

COP26 Futures We Want – Regional Profile for the Arabian Peninsula Based on Kingdom of Saudi Arabia (KSA) and United Arab Emirates (UAE)

The purpose of this region profile was to provide an evidence base to inform the production of Net Zero Future visions. A consolidated version of material contained here was used as stimulus for in-country workshops and creative translational approaches that developed a plausible vision for each country. This document provides a selection of relevant evidence for the sectors and themes identified through the scoping exercise.

Part A: Executive Summary

This profile covers the UAE and KSA and has been developed with the input from in-country academic experts Prof. Annalisa Molini and Mr Luiz Friedrich (Khalifa University, UAE) and Prof. Juan Carlos Santamarina (King Abdullah University of Science and Technology, KSA) in the context of the BEIS COP26 Futures We Want project. It sets out a synthesis of the available evidence base on regional challenges and opportunities for mitigation, adaptation, and resilience measures for both KSA and UAE and the wider Arabian Peninsula associated with climate change and a global transition to an inclusive, desirable, and resilient net-zero future.

The region is evolving rapidly and faces several key challenges and opportunities in the context of climate change and the net-zero transition period:

- At present, the regional economies are primarily dependent on fossil fuel exports. The global net-zero transition therefore could be viewed as an existential threat to the region and will require profound diversification of the economy to sustain livelihoods. On the other hand, abundant renewable energy, and energy systems expertise available in the region present unique opportunities to benefit the region from the transition.
- Oil and gas will continue to play a role in energy provision until the global energy transition is complete. During this transition, the region's oil and gas production and the associated embodied carbon in its main exports are likely to remain high even while the region itself embraces new technologies.
- As a largely hot arid desert region, water scarcity is a critical issue and habitability is highly energy intensive due to demands for cooling and water desalination/ irrigation. Rapid population growth, urbanisation, high standards of living and heavy reliance on imports, particularly food imports, further contribute to a high carbon footprint.
- Climate change will exacerbate already extreme weather conditions. Extreme temperatures potentially associated with higher humidity, and limited precipitation will further stress ecosystems.

- Unlike more temperate regions, the potential of natural carbon sinks for mitigating carbon emissions remains limited at present, but is actively being pursued in the region.

Given the oil-based economy and the limited potential for natural carbon sinks, net-zero will be challenging to achieve at the country scale for KSA and the UAE. Instead, the net-zero vision may need to address the broader context of global net-zero objectives – at least in the short-term – and involve carbon offsetting initiatives with regions better positioned to sequester carbon during the energy transition. Nevertheless, the region's centralised governance combined with sovereign oil wealth enables the rapid implementation of a far-reaching vision supported by national scale investments that have resulted in a remarkable rate of change in the region. These conditions create real opportunities to lead the way in transforming the global economy towards net-zero.

The World Resources Institute's Climate Analysis Indicators Tool (CAIT) shows that the total territorial Greenhouse Gas (GHG) emissions in 2018 (excluding international aviation and shipping) for the UAE were 263.2 MtCO₂e (27.3 tCO₂/capita), and for KSA 638.1 MtCO₂e (18.9 tCO₂/capita) ¹. Both countries have submitted Nationally Determined Contributions (NDC) commitments to climate mitigation under the Paris Agreement to reduce these emissions. The UAE's Second NDC, issued in 2020 commits to a 23.5% reduction in GHG emissions for the year 2030 relative to the business as usual (BAU) scenario for 2030 of 310 MtCO₂e ²; KSA's NDC issued in 2015 committed to abating 130 MtCO₂e annually by 2030 (estimated to be about 10-11% reduction from the BAU range) ³.

Climate Action Tracker rates these NDC's as "highly insufficient" for UAE and "critically insufficient" for KSA towards satisfying the Paris agreement's 1.5 °C limit. For reference, the US is also rated "critically insufficient", while the UK is rated "insufficient". Nevertheless, these assessments highlight the need for urgent action in the region. Climate change is already bringing rising temperatures, water scarcity, aerosols and air pollution from mineral dust and sandstorms, rising sea levels, and more frequent extreme weather events in the region, and has the potential to disrupt all major sectors of the economy by the mid-century and beyond. In the longer-term, by the end of the century, unchecked climate change could make parts of the region increasingly uninhabitable.

Adaptation and resilience to climate change are now unavoidable priorities for the region. Initiatives, some of which are already underway, include systems for more efficient collection, use and reuse of critically scarce water resources, infrastructure projects for coastal flood protection, improving the building stock and cooling technologies, and entire new sustainable/green city developments such as Masdar in UAE and Neom in KSA. Environmental resilience and natural carbon sequestration are being enhanced through "blue-carbon" ⁴ initiatives such as coastal protection with mangroves, stabilising sand dunes with vegetation and mulch, and more ambitious

soil regeneration and "regreening the desert" projects such as Wadi Hanifa (KSA), and a plan to plant 50 billion trees across the region. Promotion of alternative agricultural techniques such as indoor farming, agrivoltaics, biosaline agriculture, and drought-resistant crops may also help to preserve water resources and protect and build local food production capacity. Social interventions, such as policy directives on working in the heat, systems to alert the population to extreme weather events, and building healthcare capacity will also be essential to protect those most exposed to climate extremes.

There are numerous initiatives planned or underway in the region to reduce energy use and clean the energy supply system. Improved energy efficiency across the economy is a high priority, with KSA and UAE currently having some of the highest per capita energy consumption rates in the world. Elimination of fuel subsidies, introduction of more efficient technologies, public awareness campaigns, and policy initiatives to reduce consumption by individuals and industry are underway. Two key areas for energy efficiency improvement are water desalination and cooling: desalination is one of the most energy intensive sectors in the region (it generates 20-30%, varying by emirate, of emissions in the UAE), and cooling represents approximately 75% of all building energy consumption.

In terms of zero-carbon energy, renewable power, particularly PV solar, is rapidly scaling in the region. UAE recently achieved the lowest tariff in the world for solar energy and plans for the world's largest single-site solar plant of 5GW. UAE has also invested heavily in nuclear; and the first phase was connected to the grid in 2020. UAE has set a 50% target for renewables and nuclear by 2050, but the benefits are partially offset by new coal-fired power stations in the energy mix. KSA has similar ambitions, targeting a new record for lowest priced PV with the recently announced 1.4GW Al-Faisaliah plant at USD 0.0161/kWh; there are two large wind farms under construction; further plans for PV and concentrated solar power (CSP); transitioning from oil to greater use of natural gas for domestic consumption; and introduction of nuclear in the longer term. KSA is targeting 50% renewables and natural gas in power generation by 2030. There are other synergistic solutions in progress, such as the direct use of clean energy for water desalination which will be essential as the future demand for desalinated water will double over the coming decades to offset depleted groundwater reserves.

Still, the continued role of oil and gas to fuel the global (and regional) energy demand in the foreseeable future will require carbon capture utilisation and storage (CCUS) to abate emissions. In particular, the decarbonisation of heavy industries such as cement and steel production is challenging and large-scale deployment of CCUS will have to play a critical role in tackling industrial emissions. Yet, the technology remains expensive and still unproven at scale. Nevertheless, several CCUS pilot and research projects are underway in the region (e.g., enhanced oil recovery and storage, mineralization, and CO₂-enhanced geothermal).

Ongoing technological innovations offer good opportunities for decarbonising other sectors, e.g., surface transportation (using electric vehicles and mass-transit) and the built environment (with sustainable urban design, alternative materials, new cooling technologies, etc.). However, the main advantages of electrification are only attained when electricity is produced from renewable sources and/or from nuclear energy.

Aviation and shipping (major sectors in the UAE), along with tourism (including religious pilgrimage) are growth sectors for the region, yet their decarbonisation remains challenging and a concern regarding net-zero. Hydrogen, ammonia, sustainable aviation fuels, etc. may ultimately offer solutions.

In the longer term the region will be exposed to declining global oil and gas demand as major importers adopt net-zero. Consequently, the net-zero vision must emphasise diversification of the economy and region-wide development. Diversification is already well underway in the UAE under national strategy 'Vision 2021' launched in 2010, and the new 'Vision 2071' which details plans for the next 50 years ^{5,6}. UAE's reliance on oil and gas has reduced from 90% of GDP in 1970 to approximately 30% of GDP today, with fossil fuels now representing about 38% of exports. Similarly, KSA launched 'Vision 2030' five years ago which provides a comprehensive vision for the future development of the region ⁷. Oil and gas currently represent 23.3% of GDP in KSA, but a very significant 73% of exports, illustrating the need and scale of the required diversification. Both countries have ambitious plans to accelerate decarbonisation and increase sustainability in tandem with economic and societal development. Areas of diversification include energy innovation and clean technology, health, education, agri-tech, construction, finance, aviation and tourism, space, and other region-specific technologies. By taking an early leadership role KSA and UAE are already playing an important role in moving the whole region forward, as demonstrated for example by renewables and nuclear, hydrogen pilot projects, carbon capture and storage, and large-scale indoor farming. However, the countries' plans to address climate change are still at the early stages of development, and current construction, tourism and aviation projects are fossil-fuel-intensive.

Although net-zero is inherently challenging to the region, it also offers great opportunities for diversification and technological leadership in CCUS, renewables and clean energy symbiotic systems such as desalination. Given the very high insolation and abundant barren land, the region can become a major hub for solar energy generation and related services such as green hydrogen to support development of a global hydrogen economy. Blue hydrogen and synfuels created from reformation of fossil fuels using CCUS to minimise CO₂ emissions are also an important potential growth area. These innovations could transform domestic energy use and transportation systems, contribute to reshaping global energy solutions, and maintain export revenues and the geopolitical influence of the region. There are also numerous opportunities to lead the way with a range of novel technologies related to sustainable urban living, indoor farming, cooling technologies, and others. Attracting

inward investment and talent to support this transformation is key, along with supporting education, training, and infrastructure investment to ensure employment, livelihoods, and quality of life are maintained through and beyond the net-zero transition. At present most of the solutions for climate change are being advanced at universities and research centres in the developed world, typically above latitude 30° N, but these solutions are not necessarily suitable for the Arabian Peninsula. Therefore, a priority going forward is the continued commitment to further advancing an exceptional education system so that innovation will flourish at leading technological universities and national research centres in the region.

Indeed, there are great expectations placed on technological innovation and regional development to solve the climate crisis. However, the viability and impact of some of the proposed initiatives including CCUS, desert greening, and new sustainable 'green' megacities remain to be proven at scale.

In the meantime, behavioural change and cultural shifts towards lower-impact living are essential components for the net-zero transition. Per capita resource, energy and water consumption, and food waste in the region are among the highest in the world. Fuel subsidy reform, higher VAT rates (in KSA) and ongoing awareness campaigns are underway to encourage a shift in consumption behaviour. Further study is required to identify the best incentives that will trigger behavioural change across all sub-populations in UAE and KSA, while ensuring the costs of adaptation, mitigation and resilience are borne fairly across society without leaving vulnerable groups behind.

In conclusion, the region is developing and adopting plans towards a more sustainable future. A rapid decline in oil and gas consumption around the world would seriously affect the region and curtail its ability to undertake an orderly transition to net-zero. On the other hand, a slow response will exacerbate climate effects and its multiple ramifications on infrastructure, industry, water, food systems, liveability, and the built environment.

This profile is structured in three sections: 1. Country context, covering the economic and development contexts, and current greenhouse gas (GHG) emissions; 2. Physical climate change, covering risks, adaptation, and opportunities; and 3. Development-compatible transition, covering risks, mitigation, and opportunities. The latter half of section 3 focuses on priority sectors/themes identified by the in-country experts for the regional transition. These include energy, water, built environment, transportation, natural ecosystems, and food security. There are some notable differences between KSA and UAE but overall, the commonalities are more significant, and therefore, aside from statistical data in section 1, the evidence for the two countries has been combined to present prevalent trends and characteristics in the region.

Part B: Expert Committee Inputs

1. Country Context

Kingdom of Saudi Arabia

KSA is situated in southwest Asia, occupying approximately 80% of the Arabian Peninsula, with extensive coastlines on the Red Sea and the Arabian Gulf. KSA was founded in 1932 by Ibn Saud and has since been ruled by the Al Saud family. Under the current monarch KSA has pursued its “Vision 2030” strategy which includes investments in renewables and sustainability-orientated development projects ^{7,8}. KSA is a G20 member, a member of the WTO since 2005, and holds an important position in OPEC as the world’s largest oil exporter. KSA’s economy is the largest in the Middle East but is heavily dependent on public spending, which in turn is heavily dependent on global oil prices.

Much of the industry and investment in the region is controlled by government related entities. Aramco, the country’s state-run oil and gas company, now a publicly listed company valued at around USD 2.0 trillion, is still 98% owned by the Saudi government, and provides the vast majority of KSA’s export business and public revenues. The Public Investment Fund of Saudi Arabia (PIF) sovereign wealth fund has a two-trillion-dollar target by 2030. Its assets are diversified across the world and can be effectively used to drive the global net-zero transition, to diversify the economy, bring in new technologies, and create employment for the young national workforce ⁹. There is a strong dependence on public-private partnerships and private finance initiatives to support the more ambitious aspects of KSA’s diversification plans. For example, state-owned ACWA along with PIF are leading current renewables projects and initiatives such as green hydrogen development ^{10,11}. Renewables and alternative energy systems should be a major growth opportunity and could play an important role in the transition towards net-zero and help to maintain KSA’s geopolitical influence in the region.

United Arab Emirates

The UAE is situated in the Southeast of the Arabian Peninsula on the Gulf coast. Founded in 1972, it is a federation of seven emirates, Abu Dhabi (the capital city and political centre); Dubai (financial centre); Sharjah, Ajman, Umm Al-Quwain, Fujairah, and Ras Al Kaimah. The UAE is governed by a Supreme Council of Rulers made up of the seven emirs, who appoint the prime minister and the cabinet, but the individual emirates maintain significant independence. The president, Sheikh Khalifa bin Zayed, appointed in 2004, has pursued a pro-Western policy of modernisation, although the autonomy and differing wealth levels of the individual emirates means development and net-zero ambitions vary widely across the UAE creating some incongruities. UAE has the second largest economy in the Arabian Peninsula after KSA, based on significant oil and gas wealth, and since the federation has grown rapidly and is known

for its modern infrastructure and status as a regional trading and tourism hub. The country has a diverse culture: only 11% are native-born Emiratis.

Abu Dhabi with most of the country's oil and gas reserves is the wealthiest emirate and the Abu Dhabi Investment Authority (ADIA) holds one of the world's largest sovereign wealth funds with assets estimated at USD 650 billion and diversified holdings across the world and driving domestic investment and development in infrastructure and renewables in the country. Abu Dhabi has taken the lead on sustainability and net-zero in the country. Dubai with relatively little oil and gas reserves diversified early and has built a strong economy as a financial centre, hospitality, and aviation and shipping hub (30% of Dubai's economy is aviation), and its sovereign wealth fund, the Investment Corporation of Dubai (ICD) is also a major overseas investor with USD 300 billion in assets. The UAE economy is dominated by state-owned entities including ADNOC (Abu Dhabi National Oil Company), Abu Dhabi Ports Company, Emirates Group, Etihad Airways, Mubadala Investment Company, National Bank of Abu Dhabi, etc. The political and business climate in UAE is considered stable and the country attracts significant foreign investment which has been key to much of the development in the region, particularly in sectors such as trade, real estate, finance and insurance, manufacturing, mining, and construction. The largest source of foreign investment is the United Kingdom ¹². Changes in 2020 now allow 100% foreign ownership in a wide range of sectors including renewable energies which can be expected to facilitate significant private investment in the net-zero transition.

1.a Economic Context

1.a.i Sectors that contribute most to the countries' GDP

Table 1 presents an overview of GDP and key sectors for the two countries.

Table 1 KSA and UAE GDP statistics (Source: KSA and UAE government reported statistics) ^{13,14}

	KSA (2019 data) ¹³	UAE (2019 data) ¹⁴
GDP	USD 793 billion	USD 421 billion
Top-level GDP categories (% of GDP)	Non-oil private sector (51.0%) Government sector (25.6%) Oil and gas sector (23.3%)	Extractive industries including oil and gas (30%) Non-oil sectors (64.6%) Public admin and defence (5.4%)

Key economic sectors (% of GDP)	Real estate (14.4%)	Wholesale and retail (11.6%)
	Wholesale, retail, tourism, and hospitality (10.8%)	Construction and building (8.5%)
	Manufacturing excl. petroleum refining (9.9%)	Manufacturing (8.5%)
	Construction (6.4%)	Transport and storage (8.5%)
	Petroleum refining (3.1%)	Aviation and tourism (13%)

1.a.ii Sectors that represent growth areas for the countries economically (in absolute terms, but also as a proportion of GDP)

Both KSA and UAE experienced a fall in oil and gas revenues and contraction of their economies in 2020 due to the global disruption caused by Covid-19 ^{13,15}, but revenues are anticipated to recover to pre-Covid-19 levels in 2022 and continue to grow over the decade with recovering global economic activity ^{16,17}. In the short to medium-term this should generate strong revenues for the region to restore financial reserves and finance investments in net-zero and diversification of the economy. In the longer-term, the oil and gas sector is expected to decline as the world transitions to zero-carbon ¹⁸, and while efforts have already been carried out to diversify both economies away from fossil fuels, further diversification will be needed to reduce the dependence on oil and gas.

Growth sectors in both countries include construction, hydrocarbon-based polymers and petrochemicals, financial services, medical services, and education ^{3,5–7}. Mining and metals are an underexploited opportunity in Saudi Arabia, along with manufacturing ¹⁹. Aviation and tourism are also key elements of the future diversification plans for the region, with 30% of Dubai's GDP already coming from aviation, and KSA planning to launch a new airline and targeting tourism growth (including religious pilgrimage) ^{20–22}. Potentially the most significant growth opportunity for the region is to become a major hub for clean energy generation and related services such as green hydrogen, blue hydrogen and synthetic fuels (synfuels) generation. Other potential future growth areas based on regional expertise could include energy storage, carbon-geological storage/carbon capture utilisation and storage (CCUS), micro-nuclear plants ²³, urban development and smart cities, shelter for hot climates, efficient cooling technologies, water desalination, and agri-food technology for dryland agriculture, marginal land reclamation and soil regeneration. These growth areas are discussed further in sections 2.c.iii (Locally specific emerging sectors), and 3.c (Sectoral impacts).

It is important to recognise that growth and economic diversification that depends on fossil-fuel-intensive activities such as tourism and aviation are probably counterproductive towards a net-zero vision, unless these sectors undergo significant reshaping of their carbon footprint through technological innovation (e.g., biofuels for

aviation). Moreover, the region's plans to expand production of plastics and petrochemicals to make use of oil that might otherwise remain in the ground will have collateral environmental impacts on the planet that cannot be ignored – such as contributing to the growing crisis of global plastics waste and pollution ²⁴.

1.a.iii. Major trade-flows (goods and services) in and out of the countries today

Table 2 presents an overview of the major import and export categories of the two countries as of 2019. Both KSA and UAE are still heavily dependent on fossil fuel exports. Both KSA and UAE have limited self-sufficiency in domestic production, most notably lacking in food and agriculture, with imported food products representing more than 80% of total food requirements ²⁵. Both the countries are classified as critically dependant on the Virtual Water Trade Network, whereby embodied water is gained through food imports ^{26,27}.

Table 2 KSA and UAE Major Trade Flows (Source: Observatory of Economic Complexity OEC, 2019) ^{28,29}

	KSA (2019 data) ²⁸	UAE (2019 data) ²⁹
Exports	USD 228 billion	USD 248 billion
Imports	USD 149 billion	USD 235 billion
Key Exports	Crude petroleum (63.8%) Refined petroleum (9.57%) Hydrocarbon-based polymers (9.27%) Organic chemicals (5.66%)	Crude petroleum and gas (25.5%), Refined petroleum (13%) Hydrocarbon-based polymers (2.71%) Precious metals, gems, and jewellery (18.1%) Electrical machinery and broadcasting equipment and appliances (13.22%)
Key Imports	Machinery, appliances, and electrical equipment (20%) Cars (12.6%) Metals (8.9%) Food products (10.6%)	Gold, jewellery, and diamonds (24.6%) Electrical machinery and equipment (22.7%) Crude and refined petroleum (8.7%) Food (7.0%) Vehicles (6.1%)

1.b Development Context

1.b.i Key development indices for KSA and UAE

The region is experiencing very rapid changes; therefore, publicly available data may not fully reflect the pronounced changes of the last 2 to 5 years.

Table 3 summarises the available data on key development indices for the two countries. Both KSA and UAE already have very high Human Development Indices (HDI), which have improved substantially since 1990. In the case of KSA this represents a 22.5% increase from 1990. Similarly, for the UAE, the increase was 23.1% since 1990. On gender equality, UAE's Gender Inequality Index is very strong (ranking 18th globally), representing remarkable progress over the past 25 years (for comparison, the UK is ranked 32nd). KSA performs lower on gender equality: 64.8% of females have at least secondary education, against 72.5% for males, and female participation in the labour market was limited to about 22% in 2017; however, the situation has changed dramatically in the last 3 years as a result of new regulations that changed guardianship, allowed driving and women involvement in politics. The marked increase in female employment was not driven by government agencies, but led by the private sector; for example, the administration and support services and the accommodation and food sector experienced a 40% increase in female employment between 2019 (Q1) and 2020 (Q4) ³⁰.

Table 3 KSA and UAE Key development indices (Source: UN Human Development Report, 2020)

	KSA (2019 data) 31 32	UAE (2019 data) 33,34
Human Development Index (HDI)	0.854 (Rank 40 th)	0.890 (Rank 31 st)
Gross National Income (GNI) per capita (Constant 2017 PPP\$)	USD 47,495 (Rank 24 th)	USD 67,462 (Rank 7 th)
Gender Inequality Index (GII)	0.252 (Rank 58 th)	0.079 (Rank 18 th)
Gender Development Index (GDI)	0.896 (Rank 130 th)	0.931 (Rank 114 th)
Unemployment (% of labour force)	5.9%	2.3%
Unemployment (% of ages 15-24)	28.6%	7.3%
Gini coefficient of income or wealth inequality	45.9 *	32.5

* 2013 figure shown ³⁵

The UAE's Gini coefficient of income or wealth inequality is high with a similar level to the UK's 34.8. An up-to-date Gini coefficient of income or wealth inequality for KSA is not available, but in 2013 was estimated to be very high at 45.9, and suggests that KSA in 2013 was one of the most unequal societies in the world ³⁵. For both countries, the data on poverty and income equality are limited; furthermore, data interpretation must carefully consider the high numbers of low-income migrant workers ³⁶ and current efforts towards "Saudization" and "Emiratization". (See Figure 1 for population breakdown by ethnicity indicating the high numbers of expatriate migrant workers in both KSA and UAE, and the marked difference between the two countries in their percentages of native-born nationals: almost 70% of the population in KSA consists of Saudi Arabs, whereas Emiratis represent only 11.5% of the total population in UAE).

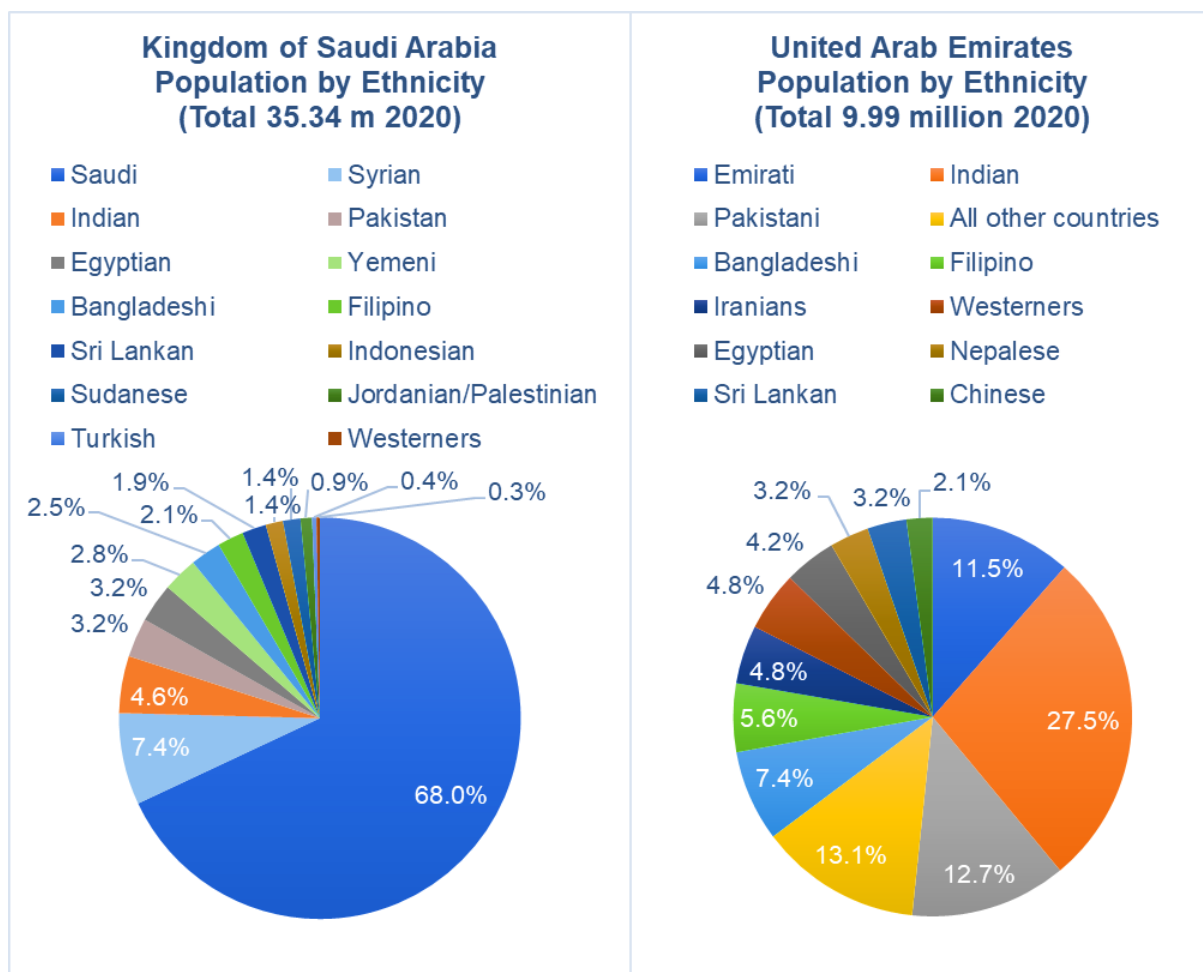


Figure 1 KSA and UAE Estimated Population Breakdown by Ethnicity (Source: Global Media Insight)^{37,38}

On the UN's Sustainable Development Goals (SDG) both KSA and UAE are making progress, but several major challenges are identified for the region related to hunger, clean water and sanitation, and climate action as shown in Table 4 (Data on poverty are unavailable for either country)³⁹.

Table 4 Assessment against the UN Sustainable Development Goals 2020 (Source: Sachs et al., 2020)^{39,40}

	KSA (2020 data)	UAE (2020 data)
SDG Index Score (Global Rank)	65.8 (Rank 97 of 166)	70.3 (Rank 71 of 166)
Major SDG challenges	SDG 2 Zero hunger SDG 5 Gender equality SDG 6 Clean water & sanitation SDG 13 Climate action	SDG 2 Zero hunger SDG 6 Clean water & sanitation SDG 12 Responsible consumption and production

		SDG 13 Climate action
Stagnating and decreasing SDG trends	SDG 4 Quality education	SDG 2 Zero hunger
	SDG 5 Gender equality	SDG 11 Sustainable cities and communities
	SDG 15 Life on Land	SDG 13 Climate action
	SDG 16 Peace, justice, and strong institutions	(decreasing)
		SDG 15 Life on land

1.b.ii The priorities and barriers to enabling the countries' sustainable, inclusive, and resilient growth

The countries both have excellent infrastructure, and as young, wealthy, and rapidly growing nations they are actively investing in ambitious projects and building capabilities and capacity for the future. KSA is undergoing a rapid cultural transformation that aims to significantly reshape the country, bringing greater gender equality and women into the workforce, more extensive educational programmes, a push for better jobs for Saudis and other factors with long-term implications for other aspects of the society and economy ^{8,41}. This may slow the population growth, generate greater awareness of sustainability issues, and drive innovation in the region, etc. Investment in youth is a priority and for example, KSA currently has 90,000 students studying overseas on scholarships to enhance the region's long-term capabilities ⁴². Similar investment is seen in the UAE to support Emiratis studying in top ranked universities both nationally and internationally ⁴³.

The priority going forward is the development of local high-quality education capabilities (attracting international researchers to address regional challenges, and developing world-class education locally with a global vision through top ranked universities and educational institutions such as KAUST and Khalifa) to allow a more universal access to quality education, and provide the pillar for a strong knowledge-based economy for the future ⁴⁴. At present most of the solutions for climate change are being advanced at universities and research centres in the developed world, typically above latitude 30° N. However, many of the most pressing problems of climate change will be between 30° N and the tropic of Capricorn, including the countries in the region of this profile. Clearly, universities and research centres in the region have a particularly important role to play in advancing solutions for these climate conditions.

1.c Development compatible greenhouse gas emissions (GHGs)

Both countries have submitted Nationally Determined Contributions (NDC) commitments to climate mitigation under the Paris Agreement to reduce emissions. The UAE 2nd NDC, dated 2020, commits to a 23.5% reduction in GHG emissions for the year 2030 relative to the business as usual (BAU) baseline scenario for 2030 of 310 MtCO_{2e} ². KSA (NDC dated 2016; KSA have not issued a 2nd declaration) has

committed to abating 130 MtCO₂e annually by 2030 (estimated to be about 10-11% reduction from the BAU range)³. However, Climate Action Tracker rates UAE's NDC's "highly insufficient", and KSA's "critically insufficient" towards satisfying the Paris agreement's 1.5 °C limit⁴⁵. For context, the USA is also rated "critically insufficient" (if all government's NDC's were in this range global warming would exceed 4 °C), China is rated "highly insufficient" (warming would reach between 3 °C and 4 °C), and the UK is rated "insufficient" (warming between 2 °C and 3 °C)⁴⁵.

1.c.i Countries' current GHG emissions profile

Table 5 summarises the current CO₂ equivalent emissions as of 2018 for the two countries, and for reference the G20 averages. Figure 2 then provides a breakdown by emissions by fuel type/source.

Table 5 CO₂ Equivalent Emissions Top Level Summary 2018 (Source: Climate Watch CAIT Data)^{1,46,47}

	KSA	UAE	G20
Total territorial emissions (MtCO ₂ e) (excluding bunker fuels)	638.1	263.2	
Territorial emissions per capita (tCO₂e/person)	18.9	27.3	7.4
Territorial emissions per GDP (tCO ₂ e/USD million)	811.3	623.5	448.4
Consumption-based CO ₂ emissions adjustment for exported/imported carbon emissions	+4.4%	+18.61%	

(Note: GHG emissions data presented in this profile is based on CAIT and GCP data as compiled by the World Resources Institute (WRI) and Climate Watch. The data are derived mostly from national energy usage data and are recognised as the most comprehensive historical dataset on global emissions available. However, the IPCC 2014 estimates uncertainty of about 8% in the data for CO₂ emissions, intermediate uncertainties of about 20% for non-CO₂ emissions, and high uncertainty of around 60% for N₂O and land-use change emissions⁴⁸).

The UAE emissions are notably higher in comparison to KSA in the areas of aviation and maritime (due to the significant international aviation and maritime hub in UAE) and fugitive emissions (due to the larger dependence on natural gas). Methane emissions from waste on a per capita are also notably higher for UAE possibly due to higher waste levels or poor waste management practices. F-gas emissions are dramatically higher in KSA due to the current industrial mix.

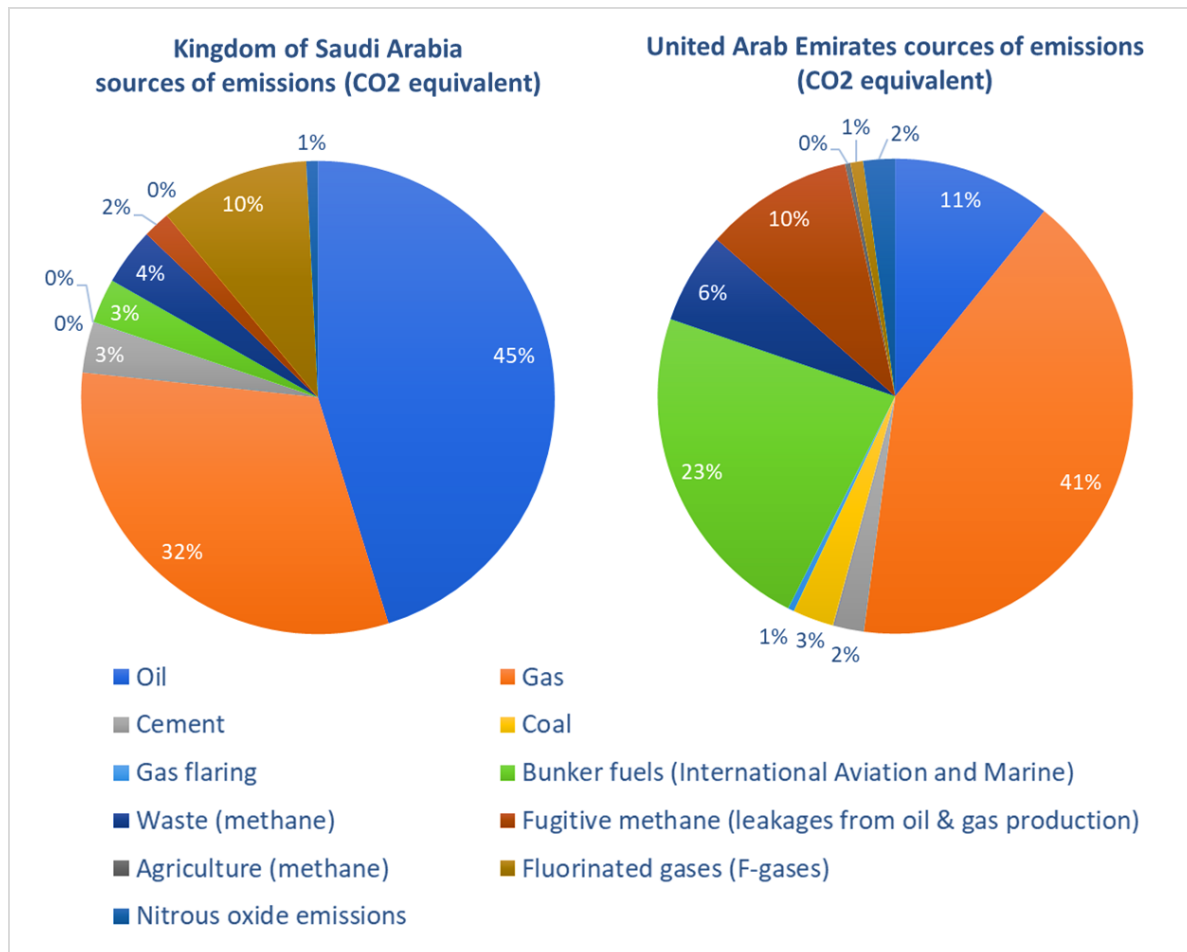


Figure 2 CO₂e Emissions by source, 2018 (Source: Climate Watch GCP & CAIT) ¹

Both KSA and UAE carbon emissions have risen steeply over the past three decades due to the compounding effect of population growth and increasing living standards. KSA's population expanded from just 3 million in 1950, to 16.2 million in 1990, to 35.3 million in 2020 and is anticipated to peak at 45.3 million by 2060 ⁴⁹ (Note: the discovery of its oil reserves dates to 1938). The UAE population has grown even more dramatically from just 70,000 in 1950, to 1.82 million in 1990 to 9.89 million in 2020, anticipated to peak at about 10.7 million in the coming decade ⁵⁰. The pre-1950's population levels and quality of life give an indication of the natural carrying capacity of the region in the absence of the oil industry without an alternative economy in place.

The analysis of historical trends in terms of per-capita consumption-and-emissions is of limited value due to the large increase in the low-income foreign workforce ¹. Nevertheless, today's per capita emissions are very high in both KSA and UAE relative to G20 averages (Table 5), through KSA emissions per capita are a similar level to Australia, the US and Canada ¹. A direct comparison with other very different countries fails to consider the carbon-intensive nature of the oil and gas industry, the energy-intensity of life in a desert environment (cooling, water desalination, irrigation), and the current stage in the development cycle of these two young countries KSA and UAE. Adjustments for embodied CO₂ emissions in exported oil and gas (negative) partially

compensate for embodied CO₂ emissions in imports (positive). Still, the corrected emissions remain high and reflect the dependency on imports and the high infrastructure investments taking place within the region.

There are notable differences in energy consumption rates within the populations of UAE and KSA. For example, Emirati households in Abu Dhabi are estimated to consume around three times the electricity of the generally smaller expatriate households. Moreover, there are distinct differences between the individual Emirates, with consumption rates significantly higher in the dominant Emirates of Abu Dhabi and Dubai ⁵¹.

1.c.ii Sector-specific GHG emissions from the sectors which are key for development

Historical GHG emissions by sector for both countries are shown in Figure 3 and Figure 4. Both countries saw a notable drop in emissions from 2016/2017 thought to be due to a drop in oil production rates and industrial output, but possibly also reflecting a shift to more efficient electricity production using combined-cycle power plants and, or successes in moderating energy demands in the region. The primary target areas for carbon emissions reductions across the region are also the sectors needed to support future development. These are:

- Electricity and heat (within the electricity and heat sector, air-conditioning represents up to 70% of residential electricity use in some regions, and this figure may have increased with the Work From Home trend ^{52–54})
- Water desalination makes up a significant component of the use of electricity and heat (Largely powered by natural gas, it is estimated to contribute 22% of Abu Dhabi's emissions, and 30% of UAE's total emissions ^{55,56}. Data for KSA is limited, but one report states desalination uses 20% of the country's total energy consumption ⁵⁷)
- Manufacturing, construction, and industrial processes
- Surface transportation
- Aviation and shipping (Particularly UAE)
- Gas extraction sector – fugitive emissions (UAE)
- Waste management – methane emissions (UAE)

A more granular breakdown showing the CO₂e emissions contribution from individual industry sectors such as oil and gas extraction and refining, and water desalination would be informative, but such data are not publicly available.

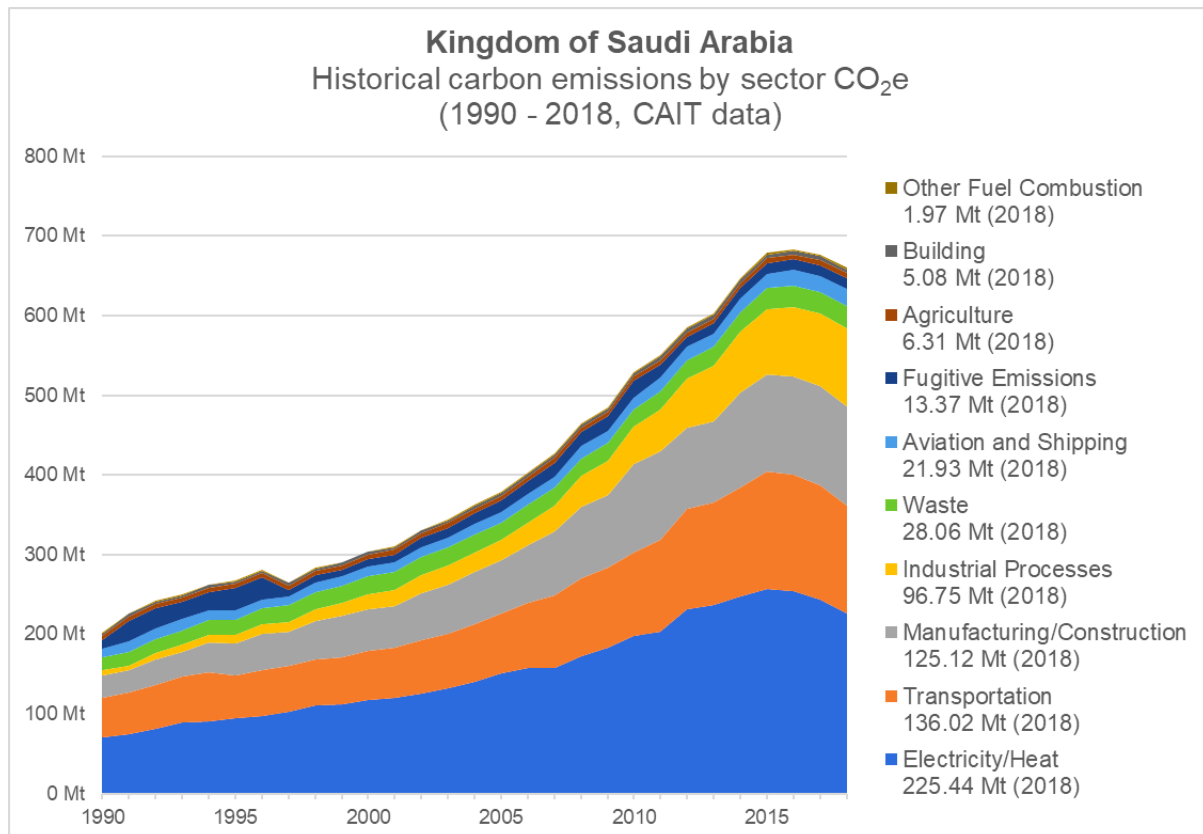


Figure 3 Greenhouse gas emissions by sector, Saudi Arabia 1990-2018 (Source: Climate Watch CAIT data) ¹

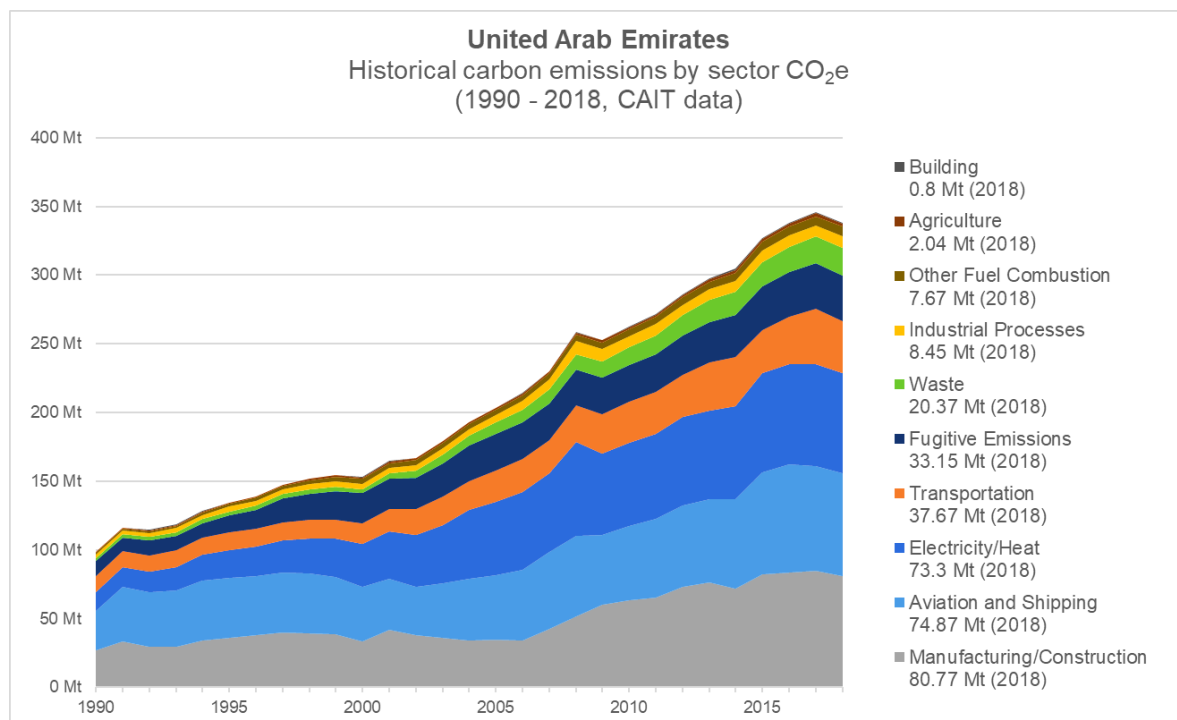


Figure 4 Greenhouse gas emissions by sector, United Arab Emirates 1990-2018 (Climate Watch CAIT data) ¹

2. Physical Climate Change – Risks, Adaptation and Opportunities

2.a Physical climate risk profile

2.a.i Physical climate risks that the region is already facing

The climate of the Arabian Peninsula is characterised by extreme temperatures, scarce and intermittent precipitation, significant atmospheric aerosol load and aridity. As a result, the Peninsula is considered to be one of the most climate-vulnerable regions in the Middle East and Southwest Asia^{58–61}. In KSA 92.4% of the country is desertic, with the remaining 7.6% (170,000 km²) at risk of desertification, while in the UAE close to 100% of the country can be classified as hot desert⁶².

Rising temperatures

Over the recent decades temperatures across the Peninsula increased at a statistically significant rate (estimated to be circa 0.63°C per decade), with observed warming higher over the northern Peninsula than over the south, and some record-breaking extremes^{58,63–66}. For example, Jeddah saw record temperatures of 52 °C in 2010⁶⁵, and a new UAE record for June was set in 2021 with a prolonged heat dome bringing a temperature of 51.8 °C⁶⁷. Studies show strong indication of an increasing temperature trend in all cities analysed, along with potential heat-island effects associated with urbanisation across the region⁶⁸. Figure 5 presents average mean temperatures in the region based on 2015 data.

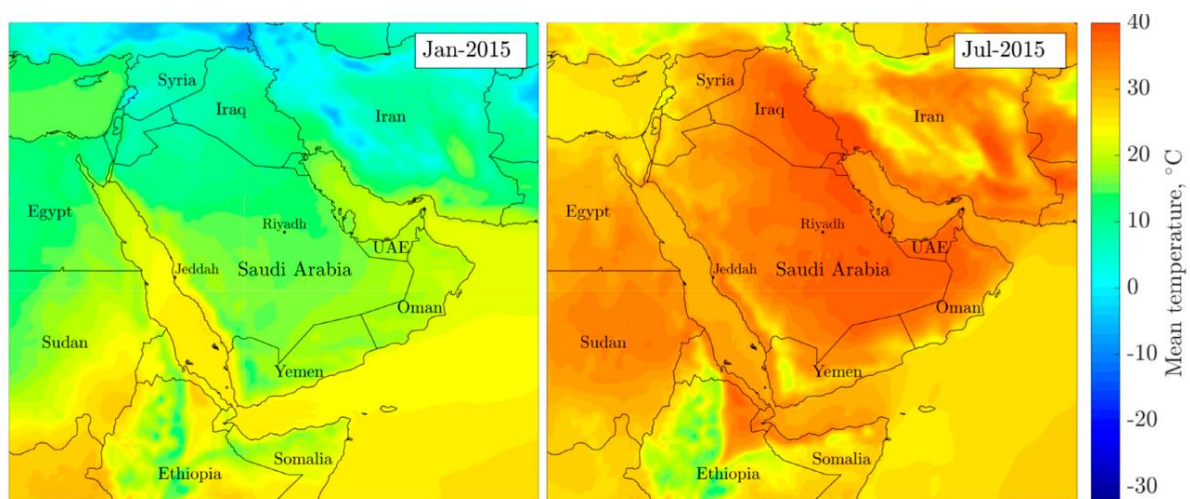


Figure 5 January 2015 (left panel) and July 2015 (right panel) mean temperatures (°C) across the region (Source: Howarth et al, 2020, based on ERA5)^{52,69}

- Average summer temperatures range from 27 °C to 45 °C, and the maxima may exceed 50 °C in some locations⁵².
- Average winter temperatures range from 8° to 20 °C in interior cities such as Riyadh, 19 °C to 29 °C on the Red Sea, and 12 °C to 25 °C on the Gulf coast in UAE⁵².

Both the Red Sea and the Arabian Gulf experience high water temperatures. In fact, the Arabian Gulf is the warmest sea in the world during summer months. (See Table 6). Periods of extreme sea temperature are becoming more frequent in the southern Gulf, and in 2017 daily maxima at reef-bottom were recorded averaging 35.9 °C for a period of almost two months, with hourly temperatures reaching 37.7 °C in some locations ^{70,71}. At such elevated temperatures coral bleaching and coral mortality are almost inevitable, and in 2017, 73% of corals in the region were lost ^{70,71}.

Table 6 Average Min/Max Sea Temperatures (°C) ⁷²

	Minimum	Maximum	Location
Red Sea North	22.3	31.4	Al Wajh
Red Sea Central	24.4	32.5	Jeddah
Red Sea South	25.5	33.8	Jizan
Gulf North (KSA)	17.6	34.3	Dammam
Gulf South (UAE)	20.4	34.9	Abu Dhabi
Gulf South (UAE)	21.3	34.7	Dubai

Humidity

Relative humidity is high year-round in the Gulf and Red Sea coastal regions, and generally greater during winter months with peak values in December and January (See Figure 6 for map of humidity levels). Coastal humidity levels typically range from 60-70%. Humidity levels and wet-bulb globe temperatures (TW; combined temperature and humidity measurement) determine comfort and habitability. The region has already recorded some of the highest TW temperatures on earth along the Gulf coast that have approached or exceeded critical physiological thresholds for human habitability (TW>35 °C) for short periods of an hour or two, and even much lower levels can have serious implications for human health and productivity ^{61,73}. Such occurrences become more likely with rising sea surface temperatures.

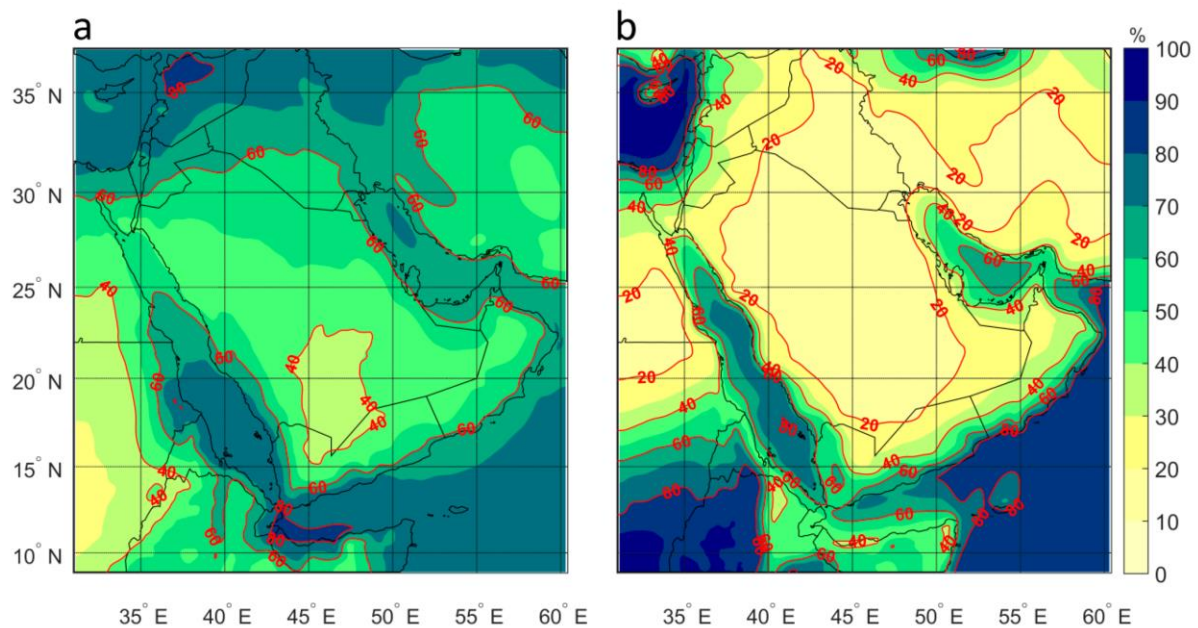


Figure 6 Mean Relative Humidity Levels (%) on the Arabian Peninsula for the months January (left panel, a), and July (right panel, b) based on observational data 1993-2015 (Source: Patlakas et al, 2019, based on downscaled ERA-Interim data) ⁷⁴

Changing precipitation and flooding

Extended spells of exceptionally hot weather, prolonged droughts even during winter months, and flash-flood-type events are defining features of the hydrological regime of arid regions like the Arabian Peninsula ^{75,76}. In particular, short and intense precipitation events can trigger severe surface-hydrologic impacts threatening the built environment and already fragile ecosystem ⁷⁵⁻⁷⁹, and increase the risk of propagation of water-borne pathogens. Climate change is expected to further exacerbate the contrast between prolonged droughts and extreme precipitation events in the region ⁸⁰.

- Annual precipitation averages between 54mm to 100mm across the region, with most rainfall falling within winter months as a consequence of cyclonic intrusions from mid-latitudes ⁸¹.
- Precipitation is highly variable in space and time, but some studies suggest precipitation levels are declining in parts of the north-central region, with some increases in the southwestern and southern Gulf region ^{58,81,82}. However, it is important to point out that the hydrological regime of arid regions is extremely intermittent, making a robust assessment of the precipitation trends in the region challenging ⁶⁶.
- Flash floods have occurred almost annually in some dry areas such as Jeddah since the 1960s, and their impact is increasing with greater urbanisation levels, with particularly damaging flooding occurring in 2009, 2010 and 2011 ^{79,83}. In

the UAE, Dubai recently committed USD 136 million to building flood defences after major flooding of the city in 2020 ⁸⁴.

Water scarcity

Water scarcity is a critical issue, and the region is increasingly dependent on expensive and energy-intensive seawater desalination to satisfy freshwater needs ⁵⁵. Beyond needs for irrigation and drinking, water availability and water quality are important indicators of health, and are intimately linked to food security, sanitation, and hygiene, and therefore the negative effects of climate change on water supply may create human health issues ⁸⁵.

- Non-renewable ground water abstraction for agriculture and forestry irrigation has greatly depleted non-renewing reserves over the past three decades ⁸⁶.
- While difficult to quantify, climate change likely impacts on the ability to regenerate freshwater reserves ⁸⁵.
- Increasing temperatures and higher rates of evapotranspiration are exacerbating water scarcity by requiring greater volumes of fresh water for agricultural irrigation ⁸⁵.
- Store and reuse of rainwater is difficult in hot desert: the region experiences about 2000 mm of potential evaporation versus 100 mm rainfall per year ⁸⁷. Additionally, cities have limited drainage and rainwater collection systems (Note: Dubai is now trying to retrofit an urban drainage network ⁸⁸)
- In contrast, managed aquifer recharge could represent a viable practice to increase groundwater storage ⁸⁹.

Mineral aerosols and air pollution

Increasing temperatures and lower precipitation reduce soil moisture and are contributing to land erosion and degradation, which may increase the frequency and severity of dust and sandstorms ^{90,91}. The frequency of dust events has increased markedly in northeast Saudi Arabia. This marked increase has been associated to drought conditions in the Fertile Crescent (Middle East), likely amplified by anthropogenic warming ⁹². The regions' cities already suffer from poor air quality, and these issues are expected to become more pronounced with further climate change creating aerosol air pollution (dust in particular) and respiratory health risks ^{93,94}. Dust and sand aerosols are also expected to have an impact on solar energy harvesting in the region ^{95–97}.

2.a.ii How these risks are likely to change by 2050 due to climate change

Temperatures and instances of extreme precipitation will continue to rise across the region over the century.

- Projected 1.4°C to 2.1°C mean change in temperature by 2050 compared to the reference period (1981-2010) based on a moderate emissions scenario (RCP 4.5/SSP2-4.5) ^{58,81,98}.
- Increase by 1.8°C to 2.7°C by 2050 compared to the reference period (1981-2010) under the worst case scenario at current emissions levels (RCP 8.5/SSP5-8.5) ^{58,81,98}.
- Projected precipitation changes are highly uncertain, but modelling suggests an annual increase in precipitation over the southern Arabian Peninsula, and a decrease over the northern Arabian Peninsula. Overall, under all emission scenarios, precipitation averaged across the region may increase by 1 – 38% by 2050 ⁵⁸. Results from the AGEDI WRF study similarly suggest an increase in average annual precipitation across UAE, with a reduction in the number of days with any precipitation, but heavier rainfall events when they do occur with potentially up to a 200% increase in maximum one-day rainfall by 2050 ⁹¹. Forecasts for KSA suggest lower overall annual precipitation over most of the country, but a similar pattern of increased intensity rainfall, increasing the probability of both droughts and floods ^{58,81}.
- Forecasts for changing relative humidity are limited, but the AGEDI WRF atmospheric model suggests humidity may increase by about 10% over the Arabian Gulf over this period ⁹¹, and the KSA NCC report suggests relative humidity may change from -12% in spring or fall to 22% in winter ⁸¹. When combined with rising temperatures, rises in relative humidity contribute non-linearly to rising wet-bulb temperatures (TW), and even under RCP4.5/SSP2-.5 wet-bulb temperatures exceeding 35 °C for three to six hours duration may occur, particularly on the Gulf coast ⁶¹.

Even under the RCP 4.5/SSP2-4.5 scenario, water scarcity, degradation of coastal, marine, and dryland ecosystems, and impacts on agriculture are anticipated ⁹⁹. Coastal areas will likely be most affected, with rising water temperatures, increasing acidification (from CO₂ absorption), and increasing salinity (from increasing evaporation rates and discharge from desalination plants) affecting marine habitats and fisheries ¹⁰⁰.

Sea levels are estimated to have risen 2 mm (± 0.5 mm) per year between 1979 and 2007 ^{101,102}. Forecasts for sea level rise through to 2050 are highly uncertain, but even if small, when combined with increasing likelihood of high impact tropical storms and cyclones and associated storm surges, will increase the risk of coastal flooding which will impact on the built environment, infrastructure, and coastal industries ¹⁰³. The

recent tropical cyclone Shaheen ¹⁰⁴ is only the second to hit the region since records began, but modelling suggests tropical cyclones will become more likely in the region, in particular for UAE, and could bring storm surges of up to 4m to Dubai by mid-century ¹⁰³.

By 2040 countries in the Arabian Peninsula are forecast to be ranked as the most water-stressed countries in the world ¹⁰⁵. Water scarcity (availability and quality), combined with rising temperatures and humidity, raises health risks by increasing the risk of water contamination, poor sanitation, food- and waterborne pathogens, and vector-borne disease in the region ^{85,106,107}.

2.a.iii Additional long-term climate risks that might be incurred before 2100

In the longer-term the average mean change in temperature for RCP 4.5/SSP2-4.5 is projected to increase by 2.3°C – 3.4°C, and annual precipitation across the Arabian Peninsula to increase by 4 – 49% by 2100 ^{58,81,98}. For RCP 8.5/SSP5-8.5 scenarios at the end of the century the mean estimated warming will exceed 5°C for the Arabian Peninsula ⁹², some of the north-central region of the KSA may exceed a 6 °C temperature rise by 2100, and annual precipitation is projected to potentially increase by 12 – 107% ^{58,81,98}. By the second half of the century, under the worst case scenario, super and ultra-extreme heatwaves are predicted with temperatures of 56 °C and higher for periods of several weeks' duration ¹⁰⁸, and wet-bulb temperatures along the Gulf and the Red Sea coastal areas that frequently approach or exceed critical physiological thresholds (TW>35 °C) for human habitability ^{61,73}. The RCP8.5/SSP5-8.5 scenario would lead to 50 - 150 days a year where the dangerous heat threshold of 41°C would be exceeded ⁹².

Agriculture and outdoor activities may become impossible in certain areas impacting on many aspects of society and the economy. This may have a critical impact in certain areas of KSA where agriculture represents the main source of economic activity, potentially leading to economic decline, migration, and depopulation. Later in the century under the worst case scenario sea-level rises are expected of between 1 and 2m, and tropical cyclones may bring storm surges of 7m with non-negligible probability towards the end of the century, which will have an increasingly significant impact on the low-lying coastal cities and infrastructure, disrupting transport and industry, probably causing many billions of dollars of losses, and possibly rendering some cities uninhabitable in the longer-term ^{100,101,103}.

2.a.iv How different physical, sociological, and economic risks and vulnerabilities interact (Correlated and cascading risks, multiple interacting risks, interconnectivity between these different physical climate risks)

Interactions between the various dimensions of physical climate change will accentuate impacts. The UAE and KSA's economic wealth provide significant resilience to cope with these environmental challenges in the short term, yet this is not

the case for less oil-rich neighbouring countries that are less able to cope with the effects of climate change. These countries may see potentially serious disruption to water and food supply chains, lead to regional conflict and changes in migration patterns that may impact the entire region. The biggest potential threat to the region would come from an unexpectedly rapid decline in oil and gas demand – the Covid-19 pandemic has provided an unprecedented worldwide test of a shock to global demand, and its effects in the region requires careful analysis to anticipate the potential implications of the energy transition.

2.b Sectoral and socioeconomic impacts of physical climate risks

2.b.i Economic sectors listed in section 1.a which are most exposed/vulnerable to physical climate risks

Of the major sectors within the region, those most exposed to physical climate change effects are the petrochemical industry; power generation; water; real estate and construction; tourism; and agriculture and fisheries.

2.b.ii Examples of how these sectors may be impacted by climate change including any material impacts on trade flows

Petrochemical industry – Extreme weather events including extreme temperatures, storm surges, flooding, strong winds and extreme precipitation from tropical cyclones, dust and sandstorms pose a critical challenge to the reliability and durability of the oil supply chain from extraction, refining and processing, to export; in particular as much of the refinery infrastructure is located in low-lying coastal areas ^{91,109}. Rising temperatures also impact on processes such as liquefaction and refining which are very temperature-dependent, and increasing aridity in the region will impact on access to water resources for refinery processes ¹¹⁰. Oil infrastructure has multi-decadal lifetimes; extreme weather conditions exacerbate ageing and performance issues, which may result in supply disruptions, outages, continuous extensive maintenance requirements, etc., with potentially billions of dollars of additional costs for the industry and end-users. Similar issues may apply to other heavy industries within the region.

Power generation – Extreme weather events may result in efficiency losses and reduced reliability of power plants and transmission gear, reduced power station output due to warmer cooling water, deterioration of power facilities, power outages, and risks from cyclones and rising sea-levels on generating infrastructure ¹¹¹. For example, in 2010 extreme temperatures combined with dust storms temporarily disabled nine power stations in Jeddah ⁶⁵. With the region heavily dependent on power for cooling and water desalination power outages can have serious implications for habitability and public health. Higher temperatures and sand and dust storms also impact efficiencies and reliability in the emerging solar and wind power sectors. At the same time, rising temperatures and increasing humidity will cause a marked increase in power demands for cooling, requiring significant expansion of infrastructure and

transmission capacity (e.g., an 11% increase is forecast in UAE by 2050 to support incremental cooling demand ⁹¹).

Water supply – With rising temperatures, demands for irrigation will increase, and therefore increasing dependence on desalination processes is inevitable for the region. Coastal-based desalination processes are susceptible to extreme weather events, flooding, and algal blooms that are likely to become more frequent with rising sea temperatures and climate change ⁹¹. Moreover, desalination is an expensive, energy, and carbon intensive process ^{55,112} that will have economic impacts, and is contributing to increased salinity in marine environments through brine discharge which reduces desalination efficiencies over time ¹¹³ and has other environmental impacts ¹¹⁴. Desalination plants are usually coastal, and supplying desalinated water to inland regions, by truck or pipeline is expensive.

Construction and real-estate – In the UAE 85% of the country's population and more than 90% of its infrastructure are located in low-lying coastal areas ². Therefore, rising sea-levels, tropical cyclones, and storm surges in coastal regions threaten coastal and offshore infrastructure, reducing the reliability of transport infrastructure and buildings and impacting on industrial and economic activity and exports, on real estate valuations, and insurance. Extreme conditions in the region will demand costly building upgrades for elevation and floodproofing, and to enhance liveability and cooling, increasing costs for building owners and end-users. These costs could reach USD 834 million per year in UAE by 2050 ⁹¹. While of lesser impact relative to many of these potential costs, the negative influence on worker productivity in extreme temperatures and humidity should also be acknowledged ^{115,116}.

Tourism – This is a growth sector in the region. However, prolonged extreme weather events, particularly extreme temperatures and humidity, along with rising sea levels may disrupt and significantly change demand in the region, and greatly undermine the economics of the industry, e.g., demanding greater investment in infrastructure to protect against flooding and storm surges and increased costs for cooling ^{117,118}. International tourism will be adversely affected by anticipated carbon taxes on aviation. This sector is energy intensive and primarily based on fossil fuels, i.e., aviation and operating in desert conditions ¹¹⁹; thus, tourism will require pronounced changes if it is to remain an active sector in a net-zero economy.

Agriculture – Higher temperatures and stronger wind patterns will contribute to land erosion and demand greater irrigation to counter evapotranspiration (some estimates suggest 16% more water will be required for summer crops by 2050 ⁸⁷), making the cost of open field agriculture increasingly unviable. Strong winds and precipitation from tropical cyclones may also cause direct damage to crops. Alternative, controlled farming techniques utilising synthetic closed or partially closed environments will be required to counter climate change effects ¹²⁰. Additionally, climate effects and extreme weather events can facilitate pest outbreaks and crop disease ⁸⁷. The devastating desert locust swarms seen in 2020 across parts of the Middle East and

Africa are attributed in part to climate change and are likely to become more frequent, and represent a significant threat to KSA ¹²¹. Moreover, the region is heavily dependent on imported foods, and is therefore vulnerable to climate effects in other countries and climate-induced instability in international food markets ⁹¹.

Fisheries – Rising water temperatures, acidification, and increased salinity of the Gulf will degrade marine habitats such as mangroves and coral reefs and undermine fish stocks in the region. Modelling suggests local extinction of up to 35% of species, and a decline in future fish catch potential of 26% by the end of the century ¹²².

2.b.iii Demographic and ethnographic groups most at risk from climatic changes

Climate change introduces risks for all, but particularly for the young, the elderly, and the poor ¹²³. While both KSA and UAE are wealthy countries, inequality levels are high and poverty is a concern in some areas, with reports suggesting an estimated 20% of Saudis living below the poverty line ^{124,125}. This risk area requires further consideration, particularly as many long-standing subsidies are now being scaled back ¹²⁶. Both KSA and UAE also have high numbers of low-income foreign workers in construction, agriculture, fisheries, and services. These groups will be the most impacted by climate change, and may potentially lack the resources for cooling and appropriate shelter from extreme temperatures, be more susceptible to water scarcity and related sanitation issues, and be routinely exposed to extreme temperatures in outdoor manual occupations ¹²⁷.

Moreover, employment opportunities may decline as the region's early rapid growth stabilises and climate change degrades land and maritime operations ¹²³. A reduction in the foreign worker population will affect both the region as well as their countries of origin that benefit from their remittances, e.g., India, Indonesia, Pakistan, Bangladesh, Egypt and the Philippines (for example, in 2014, overseas remittances sent home by migrant workers in KSA were an estimated USD 36 billion) ¹²⁸.

2.b.iv Broader risks to sustainable development within the region that arise from physical climate change

While KSA and UAE may have the resources to adapt to climate change, other countries in the broader Middle East region are likely to see acute stresses around food, water, and habitability, and deteriorating rural livelihoods. This will lead to migration from rural to urban centres, international migration, and may exacerbate unrest and political instability in the region ¹²³. The Arabian Peninsula's already significant dependency on food imports is likely to increase, exposing the region to climate change impacts well beyond its borders. For KSA and UAE, the ability to adapt to climate change depends on continued global demand for petrochemicals and transition paths typically suggest a 2050 timeframe ¹²⁹. As the net-zero transition progresses, the Arabian Peninsula particularly seems exposed to the prospect of

stranded assets, such as petrochemicals and related real estate both at home and in the many overseas investments the region has in refinery and oil and gas infrastructure ¹³⁰.

2.c Adaptation: Solutions & Opportunities

2.c.i Region-specific adaptation and resilience priorities against anticipated levels of climate change impacts

The most vulnerable areas to climate change in the region are: water, coastal, marine, and dryland ecosystems; buildings and infrastructures; agriculture and food security; and public health ^{100,131}. The following section presents an overview of key initiatives to support adaptation and transformation; some of these sectors are discussed in more depth in section 3.c Sectoral impacts.

2.c.ii Current/future solutions which have the potential to satisfy this country's adaptation needs, including transformation

Infrastructure – Solutions include flood barriers and seawalls for surge protection and stormwater drainage systems to avert flooding (e.g., major investments underway in UAE) ^{84,88}; provision of affordable cooling technologies to reduce risk to health from heat stress ⁶¹; better building controls and more efficient cooling solutions (efficient district cooling is already well developed, but newer technologies may offer enhanced performance); higher building standards and retrofitting and modernisation of older buildings for improved energy efficiency and protection from solar gain; possible use of traditional building techniques such as wind towers to create natural cooling with lower energy demands (already demonstrated in Masdar city); green roofs and urban green infrastructure to mitigate urban heat island effects (already a feature in many of the major cities in the region and all the newer developments) ^{132–134}; smart cities to improve the built-environment and liveability (subject to broader sustainability considerations); and eco-tourism initiatives to minimise environmental impact of new developments (e.g. Red Sea Development Project ¹³⁵). Building codes for new construction in UAE already incorporate more stringent requirements for flood protection, and public infrastructure upgrades are underway ².

Energy and water – Initiatives include wastewater management, treatment and reuse, including use of impaired water (i.e., reduced brine) in agriculture; dams and forced infiltration, and infrastructure investments for rainwater harvesting to reduce risks from flash-floods and to capture precious precipitation; monitoring and improvements to distribution networks to reduce leakages (various initiatives are ongoing) ¹³⁶; and enhanced irrigation and transition to low-water crops (drip irrigation has improved efficiencies by 35% in some cases) ¹³¹. Additionally, clean technologies and efficiency improvements are ongoing to reduce air pollution ⁹⁴, and reduce energy and water demands in industry; expanded renewable energy generation (particularly solar) to cut emissions; and upgrade of the region's desalination systems to improve

efficiency and meet rapidly rising capacity demands and to offset use of depleted groundwater. To enhance resilience, UAE have established freshwater reserves using desalinated water to recharge ancient aquifers to provide for emergency outages ⁵⁵, and among other initiatives, a hydro-electric energy storage project is under construction to provide power back up in the region.

Environmental resilience and regeneration – Coastal ecosystem resilience projects such as the National Blue Carbon Project in UAE aim to preserve, protect, and restore coastal habitats including mangrove forests, seagrass meadows, and saltwater marshes, and provide natural carbon capture ^{4,137–140}. KSA's similar land degradation and coral reef initiatives (e.g., KAUST partnership with NEOM to protect coral gardens ¹⁴¹), and tackling soil salinisation and soil degradation and erosion through improved agricultural techniques and soil reclamation and regeneration ^{62,142–144}. Planting of vegetation and use of oil mulch, etc. has been used and proven to stabilise sand dunes and reduce erosion and dust and sandstorms ^{81,145}; and promotion of traditional crops, hydroponics and greenhouse farming, seawater greenhouses, investing in bio-salinity research is underway to enhance agricultural performance ¹²⁰. The potential for bioenergy and bioremediation from salt-affected soils is also being explored ¹⁴⁶. Protection against pest and crop disease outbreaks will become increasingly important with climate change – KSA already has well-established national programmes in place and in 2020 deployed 40 teams to fight desert locusts ¹²¹, but these capabilities may need to be expanded in the future if threats increase.

Societal initiatives and behavioural change – Rising temperatures will likely reduce the productivity of outdoor workers and pose a fundamental threat to human wellbeing ^{115,116}, and so a mid-day break policy and a safety in heat programme to protect workers has been initiated in UAE ¹⁴⁷. Early warning systems are being implemented using technology and social media to alert the population to impending storm, flooding, pollution, and high temperature (particularly wet-bulb temperature) risks. Demand management policies and provision of smart meters to reduce energy and water usage are being implemented (e.g., 10 million smart meters rolled out over 14 months in KSA ¹⁴⁸), and policy interventions to reduce energy/water use and waste in the hospitality sector (e.g., Dubai has mandated wastewater reuse for irrigation, food composting, use of refillable dispensers, and other initiatives to become more eco-friendly ¹⁴⁹). Further education and raising public awareness of waste reduction, energy and water consumption are underway ^{55,150}. In the wake of the dramatic fall of international oil prices in 2014, in July 2015 the UAE implemented major changes to fuel prices (gasoline and diesel), essentially removing subsidies and implementing a federal-level fuel price, adjusted monthly, based on international prices. Additionally, both UAE and KSA have begun reducing electricity and water subsidies and are attempting to implement more cost-reflective tariffs, reducing wastage and improving the business case for energy/water efficiency ^{151–153}. Additionally, to enhance resilience to the extreme temperatures of climate change, governments will need to undertake

emergency public health planning, ensure public awareness of the risks, and make provision to move vulnerable people into air-conditioned locations, etc. ¹⁵⁴.

2.c.iii Locally specific emerging sectors that might be of future importance for adaptation

Potential growth areas in the region that build upon the existing energy infrastructure and resources and the expertise in operating in an extreme hot climate include:

- Urban development and smart cities – redefining the urban environment to optimise for liveability, mobility, etc.
- Shelter and construction techniques for hot climates
- Energy efficient technology to improve quality of life for less affluent individuals and communities
- Efficient air conditioning/cooling solutions
- Water desalination technologies; coupled systems based on renewables
- Aquaculture and coastal preservation
- Sustainable agriculture; indoor farming; agriculture for extreme conditions; combining renewables and agriculture
- Efficient carbon capture and sequestration (enhanced oil recovery, mineralization in mafic rocks)
- Hydrogen and synthetic fuels production and storage
- Circular-carbon technology for reusing and recycling captured carbon emissions for reuse in other industrial production processes
- Sustainable greening of the desert; soil regeneration and marginal land reclamation; nature-based solutions for the preservation of ecosystems; geoengineering initiatives and cloud seeding
- New developments in small-size nuclear reactors (e.g., for urban-scale desalination needs)

3. Development Compatible Transition – Risks, Mitigation and Opportunities

3.a. Socioeconomic and sustainable development risks of a net zero transition

3.a.i How different demographic and ethnographic groups would be impacted by a net zero transition

With the extractive industries representing 31% of the workforce in UAE ¹⁵⁵ (Statistics unavailable for KSA), a rapid transition or slowdown in the oil and gas industry would put many jobs and livelihoods at risk and unless there has been adequate diversification this could have cascading effects throughout the broader economy ¹⁵⁶. New jobs will be created in clean energy and installation work to offset this decline, but much of the manufacturing and operation will be automated ¹⁵⁷. Those most likely to suffer the greatest impact of a rapid transition will be lower-income manual workers and older workers without the skills and social mobility or educational opportunities to easily find alternative employment. Foreign workers will be the most vulnerable; in

fact, Emiratization and Saudization policies that give priority to citizens are already in place ^{14,40}. Retraining will be a priority for many parts of the economy, and younger generations will need education to prepare them for the transition to a new economy ¹⁵⁶. The costs of transition to a low-carbon economy, such as improved building efficiencies, improved cooling technologies, electric vehicles, etc. may prove prohibitive for some, although in the longer term they should deliver lower operating costs. Government support and innovative financing mechanisms will be essential to ensure broad uptake of technologies, and to ensure that the costs are borne fairly ¹⁵⁸.

Gasoline, electricity, natural gas, desalinated water, and agriculture have been heavily subsidised in the past, but subsidy reform and increases in VAT are now underway in the region, in part to tackle high consumption levels. These changes are already showing results with a reduction in energy and water use and may positively contribute to the net-zero transition ^{126,152,153,159}. The full impact of net-zero initiatives on food supply is uncertain; clearly, costs will increase if a global carbon tax is applied to international freight. On the positive side, public infrastructure investments in renewable energy, more efficient water desalination plants, increased access to public mass transit and improved urban design for sustainability should lower costs of access and deliver social equity and benefits to all. Other initiatives such as sustainable nature regeneration to support carbon sequestration should also provide broad societal benefit. However, these initiatives should be considered in the context of desert hydrology and climatology, and their net carbon budget should be considered, i.e., carbon fixed versus carbon emitted during implementation.

3.a.ii Risks to broader sustainable development within the region that could arise

The recently published International Energy Agency roadmap for net zero by 2050 proposes that renewables and nuclear power need to displace most fossil fuel use, with the share of fossil fuels falling from 80% in 2020 to just over 20% by 2050 (See Figure 7). As of 2019 it was unclear whether the 2050 goal was achievable or whether a gradual or rapid transition would prevail ¹⁶⁰. An overly rapid decline in oil and gas use around the world and a collapse in exports and stranding of production assets would seriously affect the region and may curtail its ability to undertake an orderly transition to net-zero ¹³⁰. On the other hand, a slow response will exacerbate climate effects and its multiple ramifications on infrastructure, industry, water, food systems and the built environment, including costly litigation to industries that fail to abate emissions ¹⁶¹. Therefore, early embrace of a net-zero future and appropriate diversification strategies, including investment in renewable energy systems, decarbonisation of industry and the built environment and transportation seem vital for the region.

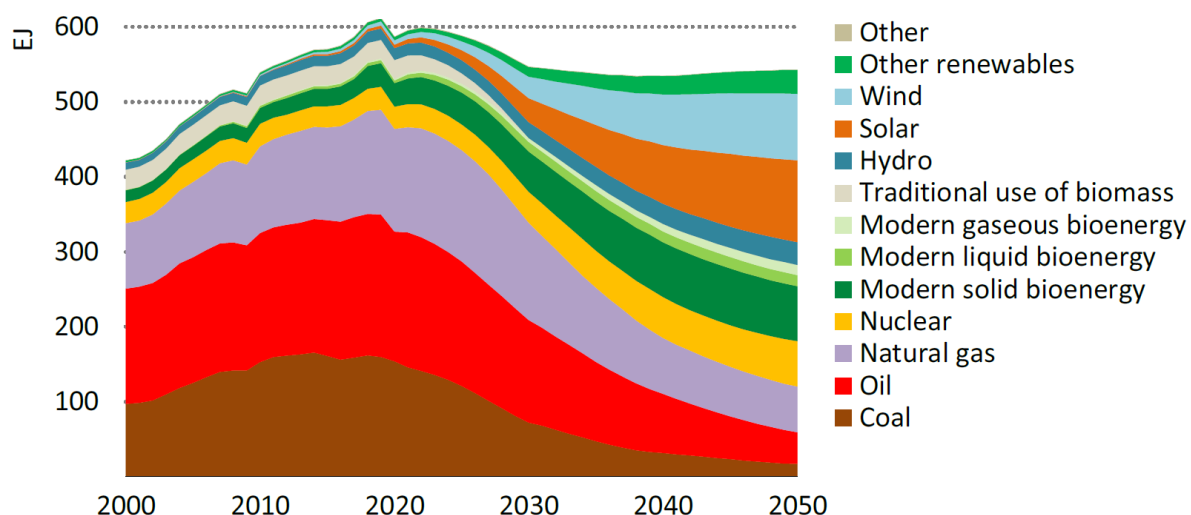


Figure 7 Total Energy Supply in Global Pathway to Net-Zero Emissions by 2050 (Source: IEA, 2021) ¹⁸

In the meantime, oil and gas will continue to play a role in energy provision until the global energy transition is complete ¹⁶². Along the way, disruptive technologies, including breakthroughs in CCUS technologies, may drastically change the path towards a net-zero future. It should be noted that even in the net-zero scenario, some oil and gas use will continue beyond 2050 for producing non-energy goods, in plants using CCUS, and in sectors where abatement is especially difficult ¹⁸. Getting the investment balance right will be critical to ensure sustainable development is supported both regionally and globally.

3.b Just Transition

3.b.i Priorities for enabling a just transition

The transition towards an equitable, net-zero and sustainable energy system must address the already pronounced inter and intra-national inequalities in power consumption and quality of life that prevail today in the region and the world. This will require reduced energy consumption by over-spenders without diminishing their quality of life, while improving the quality of life among the poorest groups and countries. These combined goals can be achieved while keeping the global power consumption stable ¹⁶³. The most critical variable towards a sustainable and equitable worldwide energy system is the role played by visionary governments and the willingness of the international community to explore global solutions beyond national boundaries.

The priorities for enabling a just transition are an inclusive approach to development that ensures all parts of society are supported in the move towards net-zero. A just transition should be based on balanced ambitions, accountability by all parties involved, visionary and accountable governance, diverse business-led solutions and

incentives, and fairness of opportunity, enabling all to participate, contribute to, and benefit from the transition ¹⁶⁴.

Many of the projects currently envisaged for the net-zero transition in the region, such as renewable energy infrastructure and alternative high-technology agriculture are large-scale corporate operations, often run by state-owned enterprises; policy and strategies must also create complementary opportunities for small and medium-sized companies to be intimately involved in the transition towards a net-zero economy ¹⁵⁷. Potential alternatives are listed next.

3.b.ii Examples of future opportunities that could enable a just transition in these countries, including adaptation to transition risks

The challenges should not be underestimated, but some examples of the potential opportunities are:

- Education to promote resource conservation and waste minimization and sustainable consumption at all scales, particularly energy, water, and food.
- Circular economy initiatives to reduce, reuse, remanufacture, recycle.
- Adaptation/ mitigation strategies towards sustainable urban living (water, food, energy, mobility, sustainable population size).
- High-efficiency, high-quality housing for hot climates.
- Distributed renewable energy generation and storage (single home to neighbourhood scales).
- Small-scale advanced, controlled environment agriculture and local farming technology (focused on home and school-scales).
- Urban and natural ecosystems preservation, adaptation, restoration. Air quality and dust control.

3.c Sectoral and socioeconomic impacts of a development compatible transition under each of the following transition pathways

Steady, orderly, persistent transition pathway

An orderly transition involves a comprehensive and inclusive strategy for adapting early to future climate change through infrastructure, environmental, and societal investments, and diversification towards a new economy based on renewables, knowledge, and technology. A series of potential technology areas have been identified where the region has the potential to become a world leader, to build a strong diversified economy, and become a major contributor to global solutions for a net-zero future on a warmer planet. By taking an early leadership role KSA and UAE are already playing an important role in moving the whole region forward, as demonstrated for example by hydrogen projects, carbon capture and storage, renewables and nuclear, and large-scale indoor farming ^{2,10,165–167}. Such innovations will assist the world in transitioning to net-zero, prevent major disruption in the less affluent countries in the region, and maintain the geopolitical influence of the region ¹⁹.

Late, disorderly transition pathway

A late disorderly transition pathway would stem from the world's reluctance to embrace the net-zero transition, to persist with the traditional fossil fuel economy, and fail to adequately adapt the economy. Demand for oil and gas will likely persist for decades, yet the later the world begins tackling its dependency on fossil fuels, the more challenging the transition will become.

The region has already started to take actions. However, coordinated efforts across the region and with the rest of the world are needed for effective progress. A delayed response will leave the region with stranded assets, and reduced resources to confront the extreme climate forecast by the end of the century. Such a scenario would result in an exodus of financial and human capitals. Worst-case scenarios could involve mass migration, societal collapse, and major conflicts over diminishing resources.

Sectoral Impacts

The following part of the profile is split by sectors as defined by the Expert Committee as priority sectors of key importance towards a net-zero transition. These are:

1. **Energy** (Energy transition, renewables, heavy industries, carbon capture)
2. **Water** (Groundwater use, desalination, wastewater reuse, and water security)
3. **Built environment** (Construction, infrastructures, cooling, and habitability)
4. **Transportation** (Surface transport, mass-transit, aviation, and shipping)
5. **Natural environment** (Ecosystem resilience, regeneration, and blue carbon storage)
6. **Food systems** (Food security and novel technologies for dryland agriculture)

In the interests of space, this profile does not include a separate sectoral analysis of tourism, yet it merits careful attention. Indeed, tourism is an important growing sector in the region – for example, the Hajj festival was anticipated to bring in USD 150 billion in income and generate 100,000 jobs from 2018-2022 ¹⁶⁸ – and KSA has set a target of attracting 15 million foreign Umrah pilgrims by 2022 and hopes to be able to accommodate 30 million foreign and 20 million Saudi pilgrims per annum by 2030. Major tourism projects include extensive infrastructure developments such as the construction of artificial islands and the operation of resorts in desert conditions which require extensive cooling and desalination systems and food imports which are inherently energy intensive ^{119,169}. Furthermore, international tourism depends on fossil-fuel-based aviation and has pronounced implications for net-zero and environmental sustainability. Whenever applicable, aspects related to tourism are discussed within the six sectors analysed next.

The region's sovereign and private wealth funds and related investments around the world bring unprecedented opportunities to define development directions within the

region (as already observed in certain sectors), as well as future global trends in energy, infrastructure, and related innovations. While publicly available data are limited, the role of the sovereign wealth funds merits further consideration in the context of a holistic strategy towards net-zero.

For each of the sectors in turn, the following questions are answered:

- 3.c.i Sectors most likely to be impacted, including material impacts on trade-flows, and considering both risks and opportunities.*
- 3.c.ii Examples of how these sectors may be impacted by a net zero transition, including any material impacts on trade flows.*
- 3.d.i Current/future solutions that can enable development-compatible emissions reduction in the region (in line with the SDGs).*
- 3.d.ii Locally specific emerging sectors that might be of future importance for development compatible mitigation.*
- 3.e Likely co-benefits and trade-offs of the solutions and opportunities identified, including, where relevant, in the context of the Sustainable Development Goals.*

Energy transition

(3.c.i Sector overview) With a major share of the world's fossil fuel reserves, and an energy intensive economy and society the region is dominated by the energy sector. Table 7 presents a summary of key metrics for fossil fuels illustrating the scale of the oil and gas sector in the region in terms of production and consumption. Electricity generation in the region is currently over 95% based on oil and gas (See Table 8); transportation is largely dependent on fossil fuels, or electricity generated by fossil fuels; gas is also the primary fuel for domestic cooking (and for heating where necessary in KSA) ¹⁷⁰; and the region's industrial sector is similarly carbon intensive as it is anchored around industries that are predominantly based on the combustion of fossil fuels (See Table 9 for a list of industrial sectors). Decarbonising the energy supply through the use of solar power, wind power (only in KSA), nuclear (currently only in UAE) and geothermal (under consideration) is underway with a significant number of further projects in the pipeline, but oil and gas will likely remain a key part of the energy mix for decades to come. Moreover, the UAE's plans to significantly expand use of imported coal to reduce domestic consumption of oil and gas are at odds with the prevailing attitude to net-zero (The UAE's first coal-fired power station, Dubai's Hassyan plant, is scheduled to open in 2021, and at 3.6GW it will be one of the largest coal-fired power stations in the Middle East) ⁵¹.

Table 7 Petroleum industry in KSA/UAE as of 2019 (Source: BP Global Energy Review 2020) ¹⁷¹

Energy Metric	Kingdom of Saudi Arabia	United Arab Emirates
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Known oil reserves	297.6 billion barrels (17.2% of world reserves) ~70 years	97.8 billion barrels (5.6% of world reserves) ~70 years
Known natural gas reserves	6.0 trillion cubic metres (3% of global reserves) ~50 years	5.9 trillion cubic metres (3% of global reserves) ~100 years
Oil production per day	11.8 million barrels per day (peak 12.4 million barrels per day) 12.4% of global production	4.00 million barrels per day (4.2% of global total)
Gas production per day	113.6 billion cubic metres per day (2.8% of global production)	62.5 billion cubic metres (1.6% of global production)
Oil consumption per day	3.79 million barrels per day (3.9% of global consumption, ranked 6 th in world for consumption)	1.04 million barrels per day (1.1% of global total)
Gas consumption per day	113.6 billion cubic metres (2.9% of global consumption)	76.0 billion cubic metres (1.9% of global consumption)
Coal consumption per day	None	0.10 Exajoules (2% of energy in UAE, but set to rise in 2021) (0.1% of global consumption)
Oil exports	8.397 million barrels per day (bunker fuel excluded) (Crude 7.198, products 1.199)	4.41 million barrels per day (Crude 2.80, products 1.61) (Imports 0.248 crude, 0.729 products)
Gas exports	None (in planning)	7.7 billion cubic metres
Refinery throughput	2.60 million barrels per day (3.1% global share)	1.10 million barrels per day (1.3% global share)

Table 8 Current power generation in KSA and UAE as of 2019 (Source: BP Global Energy Review 2020) ¹⁷¹

	Kingdom of Saudi Arabia	United Arab Emirates
Electricity generation	357.4 terawatt-hours per year (1.3% global share)	138.1 terawatt-hours (0.5% global share)
Renewable energy generation capacity	1.8 terawatt-hours per year (solar) (<0.1% of global share)	4.2 terawatt-hours per year (solar) (0.1% global share). Nuclear 12.3 terawatt-hours (1.4 GW capacity).

Percentage from renewables	0.5 %	3.0 %
Primary energy consumption per capita	322.0 Gigajoules per capita (89.4 MWh per year; 245KWh per day)	494.4 Gigajoules per capita (137 MWh per year; 376KWh per day)

Table 9 Industrial Processes and Manufacturing (Source: IndexMundi, 2021) ¹⁷²

	Kingdom of Saudi Arabia	United Arab Emirates
Industrial products	Crude oil production, Petroleum refining, Petrochemicals, Ammonia, Industrial gases, Sodium hydroxide, Cement, Fertilizer, Plastics, Metals, Commercial Ship repair, Commercial aircraft repair, Construction	Petroleum and Petrochemicals, Fishing, Aluminium, Iron, Steel, Cement, Chemicals, Fertilizer, Commercial Ship repair, Construction Materials, Handicrafts, Textiles

(3.c.ii Impact of net-zero transition) Shifting political and investor sentiment towards fossil fuels, and the prospect of costly litigation against oil and gas producers in the future will add impetus for significant change in the sector over the coming decades ¹⁶¹. Indicative of the recognition of the need for action the Net-Zero Producers Forum led by the US has recently been established between the energy ministries of Canada, Norway, Qatar, KSA, and the US, collectively representing 40% of global oil and gas production, with the stated objective of developing pragmatic net-zero emission strategies ^{173,174}. The net-zero transition will demand radical shifts in technologies, operations, and consumer practices across all sectors of the economy. The net-zero transition towards zero-carbon energy will be capital intensive and heavily dependent on innovative technologies, but the opportunity to build a regional hub in renewable/clean energies could be a strong motivation for change. The rapid rise in renewable energy investment over the past few years combined with falling prices for PV suggests financing these projects should not be a major barrier going forward ¹⁷⁵, and the region already has the necessary international collaborations and partnership in place to scale up. Much of the needed technology is currently imported, but there is some domestic capability in KSA for production of solar cells, modules, inverters, tracking systems, mounting systems, and cabling, and integration and operational expertise so the domestic sector which should be well positioned to benefit from the transition ¹⁷⁶. State led developments and Public-Private Partnerships are established mechanisms for this process ¹¹.

Decarbonising the petroleum and heavy industrial activities will be more challenging and costly, and leapfrog technological solutions are still needed. Carbon Capture Utilisation and Storage (CCUS) must be part of the energy strategy for the region for the next decades, but it remains costly and has an unproven certainty of execution at

large scales. In the short term, a regional energy strategy must involve cultural changes towards conservation, technological choices with increased efficiency, cleaner production technologies, transition to electrical energy (which benefits from more efficient centralized production), more extensive internal use of natural gas in place of oil and coal combustion (coal is currently used in steel and cement sectors in UAE), and increased investment into renewables. UAE claims the carbon intensity of its aluminium industry is among the best in the world, and in 2020 announced ambitions to reduce GHG emissions in oil and gas production by 25% by 2030 relative to 2020 levels ². It is also important to highlight that both UAE and KSA have committed to zero-flaring from gas extraction operations by 2030. Technologies and solutions are already proven to eliminate the need for flaring and for detection and fixing methane leaks.

It should be noted that emissions from oil and gas extraction vary considerably by region. Oil production in UAE and particularly KSA have relatively low carbon intensity when compared with other oil-producing nations ¹⁷⁷. While such claims have been disputed ¹⁷⁸ and further verification is required, the environmental cost of unclean production should be factored into future oil prices worldwide.

(3.d.i Current/future solutions) Renewable energy initiatives in the region at present are primarily solar PV, and both countries have good potential for concentrated solar thermal power ¹⁷⁹. There is significant opportunity for biomass waste-to-power generation in both UAE and KSA ^{2,180,181}. Wind power and geothermal are considered in KSA, and in fact, KSA has considerable geothermal resources ^{182,183}. Nuclear is also an important area of investment in UAE and planned in KSA.

Installations are underway across the region, and UAE claims investment of USD 40 billion to date in development of zero-carbon energy ², and has announced ambitious targets to increase solar capacity to approximately 10% of demand by 2025, and emissions-free energy (solar and nuclear) to 50% by 2050 ^{184,185} (The balance will remain primarily fossil fuels including coal). The plans include an ambitious pipeline of projects including the world's largest single-site PV/CSP power plant – Al Maktoum Solar Park – with 5GW capacity, of which 1GW is already installed (Phases 1-3) and an additional 950 MW (CSP and PV; Phase 4) to be operational in 2022 ^{186–189}. Building-mounted PV installations are also being encouraged to expand capacity in Dubai, although dust/cleaning requirements and legal factors limit uptake ^{190,191}. To manage intermittency of renewables UAE has installed the world's largest battery to date, a 108 MW/648 MWh sodium-sulphur battery plant in Abu Dhabi, and Dubai Electricity & Water Authority (DEWA) is developing a 250MW pumped-storage hydropower project forecast for completion in 2024 ^{2,192}. UAE has also recently connected its first nuclear plant to the national grid delivering 1.4GW of baseload capacity, and the second phase will increase this to four plants with a total of 5.6GW capacity by 2025 ¹⁹³. Although small in comparison, planned waste-to-energy projects include a 100MW plant in Abu Dhabi, a 60MW plant in Dubai, and an 80MW plant in

Sharjah, aiming to convert almost 100% of organic waste to energy, and reduce waste to landfill by 75% ¹⁹⁴.

KSA has announced plans to increase the share of natural gas and renewables in power generation to 50% by 2030, with ambitious solar energy plans including K.A.CARE's renewable energy program recommending a total of 41GW by 2032 made up of 16GW from PV and 25GW from concentrated solar power CSP ¹⁹⁵. The Sakaka utility-scale 300MW solar PV plant was opened in 2021, and a follow-on 1.5GW plant, Sudair Solar PV, was announced in 2021 ¹¹. The first utility-scale onshore wind farm is also under construction, Dumat Al-Jandal 400MW, due for completion in 2022, and there are proposed plans to develop up to 30 farms in the future. ^{196,197}. KSA is exploring utility-scale deployment of offshore wind farms, and also has future plans for nuclear power ¹⁹⁸.

The price of solar PV power is falling rapidly in the region and UAE has recently achieved some of the lowest tariff prices in the world ^{199–201}, and KSA is targeting an even lower rate of USD 0.0161/kWh with the recently announced 1.4GW Al-Faisaliah plant ²⁰². Therefore, power generation should prove one of the easier sectors to decarbonise. Nonetheless, with anticipated electrification of transportation, industry and desalination over the coming years, electricity demand will rise steeply and the current plans to reduce emissions will not be adequate to offset demand growth.

Regional energy consumption per capita is among the highest in the world, therefore in addition to clean energy initiatives, there are also initiatives underway to increase the efficiency of consumption ^{1,198,203}. Two of the primary targets are reducing the energy used for cooling of buildings ^{204–207} and for water desalination. UAE for example has set a federal target to reduce energy consumption by 40% by the year 2050 ². Other initiatives, discussed in Section 2.c.ii in this profile, include introducing smart metering, awareness and education, deployment of new more efficient technologies, and pricing signals to change behaviour ¹⁹⁸.

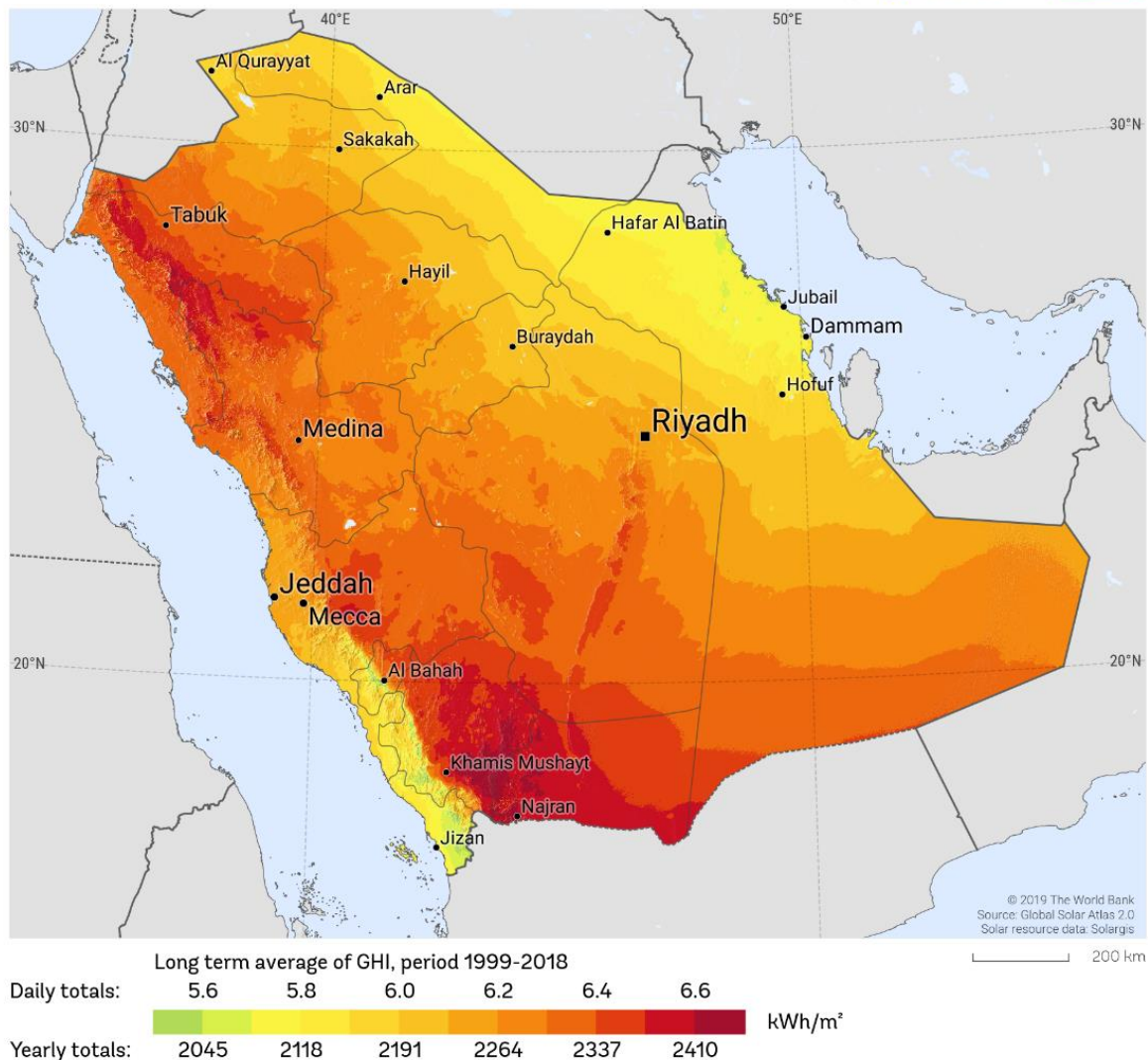
(3.d.i Bigger-picture future solutions) Renewable energy sources will play a central role in decarbonising energy consumption and transportation in the region. If implemented at scale, it would reshape the regional economy, and establish the region as a global zero-carbon energy hub ¹⁹. Solar is the most obvious renewable energy choice; with high insolation rates the region receives on average over 10 hours of sunshine for 350 days per year ¹⁵⁷ and a global horizontal irradiance in the range of 5-9 kWh/m²/day ^{179,208} (See Figures 8 & 9 from Solargis²⁰⁹). For reference these figures are more than double the highest available rates on the south coast of the UK. Dust, humidity, and elevated temperatures degrade the performance of solar photovoltaics, and part of the produced energy must be utilized for cleaning and maintenance, but nonetheless performance in the region is still high ¹⁵⁷. Geothermal and wind power also have good potential in KSA. See Figure 10 for a map of geothermal resources in the region; Figure 11 for map of areas considered most suitable for onshore wind power generation; and Figure 12 for suitable areas for offshore wind power generation.

Given the vast areas of open unutilised barren desert (particularly in KSA) the region has potential to generate immense surplus renewable electrical power and become a key green energy exporter – either exporting electricity (including direct connection with North Africa, and integration with connections to Europe), or using the electricity for production of carbon-neutral synthetic fuels, green hydrogen (using renewable or nuclear energy to split water) or blue hydrogen (produced from natural gas), or driving energy-intensive industrial processes such as steel production and aluminium smelting/recycling for export ²¹⁰. Hydrogen presents technical challenges, but it is a versatile fuel with very high energy density; therefore, hydrogen offers salient advantages for decarbonisation of the transportation sector, among other applications. ^{18,211}. Pilot green hydrogen plants are under construction in KSA (to produce 650 tonnes/day) ¹⁰ and UAE ¹⁶⁵, and blue hydrogen produced by reforming natural gas could be a viable alternative if coupled with CCUS ²¹².

Despite the promise of a renewables-based economy, various challenges can be anticipated. Low market prices for oil and gas will reduce state revenues to finance the transition, and favour the burning of fossil fuels locally rather than investing in renewables ²¹³. Concerns over jeopardising existing investments in the petroleum sector (many concessions for oil fields have multi-decadal contractual obligations, and production assets also typically have multi-decadal lifespans), and the risk of creating stranded assets and writing-off billions of dollars of investments in the region will affect the speed of the transition ¹³⁰. Moreover, building an export-based renewables industry presupposes that hydrogen, synthetic fuels, or other mechanisms for storing and exporting energy are adopted at scale. While the region, and the oil and gas sector in general, may be well-positioned to lead a transition to alternative fuels, generation, particularly of green hydrogen is expensive at present, and there are issues around storage, transport, and safety ²¹¹. Global and country-level policy decisions related to investment strategies, infrastructure development, and carbon taxes/credits will affect the future role of hydrogen in the economy ²¹¹, while technologies such as CCUS if proven viable and affordable at scale, or a global resurgence in nuclear may also change the focus in the future. In short, while renewables will play a central role in the region's future, inertia related to fossil fuel infrastructure/economy and uncertainties may delay the transition ^{129,160}.

GLOBAL HORIZONTAL IRRADIATION

SAUDI ARABIA

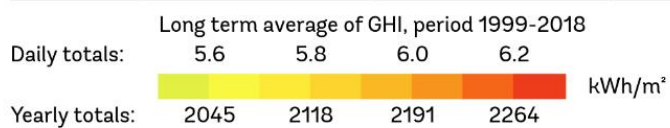
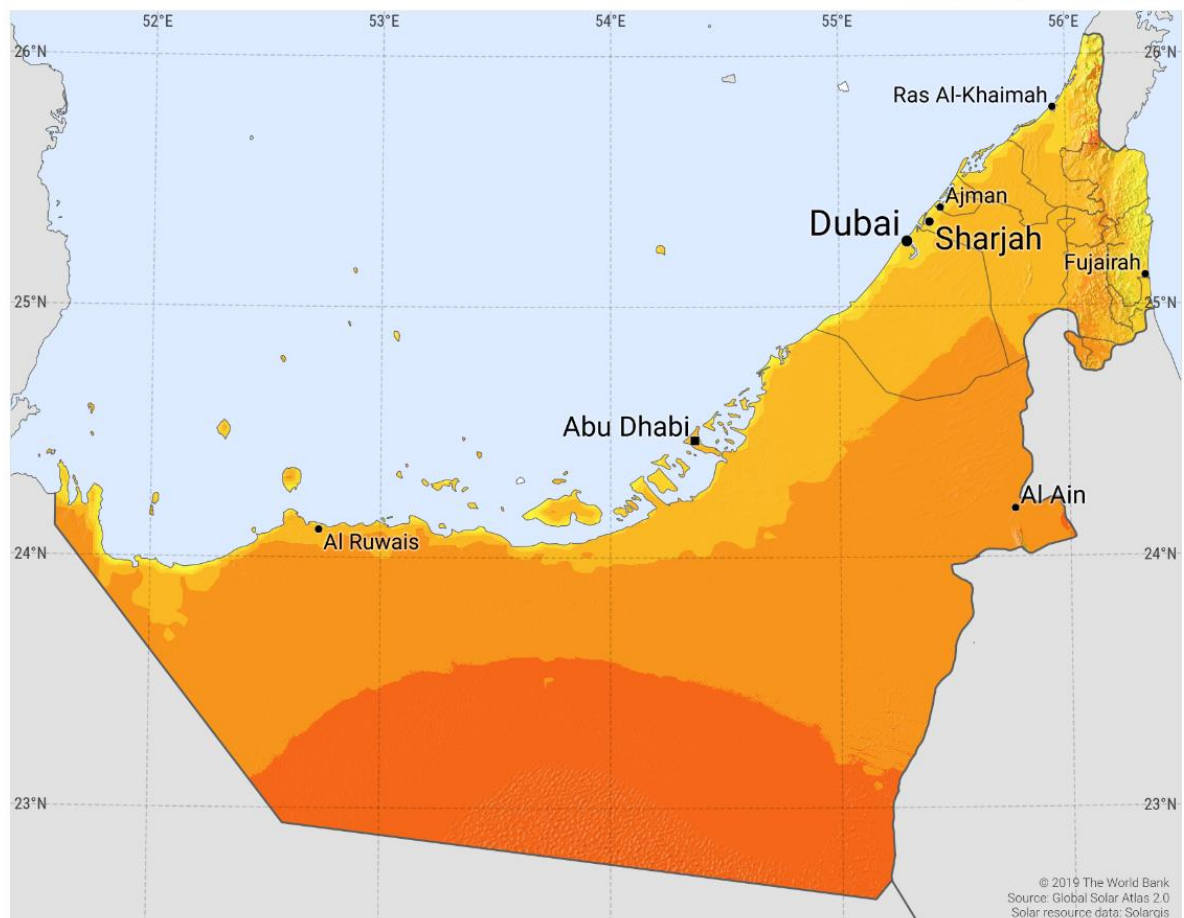


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Figure 8 Saudi Arabia – Estimated solar energy available for PV power generation and other energy applications © 2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis²⁰⁹

GLOBAL HORIZONTAL IRRADIATION

UNITED ARAB EMIRATES



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Figure 9 United Arab Emirates – Estimated solar energy available for PV power generation and other energy applications © 2019 The World Bank, Source: Global Solar Atlas 2.0, Solar resource data: Solargis²⁰⁹



Figure 10 Major geothermal features in Saudi Arabia. Volcanic fields (filled red areas), hot springs (red triangles). (Source: Lashin et al, 2020) ¹⁸³

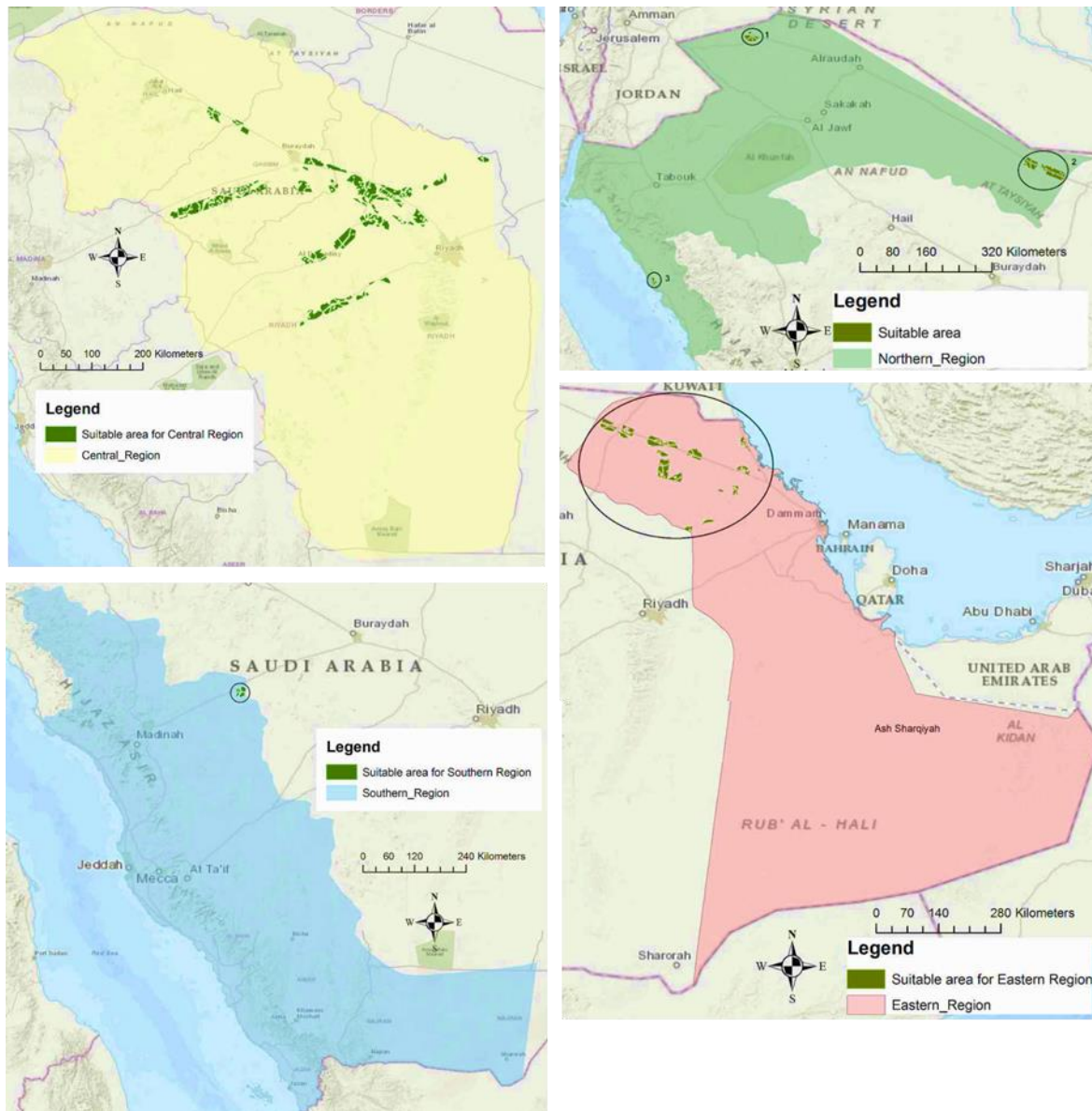


Figure 11 Suitable sites for Onshore Wind Power Generation in Saudi Arabia (Source: Rehman et al, 2020) ²¹⁴. (Assessment based on availability of wind resources, proximity to national grid connection, road and highways access, safe distance from aerodromes, suitable distance from populated settlements, parks, and other public places),

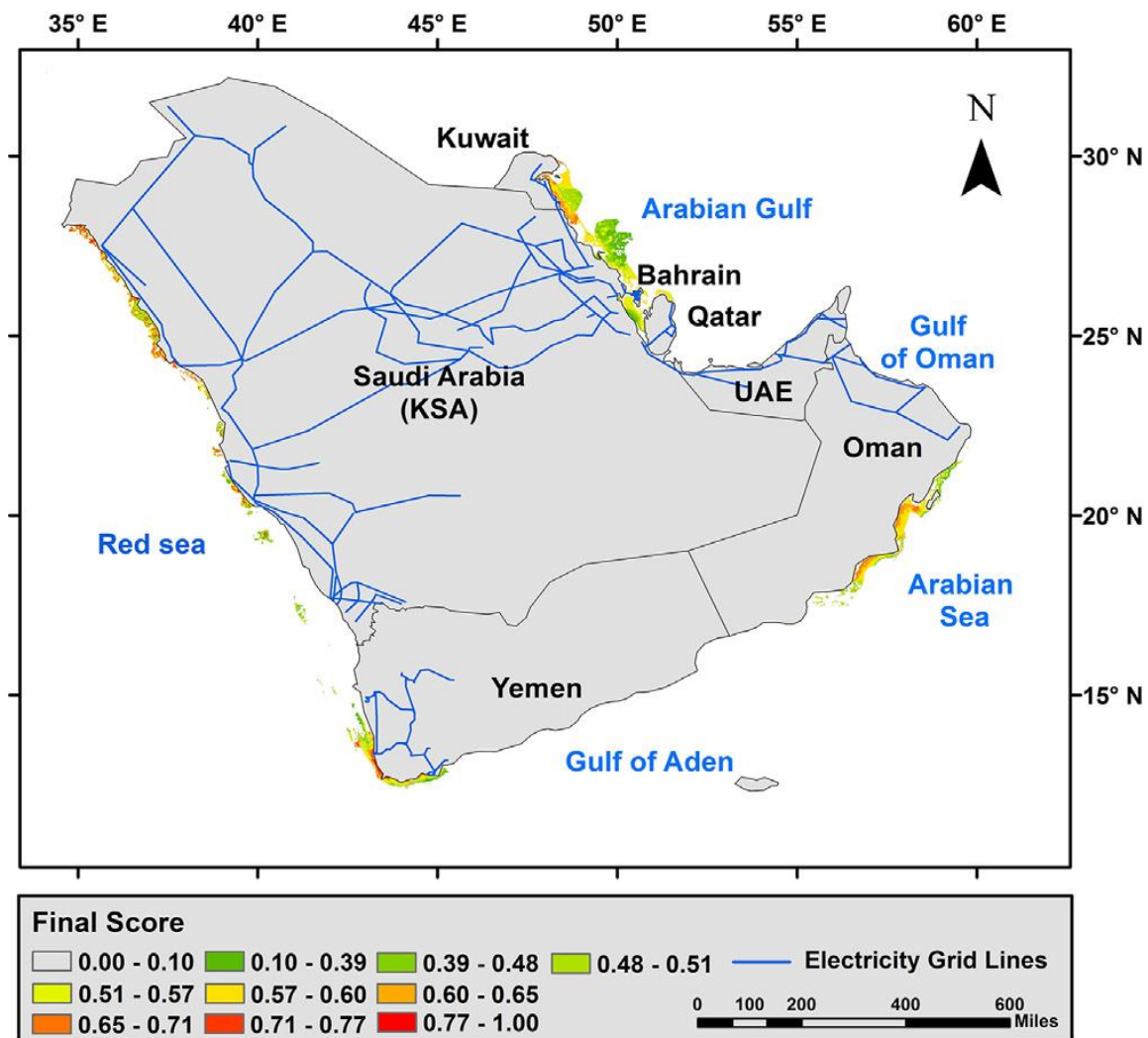


Figure 12 Offshore Wind Energy Suitability Map around the Arabian Peninsula (Source: Bahaj, 2020) ²¹⁵. (Based on suitable wind availability, national grid connectivity, exclusion of marine reserved parks, shipping routes, and oil extraction; 0.0 score is not a suitable area; 1.00 represents areas of the highest possible suitability. Grid availability is shown by blue line)

(3.d.ii Locally emerging specific solutions) The scale of the transition means that despite active decarbonisation plans, existing oil and gas-powered plants may remain in operation for decades to come. Therefore, for large static applications such as industrial processes and power generation, complementary Carbon Capture Utilisation and Storage (CCUS) technologies will be required to reduce carbon emissions during the transition. Figure 13 illustrates how the region might develop carbon-neutral energy hubs integrating multiple parts of the industrial system with CCUS to support decarbonisation. Pilot CCUS schemes are now running in both KSA and UAE, with the UAE plant capable of storing 0.8 MtCO₂ per year ^{2,166}. Various technologies can be used for CCUS, and some components of these systems are already well developed and proven in existing applications. However, CCUS implies high capital and operating costs (estimated worldwide costs will be several

percentages of GDP, i.e., comparable to military expenditures), it is energy demanding (may impose a 10–30% parasitic energy burden on operations), some implementations have high water demands (e.g., for mineralization), and public perceptions remain significant barriers to adoption ^{216,217}. Large-scale adoption will likely require regulatory intervention to make CCUS mandatory, and/or a robust global carbon pricing/credit system to incentive/finance adoption. The region can lead the development of CCUS towards a technical and economically viable solution that is part of an integral energy strategy around the oil and gas sector during the transition.

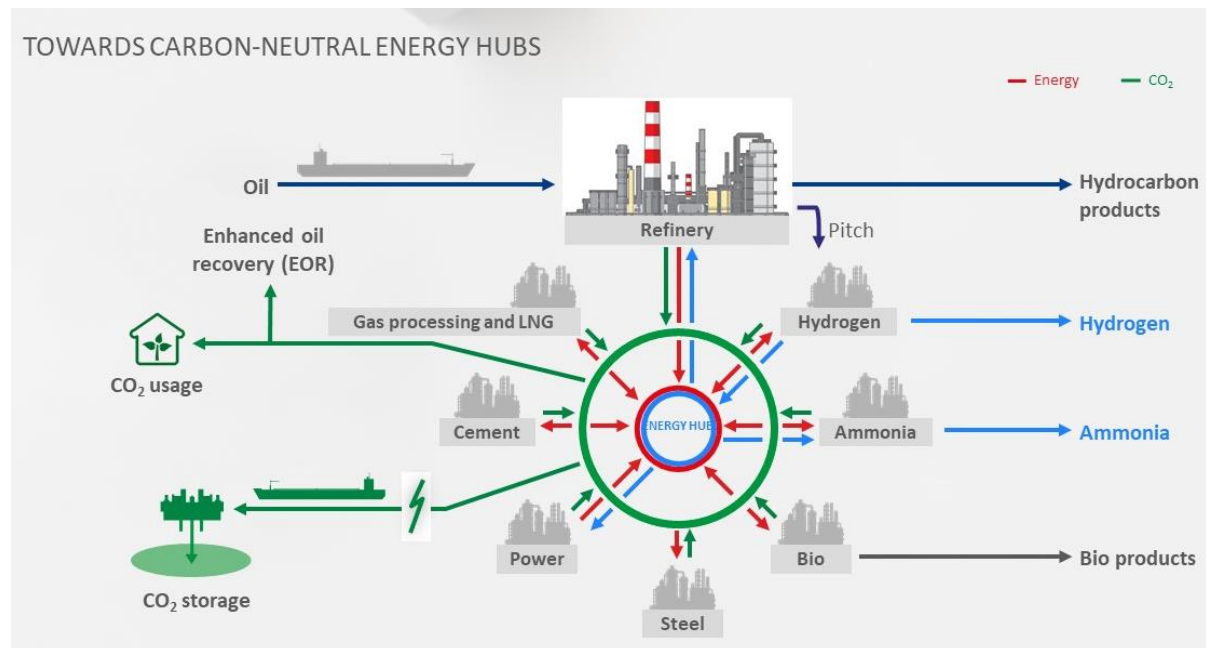


Figure 13 Carbon Capture Utilisation and Storage (CCUS) Schematic (Source: Shell, 2021)

Building on CCUS, KSA launched the concept of the Circular Carbon Economy (CCE), in 2020 during its presidency of the G20. CCE adapts the circular economy concept for carbon to “reduce, reuse, recycle, remove”. The framework includes reusing and recycling captured carbon emissions for reuse in other industrial production such as plastics, chemicals, and synthetic fuels, and removing carbon through direct air capture and natural sequestration ^{198,218}. As such the CCE framework potentially offers an integrated approach to transitioning towards net-zero according to resource availability and national circumstances ²¹⁹. Critics of CCE argue that CO₂ reuse opportunities are limited, and recycling simply shifts the emissions problems elsewhere, and worse, the concept raises false expectations of currently unproven technological solutions, and risks undermining more ambitious policy interventions and mitigation initiatives ²¹⁷. By far the largest application for CO₂ at present is for enhanced oil recovery (EOR), whereby CO₂ is injected into oil reservoirs to assist oil extraction – enabling more extraction may prove counterproductive to net-zero objectives ^{220,221}. Nonetheless, beyond its detractors, the G20 Leaders’ Summit and Communique 2020 endorsed the framework, albeit with an emphasis on “Reduce” ²²²,

and national research labs, industry, and academic institutions in KSA and elsewhere are actively exploring the multiple dimensions of the circular carbon initiative.

(3.e Likely co-benefits/trade-offs) Beyond carbon reduction objectives and contribution to SDG7 (affordable and clean energy) and SDG13 (climate action), renewables should bring down costs for services such as cooling and water and emission-free transport, making them more accessible and affordable for all, contributing to SDG3 (good health and wellbeing), and SDG6 (clean water). Additionally, clean energy reduces air pollution, particularly in the major cities, and reduces the environmental degradation and pollution from extractive and refining operations, so contributing to SDG 11 (sustainable cities and communities) and delivering environmental benefits for SDG14 (life below water) and SDG15 (life on land). Efficiency initiatives currently being implemented to reduce excessive usage will contribute to SDG12 (responsible consumption and production), although access to cheaper energy may ultimately deliver rebound effects and increased consumption in other areas of the economy and society ²²³. Furthermore, while jobs in the petroleum sector are certainly at risk in the longer term, decarbonising industry and the power generation sector should offset this by creating new employment opportunities in advanced technology development and implementation ^{156,157}. Broader diversification of the economy away from fossil fuels in areas such as manufacturing, services, aviation, and tourism will bring other employment opportunities and broader economic opportunities and stability to the region, contributing positively to SDG5 (gender equality), SDG8 (decent work and economic growth), and SDG9 (industry, innovation, and infrastructure).

Water security

(3.c.i Overview) As highlighted in Section 2.a.i, water scarcity is a critical issue for the region's habitability and food security. There are no permanent rivers or lakes in the region, deep groundwater aquifers are significantly depleted and predominantly non-renewable (fossil groundwater), and rainfall is limited and difficult to capture ⁸⁷. Available water resources from artificial groundwater recharge, desalination, wastewater treatment, and surface water harvesting are far below levels of demand, and water availability per capita in KSA, and particularly in UAE, is considered well below absolute water poverty levels (See Figure 14) ²²⁴. With rates of water abstraction far exceeding recharge rates the ancient aquifers in KSA are expected to be entirely depleted within 25 years ²²⁵; in the UAE within 50 years ²²⁶.

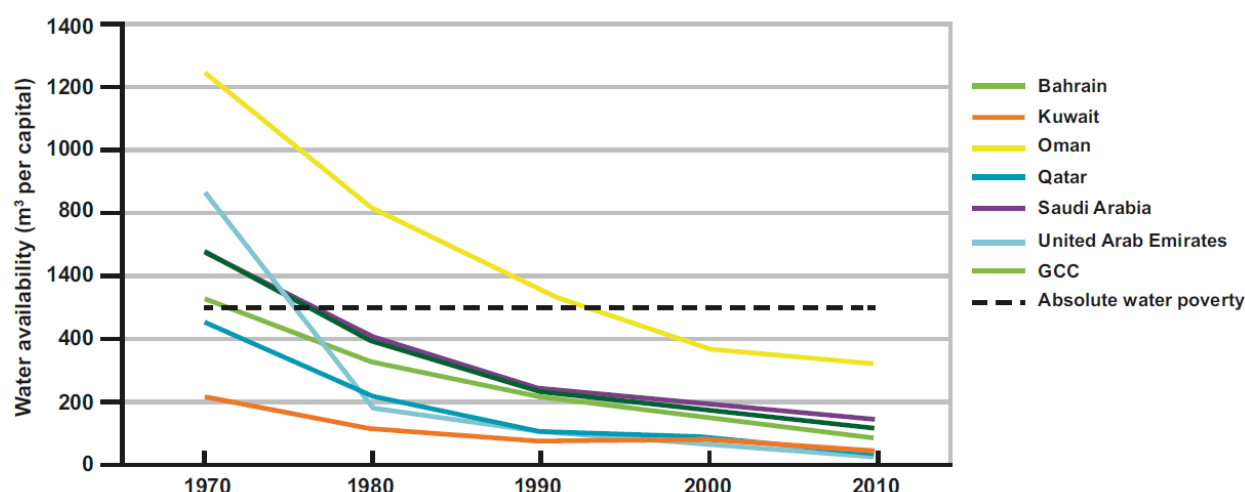


Figure 14 Per capita water availability trends in GCC (1970-2010) (Source: Alsharhan & Zeinelabidin, 2020, based on World Bank 2005 data) ²²⁴

Compounding water scarcity, the region has some of the highest domestic per capita usage rates of water in the world ¹⁰¹, and KSA also has one of the highest water loss rates in the world, with losses of up to 40% in some areas due to aging and leaking distribution systems ¹³⁶. Table 10 presents available data on water sources and usage in KSA and UAE.

Table 10 Water sources and usage within KSA/UAE (Sources: Various) ^{55,225,227}

	KSA (2017) ²²⁵	UAE (2017) ^{55,227}
Water sources	90.3% Groundwater 4.6% Surface water 4.4% Desalination 0.7% Treated wastewater	43.7% Groundwater 41.4% Desalination 14.5% Treated wastewater 0.4% Surface water
Percent renewable water of total withdrawn from aquifers	10%	4%
Water use	87% Agriculture 9% Municipalities 4% industry	60% Agriculture (39% positive agriculture, 11% greening and landscaping, 10% forestry) 31% Municipalities 9% Industry
Desalinated water volume	6.6 million m ³ /day	5.4 million m ³ /day ^{55,228}
Growth forecast for desalination	Has been growing 7 to 8% annually, and	Increase of 30% by 2030 ⁵⁵ 100% increase by 2050

(3.c.ii Impact of net-zero transition) Efficiency improvements, particularly in agriculture, and initiatives to reuse wastewater and improve surface water harvesting are important, but even so the region will be increasingly dependent on energy-intensive desalination processes for drinking water and in the not-too-distant future for crop irrigation ⁸⁶. Water desalination is undertaken either with thermal desalination using heat to vaporise fresh water, or membrane desalination (such as reverse osmosis, RO) where high pressure electrically powered pumps separate freshwater from seawater by passing it through a membrane ²²⁹. These are energy intensive processes, and desalination is currently estimated to contribute 20-30% (varying by location) of the region's total CO₂ emissions ⁵⁵⁻⁵⁷. The transition to net-zero will therefore necessitate a major shift to more carbon-efficient reverse osmosis/renewables desalination technologies, and at the same time a dramatic improvement in water management and usage. Figure 15 and Figure 16 present data on desalination production capacity illustrating the scale of the sector on the Red Sea and the Arabian Gulf) ²²⁴.

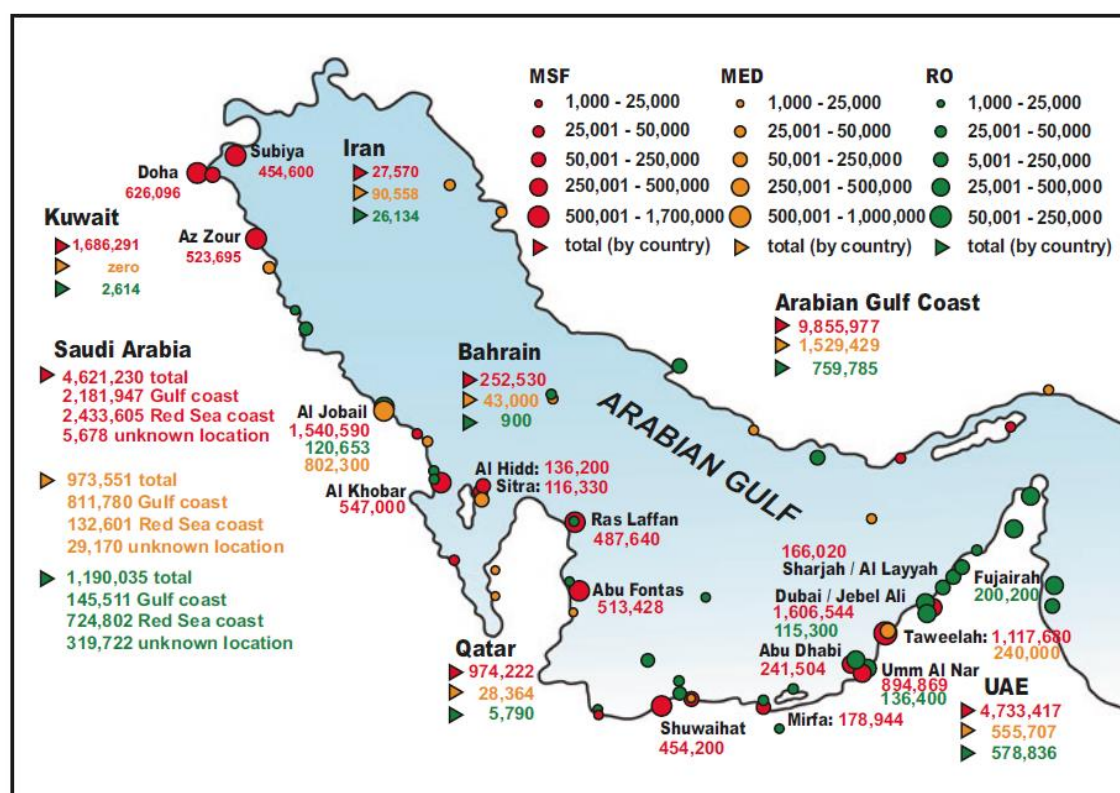


Figure 15 Water desalination capacities in the Arabian Gulf in m³/day (Source: Alsharhan & Zeinelabidin, 2020) ²²⁴

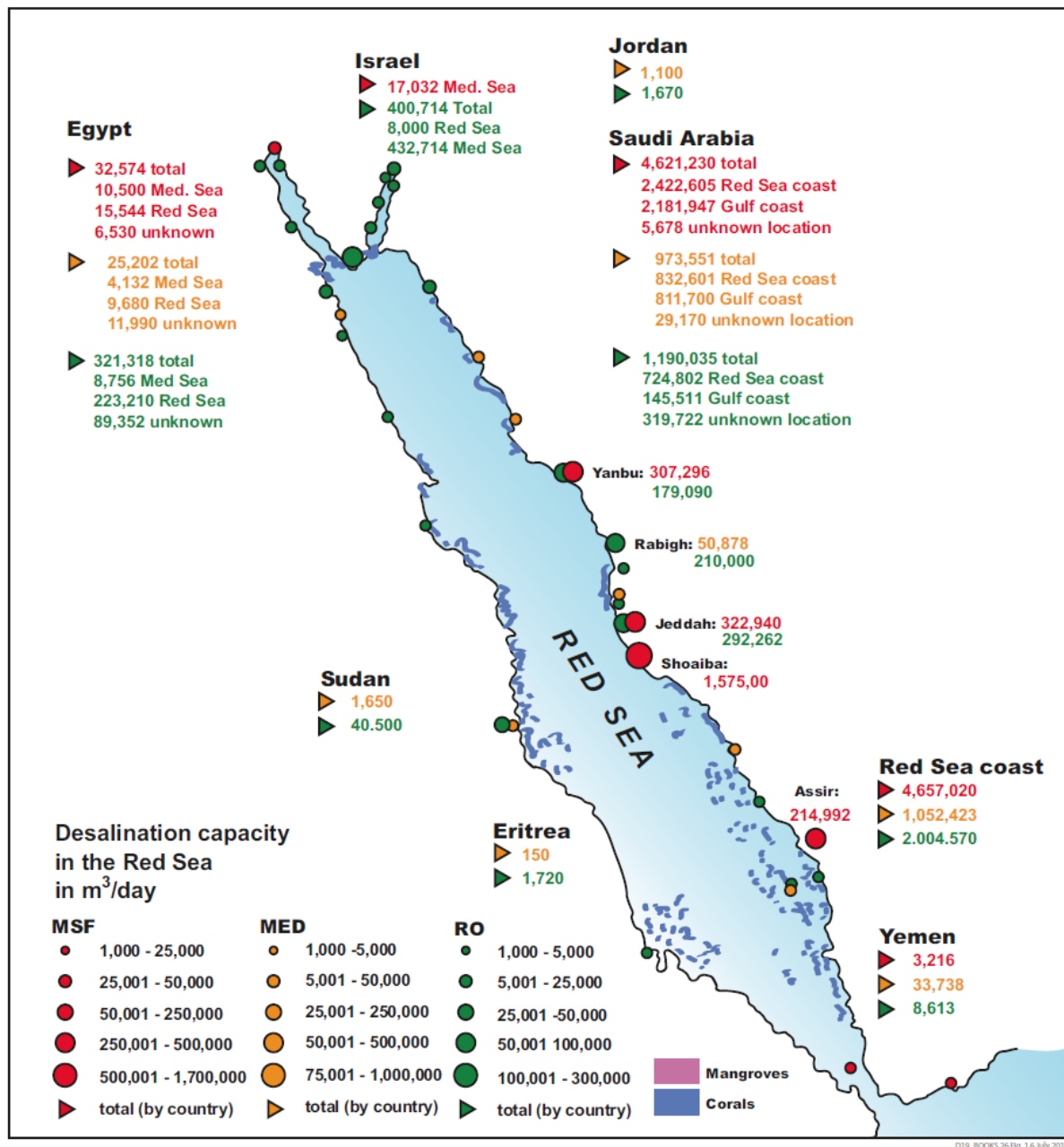


Figure 16 Water desalination capacities in the Red Sea in m³/day (Source: Alsharhan & Zeinelabidin, 2020)²²⁴

(3.d.i Current/future solutions) Water desalination in the region is progressively becoming more reliant on electricity alone (RO technologies), but thermally driven desalination is still extensively used. In both cases fossil fuel consumption is intimately involved in water desalination^{55,228}. For example, in the UAE 83% of desalination capacity currently consists of thermal plants, which are estimated to consume up to 3.5 times more energy per unit than RO⁵⁶. These desalination plants are often co-generation plants producing electricity and water, and while this has benefits, it also leads to inefficiencies caused by seasonal variations in electricity demand forcing the plants to operate sub-optimally⁵⁶. The Emirates Water Electricity Company (EWEC) recently announced an ambitious plan to halve the carbon footprint associated with its

water and power generation by 2025 from 2020 levels, by adopting RO desalination technology and renewables ²³⁰ (Targeting 50% of supply from RO by 2036 ²). Note, the most efficient RO technologies available today are from Japan and Israel.

In addition to improved desalination technologies, solutions focus on conservation of water resources, and demand management. Conservation techniques include better capture of run-off, increased dam storage capacity (accounting for climatic constraints and elevated evaporation rates), artificial recharge, forced infiltration and rainwater harvesting ^{89,136}, along with novel irrigation, such as drip irrigation (35% savings in water use), and transition to low-water crops ^{131,224}. Treatment and reuse of grey wastewater, and efforts in KSA to use impaired water (i.e. reduced brine) for agricultural irrigation are important initiatives, and although there has been considerable progress over the past decade, more could be done to better utilise wastewater ^{40,225,231}. UAE has announced plans to increase use of treated wastewater from 75% today to 95% by 2036 ⁵⁵, while KSA plans to reach 75% in this decade as part of its Vision 2030. Monitoring technologies and improvements to distribution networks to reduce leakages are another key component in enhancing water efficiency ¹³⁶.

Demand management initiatives focus on end-users, and for example, in 2019 KSA announced objectives to reduce water use from 263 to 150 litres per capita per day by 2030 – an ambitious 43% reduction – to be achieved through changing individuals' behaviours through water awareness campaigns. ¹³⁶ UAE has similarly announced plans to reduce consumption by 20% per capita by 2036 ⁵⁵. In both countries a key part of the strategy to changing behaviours has been to reduce subsidies and introduce cost-reflective tariffs for agricultural irrigation and domestic water use to discourage waste ^{152,153}. Other initiatives include encouraging, subsidising, or regulating the adoption of readily available technologies such as low-flow shower heads, low-flush toilets, reduced load washing machines, and installation of sensor-based taps in public places ^{149,232}.

(3.d.ii Locally specific emerging solutions) There is potential to combine desalination with renewable energies to eliminate operational carbon emissions ²²⁹. Options include using solar photovoltaics (PV) or wind power combined with reverse osmosis plants. Solar thermal, notably concentrating solar thermal (CSP) ²³³, or geothermal are well suited to thermal desalination ^{56,229,234}. Combining renewables with water desalination enables excess power generation to be absorbed and so could be a cost-effective alternative to expensive battery storage to smooth intermittent generating sources. Nuclear power is also a good match with desalination processes, providing 24 hours production, and various small-scale nuclear desalination systems are in development ^{193,235}.

Brine from desalination plants released into the sea raises the local salinity and affects marine organisms ^{234,236,237}. The Gulf is a shallow body of water with only 35 m average water depth, is almost fully enclosed, the average evaporation rate is 2m/year, and

has minor and sporadic freshwater feeds. Consequently, while the normal range of ocean salinity is 27 – 33 grams per litre (g/l or ‰), the average Gulf concentration is 45 g/l, it can reach 75 g/l in the area between Bahrain and Qatar, and localised salinity around brine discharge points can be even higher ^{237,238}. Similar yet milder observations apply to the Red Sea. A 2011 study estimated Gulf salinity levels would rise by 2.24 g/l by 2050, and the Red Sea by 1.16 g/l by 2050 as a result of desalination processes ²³⁷. The media has coined the term “peak salt” to describe the impending risk to desalinated water supplies in the region, although there appears to be little scientific data to identify the levels at which salination approaches critical limits for ecosystems and desalination processes ^{237–241}. (Note: salinisation due to ocean evaporation is overall much larger than anthropogenic processes, but desalination plants create pronounced localised effects on coastal regions). Innovation in brine management is therefore essential, and research suggests there may be economic opportunities such as salts, metal recovery, etc. from the waste brine that could be commercially exploited ²³⁴.

(3.e Likely co-benefits/trade-offs) Enhancing water management and delivering affordable/emission-free water within the region is of critical importance. Beyond net-zero carbon reductions, the initiatives have broad benefits and are essential for progress against SDG6 (clean water and sanitation), and SDG3 (good health and well-being) as water plays a fundamental role in sanitation and public health. Ongoing initiatives to encourage responsible usage contribute to SDG12 (responsible consumption and production). Improved water management facilitates improved biodiversity and food security in the region, contributing at least in part to SDG2 (zero hunger), and SDG15 (life on land). Treatment and reuse of wastewater could make an important contribution to the region’s water needs, but potential negative externalities on the environment and human health need to be carefully managed ²²⁵.

Built environment and habitability

(3.c.i Overview) The built environment is fundamental to adaptation and resilience to climate change, is a significant contributor to carbon emissions, and plays a defining role in determining broader sustainability in society. Several green city initiatives have already been partially implemented within the region, including Masdar City in UAE, and King Abdullah Economic City in KSA ^{242–245}, and major new developments are planned in the coming years such as the ambitious Neom project on the Red Sea, with a focus on green sustainable zero-carbon cities, business hubs for innovation, luxury tourism, and building capacity for religious tourism for the millions of pilgrims visiting every year for Hajj and Umrah ^{246–248}.

(3.c.ii Impact of net-zero transition) The transition to net-zero requires action on three fronts. Firstly, tackling the high embodied carbon of the building fabric – predominantly concrete and steel at present; Secondly, reducing the in-use energy and water intensity of the buildings to reduce per capita consumption, particularly for cooling; and Thirdly, redesign of the urban environment to embed sustainability into

lifestyles (e.g., using land sustainably, reducing impact of waste, developing energy-efficient transportation systems and connectivity, effective management of water resources, efficient district cooling, and wastewater management in the built environment ²⁴⁹). Other factors to be considered include addressing the needs of the burgeoning urban youth population of KSA in terms of education, employment, recreation, health and affordable housing ²⁵⁰. The region has considerable domestic industrial capabilities in construction and construction materials and is well positioned to benefit from innovation in the sector and potentially develop new export opportunities.

(3.d.i Current/future solutions) The selection of low-carbon materials rather than carbon-intense steel and concrete, and designs that minimize material costs and carbon emissions will lead to new design concepts aligned with a net-zero vision ^{251–253}. Significant in-use efficiencies have been demonstrated with designs to dissipate heat and reduce solar gain, e.g., appropriate thermal mass, improved insulation, and triple glazing ²⁵¹. Reducing the carbon intensity of the built environment for hot climates requires novel building materials and technologies, but many technologies already exist that can be applied to improve performance and liveability, and to retrofit older building stock. More research is required into the use of traditional regional building concepts like wind towers for natural cooling, traditional building materials, optimum urban density and building heights to minimise carbon emissions, etc. ^{254,255}. Importantly, building designs should be optimised for the local climate – in KSA there are several distinct climatic zones across the country that should be considered ²⁵¹. UAE has introduced locally-relevant building codes, but existing building codes still need further review to explore how new sustainable building codes and policy intervention might be used to drive the most appropriate development – for example, some of the LEED building standards are inappropriate for hot climates ²⁵⁶. Both KSA and UAE are investing in green buildings applying the latest LEED building codes, and undertaking some retrofit initiatives ^{256,257}. For example, Abu Dhabi has rolled out an initiative to retrofit government buildings, and Dubai has set a target to retrofit 30,000 buildings by 2030 ².

(3.d.ii Locally specific emerging solutions) KSA has a stated ambition to become the world's largest investor in sustainable buildings ²⁵⁶, and along with UAE, has the potential to become a global leader in design of modern urban environments and sustainable cities. Unlike most of the developed world the region has the resources, the space, and the development needs, to develop entire new cities “from-the-ground-up” providing an unprecedented opportunity to reconceptualise the urban environment and integrate sustainability and zero-carbon from the outset ⁴⁰. UAE has built the first “green city” in the region, Masdar city in Abu Dhabi, supported with a 10MW solar plant, utilising electric public transport, low-rise energy-efficient housing, narrow shaded streets to encourage walking, and other initiatives to facilitate sustainable living ^{242,258}. While Masdar city demonstrates what may be achievable and some elements of a pathway to carbon-neutral urban environments, it has not been the

success that was envisaged to date, and currently is only 10% of the original plans and remains significantly under-occupied ^{243,259}. A similar initiative, King Abdullah Economic City on the Red Sea in KSA ^{244,245}, was launched a decade ago, with a similar vision of sustainable living for a population of 2 million. To date there are only 10,000 residents ²⁶⁰. More recently, Dubai has announced plans for a green city development, and KSA has announced far more ambitious plans for a high-tech 500-billion-dollar megacity, “Neom City”, and “The Line”, to be built in the desert on the Red Sea coast.

The plans for Neom envisage a megacity that serves as a major new regional hub for commerce, innovation, and tourism. The developments will be powered entirely by clean energy, with extensive green public spaces, no surface roads and cars, extensive underground public mass transit systems, flying drones and water taxis, using innovative new building technologies such as 3D printing, integrated circular economy waste management solutions, robots and AI and an array of other emerging technologies to support sustainable and resource efficient green living ^{247,260,261}. While the vision is certainly remarkable, critics question these projects’ sustainability, highlight their environmental impact (e.g., Neom plans major development and artificial islands on the Red Sea), and remark the inherently energy-intensive construction and operation of such projects in desert environments ^{245,261–263}. In the meantime, such projects are inspiring and have the potential to drive innovation and the emergence of disruptive technologies with regional and global implications.

Retrofitting existing cities rather than building entirely new cities is a clear immediate need with a marked impact for the population at large. This will involve actions towards water use and reuse, transportation, air quality, shelters, and local environment, among others. Efficient cooling technologies suitable for extreme temperature environments to replace older F-gas cooling systems will bring marked improvements to shelter retrofitting ¹⁴⁷. The development of efficient cooling technologies would create a large market for the region and export opportunities to assist populations with similar climate challenges across the world in tropical and subtropical zones ²⁶⁴.

(3.e Likely co-benefits/trade-offs) Improving and greening the built environment and providing affordable and efficient cooling presents a broad range of co-benefits. Firstly, it will create new employment in green jobs, enhance labour productivity and so contribute positively to SDG8 (decent work and economic growth) and SDG9 (industry, innovation, and infrastructure). It will also reduce morbidity and mortality, and provide a wide array of liveability and well-being benefits, etc. offering multiplicative benefits to society ¹⁴⁷, and contributing significantly to SDG3 (good health and wellbeing), SDG10 (reduced inequalities) and SDG 11 (sustainable cities and communities). The more ambitious projects that reconceptualise urban living with features such as walkable green spaces, and integrated circular economy solutions offer the potential to contribute to broader objectives around SDG12 (responsible consumption and production), SDG13 (climate action), and bring an integrated

approach to delivering on SDG15 (life on land). However, implementation must carefully address environmental implications (e.g., water needs) and societal factors (e.g., broad societal benefits).

Transportation

(3.c.i Overview) GHG emissions per capita from road transportation have risen rapidly over the past decade together with heightening living standards, rapid development, and urbanisation ²⁶⁵. This has been driven by subsidised gasoline prices and ample roadside parking, and, even with subsidies removed (in UAE) a lack of public transport options makes inefficient private transport the dominant means of urban travel ²⁵⁷. UAE and KSA have made considerable investments in bus rapid transit (BRT) systems and light rail transit (LRT) in some major cities although much more needs to be done to encourage uptake and lessen dependence on private cars ²⁵⁷.

Aviation is also a major emissions sector, with the UAE an aviation travel hub with two global carriers, and aviation and tourism development key parts of the future diversification plans for both UAE and KSA ^{20,21,266}. Tourism, particularly religious tourism, is considered a major growth sector in KSA and a key part of the kingdom's diversification plans over the coming decades, and these plans would result in a dramatic rise in emissions from the sector unless action is taken to decarbonise transportation.

(3.c.ii Impact of net-zero transition) Electric vehicles (EV) seem to offer the most viable solution for ground transportation if electricity is produced by non-fossil fuel sources. Automotive production in the region (some assembly lines for buses and trucks, and some aftermarket component manufacture ²⁶⁷) is not strongly positioned to benefit from the EV revolution, so although there may be some benefit, the majority of EV requirements are expected to be satisfied through imports. Investment in urban mass-transit systems and new aviation technologies in the future will also necessitate substantial imports. As the world transitions to EVs over the coming decades the region will see a decline in demand for fossil fuels only if the increased demand for electricity is satisfied by renewable sources or nuclear power.

(3.d.i Current/future solutions) To date, electric vehicles (EVs) are a small part of ground transportation in KSA and UAE but as production and charging infrastructure scale up adoption is expected to rise. In the short-term the UAE is prioritising conversion from gasoline and diesel to compressed natural gas (LPG), focusing on taxis, buses and commercial vehicles, and the availability of low-cost LPG in the region may perhaps delay the transition to EVs. However, electric vehicles are a stated priority, and Dubai's Green Mobility Strategy is targeting a 2% share of EVs, and a 30% share of government vehicles by 2030 ²⁶⁸. Promotional campaigns are in place to encourage uptake ²⁶⁹ and charger networks are expanding, albeit low at present, with 155 charging stations in UAE and just 13 so far in KSA ²⁷⁰. The pace of the EV

revolution is surprisingly slow given the wealth and high living standards of the region, but nonetheless, carbon neutrality in road transportation may be feasible within the next two decades. Other forms of personal mobility such as e-scooters are also now being trialling in Dubai and can be expected to roll out across other major cities ²⁷¹. The impact of extreme temperatures and humidity on EVs and charging infrastructure is not clear but may demand region-specific innovations.

In parallel, use of electric urban mass-transit systems is a more important part of the regional transport strategy. To this end, KSA plans to invest USD 48 billion by 2024 on upgrading and decarbonising the nation's rail system, including an extensive new metro system in Riyadh ²⁷². Some of the intercity lines in KSA are already electrified, such as the 450km high-speed line from Medina to Mecca that will be a key asset in tourism in the region. Similarly, UAE is investing heavily in urban transit systems, such as the recently announced Hyperloop project linking Abu Dhabi and Dubai ²⁷³, and is in the second stage of building a 1,200 km-long rail network linking all the major UAE industrial ports that aims to reduce road freight transport, and cut GHG emissions by 70-80% ²⁷⁴. Long-distance freight rail in both KSA and UAE uses diesel electric locomotives.

Centralized electric power generation benefits from higher efficiency compared to individual gasoline engines in private vehicles. Yet, and most importantly, the GHG emissions benefits of electrification of surface transport are only fully realised if electricity is produced from renewable sources, nuclear energy, or if gas and oil power plants are intimately linked to carbon capture and storage infrastructure. At present renewables and nuclear are still a very small fraction of the electricity supply system.

Aviation and shipping sectors will be more difficult to decarbonise. Small-scale electric aviation and marine use has been demonstrated, and solutions such as EVTOL air taxis are now close to commercialisation ²⁷⁵ and are envisaged as a key part of the futuristic Neom city development in KSA ²⁴⁷. However, battery technologies are unable to provide the range required for large-scale passenger and cargo aviation and shipping applications. As a result, these sectors will probably need to switch to more expensive biofuels, hydrogen, ammonia, or synthetic fuels to reach net-zero objectives, and in the short to medium term the aviation sector will almost certainly have to rely on carbon offset schemes to reduce climate impacts. Overall, it is difficult to reconcile aviation and tourism within a net-zero future in the near term.

(3.d.ii Locally/specific emerging solutions) The region could establish itself as a hub for the development and deployment of new low carbon aviation and shipping fuel technologies and has an ambition to lead the way with electric flying vehicles and drones. Development of battery technologies for EVs and storage that are optimised for stability and performance in extreme summer temperatures could potentially also be a growth area for the region.

(3.e Likely co-benefits/trade-offs) Beyond carbon reduction, additional benefits from the electrification of transportation and shifts to alternative modes of transport should bring a significant improvement to urban air quality ^{94,276,277}, reduction of noise pollution, a reduction in traffic congestion within the major cities, and physical benefits from walking and cycling – weather permitting ²⁷⁸. Beyond human and ecosystem health, mass transit systems should also promote efficiency, and effectiveness, accessibility, and social equity by serving communities without personal transport ²⁷⁹, contributing to SDG10 (reduced inequalities) and SDG11 (sustainable cities and communities). Future urban developments should explore the potential for designing urban environments that minimise car utilisation and enhance liveability – cities optimised for walking and cycling (subject to temperature/humidity considerations and the effects of climate change) and connectivity, public transportation, and alternative mobility solutions. Optimising for the “last mile” between station and home is critical for success, requiring integrated urban planning and behavioural adaptation. This may necessitate new service provision such as on-demand delivery services ^{249,257}, and concerted effort to raise awareness of the benefits of mass transit and encourage adoption ²⁵⁷. Events such as the Covid-19 pandemic may temporarily increase preferences for less-sustainable private or low-density transport systems ²⁸⁰.

Natural Environment

(3.c.i Overview) The natural environment of the Arabian Peninsula is a largely arid desert, with little arable land, scarce water resources, and fragile and sensitive ecosystems. The interior includes pockets of flora and fauna in mountain forests and woodland in KSA, and scrubland, wadi ecosystems and irrigated agriculture in both countries ¹³¹. The mountainous regions of KSA host significant biodiversity and are perhaps the most suitable regions for regenerative greening actions such as tree planting. Much of the region’s biodiversity is also concentrated in the coastal areas in the wetlands, mangrove swamps, mud/sand flats (sabkha), seagrass beds, and extensive coral reefs of the Arabian Gulf and the Red Sea. These coastal resources serve valuable ecological and economic functions for the region, providing food and nurseries for marine organisms and wildlife, providing natural protection against erosion and flooding, supporting fisheries and tourism industries, and contributing to human health and wellbeing ²⁸¹ (See *Figure 17* for geographical data).

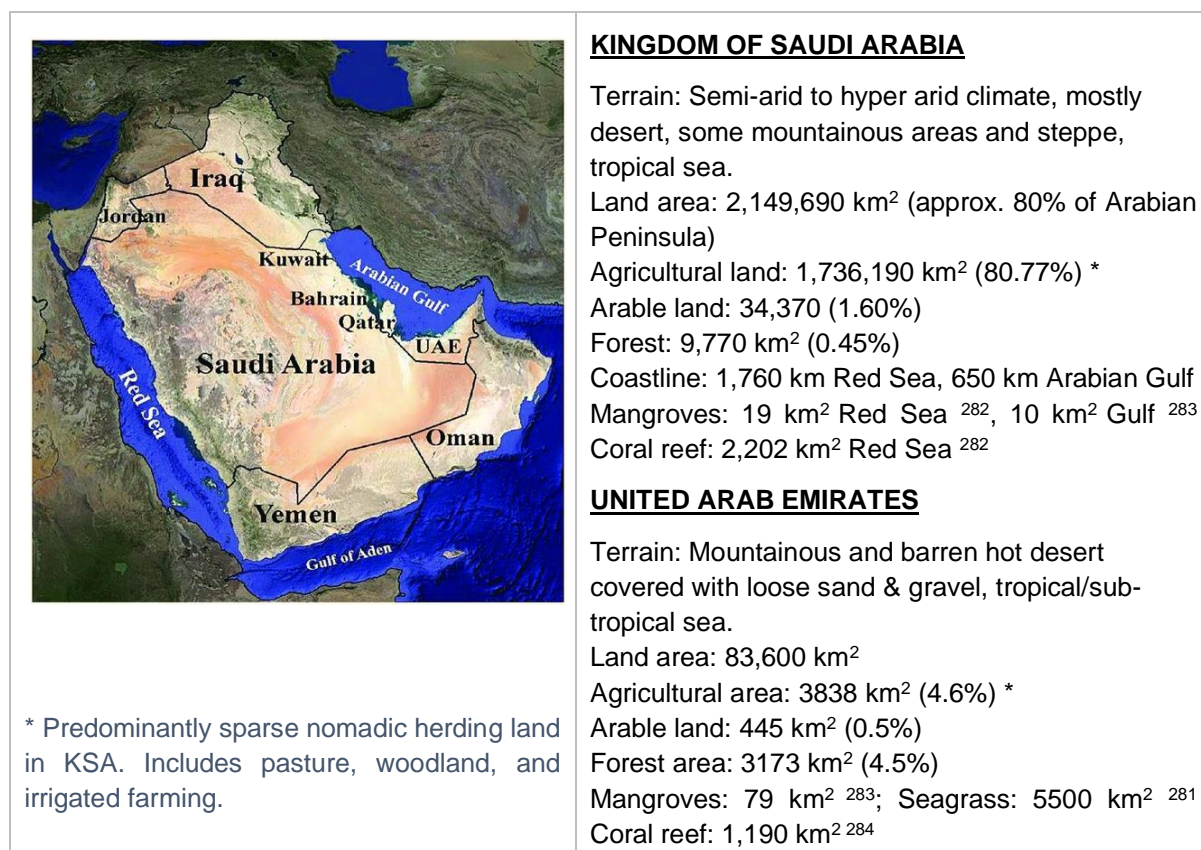


Figure 17 Geography of KSA/UAE (Source: World Bank/UN FAO, 2018 data) ²⁸⁵

These critical ecosystems are increasingly being threatened by anthropogenic activities associated with industrialisation and urbanisation including dredging, industrial effluent, oil spills, brine water discharge, sewage discharge, boat traffic, and invasive species, combined with climate-change effects of rising surface temperatures, sea-level rise, and acidification of the oceans ^{131,281,286}. The impact is seen in algal blooms and “red tides”, coral bleaching, and eutrophication which are increasing in frequency and severity ^{85,101,281}. Coral reefs are the most vulnerable, and even relatively robust ecosystems such as mangroves are not immune, suffering from dwarfism caused by high salinity ^{281,282,284}. Decline in these resources will have myriad implications and directly impact industry sectors such as fisheries, tourism, and desalination and water availability ^{91,286–288}.

(3.c.ii Impact of net-zero transition) The net-zero transition can have distinct effects for the natural environment in the region. A transition away from fossil fuels and mitigation of the worst of climate change will of course be beneficial for ecosystem health – reducing hydrocarbon pollution and associated industrial effluents and averting the most serious consequences of climate change anticipated over the coming decades. On the other hand, the net-zero transition necessitates alternative economic activity to replace oil and gas, and the region’s current development plans envisage further rapid urban development of coastal cities and a sharp increase in

tourism, such as the extensive developments along the Red Sea coast ²⁸⁹. These developments, if not managed carefully, risk creating further environmental stresses.

(3.d.i Current/future solutions) Awareness of the need to protect and regenerate the natural environment is rising across the region, and various policy initiatives are underway, including changing agricultural practices, promoting nature-based solutions, establishing marine protection reserves and nature reserves, reintroducing indigenous wildlife ²⁹⁰, and various regeneration activities both inland and in coastal areas ^{4,91,284}. With regards specifically to the net-zero transition, the natural environment of wetlands and mangroves and seagrass serve as natural carbon sinks for sequestering and cycling atmospheric carbon, referred to as “blue carbon” ^{4,137–139}. Research is needed to better understand the sequestration potential of each blue carbon ecosystem ¹³⁹ but in 2013 the mangroves in UAE were estimated to hold 41 MtCO₂e ¹³⁸. Although annual sequestration rates may be small relative to the region’s overall emissions and more verdant parts of the world, given the multiple benefits of these resources they are certainly worth protecting and expanding. From 1972 to 2000 coastal developments in UAE reduced mangroves from 122 km² to just 27 km², while wetlands declined from 432 km² to 168 km² ²⁹¹. However, over the past 20 years UAE has run successful regenerative projects and the spatial extent of mangrove swamps are estimated to now cover approximately 79 km² in the region ^{283,292}. The UAE has ambitious plans for doubling or tripling the area in the future, but whether this is achievable is unclear ²⁹³. Similar regeneration initiatives have been successfully implemented in KSA, and future plans are envisaged for the Red Sea coast.

There have also been successful attempts to expand vegetation cover and forest inland and in and around the cities, with green landscaping, sand dune stabilisation, irrigated plantations and recreational parks ²⁹⁴. For example, by 2014 the UAE had established 3,170 km² of forest, 1,850 km² of date palms, and 836 km² of Sabkha, largely fed with piped groundwater ^{295,296}. Greening of cities including Abu Dhabi and Dubai and Riyadh using indigenous trees and plants that grow naturally in the region is also ongoing ^{296,297}. A notable ecosystem regeneration project is Wadi Hanifa running through Riyadh that uses treated wastewater from the city to recreate the original oasis of the region, with lakes and wetland supporting biodiversity, agriculture, and creating an attractive natural environment for denizens ^{298,299}. Wadi Hanifa potentially offers a blueprint for further regenerative initiatives in the region, but it should be noted that treated wastewater could perhaps be more effectively used to meet essential water needs. The long-term viability of these initiatives in the face of declining groundwater reserves and increasing temperatures and greater evapotranspiration caused by climate change remain unclear.

(3.d.ii Locally specific/emerging solutions) The recently announced “Saudi Green Initiative”, builds on the previous environmental efforts under KSA’s Vision 2030 programme, presenting ambitious plans to plant 10 billion trees in KSA, and a broader regional initiative to plant an additional 40 billion trees across the Arabian Peninsula

to combat desertification, regenerate areas of desert, and assist in emissions sequestration and climate change mitigation (A total of 50 billion trees covering approximately 2 million km² of degraded land) ^{300,301}. The aim of these projects is to create resilient vegetation and tree cover that ultimately survive unsupported, relying on natural systems to stimulate, capture and retain rainfall and surface water. Once established such forests may potentially create a micro-climate that promotes precipitation, although it is questionable whether precipitation levels would approach self-sustaining levels ^{302,303}. Small scale projects, such as Al Baydha in western KSA have demonstrated some success despite the unforgiving arid environment ³⁰⁴. However, greening the desert on any meaningful scale is challenging, dependent on extensive energy and irrigation until well established, and with groundwater resources now greatly depleted and the high costs of water desalination it is not clear how this might be achieved. Cloud-seeding has been suggested as a potential solution, and the UAE's Rain Enhancement Research Program operated by the National Center of Meteorology (NCM) 2019 ran over 185 cloud-seeding operations in 2019 claiming a 10-30% increase in rainfall ^{305,306}. However, peer-reviewed literature on the topic remains scarce, and it is hard to assess the impact of cloud seeding based on available data. Other potential nature-based solutions such as soil regeneration may be more suitable/efficient and provide higher benefits in drylands, and offer potential for carbon sequestration. Soil-based actions include remodelling the topography to reduce water run-off and soil erosion, creating wind breaks to protect top soil, and introduction of manure and fertilizers to improve soil nutrients, water infiltration and increase microbial activity, and introduction of annual weeds between trees to provide organic mass for soil improvement ³⁰⁷. Satellite remote sensing and related capabilities for soil and water monitoring could be explored further to support decision making, assessment of targets, and support net-zero related risks.

(3.e Likely co-benefits/trade-offs) Protecting, regenerating, and expanding natural resources in the region and greening cities brings a wealth of benefits for the environment, society, and the economy that go well beyond net-zero objectives – these include improving biodiversity and supporting wildlife, cooling temperatures, cleaning the air, creating economic activity, supporting livelihoods, improving regional food self-sufficiency, and improving human well-being. These contribute towards a range of SDG goals including SDG3 (good health and well-being), SDG11 (sustainable cities), SDG14 (life below water), and SDG15 (life on land). However, careful assessment is required of the overall carbon cycle of the projects and the probability of establishing self-sustaining ecosystems in the face of increasingly harsh climatic conditions. Any initiatives that are dependent on long-term artificial irrigation and particularly the unsustainable use of groundwater will ultimately prove unviable.

Food systems and food security

(3.c.i Overview) The region has limited domestic food production capacity, relying heavily on overseas agriculture and production, with 80-90% of food requirements

satisfied through imports ³⁰⁸. Moreover, the already limited production capacity within the region is at considerable risk from depleting non-renewing water reserves and the effects of climate change. Strikingly, given these constraints, food waste in the region is among the highest in the world, estimated to be 427 kg per person per year in KSA, and 197 kg per person per year in the UAE where studies suggest 38% of all prepared food is wasted ^{309–311}. (This compares with 95-115 kg/person in Europe). Studies suggest hospitality and tourism are the biggest sources of food waste ³¹². As such, plans to radically increase tourism in the region over the coming decades will further increase demands for food imports presenting yet another sustainability challenge.

(3.c.ii Impact of net-zero transition) With strong economies the dependence on imports is not considered a major risk at present; however, the region could find itself exposed to climate-induced disruption both at home and in overseas agriculture and food markets in the future ³¹³. Moreover, the carbon footprint of the food imports is significant and needs to be considered as part of the net-zero transition. Domestic food security is an important objective for the region, but water scarcity is a key barrier to domestic food production (in KSA only 1.5% of the land is arable, but uses over 80% of the Kingdom's non-renewable water resources ³¹⁴). The regions' already overexploited freshwater resources are being impacted by climate change, and while water can be generated through desalination this is expensive for most agriculture which limits the potential for further expansion of the food sector ³¹³.

(3.d.i Current/future solutions) In the past, efforts were made to increase domestic production through irrigated agriculture (see Figure 18), and a decade ago KSA was the sixth largest exporter of wheat in the world ³¹⁵. In recent years however, the region has significantly scaled back irrigated agriculture of cereals due to catastrophic groundwater depletion, but rather than curtailing water use this seems to have simply shifted production to higher value crops ^{315,316}.

An alternative ongoing strategy has been the acquisition of agricultural land in water-rich, land-rich third-party countries across the world to secure food for the region, e.g., in Pakistan, Sudan, US ^{317,318}. The water embodied in imported crops and foods – virtual water – reduces pressure on limited water resources in the Arabian Peninsula. This strategy has the additional benefit of obtaining food for the population at a significant discount relative to buying on global markets. However, it is a controversial practice, often presented as land grabs, that can create resource constraints, and potentially catastrophic groundwater depletion and food shortages for local communities in these overseas markets ^{317,319,320}. Climate change effects on these investments in already water stressed regions such as Pakistan and the Southwest US, may have a cascading effect on food security in the Arabian Peninsula.



Figure 18 Irrigated agriculture in the desert (1km diameter) - Saudi Arabia (Source: www.expo2015.org)

For agriculture in arid regions solutions can be open field solutions, or controlled solutions within a synthetic indoor environment³⁰⁵. For open field solutions efforts are ongoing to improve domestic dry-land agriculture and water efficiency through novel irrigation and better capture of precipitation and use of wastewater^{40,225,231}. Initiatives are also underway to improve soil health and address erosion and salinisation¹²⁰. Reintroduction of traditional and other drought-resistant crops and plants that can withstand high salt concentrations are also being explored^{313,321–324}. Sophisticated technologies are also being deployed to improve agriculture such as satellite sensing and thermal imaging to monitor and enhance water use^{314,325}, liquid nano clay treatments³¹⁴, and hydrophobic sand³²⁶ to improve moisture retention in agricultural soils. Another area of innovation is agrivoltaics, combining partially transparent solar panels for energy generation with agricultural production to optimise land use and economic return, and at the same time provide resilience to climate effects by shielding crops from harsh sunlight and wind and improving water retention^{327–329}. Aquaculture is also a focus of innovation, using sea pens, and onshore tanks, and this is now the fastest growing area of domestic food production in KSA^{314,330}. Education, awareness, and training are of foremost importance in tackling poor agricultural practices and disseminating new alternatives.

(3.d.ii Locally specific emerging solutions) Innovative agriculture such as controlled indoor vertical farming, seawater greenhouses and biosaline agriculture, and genetically modified climate-resilient crops are some of the potential future

solutions being explored to provide further domestic food production capabilities^{62,142–144,305}. For example, Dubai has recently announced ambitious plans for a “city” of vertical farms^{167,331}. Greenhouses and indoor vertical farming reduce water loss from evapotranspiration and can be expected to save considerable volumes of water and offset the limited arable land and water scarcity³³². However, these innovative solutions are energy intensive possibly requiring desalinated water and extensive cooling, and often involve trade-offs in terms of costs, resources, nutrition, and jobs, so whether these are more sustainable or lower carbon, or even affordable is not yet clear³⁰⁵. Nonetheless, these initiatives, implemented at unprecedented scale and with a focus on technology may enable the region to enhance food security and become a leader in novel agricultural techniques.

Beyond these technological solutions there is also a need for education and policies to reduce food waste. Individual household waste is high due to poor planning or awareness, and likely exacerbated by high food subsidies, while the biggest area of food waste is in hospitality, particularly festivals and events where it is customary to provide excess food^{310,311}. Besides the economic and ecological footprint of wasted embodied water, energy and resources, food waste also contributes to landfill and is a major contributor to methane gas emissions³⁰⁹. Policy will need to raise awareness and encourage a cultural shift in consumers and industry to address this issue, with careful consideration of the role and appropriateness of subsidies. A successful example is recent regulation in Dubai to force hotels to adopt more eco-friendly policies and reduced consumption. Proactive approaches to tackle food waste include offering half-sized meal portions, promoting à la carte menus, and reducing buffet quantities¹⁴⁹.

(3.e Likely co-benefits/trade-offs) Despite a small agricultural sector, KSA exports a range of food products, including dates, poultry, dairy, and a variety of fruits and vegetables³¹⁶. An appraisal of whether this is the most effective use of limited productive land and water resources may be beneficial. Expanding the domestic food production capacity could bring several potential benefits – access to fresher foods and enhanced nutrition, greater regional food security, and regional employment – but only if this is done in combination with radical reduction in water consumption. This could offer progress against SDG3 (good health and well-being), and possibly SDG8 (decent work and economic growth), and SDG9 (industry innovation and infrastructure). KSA’s policy of Saudization and reducing dependence on migrant workers may work against the traditional open field agriculture which has traditionally relied on low-cost labour³¹⁵, accelerating a shift to more high-tech, water-efficient, enclosed farming.

4. Definitions of Key Terms

Mitigation The lessening of the potential adverse impacts of physical hazards through actions that reduce hazard, exposure, and vulnerability.

Adaptation The process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.

Resilience The ability of a system and its component parts to anticipate, absorb, accommodate or re- cover from the effects of a hazardous event in a timely and efficient manner while retaining the same basic structure and ways of functioning, the capacity for self-organization and the capacity to adapt to stress and change.

Vulnerability The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes.

Risk The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.

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