2</sub>-market for the use of CO<sub>2</sub> at scale, any practice-oriented CCE policy framework will face a range of highly complex implementation challenges. For example, the re-use pillar of the CCE raises serious carbon leakage concerns as making this truly circular will require sensor-based measurement of emissions in real-time along complex supply chains and across regions and state borders.

Even with the implementation of a highly complex and costly carbon leakage monitoring system, one could argue that the propagated carbon processes are not truly circular due to the absence of a closed loop. The CCE Guide acknowledges this by stating that "the process of closing the loop in the circular carbon economy will be ongoing and evolving over the coming decades" (KAPSARC 2020). In reality, the CCE follows a linear process of producing and consuming fossil fuels, where carbon emissions are either withheld from the atmosphere or released when fuels are burned without CCS, such as in the case of synthetic jet fuel.

An obvious counterargument to implementing an intrinsically complex CCE system is that there is a simpler and more cost-effective way to ensure that CO<sub>2</sub> is removed from the system permanently – namely removing state support for fossil fuels and pricing emissions (Schröder et al. 2021).



Fossil fuel subsidies structurally undermine global efforts to mitigate climate change, including distorting the costs and prices that inform the decisions of many producers, investors, and consumers, thereby perpetuating older technologies and carbon-intensive modes of production (Fossil Fuel Subsidy Tracker 2023). Globally, total fossil fuel subsidies amounted to a staggering seven trillion USD in 2022, equivalent to nearly 7.1% of global GDP (Black et al. 2023). Explicit subsidies (whereby the domestic price for a traded fuel is below the international price) accounted for 18% of the total while implicit subsidies (undercharging for environmental costs and forgone consumption taxes) accounted for 82% (Black et al. 2023). Saudi Arabia spend a total of 129 billion USD in explicit subsidies, constituting almost 14% of its GDP (Black et al. 2023). In terms of fuel types and end-use electricity, Saudi Arabia spent almost 77 billion USD in consumer subsidies (Table 3).

Country	Beneficiary	Mechanism	End-use electricity	Natural gas	Petroleum	Coal	Grand total
#1: Russia	Consumer	Induced transfer	\$63,045,333,600	\$97,812,225,535	\$0	\$0	\$160,857,559,135
#2: Iran	Consumer	Induced transfer	\$29,515,111,643	\$45,252,120,727	\$52,193,180,226	\$0	\$126,960,412,596
#3: China	Consumer	Direct budgetary transfer	\$0	\$95,801,000	\$4,868,124,000	\$8,390,756,000	\$13,354,681,000
		Induced transfer	\$54,609,858,560	\$19,041,575,584	\$0	\$0	\$73,651,434,144
	General services	Direct budgetary transfer	\$0	\$20,082,000	\$22,333,000	\$542,662,000	\$585,077,000
	Producer	Direct budgetary transfer	\$0	\$1,219,056,000	\$1,708,166,000	\$822,786,000	\$3,750,008,000
#4: Saudi Arabia	Consumer	Induced transfer	\$25,299,813,980	\$16,564,047,232	\$35,080,273,114	\$0	\$76,944,134,326
#5: India	Consumer	Direct budgetary transfer	\$0	\$103,175,000	\$582,028,000	\$0	\$685,203,000
		Induced transfer	\$19,257,546,752	\$2,389,016,976	\$33,289,618,944	\$0	\$54,936,182,672
		Direct budgetary transfer	\$0	\$0	\$5,090,000	\$51,636,000	\$56,726,000
		Direct budgetary transfer	\$0	\$0	\$0	\$6,875,000	\$6,875,000

Table 3: Top five countries (2022) in fossil fuel subsidies defined according to beneficiaries, mechanisms, and fuel types. Source: Fossil Fuel Subsidy Tracker (2023).<sup>11</sup>

The complexities of these divergent estimates aside, the central message is that Saudi Arabia is currently among the top five nations of the world in terms of fossil fuel subsidies. This fact undermines the validity of the Kingdom’s net-zero narrative as these subsidies perpetuate the use of fossil fuels, leading to higher GHG emissions and delaying the transition to a sustainable, low-carbon economy. By preventing international price signals from reaching consumers, fossil fuel subsidies create an uneven playing field where renewable and low-carbon technologies cannot compete fairly, thereby discouraging investment and slowing adoption and advancement of these technologies.

11 The Fossil Fuel Subsidy Tracker incorporates estimates of fossil fuel subsidies and other support measures for 192 economies and is updated once a year as latest data from source organisations become available. The estimates are gathered from three international databases: The OECD Inventory of Support Measures for Fossil Fuels, the IEA Energy subsidies database and the IMF Fossil Fuel Subsidies database. Estimates from the three organisations are based on two different approaches, which provide complementary information. As a result, the estimates presented in the Fossil Fuel Subsidy Tracker may be under-estimates of actual subsidy totals. This is because the OECD Inventory may have not captured all support measures or because those that were captured have not been fully quantified.

Carbon pricing can be one of the most powerful tools available to policymakers to incentivise emissions reduction as part of an integrated policy mix. Recent data shows that carbon pricing revenues in 2023 exceeded 100 billion USD for the first time, driven by the high prices in the EU's Emissions Trading System (ETS), which continued to account for the bulk of carbon pricing revenues worldwide (World Bank 2023).

Unlike carbon taxation and the market-based “cap-and-trade” approach of the ETS, Saudi Arabia launched a crediting mechanism called the Greenhouse Gas Crediting and Offsetting Mechanism (GCOM) in 2024. Carbon credits are created compared to a baseline and these can be sold to an interested company that want to make voluntary green claims. A general critique of Voluntary Carbon Markets (VCM) is that lax rules about setting a baseline, and the lack of oversight have led to a reputational problem and accusations of greenwashing (Delbeke 2024). A persistent oversupply of credits and an inability to deal with integrity issues rendered the VCM as a whole dysfunctional and ineffective (ibid.).

As an initiative under the PIF, GCOM seems to have been set-up as a learning-by-doing exercise, allowing the likes of Aramco and the Saudi Basic Industries Corporation (SABIC) to familiarise themselves with emissions measurement and verification, and helping to create a basic infrastructure that later might evolve into a fully-fledged carbon pricing instrument. Putting a price on carbon would effectively provide an economic signal to producers and consumers to adopt to greener practices and invest in cleaner technologies. This seems to be a more straightforward endeavour than establishing and guaranteeing an “GHG-tight” CCE system.

### **iii. Renewables: Requirements, Targets, and Implementation**

Since domestic oil consumption is heavily subsidised and exports are priced based on global benchmarks, the target of displacing this fossil fuel from the Saudi electricity generation capacity with 50% renewable energy sources and 50% natural gas by 2030 allows for increased hydrocarbon exports and revenues. This is in line with the emphasis in the NDC on long-term national economic growth based on a robust contribution from oil exports and lowering the domestic emissions baseline. But what would it take to fulfil this ambition, and what is the current state of play as regards the decarbonisation of the Kingdom's highly carbon intensive electricity generation system?

In 2021, Saudi Arabia's electricity generation capacity amounted to 367 TWh (EIA 2023). Using Fraunhofer's AI-tool FhGenie (based on Microsoft Azure OpenAI Service), two calculations estimate that converting half of this generation capacity could require approximately between 113 and 118 gigawatts (GW) of installed renewables capacity by 2030 (Annex 2).

Since 2022, the country has added over two GW of renewable power capacity, which is a 300% increase from the cumulative capacity addition of just 700 MW during the decade before (Saudi & Middle East Green Initiatives 2023). Currently, there are 30 GW of solar and wind projects under development as part of the National Renewable Energy Program (NREP), which is overseen by the Ministry of Energy (Renewable Vision 2024). Additionally, the Saudi Power Procurement Company (SPPC) has issued a request for qualification for a new round of solar and wind power projects with a total capacity of 4.5 GW under the NREP (Principal Buyer 2024).

With the strengthening of policies, a consistent call for competitive auctions, and continuing world record low bids for its projects, Saudi Arabia's renewable power capacity at its present pace is expected to increase at a compound annual growth rate (CAGR) of 40.1% during the 2023–30 period and estimated to reach 31.6 GW and 63.1 GW by 2030 and 2035 respectively (Global Data 2024).

Yet the Saudi Ministry of Energy (MOE) has set the bar even higher, as it has targeted to tender renewable energy projects with a total capacity of 20 GW annually from 2024 onwards, aiming to reach between 100 and 130 gigawatts by 2030, depending on electricity demand growth (Ministry of Energy 2024). Aligned with these ambitions, the Geographic Survey Project for Renewable Energy sites in the Kingdom was launched in June 2024. This project aims to identify the best sites for renewable projects by installing 1,200 stations for a comprehensive measurement of solar and wind energy potential across all the Kingdom's regions (Ministry of Energy 2024).

Figure 7 summarises the estimations at this substantial CAGR and the most recent target by the MOE while suggesting a possible tender target of ten GW annually for the post-2030 period.

### Cumulative renewables capacity (GW)

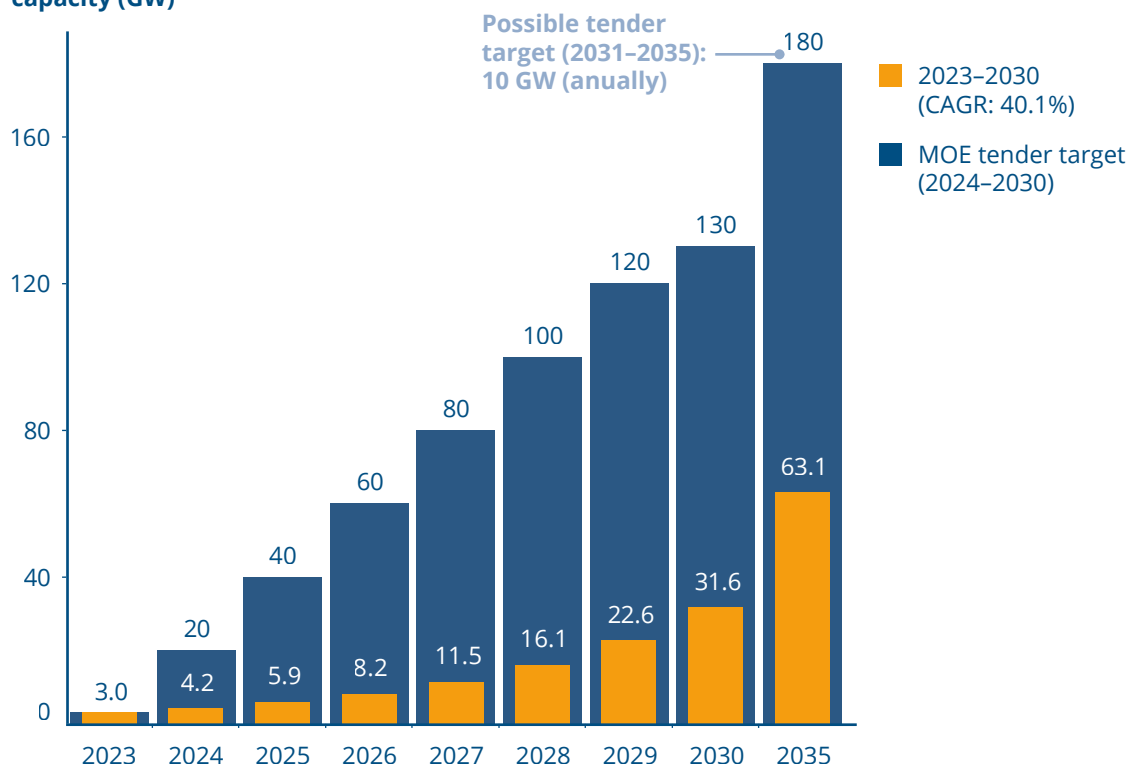


Figure 7: Cumulative Saudi renewable power capacity, including CAGR, government tender target (2030) and beyond. Sources: Global Data (2024); KSA Ministry of Energy (2024) and own suggestion for 2031–2035.

Even under a generous CAGR, the short analysis provided here shows the considerable gap between the Kingdom's ambitions and actions as regards achieving 50% of its power mix from renewable energy by 2030. Together with other GCC countries, however, Saudi Arabia's competitive bids have achieved amongst the lowest prices for solar power anywhere in the world. The very low costs achieved can be attributed to the high-quality solar resources, the large scale of the projects, confidence in their low technical and commercial risk levels, a low cost of capital, and the ease of permitting, which allows for swift and predictable execution (Apostoleris 2021). These advantages could allow the Kingdom to considerably step-up the current pace and install more than 20 GW in annual awards and completions, particularly when including additional renewables dedicated to hydrogen (Mills 2024).

## iv. Clean Hydrogen: Domestic Incentives vs. Export Ambitions

The Saudi government views clean hydrogen and its applications as a central component across the 4Rs of the CCE and as a critical enabler in decarbonising hard-to-abate sectors (IEA 2020). The SGI mentions that the Kingdom aims to become the world's leading producer and exporter of hydrogen by producing more than four million metric tons per year (mtpa) and capturing more than 27 million tons of CO<sub>2e</sub> (SGI n.d.). Although it is not specified what the SGI means with "clean" hydrogen, we assume here that this refers to renewable and fossil gas-based variants, the latter with extremely low methane emissions and high carbon capture rates. Additionally, the SGI does not specify which part of the four million tons will be produced with renewables and which part with natural gas. In its 2023 sustainability report, Aramco announced a production target of 11 mtpa for blue ammonia by 2030 (Aramco 2023). This volume of ammonia would require approximately two mtpa of blue hydrogen. Based on reporting that the renewables-based NEOM region has "various scenarios that go all the way from 15 GW to 30 GW of installed electrolyser capacity" in mind, it is not inconceivable to envisage a one mtpa of "green hydrogen" production target by 2030 (Carpenter 2021).

Currently, Saudi Arabia's clean hydrogen projects like the NEOM Green Hydrogen Company are export-oriented. Existing grey hydrogen production in the Kingdom is approximately 2.5 mtpa with main usage in refineries and for ammonia, methanol, and steel production (IRENA 2023).<sup>12</sup> In a 1.5°C scenario, and based on primary estimations, the Kingdom could become the country with the sixth highest domestic hydrogen demand by 2050, after China, India, the United States, Russia, and Japan (IRENA 2022). As an essential part of the Saudi net-zero narrative, there is a strong need to implement clean hydrogen development policies and create a conducive environment in which a domestic hydrogen market can develop and expand (Saxena et al. 2024). Beyond a focus on export, incentive schemes and appropriate policy measures are required to develop renewable and low-carbon hydrogen and CCUS supply chains for domestic demand creation including:

- ▶ A regulatory framework for the licensing, distribution, and pricing of hydrogen projects.
- ▶ Introduction and funding of incentive schemes to scale up production and demand, focused on promoting specific use cases in industry, transport, and electricity (Almazeedi 2024).
- ▶ System integration and rapidly developing value chains and business models, including infrastructure, human capital, and demand.
- ▶ Research, development, demonstration, and innovation (RDD&I) competition, i.e. creating a dynamic and competitive institutional capacity along the hydrogen value chain by translating academic research to industrial deployment and manufacturing capacities (Saxena et al. 2024).

For both its renewable and clean hydrogen ambitions, the result of not implementing the necessary and effective domestic incentives could lead to the paradoxical situation of transforming the Kingdom into a green energy exporter while maintaining hydrocarbons at the centre of its economy and without changing existing economic rigidities (Delivorias and De Martini 2023).

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12 Production of grey hydrogen in the GCC causes around 80 Mt of GHG emissions, assuming an average of 10 kilogrammes of carbon dioxide per kilogramme of hydrogen (kg CO<sub>2</sub>/kg hydrogen).

## v. State-Owned Industry Carbon Action

There is an important role for state-owned enterprises (SOEs), acting as prime movers, particularly in hard-to-abate sectors. SOEs are not only major emitters, but, due to their size and power, they have the ability to better use existing infrastructure, to invest in future infrastructure, and to motivate early demand commitments.

In the Kingdom, SABIC and Aramco have both voluntarily announced net-zero GHG emission targets for 2050. They also have included several initiatives like efficiency improvements, renewable energy capacity targets, electrification, CCUS targets, and the commercialisation of renewable and low-carbon hydrogen (Aramco 2023; SABIC 2023).<sup>13</sup>

However, national oil companies (NOCs) are laggards compared to shareholder-owned oil majors when it comes to low-carbon capital due to drivers such as emerging carbon pricing instruments and shareholder pressure. The shareholder-owned oil majors were estimated to have allocated 15 billion USD – some 15% of their capital budgets in 2022 — toward diversifying capital investment into clean electricity, carbon offsets and trading, and electric vehicle charging, while European international oil companies (IOCs) allocated around 20% of their capital budgets. Capital guidance from NOCs was far less: five billion USD was allocated, which amounted to less than 5% of capital budgets on average (Portela 2022).

A recent assessment of the low-carbon ambitions of 17 oil and gas companies, i.e. six integrated energy companies (IECs), three IOCs, Aramco, and seven other NOCs, notes an accelerating pace of investments in this area (Haris et al. 2022). From 2017 to 2022, the 17 companies invested approximately 74 billion USD in low-carbon solutions. Unsurprisingly, the six IECs (BP, Chevron, Eni, ExxonMobil, Shell, and TotalEnergies) contributed to about 80% of low-carbon investments over this period and are expected to continue to dominate investment activity. This is perverse in the sense that roughly 60% of the world's oil is produced by NOCs and their operations release more GHGs than those of IOCs (Krane and Braun 2024). However, they have made fewer climate commitments, and their emissions and decarbonisation plans face less scrutiny; they also have less exposure to litigation and policy risk than IOCs. Much of this is owing to the protection provided by sovereign ownership and lack of exposure to activist shareholders (Krane and Braun 2024).

There is the need to assess the long-term impacts of the SGI target of planting 600 million trees by 2030 on emissions in the Kingdom, on which considerable progress had been made (Gulf Business 2023). However, as for now there is insufficient information, and it is beyond the scope of this study. Similarly, further inquiry is required on the tangible results in terms of actual GHG reductions of the Kingdom's participation in intergovernmental institutions, such as the Global Methane Initiative, Mission Innovation, and the Net-Zero Producers Forum. In any case, the main points discussed in this section are considered to be of a higher requirement for establishing a viable net-zero Saudi narrative than the side-issues in the final paragraph.

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13 Regarding renewables, both Aramco and SABIC are targeting a capacity of 12 GW by 2030. Regarding CCUS, Aramco aims to have a 11 MtCO<sub>2</sub>eq per year capacity by 2035 (through a CCS hub in the city of Jubail) while SABIC plans to capture a total of four mtpa of CO<sub>2</sub> annually while aiming for two mtpa annually by 2030.

# Saudi Arabia's Net-Zero Pathways

As previously mentioned, a difficulty with the current Saudi NDC is the fact that it does not specify a business-as-usual scenario. Overall, there is a lack of comprehensive analysis of the long-term implications of various climate-related initiatives and policies adopted by the Kingdom. Using a modified version of the Global Change Analysis Model (GCAM v6.0), a recent project by the King Abdullah Petroleum Studies and Research Center (KAPSARC) called Adaptation & Mitigation Partnership (CAMP) has quantitatively considered four scenarios with a view to 2060 (Table 4).

Scenario name	Policies and mitigation target
<b>No Policy</b> <i>(baseline that does not consider any climate policy or policies implemented)</i>	<ul style="list-style-type: none"> <li>› No energy efficiency gains in the building and transport sectors</li> <li>› No energy price reforms, i.e., subsidised fuel prices continue</li> <li>› No climate mitigation policy, i.e., no NDC target</li> <li>› No market/support for low-carbon technologies</li> </ul>
<b>Current Policy</b> <i>(long-term impact of policies and initiatives implemented today in supply and demand sectors)</i>	<ul style="list-style-type: none"> <li>› Energy efficiency gains are reflected based on various initiatives by SEEC* in the end-use sectors</li> <li>› Reflects energy pricing reforms by calibrating the 2020 fuel prices in the model to the actual fuel prices in Saudi Arabia post two rounds of reforms (2016 and 2018)</li> <li>› Electricity generation capacity of renewable (50%) and gas-based plants (50%)</li> </ul>
<b>NDC (Continued)</b>	<ul style="list-style-type: none"> <li>› Includes the policies from Current Policy scenario and meets NDC target of emissions reduction of 278 MTCO<sub>2</sub>eq by 2030 compared to No Policy scenario</li> <li>› Beyond 2030, continuation of the same declining rate of GHG intensity of the economy as achieved from 2020 to 2030 to meet the NDC target</li> </ul>
<b>Net-Zero 2060</b>	In addition to the NDCs Continued scenario, the net GHG emissions beyond 2030 linearly decline to zero by 2060

Table 4: Scenario design and key assumptions. Source: Kamboj et al. 2023. \*SEEC is the acronym for the Saudi Energy Efficiency Center.

Taking total GHG emissions of the Kingdom in 2015 (722 MtCO<sub>2</sub>eq) as a model base year, Figure 8 shows the modelled GHG emissions (MtCO<sub>2</sub>eq) trajectories for the four scenarios described in Table 4.



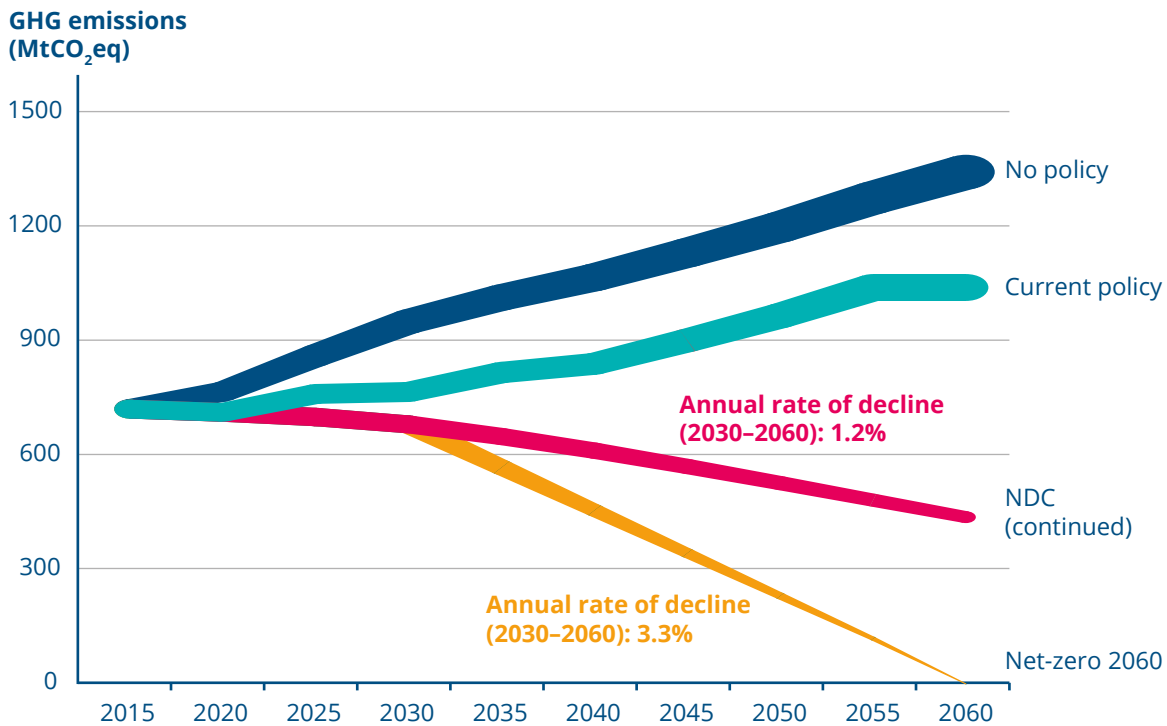


Figure 8: Modelled GHG emissions trajectory for the four CAMP scenarios. Source: KAPSARC CAMP (2023).

Compared to the baseline No Policy scenario, the Current Policy scenario provides a BAU scenario that shows a reduction of 185 MtCO<sub>2</sub>eq GHG emissions by 2030, or 93 MtCO<sub>2</sub>eq short of meeting the NDC target of reducing 278 MtCO<sub>2</sub>eq, achieved by the combination of currently implemented and planned policies and initiatives (Kamboj et al. 2023). Assuming Saudi Arabia continues with the same GHG intensity reduction rate achieved from 2020 to 2030 to meet the NDC target, the GHG emissions decline at an annual rate of 1.2% by 2060, a pathway represented by the NDC Continued scenario (Kamboj et al. 2023). The Net-Zero scenario, which linearly declines GHG emissions to zero between 2030 and 2060, results in a GHG emissions reduction rate of 3.3% annually. This means that “fully implementing the Green Initiative” alone will be insufficient in helping Saudi Arabia meet its net-zero emissions target. The Net-Zero scenario implies that the Kingdom will have to triple its ambition of reducing emissions in the next round of updating NDCs.

CAMP also includes the required sectoral contributions to achieving net-zero GHG emissions relative to the baseline in the No Policy scenario. Decarbonising electricity generation with 50% renewables and natural gas (with carbon capture and storage) by 2030 and beyond can save 140 MtCO<sub>2</sub> emissions and 82 MtCO<sub>2</sub> emissions respectively per year and up to 2060. Industries in the Kingdom, such as petrochemical (56 MtCO<sub>2</sub> emissions per year) and cement (41 MtCO<sub>2</sub> emissions per year) have the greatest potential for reduction. The Kingdom will have to transform its carbon-intensive transport sector by shifting towards public modes of transport, the continuation of fuel efficiency standards, and a vast market uptake of clean vehicle technologies for cars and trucks (Kamboj et al. 2023).

Under the “Remove” pillar of the CCE approach and allowing for a continuing central role of hydrocarbons in the Saudi economy, the CAMP analysis highlights the crucial role of carbon dioxide removal technologies like CCS and direct air capture (DAC). The Kingdom must deploy these technologies to remove 371 MtCO<sub>2</sub> emissions per year to offset overall GHG emissions by 2060. CAMP also underlines the dramatic decline in the GHG emissions intensity of GDP in the two main scenarios (Table 5).

Scenario	CAGR GHG intensity of GDP	
	2020-2030	2030-2060
<b>NDC Continued</b>	<b>-4%</b>	<b>-4%</b>
<b>Net-Zero 2060</b>	<b>-4%</b>	<b>-25%</b>

*Table 5: Growth rates of GHG intensity and emissions decline in the NDC Continued and NZ 2060 scenarios. Source: Kamboj et al. 2023.*

Simultaneously, the project incentivises further research into other pathways towards net-zero and their potential trade-offs, while also providing an early assessment of the gargantuan task of creating economies of scale for carbon removal and net-zero technologies that are needed to make the 4Rs of the CCE work in practice. Required technologies needed for achieving “net-zero” emissions and in the ‘Remove’ pillar of the CCE such as CCS and DAC are not yet commercially available at scale, partly because there is insufficient demand (Ertl et al. 2024).

# Europe and Saudi Arabia's Net-Zero Narrative

The European Union (EU) was Saudi Arabia's second largest trading partner in 2021 with 14.8% of the Kingdom's global trade (European Union External Action Service 2022). After China, the USA., the UAE, and India, Germany ranked as Saudi Arabia's fifth export partner in 2021 (Germany Trade & Invest 2024). Saudi Arabia, in turn, ranked as the EU's 15th trading partner in goods, with an EU market share of 1.4% in 2023 (European Commission 2024).

In order for the Saudi net-zero narrative to be realised, including the goals set out in Vision 2030, a huge amount of short-term capital is needed. This essentially requires maintaining relatively high oil prices now and sustaining Saudi Arabia's share of sales in the global oil market. Russia and China are key to the Kingdom's strategy. Russia is the world's second-largest exporter of oil, and Moscow's cooperation is essential to establish and maintain production agreements aimed at sustaining the price of oil. China is the world's leading importer of oil and therefore essential to the Saudis maintaining their market share – a position that has grown more vulnerable now that Russia is seeking a greater share of the Chinese market, having been shunned by its European customers after its invasion of Ukraine (Gause III 2024).

In this fluid geopolitical and economic setting, in which the Kingdom's historic reliance on the U.S. has become weaker, and where its government wants the flexibility to deal with China and Russia (and even Iran) on political and economic issues of national importance, the EU is trying to collaborate with the Saudis on climate and energy policy with more impetus.

Even if the world after Russia's invasion of Ukraine offers the Kingdom and the other GCC states additional geopolitical and climate incentive to position themselves as reliable providers of clean energy imports for Europe, differing interests and a lack of coordination has led to a "rhetoric-reality gap".

Europe is focused on eliminating society-wide carbon emissions in the medium to long term, and seeks an energy partnership with Gulf countries, particularly in the area of renewable energies. Natural gas is supposed to act as a transitional energy source. The Saudi net-zero narrative, however, sees a long-term role for low-carbon production of oil and gas (enabled by CCUS), with renewables and clean hydrogen as a means of diversifying its oil-rent-based economy and generating additional revenue streams.

As part of the EU's energy strategy to phase out Russian fossil fuel imports called REPowerEU, the strategic partnership with the Gulf formulates an ambitious package of energy policy goals to expand cooperation with the Gulf states. On paper, the EU has demonstrated that it can respond to new geopolitical realities quickly by making far-reaching political adjustments within a very short space of time. In practice, however, as opposed to acting as a coordinated bloc, the EU member states' approach is one of internal competition, with each member state attempting to sign bilateral energy partnerships with countries in the Gulf region (Dienstbier and Ertl 2023).

Saudi Arabia has just started ramping up its renewables to decarbonise its carbon-intensive electricity generation capacity. Fulfilling this goal while simultaneously ramping up renewables capacity for Europe’s hydrogen import requires certain preconditions. It is only realistic if the EU and Saudi Arabia agree, inter alia, on a joint development and import-export policy framework that incentivises investment, enhances the bankability of projects, and much more. So far, several factors have undermined the EU’s ability to act as a coherent and assertive player with high potential partners such as Saudi Arabia. These include:

- › The incoherence of national regulatory approaches to support a European market for hydrogen.
- › Lack of a coordinated development of storage, pipeline facilities, and port infrastructure.
- › Lack of off-take agreements and other investment signals on the European side.
- › An overall focus on renewables-based production, excluding technological routes related to natural gas and CCUS, and a related policy framework on low-carbon hydrogen (Braun, Van Wijk, and Westphal 2024).

At the bilateral level, Germany and Saudi Arabia have signalled their commitment to collaborate via working groups with the aim of implementing concrete hydrogen projects in the short-term and establishing a sustainable supply chain for its derivatives (Braun et al. 2022). Despite these good intentions, the gap between rhetoric and reality is underlined by the fact that no concrete EU agreement with a GCC state on hydrogen or any other energy matter has been concluded thus far (Table 6).

Date	EU country	Fuel type	Type of agreement	Description
02.02.2023	<b>France</b>	Other	Indicative-Intergovernmental	MoU in which parties envisage cooperation in renewable energy sources, hydrogen, CCUS.
17.11.2022	<b>Germany</b>	Hydrogen	Indicative-Intergovernmental (& infrastructure implications)	Import of ammonia from Saudi Arabia to port of Hamburg beginning in 2026.
27.07.2022	<b>Greece</b>	Other	Indicative-Intergovernmental	Agreement sets a framework for bil. cooperation in renewable energy, electrical interconnection, export of electricity to Greece and Europe, transport of clean hydrogen to Europe, energy efficiency, and the oil, gas, and petrochemical industry.
12.01.2022	<b>Poland</b>	Oil	Binding – Mixed	PKN ORLEN (70% stake in a 210,000 barrel-per-day refinery in Gdansk, with Aramco acquiring equity stakes (30%) in the refinery and 100% in a wholesale).

*Table 6: Bilateral energy agreements between EU member states and Saudi Arabia (latest update: April 2024). Source: European Council on Foreign Relations (2024).*

The EU and its member states are starting to develop policies and capacities that allow for deeper and wider avenues of cooperation with Saudi Arabia’s net-zero narrative. The accounting rules for low-carbon hydrogen and its derivatives are currently being drafted by the European Commission as part of a delegated Act on the Internal Gas and Hydrogen Market Directive. The outcome of the draft "Low Carbon Hydrogen DA" could be very important for Saudi Arabia’s plans to produce and export blue hydrogen and ammonia to the EU market.

To allow for the necessary swift rollout of renewable hydrogen, Germany's hydrogen import strategy allows for demand and import of low-carbon hydrogen, provided that the emissions threshold (approx. 3.4 kg of CO<sub>2</sub>-eq./kg H<sub>2</sub>) defined in the EU Internal Gas and Hydrogen Market Directive is adhered to (Federal Government of Germany 2024).

The aim of the European Commission's proposed Industrial Carbon Management strategy is to make captured CO<sub>2</sub> a tradable commodity by establishing a "single European CO<sub>2</sub>-market". This is to occur through a set of actions at the EU and national levels and creating a more attractive environment for investments in industrial technologies (European Commission n.d.). The proposed update of the EU's CCS Directive in 2024 is an initial step in providing guidance for member states regarding specific permitting processes, the goal being to establish an EU market for CO<sub>2</sub> storage services, and to attract investment (European Commission 2024ii). Key updates here focus on novel CO<sub>2</sub> storage technologies in mafic/basalt rocks and depleted hydrocarbon reservoirs, CCS value chain aspects, corrosion and safety issues, and the regulatory transition from hydrocarbon production to CO<sub>2</sub> storage. Supported at the national level, a European infrastructure for CCS is underway, with five European countries (Belgium, Denmark, Norway, Sweden, the Netherlands) allowing for cross-border transport and geological storage (Government of the Netherlands 2024). One further step in the direction of an EU-wide CO<sub>2</sub> market is the provisional agreement adopted by the European Parliament on Carbon Removals and Carbon Farming Regulation. This regulation creates the first EU-wide voluntary framework for certifying carbon removals, carbon farming, and carbon storage in products across Europe (European Commission n.d.ii).

Were the Saudi government to make tangible efforts regarding redirecting its vast support for fossil fuel subsidies towards clean energy alternatives as part of its net-zero narrative, this would certainly provide an opening for cooperation with the EU and its policy goal to level the playing field for truly affordable, clean energy services. Several months into its test-phase, the EU's Carbon Border Adjustment Mechanism aims to incentivise carbon prices in countries producing goods consumed in the EU. Given that the EU is the Kingdom's second largest trading partner, and considering the country has well-developed governance structures, it seems reasonable to consider that Saudi Arabia ought to swiftly move beyond the voluntary learning-by-doing phase of the Greenhouse Gas Crediting and Offsetting Mechanism (GCOM) in order to develop its own carbon taxation, thereby keeping carbon revenues themselves instead of paying them to the EU (Delbeke 2024). The EU may have to accept, however, that the Kingdom may establish an ETS or carbon system dissimilar to its own and start to elaborate criteria against which mutual recognition could be established (ibid.).

# Conclusion

Alarmingly, Saudi Arabia and the Gulf region at large are experiencing a more accelerated warming trend than the global average, and thus find themselves at the front line of climate change. The variation in climate outcomes projected from different climate models and scenarios mentioned in this study underscores the importance of Saudi decisions and actions today in shaping its climate future.

The Kingdom is trying to convince the world of its own particular net-zero narrative: simultaneously shaping the energy transition in such a way as to retain a greater long-term role for hydrocarbons, while also positioning itself as a leader in sustainable development. This narrative sees a long-term role for “climate-neutral” production of oil and gas (made possible by CCUS), and with renewables and clean hydrogen used as means to diversify the country’s oil-rent-based economy and generate additional revenue streams.

This study argues that there is currently a substantial gap between the Kingdom’s ambitions and its effective actions, and questions some of the practical complexities related to the implementation of the Circular Carbon Economy. Considering current policies and actions, this study has found the Saudi net-zero narrative to still be at the drawing board stage, with a great deal of policy details still lacking before the system design can be pronounced effective.

The CCE approach is one of the central premises of the Saudi net-zero world narrative. However, the study argues that any practice-oriented CCE policy framework will face a range of highly complex implementation challenges. An obvious counterargument to implementing an intrinsically complex CCE system is that there is a simpler and more cost-effective way to ensure that CO<sub>2</sub> is removed from the system permanently – namely removing state support for fossil fuels and pricing emissions. Saudi Arabia is among the top five nations of the world in terms of fossil fuel subsidies. This perpetuates the use of fossil fuels, leading to higher GHG emissions and delaying the transition to a sustainable, low-carbon economy. Another dichotomy in the Saudi net-zero narrative is that emissions reduction targets are explicitly based on a scenario with substantial fossil fuel exports.

Most of the current Saudi energy transition initiatives, such as the NEOM Green Hydrogen Company project, are export-oriented. And despite a recent and much needed increase in domestic decarbonisation efforts, national targets – such as displacing fossil fuel from the Saudi electricity generation capacity with 50% renewable energy sources and 50% natural gas by 2030 – are characterised by a substantial “ambition-implementation” gap. Regarding the Kingdom’s hydrogen ambitions, and also in the context of its net-zero target, there is a strong need to develop clean hydrogen policies and create a conducive environment in which a domestic hydrogen market can develop and expand.

Recent modelling work by KAPSARC shows that current government policies and initiatives fall short of meeting the current NDC target by 2030. With a view to its long-term goal of reaching net-zero by 2060, the Kingdom will have to triple its emissions reduction ambitions. An initial sectoral breakdown shows the staggering emissions reductions required and the necessary, large-scale application of technologies such as CCS and DAC that are not yet commercially available at scale.



In the current complex and fluid geopolitical playing field, Saudi Arabia and the EU, albeit strong trading partners, often find themselves to have divergent interests. In this context, the EU is struggling to implement a pragmatic and result-based climate and energy cooperation with the Kingdom. The preference of EU member states for bilateral collaboration and a lack of proper investment signals constitute further obstacles that hinder the realisation of a closer partnership between the EU and the Kingdom. As a sign of progress, the study points towards emerging policies and capacities in Europe that are aimed at making carbon a tradeable commodity, and which allow for deeper and wider avenues of cooperation with Saudi Arabia's CCE approach.

Although this study presents a critical analysis of the state of play of the Saudi net-zero narrative, it has also aimed to make clear that rapid progress on implementation across (any of) the 4Rs of the CCE is highly anticipated and should be supported strategically and pragmatically by the EU, and by the Kingdom's most prominent European partner: Germany.

As G20-member and the largest economy in the MENA region, Saudi Arabia wields significant (geo-) political and economic influence. The Kingdom is the world's largest crude oil exporter and its sole swing producer. The low cost and relatively low CO<sub>2</sub> intensity of its oil production allow Saudi's national oil champion Aramco to present itself as the optimal choice to serve a climate-stressed market, even one in decline.

The Kingdom is a nation with large vertically integrated industries, heavily dependent on oil exports, and one which aims to achieve net-zero. As such, it is important that the CCE approach is implemented by a clear and effective regulatory framework and policies that prove its potential beyond CCUS. The reward for successful implementation of Saudi Arabia's Net Zero 2060 ambition could be significant. A Kingdom aiming to retain geostrategic importance as the world's central banker of oil could leverage domestic decarbonisation to establish credibility in the global climate arena. This would revitalise the Kingdom's influence and allow Saudi policymakers to shape the energy transition in such a way as to ensure a greater long-term role for cleaner hydrocarbons.

# References

- A** Al Ghareeb, Zeid. KAUST Hydrogen Seminar: Future of Hydrogen in the Middle East. Presented at the Future of Hydrogen in the Middle East, KAUST Clean Combustion Center, August 2022. <https://ccrc.kaust.edu.sa/hydrogenseminars2022/speakers/speakers-details/dr.-zeid-al-ghareeb> (last accessed: 17.10.2024).

Almazeedi, Wael. Hydrogen Investment: Carving out a Competitive Position for the MENA Region in the Energy Transition. In: *The Clean Hydrogen Economy and Saudi Arabia: Domestic Developments and International Opportunities*, edited by Rami Shabaneh, Jitendra Roychoudhury, Jan Frederik Braun, and Saumitra Saxena, 157–207. Environment & Economics. London: Routledge, 2024. <https://www.taylorfrancis.com/chapters/oa-edit/10.4324/9781003294290-9/hydrogen-investment-wa-el-almazeedi?context=ubx&refId=db86c996-9e33-40a3-a5d7-a3d47050277> (last accessed: 17.10.2024).

Almazroui, Mansour. Rainfall Trends and Extremes in Saudi Arabia in Recent Decades. *Atmosphere* 11, no. 9 (September 2020a): 964. <https://doi.org/10.3390/atmos11090964> (last accessed: 17.10.2024).

Almazroui, Mansour. Summer Maximum Temperature over the Gulf Cooperation Council States in the Twenty-First Century: Multimodel Simulations Overview. *Arabian Journal of Geosciences* 13, no. 12 (15 June 2020b): 477. <https://doi.org/10.1007/s12517-020-05537-x> (last accessed: 17.10.2024).

Arab News. First Day of Arab-China Conference Sees Signing of 30 Deals Worth \$10 Billion. Arab News, 11 June 2023. <https://www.arabnews.com/node/2319731/business-economy> (last accessed: 17.10.2024).

Arab News. Saudi Arabia Targets Carbon Capture of 44m Tons by 2035: Energy Minister. Arab News, 16 November 2022. <https://arab.news/b3er6> (last accessed: 17.10.2024).

AlSarmi, Said Hamed, and Richard Washington. Changes in Climate Extremes in the Arabian Peninsula: Analysis of Daily Data. *International Journal of Climatology* 34, no. 5 (2014): 1329–45. <https://doi.org/10.1002/joc.3772> (last accessed: 17.10.2024).

AlSarmi, Said, and Richard Washington. Recent Observed Climate Change over the Arabian Peninsula. *Journal of Geophysical Research: Atmospheres* 116, no. D11 (2011). <https://doi.org/10.1029/2010JD015459> (last accessed: 17.10.2024).

Al Shehri, Thamer, Jan Frederik Braun, Nicholas Howarth, Alessandro Lanza, and Mari Luomi. Saudi Arabia's Climate Change Policy and the Circular Carbon Economy Approach. *Climate Policy* 23, no. 2 (22 May 2022): 151–67. <https://doi.org/10.1080/14693062.2022.2070118> (last accessed: 17.10.2024).

Apostoleris, Harry, Amal Al Ghaferi, and Matteo Chiesa. What Is Going on with Middle Eastern Solar Prices, and What Does It Mean for the Rest of Us? *Progress in Photovoltaics: Research and Applications* 29, no. 6 (2021): 638–48. <https://doi.org/10.1002/pip.3414> (last accessed: 17.10.2024).

Aramco. Aramco Sustainability Report 2023: Investing in Growth Innovating for Sustainability. Dhahran: Aramco, 2023. <https://www.aramco.com/-/media/publications/corporate-reports/sustainability-reports/report-2023/english/2023-saudi-aramco-sustainability-report-full-en.pdf> (last accessed: 17.10.2024).

- B** Belaid, Fateh, and Mohammad AlDubyan. The Role of Building Energy Efficiency in Shaping the Energy Transition in Saudi Arabia: Key Challenges and Initiatives. Commentary. Riyadh: KAPSARC, February 2022. <https://www.kapsarc.org/research/publications/the-role-of-building-energy-efficiency-in-shaping-the-energy-transition-in-saudi-arabia-key-challenges-and-initiatives/> (last accessed: 17.10.2024).

Black, Simon, Antung Liu, Ian Parry, and Nate Vernon. IMF Fossil Fuel Subsidies Data: 2023 Update. Working Paper. Washington D.C.: International Monetary Fund, August 2023. <https://www.imf.org/-/media/Files/Publications/WP/2023/English/wpiea2023169-print-pdf.ashx> (last accessed: 17.10.2024).

Braun, Jan Frederik, Ad Van Wijk, and Kirsten Westphal. Europe's Hydrogen Pathways: Toward a Balanced Partnership with Saudi Arabia and the Gulf. In: *The Clean Hydrogen Economy and Saudi Arabia*, edited by Rami Shabaneh, Jitendra Roychoudhury, Jan Frederik Braun, and Saumitra Saxena, 208–58. 1st ed. London: Routledge, 2024. <https://doi.org/10.4324/9781003294290-10> (last accessed: 17.10.2024).

Braun, Jan Frederik, Matthias Schimmel, Rami Shabaneh, Karoline Steinbacher, Jitendra Roychoudhury, Saumitra Saxena, and Diego Bietenholz. Hydrogen Cooperation Potential between Saudi Arabia and Germany: A Joint Study by the Saudi-German Energy Dialogue. Berlin: German Federal Ministry for Economic Affairs and Climate Action, 30 August 2022. <https://www.bmwk.de/Redaktion/EN/Downloads/J/joint-study-saudi-german-energy-dialogue.html> (last accessed: 17.10.2024).

- C** Carpenter, Claudia. Saudi Arabia's Future City Neom Plans Hydrogen-Based Ecosystem. S&P Global Platts, 2021. <https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/electric-power/020921-saudi-arabias-future-city-neom-plans-hydrogen-based-ecosystem>.

Climate Trace. Climate TRACE. <https://climatetrace.org> (last accessed: 21.08.2024).

Climate Action Tracker. Country Profile: Saudi Arabia. <https://climateactiontracker.org/countries/saudi-arabia/> (last accessed: 01.12.2023).

Cornwell, Alexander. 'What Caused Dubai Floods? Experts Cite Climate Change, Not Cloud Seeding'. Reuters, 18 April 2024, sec. Middle East. <https://www.reuters.com/world/middle-east/what-caused-storm-that-brought-dubai-standstill-2024-04-17/>.

- D** Delbeke, Jos. How the EU Can Support Carbon Pricing at Global Level. Policy Analysis. STG Policy Papers. Florence: European University Institute, April 2024. <https://doi.org/10.2870/167326> (last accessed: 17.10.2024).

Delivorias, Angelos, and Alessandra De Martini. EU Energy Partnerships: Saudi Arabia. EPRS | European Parliamentary Research Service, September 2023. [https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/753942/EPRS\\_BRI\(2023\)753942\\_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2023/753942/EPRS_BRI(2023)753942_EN.pdf) (last accessed: 17.10.2024).

Dienstbier, Philipp, and Veronika Ertl. Big Plans, Limited Progress: EU Energy Partnerships with the Gulf. International Reports. Berlin: Konrad-Adenauer-Stiftung, 18 December 2023. <https://www.kas.de/en/web/auslandsinformationen/artikel/detail/-/content/grosse-plaene-kleine-fortschritte> (last accessed: 17.10.2024).

- E** Energy Institute. 2024 Statistical Review of World Energy. <https://www.energyinst.org/statistical-review> (last accessed: 21.08.2024).

Ertl, Veronika, Benjamin Nickels, and Hamza Saidi. Climate Change and Geopolitical Dynamics in the Middle East and North Africa. Konrad-Adenauer-Stiftung Regional Programme Energy Security and Climate Change MENA, 2024. [https://www.kas.de/documents/264147/264196/Climate+Change+and+Geopolitical+Dynamics+in+the+Middle+East+and+North+Africa\\_Navigating+Challenges+and+Opportunities+for+Regional+Security.pdf/6ae48465-a29d-da0c-c750-3a281deae77?version=1.1&t=1721400548623](https://www.kas.de/documents/264147/264196/Climate+Change+and+Geopolitical+Dynamics+in+the+Middle+East+and+North+Africa_Navigating+Challenges+and+Opportunities+for+Regional+Security.pdf/6ae48465-a29d-da0c-c750-3a281deae77?version=1.1&t=1721400548623) (last accessed: 17.10.2024).

European Commission. Industrial Carbon Management. European Commission, n.d. [https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/industrial-carbon-management\\_en](https://energy.ec.europa.eu/topics/carbon-management-and-fossil-fuels/industrial-carbon-management_en) (last accessed: 17.10.2024).

European Commission. Carbon Removals and Carbon Farming. European Commission, n.d.ii. [https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming\\_en](https://climate.ec.europa.eu/eu-action/carbon-removals-and-carbon-farming_en) (last accessed: 17.10.2024).

European Commission. European Union, Trade in Goods with Saudi Arabia. Brussels: European Commission, 15 May 2024. [https://webgate.ec.europa.eu/isdb\\_results/factsheets/country/details\\_saudi-arabia\\_en.pdf](https://webgate.ec.europa.eu/isdb_results/factsheets/country/details_saudi-arabia_en.pdf) (last accessed: 17.10.2024).

European Commission. The European Commission Publishes Revised Guidance Documents to the CCS Directive. European Commission, 23 July 2024ii. [https://climate.ec.europa.eu/news-your-voice/news/european-commission-publishes-revised-guidance-documents-ccs-directive-2024-07-23\\_en](https://climate.ec.europa.eu/news-your-voice/news/european-commission-publishes-revised-guidance-documents-ccs-directive-2024-07-23_en) (last accessed: 17.10.2024).

European Council on Foreign Relations. EU Energy Deals Tracker. ECFR, April 2024. <https://ecfr.eu/special/energy-deals-tracker/> (last accessed: 17.10.2024).

European Union External Action Service. Saudi Arabia and the EU, 28 April 2022. [https://www.eeas.europa.eu/delegations/saudi-arabia/saudi-arabia-and-eu\\_en?s=208](https://www.eeas.europa.eu/delegations/saudi-arabia/saudi-arabia-and-eu_en?s=208) (last accessed: 17.10.2024).

- F** Fattouh, Bassam. National Energy Companies in the GCC: Context and Strategies. Presented at the OIES, Oxford, July 2024. [https://www.linkedin.com/posts/oxford-institute-for-energy-studies\\_national-energy-companies-in-the-gcc-context-activity-7227269106033455105-HZHC](https://www.linkedin.com/posts/oxford-institute-for-energy-studies_national-energy-companies-in-the-gcc-context-activity-7227269106033455105-HZHC) (last accessed: 17.10.2024).

Fossil Fuel Subsidy Tracker. Fossil Fuel Subsidy Tracker. Fossil Fuel Subsidies (update: December 2023). <https://fossilfuelsubsidytracker.org/> (last accessed: 17.10.2024).

Farand, Chloé. Saudi Arabia Censors Fossil Fuel Subsidy Discussion as G20 Host. *Climate Home News*, 2020. <https://www.climatechangenews.com/2020/07/14/saudi-arabia-censors-fossil-fuel-subsidy-discussion-g20-host/> (last accessed: 17.10.2024).

Federal Government of Germany. Import Strategy for Hydrogen and Hydrogen Derivatives. Berlin: Federal Ministry for Economic Affairs and Climate Action (BMWK), July 2024. [https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/importstrategy-hydrogen.pdf?\\_\\_blob=publicationFile&v=7](https://www.bmwk.de/Redaktion/EN/Publikationen/Energie/importstrategy-hydrogen.pdf?__blob=publicationFile&v=7) (last accessed: 17.10.2024).

Fraunhofer-Gesellschaft. FhGenie: The Fraunhofer-Gesellschaft launches an internal AI chatbot. August 2023. <https://www.fraunhofer.de/en/press/research-news/2023/august-2023/fhgenie-the-fraunhofer-gesellschaft-launches-an-internal-ai-chatbot.html> (last accessed: 17.10.2024).

- G** Gasim, Anwar A., Paolo Agnolucci, Paul Ekins, and Vincenzo De Lipsis. Modeling Final Energy Demand and the Impacts of Energy Price Reform in Saudi Arabia. *Energy Economics* 120 (1 April 2023): 106589. <https://doi.org/10.1016/j.eneco.2023.106589> (last accessed: 17.10.2024).

Gause III, F. Gregory. The Limits of a U.S.-Saudi Security Deal. *Foreign Affairs*, 2 August 2024. <https://www.foreignaffairs.com/saudi-arabia/limits-us-saudi-security-deal-china-russia> (last accessed: 17.10.2024).

Germany Trade & Invest. Wirtschaftsdaten Kompakt: Saudi-Arabien, May 2024. [https://www.gtai.de/resource/blob/14852/06a9dc7e591a31630f81816e22fdb544/GTAI-Wirtschaftsdaten\\_Mai\\_2024\\_Saudi-Arabien.pdf](https://www.gtai.de/resource/blob/14852/06a9dc7e591a31630f81816e22fdb544/GTAI-Wirtschaftsdaten_Mai_2024_Saudi-Arabien.pdf) (last accessed: 17.10.2024).

Global Data. Saudi Arabia Could Reach Closer to 130GW Renewable Capacity Target by 2030 with Robust Policy Implementation, Says GlobalData. *GlobalData* (blog), 17 April 2024. <https://www.globaldata.com/media/power/saudi-arabia-reach-closer-130gw-renewable-capacity-target-2030-robust-policy-implementation-says-globaldata/> (last accessed: 17.10.2024).

Government of the Netherlands. Five northern European countries conclude international arrangements on transport and storage of carbon across borders – News item – Government. nl. Nieuwsbericht. Ministerie van Algemene Zaken, 15 April 2024. <https://www.government.nl/latest/news/2024/04/15/five-northern-european-countries-conclude-international-arrangements-on-transport-and-storage-of-carbon-across-borders> (last accessed: 17.10.2024).

Gulf Business. Saudi Green Initiative Plants 43 Million Trees, Shrubs since Launch, 4 December 2023. <https://gulfbusiness.com/saudi-green-initiative-milestones-showcased-cop28/> (last accessed: 17.10.2024).

- H** Haris, Ilshat, Rebecca Fitz, Emmanuel Ricolfi, Yudhveer Thakkar, and Chukwudi Udeani. How Energy Companies Can Organize for the Low-Carbon Era. Boston Consulting Group, 18 November 2022. <https://mkt-bcg-com-public-pdfs.s3.amazonaws.com/prod/how-energy-companies-can-implement-low-carbon-solutions.pdf>.

Hausfather, Zeke, and Glen P. Peters. RCP8.5 Is a Problematic Scenario for near-Term Emissions. *Proceedings of the National Academy of Sciences* 117, no. 45 (10 November 2020): 27791–92. <https://doi.org/10.1073/pnas.2017124117> (last accessed: 17.10.2024).

- I** IEA. Country Analysis Brief: Saudi Arabia. Washington D.C.: U.S. Energy Information Administration, 2023. [https://www.eia.gov/international/content/analysis/countries\\_long/Saudi\\_Arabia/pdf/saudi\\_arabia\\_2023.pdf](https://www.eia.gov/international/content/analysis/countries_long/Saudi_Arabia/pdf/saudi_arabia_2023.pdf).

IMF. Saudi Arabia 2023 Article IV Consultation – Press Release; Staff Report; and Informational Annex. IMF Country Report. International Monetary Fund, September 2023. <https://www.imf.org/en/Publications/CR/Issues/2023/09/05/Saudi-Arabia-2023-Article-IV-Consultation-Press-Release-Staff-Report-and-Informational-Annex-538823> (last accessed: 17.10.2024).

IMF. Saudi Arabia: Selected Issues. IMF Country Report. No 22, Issue 275. International Monetary Fund, August 2022. <https://www.elibrary.imf.org/view/journals/002/2022/275/002.2022.issue-275-en.xml> (last accessed: 17.10.2024).

IRENA. Renewable Energy Markets: GCC 2023. Abu Dhabi: International Renewable Energy Agency, December 2023. <https://www.irena.org/Publications/2023/Dec/Renewable-energy-market-analysis-GCC> (last accessed: 17.10.2024).

IRENA. Global Hydrogen Trade to Meet the 1.5°C Climate Goal: Part I – Trade Outlook for 2050 and Way Forward. Abu Dhabi: International Renewable Energy Agency, July 2022. <https://irena.org/publications/2022/Jul/Global-Hydrogen-Trade-Outlook>.

**K** Kamboj, Puneet, Mohamad Hejazi, Yang Qiu, Page Kyle, and Gokul Iyer. Long-Term Decarbonization Pathway for Saudi Arabia To Reach Net Zero GHG Emissions by 2060. Discussion Paper. Riyadh: KAPSARC, November 2023. <https://www.kapsarc.org/research/publications/long-term-decarbonization-pathway-for-saudi-arabia-to-reach-net-zero-ghg-emissions-by-2060/> (last accessed: 17.10.2024).

KAPSARC. Circular Carbon Economy Index – 2023 Edition. n.d. <https://cceindex.kapsarc.org/> (last accessed: 17.10.2024).

KAPSARC. CCE Guide Overview: A Guide to the Circular Carbon Economy. Circular Carbon Economy. Riyadh: King Abdullah Petroleum Studies and Research Center (KAPSARC), August 2020. <https://www.cceguide.org/> (last accessed: 17.10.2024).

KAPSARC CAMP. Climate Adaptation & Mitigation Partnership, 2023. <https://apps.kapsarc.org/camp/home> (last accessed: 17.10.2024).

Kingdom of Saudi Arabia. Updated First Nationally Determined Contribution of the Kingdom of Saudi Arabia under the UNFCCC. UNFCCC, October 2021. <https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Saudi%20Arabia%20First/KSA%20NDC%202021%20FINAL%20v24%20Submitted%20to%20UNFCCC.pdf>.

Krane, Jim. Net Zero Saudi Arabia: How Green Can the Oil Kingdom Get? Working Paper. Houston: Rice University's Baker Institute for Public Policy, 27 October 2022. <https://www.bakerinstitute.org/research/net-zero-saudi-arabia-how-green-can-oil-kingdom-get> (last accessed: 17.10.2024).

Krane, Jim. The Bottom of the Barrel: Saudi Aramco and Global Climate Action. Working Paper. Houston: Rice University's Baker Institute for Public Policy, 8 January 2021. <https://www.bakerinstitute.org/media/files/files/4920158a/ces-wp-saudiaramco-010821.pdf> (last accessed: 17.10.2024).

Krane, Jim. Energy Governance in Saudi Arabia: An Assessment of the Kingdom's Resources, Policies, and Climate Approach. Center for Energy Studies. Houston: Rice University's Baker Institute for Public Policy, 22 January 2019. <https://www.bakerinstitute.org/research/energy-governance-saudi-arabia> (last accessed: 17.10.2024).

- Krane, Jim, and Jan Frederik Braun. Saudi Aramco's Clean Hydrogen Efforts: Between Economic Diversification and Effective Climate Action. In: *The Clean Hydrogen Economy and Saudi Arabia*, edited by Rami Shabaneh, Jitendra Roychoudhury, Jan Frederik Braun, and Saumitra Saxena, 63–81. 1st ed. London: Routledge, 2024. <https://doi.org/10.4324/9781003294290-4> (last accessed: 17.10.2024).
- L** Lo, Joe. Saudis and Europeans Reach Compromise on Climate as G20 Projects Unity. *Climate Home News*, 2020. <https://www.climatechangenews.com/2020/11/23/saudis-europeans-reach-compromise-climate-g20-projects-unity/> (last accessed: 17.10.2024).
- Luomi, Mari. COP 27 and Different Narratives for a Net-Zero World. *Arab Gulf States Institute in Washington* (blog), 8 December 2022. <https://agsiw.org/cop-27-and-different-narratives-for-a-net-zero-world/> (last accessed: 17.10.2024).
- M** Maalouf, Fadi. NetZero in GCC: Status Update. *Energy Oman* Issue 13, July 2024. <https://energyoman.net/> (last accessed: 17.10.2024).
- McCabe, Matthew, Mashael AlShalan, Mohamad Hejazi, Hylke Beck, Fernando T. Maestre, Emilio Guirado, Raquel S. Peixoto, et al. Climate Futures Report: Saudi Arabia in a 3 Degrees Warmer World, 11 October 2023. <http://hdl.handle.net/10754/694868> (last accessed: 17.10.2024).
- Michaelson, Ruth, and Patrick Greenfield. "False Solutions": Scepticism over Saudi Carbon Capture Plan. *The Guardian*, 19 November 2022. <https://www.theguardian.com/environment/2022/nov/19/false-solutions-scepticism-over-saudi-carbon-capture-plan> (last accessed: 17.10.2024).
- Mills, Robin. Sunspot: The Rise of Renewables in the Gulf. *Center on Global Energy Policy at Columbia University SIPA | CGEP* (blog) 11 April 2024. <https://www.energypolicy.columbia.edu/sunspot-the-rise-of-renewables-in-the-gulf/> (last accessed: 17.10.2024).
- Ministry of Energy. The Ministry of Energy Launches the Unprecedented Geographical Survey Project for Renewable Energy Sites in the Kingdom of Saudi Arabia, 24 June 2024. <https://www.moenergy.gov.sa/en/MediaCenter/News/Pages/Ministry-launches-groundbreaking-survey-for-renewable-energy-sites-in-Saudi-Arabia.aspx?s=09> (last accessed: 17.10.2024).
- Mordor Intelligence. Saudi Arabia Power Generation Market Size & Share Analysis – Growth Trends & Forecasts (2024–2029). n.d. <https://www.mordorintelligence.com/industry-reports/saudi-arabia-power-market> (last accessed: 04.08.2024).
- N** NKC. Kingdom of Saudi Arabia: Progress on Its Net-Zero Pathway. In: *Empowering Climate Action from Oil and Gas Producing Economies: 15–21*. Net-Zero Knowledge Consortium, 2023. [https://www.netzeroknowledge.org/wp-content/uploads/2023/12/NKC\\_Report\\_December\\_2023.pdf](https://www.netzeroknowledge.org/wp-content/uploads/2023/12/NKC_Report_December_2023.pdf) (last accessed: 17.10.2024).
- P** Portela, Raphael. Opinion: How Are Global NOCs Tackling the Energy Transition? *Wood Mackenzie* (blog), 29 March 2022. <https://www.woodmac.com/news/opinion/how-are-nocs-tackling-the-energy-transition/> (last accessed: 17.10.2024).
- Principal Buyer. 'SPPC Announces the Release of RFQ for Round 6 Solar and Wind Projects with Total Capacity of 4500 MW – Saudi Power Procurement Company', 24 September 2024. <https://spb.com.sa/sppc-announces-the-release-of-rfq-for-round-6-solar-and-wind-projects-with-total-capacity-of-4500-mw/>.



- R** Renewable Vision. 'Renewable Energy Projects in Saudi Arabia', 2024. <https://renewable.vision/saudi-arabia-re/>.
- Reuters. 'Dubai to Boost Rainwater Drainage System with \$8.2 Billion Project'. Reuters, 25 June 2024, sec. Environment. <https://www.reuters.com/business/environment/dubai-boost-rainwater-drainage-system-with-82-billion-project-2024-06-25/>.
- RICCAR. Arab Climate Change Assessment Report. E/ESCWA/SDPD/2017/RICCAR/Report. Beirut: ESCWA, 2017.
- Ritchie, Justin, and Hadi Dowlatabadi. Why Do Climate Change Scenarios Return to Coal? *Energy* 140 (1 December 2017): 1276–91. <https://doi.org/10.1016/j.energy.2017.08.083> (last accessed: 17.10.2024).
- Rundell, David H. *Vision or Mirage: Saudi Arabia at the Crossroads*. London: I.B. Tauris, 2020.
- S** SABIC. Sustainable Growth for a Better World: Sustainability Report 2022. Riyadh: SABIC Global Headquarters, 2023. [https://www.sabic.com/en/Images/SABIC\\_Sustainability\\_2022\\_EN\\_120224\\_tcm1010-40888.pdf](https://www.sabic.com/en/Images/SABIC_Sustainability_2022_EN_120224_tcm1010-40888.pdf) (last accessed: 17.10.2024).
- Saudi & Middle East Green Initiatives. Saudi Arabia Announces 300% Increase in Installed Renewables Capacity, 43.9 Million Trees Planted since Launch of Saudi Green Initiative, 4 December 2023. <https://www.greeninitiatives.gov.sa/knowledge-hub/saudi-arabia-announces-300-increase-in-installed-renewables-capacity-439-million-trees-planted-since-launch-of-saudi-green-initiative> (last accessed: 17.10.2024).
- Saxena, Saumitra, Jan Frederik Braun, Rami Shabaneh, and Jitendra Roychoudhury. The Clean Hydrogen Economy and Saudi Arabia: Findings and Final Thoughts. In: *The Clean Hydrogen Economy and Saudi Arabia*, edited by Rami Shabaneh, Jitendra Roychoudhury, Jan Frederik Braun, and Saumitra Saxena, 713–50. 1st ed. London: Routledge, 2024. <https://doi.org/10.4324/9781003294290-31> (last accessed: 17.10.2024).
- SGI. Saudi Green Initiative. Saudi Green Initiative. n.d. <https://www.saudigreeninitiative.org/>.
- Schroeder, Patrick, Siân Bradley, and Glada Lahn. G20 Endorses Circular Carbon Economy: But Do We Need It? Chatham House – International Affairs Think Tank, 25 August 2021. <https://www.chathamhouse.org/2020/11/g20-endorses-circular-carbon-economy-do-we-need-it> (last accessed: 17.10.2024).
- Shannak, Sa'd, Jeyhun Mikayilov, and Rubal Dua. How to Mitigate Transportation Emissions in Saudi Arabia? The Role of Energy Price Governance. Discussion Paper. Riyadh: KAPSARC, 29 May 2022. <https://www.kapsarc.org/research/publications/how-to-mitigate-transportation-emissions-in-saudi-arabia-the-role-of-energy-price-governance/> (last accessed: 17.10.2024).
- Sheldon, Tamara L., and Rubal Dua. How Responsive Is Saudi New Vehicle Fleet Fuel Economy to Fuel-and Vehicle-Price Policy Levers? *Energy Economics* 97 (1 May 2021): 105026. <https://doi.org/10.1016/j.eneco.2020.105026> (last accessed: 17.10.2024).
- SPA. HRH Crown Prince Announces: "The Saudi Green Initiative and The Middle East Green Initiative". Saudi Press Agency, 27 March 2021a. <https://www.spa.gov.sa/w1531739> (last accessed: 17.10.2024).

SPA. Minister of Energy Sets Saudi Goal to Reach Net Zero Carbon Emissions in 2060. Saudi Press Agency, 23 October 2021b. <https://www.spa.gov.sa/2297769> (last accessed: 17.10.2024).

**U** United Nations. World Population Prospects 2024, July 2024. <https://desapublications.un.org/publications/world-population-prospects-2024-summary-results> (last accessed: 17.10.2024).

**W** World Bank. State and Trends of Carbon Pricing 2023. Washington D.C.: World Bank, May 2023. <https://openknowledge.worldbank.org/entities/publication/58f2a409-9bb7-4ee6-899d-be47835c838f> (last accessed: 17.10.2024).

World Bank Group CCKP. Climate Change Knowledge Portal. <https://climateknowledgeportal.worldbank.org/> (last accessed: 10.07.2024).

World Bank Group CCKP. Metadata for the Climate Change Knowledge Portal (CCKP). Washington D.C.: World Bank, January 2021.

World Bank Group. Gross domestic product 2022, n.d. [https://databankfiles.worldbank.org/public/ddpext\\_download/GDP.pdf?o=10357](https://databankfiles.worldbank.org/public/ddpext_download/GDP.pdf?o=10357) (last accessed: 26.08.2024).

World Bank Group. GDP (current US\$) – Middle East & North Africa, n.d.ii. <https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=ZQ> (last accessed: 21.08.2024).

# Annex 1: Climate Change in the Gulf Region

A few remarks on the y and x-axes of Figures 3a and 3b, i.e., Representative Concentration Pathway (RCP) scenarios and the projections. RCP is a greenhouse gas concentration (not emissions) pathway adopted by the Intergovernmental Panel on Climate Change (IPCC). Two greenhouse gas (GHG) concentration scenarios are assumed to predict the impacts of future climate change in the GCC from the middle towards the end of the century. These scenarios are based on the IPCC's RCP trajectories: RCP4.5 and RCP8.5. RCP8.5 represents a pathway that could deliver a temperature increase of about 4.3°C by 2100, relative to pre-industrial temperatures. The RCP4.5 pathway most likely results in a global temperature rise between 2°C and 3°C by 2100, again, relative to pre-industrial temperatures.

Regarding projections, the reference period represents the actual number of days based on a 20-year ensemble mean from 1986–2005 as defined by the IPCC in their Fifth Assessment Report. The IPCC defines future periods as near-, mid-, and end-century. Near-century is defined as 2016–2035 and is avoided in this paper as there is debate, for example, in the GCC, whether near-century projections are indicative of climate change or climate variability. A second reason is that many studies look further, i.e., 2050 and beyond, is because RCP4.5 and RCP8.5 start to diverge around mid-century.

The projection maps indicate the difference in the number of days/years compared to the reference period rather than predict the actual number of days themselves. The projections are also mapped based on a 20-year mean because of year-to-year variability and uncertainty, particularly for precipitation.

# Annex 2: Calculating Saudi Arabia's Renewables Generation Capacity (2030)

To calculate the number of renewables required to convert half of Saudi Arabia's electricity capacity by 2030, and converting the required generation to capacity in GW, the following question is stated:

**Having 183.5 TWh electricity generation capacity in 2021, and assuming a Compound Annual Growth Rate (CAGR) of 5.80%, how much capacity (converted to generation in GW) of solar PV (capacity factor: 30%) and wind (capacity factor: 35%) does Saudi Arabia need to generate, with solar PV generating 90% and wind 10% of capacity in 2030?**

Explanation of assumptions:

- ▶ 183.5 TWh electricity generation capacity in 2021 is half of Saudi Arabia's electricity generation (TWh) (IEA 2023).
- ▶ The Compound Annual Growth Rate (CAGR) of 5.80% for 2021 to 2030 is taken from the assumption that the Saudi power market size is estimated to grow at a CAGR of 5.80% during the forecast period of 2024 to 2029 (Mordor Intelligence n.d.).

Using Fraunhofer's internal AI chatbot FhGenie, which is based on Microsoft Azure OpenAI Service, two calculations are presented here (Fraunhofer-Gesellschaft 2023).

## Calculation 1 (FhGenie – Chat: GPT 4o)

To determine the required capacity of solar PV and wind in Saudi Arabia for 2030, we need to follow these steps:

1. Calculate the total electricity generation capacity for 2030 using the Compound Annual Growth Rate (CAGR).
2. Determine the required generation from solar PV and wind based on the given percentages.
3. Convert the required generation to capacity in GW using the capacity factors.

## Step 1: Calculate Total Electricity Generation Capacity for 2030

The formula for future value using CAGR is:

$$\text{Future Value} = \text{Present Value} \times (1 + \text{CAGR})^{\text{number of years}}$$

Given:

- Present Value (2021) = 183.5 TWh
- CAGR = 5.80% = 0.058
- Number of years = 2030 - 2021 = 9

$$\text{Future Value (2030)} = 183.5 \times (1 + 0.058)^9$$

$$\text{Future Value (2030)} \approx 183.5 \times 1.718 \approx 315.15 \text{ TWh}$$

## Step 2: Determine Required Generation from Solar PV and Wind

- Solar PV (90% of total capacity):

$$315.15 \times 0.90 = 283.635 \text{ TWh}$$

- Wind (10% of total capacity):

$$315.15 \times 0.10 = 31.515 \text{ TWh}$$

## Step 3: Convert Required Generation to Capacity in GW

The formula to convert TWh to GW using the capacity factor is:

$$\text{Capacity (GW)} = \frac{\text{Generation (TWh)}}{\text{Capacity Factor} \times \text{Hours in a Year}}$$

- Hours in a year = 8760

For Solar PV (Capacity Factor 30% = 0.30):

$$\text{Capacity (GW)} = \frac{283.635}{0.30 \times 8760} \approx 107.8 \text{ GW}$$

For Wind (Capacity Factor 35% = 0.35):

$$\text{Capacity (GW)} = \frac{31.515}{0.35 \times 8760} \approx 10.3 \text{ GW}$$

## Summary

Saudi Arabia needs approximately 107.8 GW of solar PV capacity and 10.3 GW of wind capacity by 2030 to meet the projected electricity generation requirements.

Type	Required installed capacity (GW) in Saudi Arabia (2030)
Solar PV	107.8
Wind	10.3
Source:	FhGenie (Chat: GPT 4o)

## Calculation 2 (FhGenie – Chat: GPT 4 Turbo)<sup>14</sup>

To find the installed capacity of solar PV and wind in Saudi Arabia by 2030, we first need to calculate the total electricity generation capacity in 2030 using the given CAGR (Compound Annual Growth Rate).

### 1. Calculate the total installed capacity in 2030:

- Initial capacity in 2021 (C<sub>0</sub>): 184 TWh
- CAGR: 5.80%
- Number of years (n): 2030 - 2021 = 9 years

The formula for future value using CAGR is:

$$C_{2030} = C_0 \times (1 + \text{CAGR})^n$$

$$C_{2030} = 184 \times (1 + 0.058)^9$$

$$C_{2030} = 184 \times 1.058^9$$

$$C_{2030} = 184 \times 1.6307 \approx 299.97 \text{ TWh}$$

### 2. Convert TWh to GW assuming full year operation:

- Hours in a year = 8760 hours
- Capacity in GW = TWh / (hours in a year / 1000)

$$\text{Capacity in GW} = \frac{299.97 \text{ TWh}}{8760 \text{ hours/year}} \times 1000$$

$$\text{Capacity in GW} = 34.25 \text{ GW}$$

<sup>14</sup> FhGenie – GPT 4 Turbo Preview has a slower response than GPT 4o but is more accurate in its calculation. Hence we have included it here as an alternative calculation.

### 3. Calculate the required capacity for solar PV and wind:

- Solar PV should generate 90% of the electricity
- Wind should generate 10% of the electricity

$$\text{Solar PV capacity} = 34.25 \text{ GW} \times 0.90 = 30.825 \text{ GW}$$

$$\text{Wind capacity} = 34.25 \text{ GW} \times 0.10 = 3.425 \text{ GW}$$

### 4. Adjust for capacity factors:

- Capacity factor for solar PV = 30%
- Capacity factor for wind = 35%

$$\text{Adjusted Solar PV capacity} = \frac{30.825 \text{ GW}}{0.30} = 102.75 \text{ GW}$$

$$\text{Adjusted Wind capacity} = \frac{3.425 \text{ GW}}{0.35} = 9.786 \text{ GW}$$

Type	Required installed capacity (GW) in Saudi Arabia (2030)
Solar PV	102.75
Wind	9.8
Source:	FhGenie (Chat: GPT 4 Turbo)

These values represent the installed capacities needed for solar PV and wind to meet the projected electricity generation requirements in Saudi Arabia by 2030, given the specified distribution and capacity factors.



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