Pathways to faster decarbonization in the GCC's power sector

Accelerating the energy transition with a combination of renewables and gas power

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Executive Summary

The Gulf Cooperation Council (GCC) countries have increased their focus on taking actions to address climate change concerns. However, there is an urgent need to further accelerate decarbonization[i] efforts, especially in the region's power sector, by leveraging its tremendous renewables potential together with its abundant natural gas reserves, while transitioning away from liquid fuels.

The world is in a race to reach net-zero emissions to counter global warming and reverse climate change. 197 countries have signed up to reduce their greenhouse gas (GHG) emissions through Nationally Determined Contributions (NDCs) under the United Nations Framework Convention on Climate Change (UNFCCC). Countries are disrupting their energy mixes, attempting to integrate cleaner fuels, and phasing out high-emission sources—leading to a focus on the energy sector—given its 73.2% contribution to total GHG emissions.[1]

The Gulf Cooperation Council (GCC)—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE)—home to some of the world's largest hydrocarbon producers and exporters, constitutes a 2.7% share of global GHG emissions[2] but is host to a population that is less than one third that percentage. Average annual per capita carbon dioxide (CO_2) and GHG emissions for the region also stand at well above the world average, driven by various elements, including the need for power for cooling and seawater desalination, a significant proportion of liquid fuels in the energy mix, the presence of energy-intensive industries such as smelters, petrochemicals, and cement, as well as other factors. Spurred by concerns of additional negative emissions impact from ongoing economic development, urbanization, and industrialization, countries in the GCC have committed to emissions reductions through their individual NDCs. Qatar and Saudi Arabia, together with Canada, Norway, and the United States—countries that collectively represent 40% of global oil and gas production—are also founding members of the Net-Zero Producers Forum. The forum aims to develop pragmatic net-zero emission strategies, in line with each country's national circumstances.[3]

[i]Decarbonization in this paper is intended to mean the reduction of carbon emissions on a gram per kilowatt hour basis.

FIGURE 1: Average annual per capita emissions, 2018[4,5]

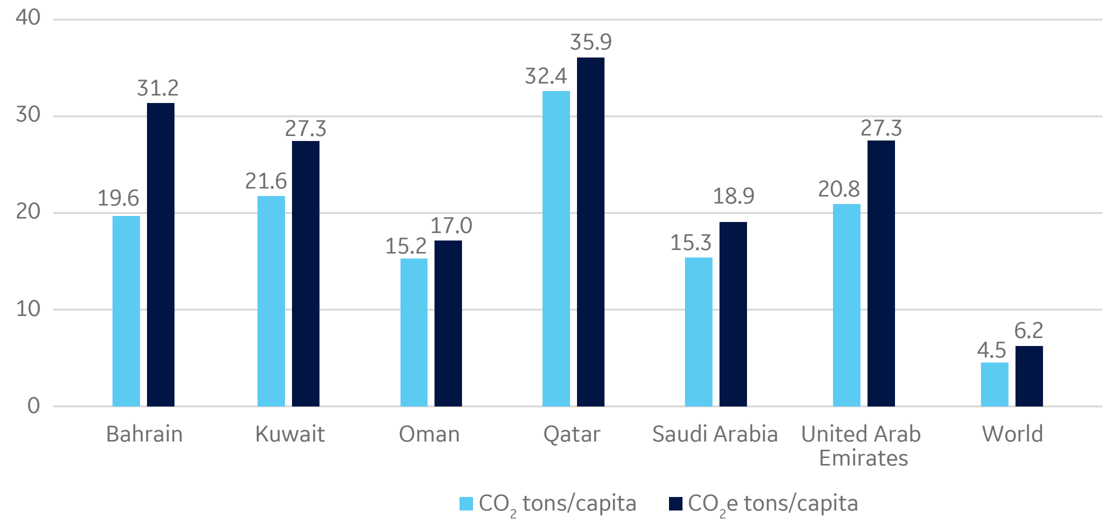

FIGURE 2: Decarbonization commitments across the GCC

BAHRAIN

Bahrain's commitment to the Paris Climate Agreement involves a combined approach comprising a renewable energy generation target of 5% by 2025 and 10% by 2035[6] and reduction in energy consumption by 6% by 2025.[7]

KUWAIT

Kuwait is seeking to achieve 15% of its electricity generation from renewable sources by 2030,[8] while concurrently improving the generation efficiency of its power plants by 15% and reducing energy consumption by 30%.[9]

OMAN

As per the second NDC, Oman plans to slow GHG emission growth and reduce emissions by 7% in 2030[10] compared to the Business as Usual (BAU) scenario. Renewable energy installations coupled with energy efficiency implementations across end users will form the cornerstone for the country achieving its stated NDCs in 2030. While Oman plans to increase renewable energy penetration in the energy mix to 20% by 2030,[11] this is proposed to be increased further to 35–39% by 2040.

QATAR

As per its latest communication to the UNFCCC, Qatar's NDC[12] intends to reduce 25% of its GHG emissions by 2030 as compared to the baseline scenario in 2019. Qatar's NDC will focus on the energy industry including transportation & downstream sectors, building & construction, water management, waste and infrastructure as modalities to achieve its committed NDCs.

SAUDI ARABIA

Saudi Arabia declared in 2015 an aim to annually abate up to 130 million tons of carbon dioxide equivalent ($MtCO_2e$)—approximately 20% of the country's current annual GHG emissions—by 2030.[13] Saudi Arabia's latest electricity diversification plans seek a 50% or 58.7 GW contribution from renewable energy, while the remainder is expected to be generated through gas power projects, primarily large scale combined cycle plants. The Saudi Energy Efficiency Programme (SEEP) is one of the key areas of focus, through which the country seeks to reduce energy consumption across the construction, utility, industrial, and transportation sectors by 20% by 2030.[14] Saudi Aramco, the national operating company for oil and gas, is a participant of the Oil and Gas Climate Initiative (OGCI), and has committed[15] to reduce carbon intensity across its business operations.

UAE

The United Arab Emirates announced the UAE Net Zero by 2050 Strategic Initiative in October 2021. This makes the UAE the first country in the Middle East and North Africa (MENA) region to announce the intention to achieve net-zero emissions by 2050. The plan involves an investment of AED 600 billion (over US$163 billion) in clean energy. The Ministry of Climate Change and Environment (MOCCAE) will lead efforts to execute the initiative and ensure collaboration at a national level.[16]

Executive Summary (continued)

Renewables are an excellent solution to address the climate challenge, especially as technological advancements and supportive policy frameworks have brought the costs of renewable power generation down. Consequently, there has been an extraordinary 69% compound annual growth rate (CAGR) in installed renewables capacity in the GCC between 2015 and 2020, albeit from a very low starting point, from 0.17 GW to 2.45 GW.[17]

However, the rapid integration of renewable power into grid infrastructure also has the potential to create its own set of challenges—especially around grid instability. Early adopters of renewables are realizing the need to strengthen grids with additional technologies, to achieve critically required levels of flexibility, scalability, dependability, and to maintain grid inertia,[ii] the absence of which can result in instability, power quality issues, and blackouts.

Gas power has emerged as a solution in this environment. Offering the lowest carbon emissions per megawatt hour of power generated among all fossil fuels, reaching as low as 310 grams of carbon dioxide per kilowatt hour (gCO_2/kWh), versus about 547–935 gCO_2/kWh or more for liquid fuel plants, and 750–1,000 gCO_2/kWh for coal-fired power plants,[18–21] gas can act as a force multiplier for renewables, complementing alternative energy sources that can be variable with reliable, on-demand electricity that can be ramped up or down rapidly. Gas power plants can also be deployed relatively quickly, with trailer mounted TM2500* aeroderivative gas power plants rated at 34 megawatts (MW) deployable in as little as a manner of weeks to months. The growth in gas power generation has been enabled by the increasing availability and affordability of natural gas. Moreover, **technology advancements mean that a dollar spent on gas turbine technology today does not necessarily equal a dollar spent on a carbon footprint for the life of the asset. Developments in hydrogen-based power generation and carbon capture and sequestration (CCS) mean that gas turbines can be a long-term destination technology and not just a bridging technology today.**

Nuclear energy is also beginning to come online in the region, contributing to the transition to cleaner energy as a dependable source of carbon-free power.

> *GE believes that the accelerated and strategic deployment of renewables and gas power in the GCC can change the trajectory for climate change, enabling substantive reductions in emissions quickly, while in parallel continuing to advance the technologies for low or near-zero carbon power generation.*

While there is no 'one size fits all' formula, and multiple technologies and fuel sources will contribute to the long-term power mix globally as well as in the GCC, **the focus of this white paper is to elevate the emphasis on renewables and gas power as urgently needed solutions to change the near-term trajectory on climate change.**

Together, renewables and gas power can help the GCC countries address the energy trilemma of securing more reliable, affordable, and sustainable power for present and future generations.

Systemic interventions will also be needed beyond power generation to facilitate the decarbonization of the GCC's power sector. Grid transmission and distribution infrastructure will have to be strengthened further and digital solutions deployed, to enhance system visibility, responsiveness, reliability, and performance as more variable power sources come online.

Demand side management will be another critical part of the puzzle. The GCC countries are among the highest per capita consumers of electricity in the world, ranging from 103% to 430% above the global average of 3.5 megawatt hours (MWh) per capita.[22] Moreover, peak electricity demand is expected to increase by 7.5% CAGR, from the current 122 GW to over 250 GW in 2030,[23] creating the additional challenge of trying to reduce GHG emissions, while producing more electricity in the future. Strong actions are thus needed to raise further awareness on and encourage behavioral changes to reduce energy consumption, complementing efforts that governments in the GCC have already started to take in this area.

Given the anticipated increase in future power demand, financial institutions and innovative public private partnerships will also have a key role to play in ensuring access to adequate resources to further modernize and decarbonize the region's power sector.

Governments, the private sector, and civil society across the GCC all need to work collectively towards addressing the climate challenge. However, governments will have to take the lead to proactively structure policies, frameworks, and marketplaces that are conducive for participation by private investors and encourage the adoption of lower carbon technologies including CCS.

[ii] Inertia in power systems refers to stored energy in large rotating generators which becomes available when a large power plant trips offline to temporarily make up for the lost power from the failed generator. Inverter-based resources like solar PV, wind, and battery storage do not provide this synchronous inertia offered by steam and gas turbine driven generators. As penetration of renewables in the grid increases, due considerations will have to be made to accommodate inertia in future power networks.

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The Power Sector: A Key Area of Focus to Drive Decarbonization in the GCC

The GCC is witnessing an unprecedented energy transition that will have a significant impact on society and industry.

The power generation mix is expected to evolve significantly, on the back of measures like growing investment in grid-scale renewable energy technologies, continued absolute increases in gas power, on-going developments around nuclear in countries like the UAE and Saudi Arabia, adoption of waste-to-energy plants, evolution of the hydrogen economy, development of solar hybrid systems, and investments in other power sources. This diversification strategy can allow the GCC to decarbonize the energy mix effectively, while balancing variable renewables with stable, base load power.

The energy sector makes up an 83% share of total GHG emissions in the GCC, of which 44% is attributable to power and heat generation.[24] While emissions from other sectors of the economy such as oil and gas, transportation, and industry must not be ignored, a concentrated focus on decarbonizing the power sector can lead to fast, deep emissions reductions at scale.

The GCC has traditionally relied heavily on hydrocarbon reserves to meet the domestic demand for electricity. In 2019, thermal power through liquid fuel and gas-fired power stations accounted for 98.7% of the installed power generation capacity.[25] Of this, over a third comprised of liquid fuels—see Figure 3.

This presents an opportunity for significant decarbonization through fuel substitution across the region, replacing liquids with renewables, gas, and other power sources. Leveraging gas, abundantly available in the region, can help achieve quick wins, while freeing up liquid feedstock for revenue-generating downstream applications. See Figure 4 for a comparison of emissions by technology using traditional fossil fuels for power generation.

Looking ahead, advancements in hydrogen-based power generation and CCS solutions also mean that a dollar spent on gas turbine technology today does not equal a dollar spent on a carbon footprint for the life of the asset. Gas turbines can be a destination technology as the GCC moves towards a lower carbon energy future.

FIGURE 3: Thermal electricity generation capacity by fuel type, GCC, 2019

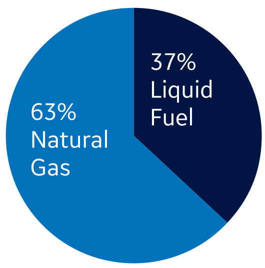


FIGURE 4: Emissions intensity by technology in grams of carbon dioxide per kilowatt hour (gCO_2/kWh)[26–29]

Combined cycle gas turbines:
307–395

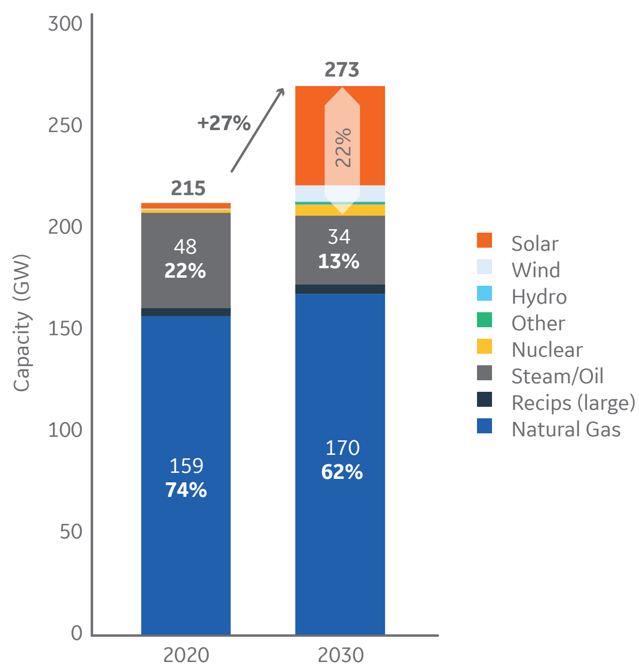
Simple cycle gas turbines:
490–565

Liquid fuel power plants:
547–935

Coal power plants:
750–1,000

Gas power generates the lowest emissions among traditional forms of fossil fuels.

FIGURE 5: A perspective on the future energy mix in the GCC[30]



Evolution of Renewables in the GCC: Opportunities and Challenges

The GCC has quickly emerged as a hotspot for renewable energy investments that have the potential to make the region a world leader in the industry.

Renewable energy across the GCC has grown at a staggering 69% CAGR (2015–2020), reaching a cumulative total of 2.4 GW in 2020, see Figure 6.

THE ADOPTION OF RENEWABLES IS BEING DRIVEN BY FUNDAMENTALLY SOUND FACTORS

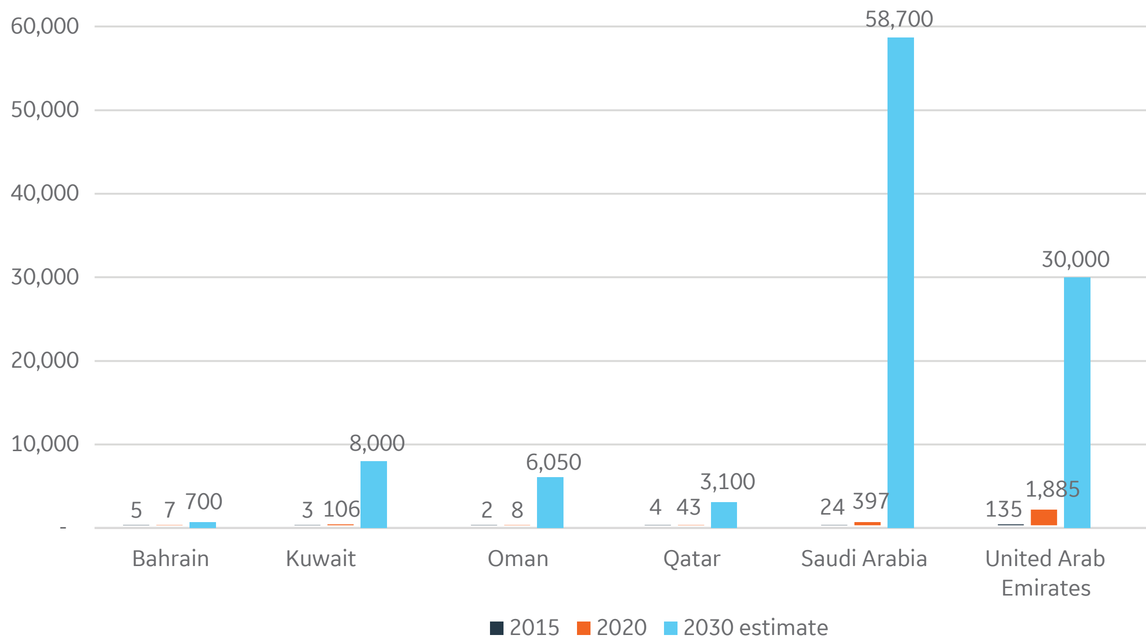
Several dynamics are accelerating the adoption of renewable energy, particularly solar photovoltaic (PV) technology, in the GCC.

- **Suitability for grid scale projects:** A suitability analysis for solar PV technology undertaken by the International Renewable Energy Agency (IRENA) in the GCC reveals a potential capacity for 608 GW of solar PV by developing just 1% of the suitable area.

- **Decreasing technology costs and levelized cost of electricity (LCOE) at a global and regional level:** Solar PV module costs continue to decline driven by optimization in manufacturing processes and gains in efficiency. Crystalline PV module prices have declined by around 90% since 2010.

Module costs have declined by as much as 30% and the total installed cost for utility-scale solar PV plants has declined by at least 74%. A relative comparison of solar PV module prices between 2013 and 2019 indicates that Saudi Arabia is the second country after France to have witnessed the highest decline in solar PV module prices.[32, 33] Such declines in technology and balance of system (BoS) costs, coupled with an increase in the average size/installed capacity of utility scale projects, have resulted in significant LCOE reductions for solar PV and concentrated solar power (CSP) projects globally, including in the GCC.

FIGURE 6: Evolution of renewable energy in the GCC: Installed capacity (MW), 2015 to 2030[31]



Specifically, the GCC has witnessed a massive 73% drop in tendered tariffs, particularly evident in how the UAE has been able to achieve one of the lowest LCOE globally for its recently awarded projects, with the Al Dhafra Solar PV project achieving an LCOE of US$ 0.0135/kWh and the MBR Al Maktoum Solar CSP project achieving an LCOE of US$ 0.073/kWh[35]—see Figures 7 and 8.

- **Technological advances:** Beyond costs, improvements in technology have made it increasingly feasible to adopt various renewable energy solutions in the GCC. Differently shaped blades like those with curved tips and other proprietary design technologies can allow larger wind turbines to be installed across onshore locations that were previously not suitable, while also enhancing energy production at different wind speeds. For lower wind speeds such as those witnessed across the GCC, turbines with a large rotor diameter are an excellent option. Longer blades allow greater wind accessibility, which in turn provides greater torque to power the generators. In addition to an increase in the span of turbine blades, wind turbine towers are also increasing in size. Longer wind turbine blades and taller turbines thus improve annual energy production (AEP) and help drive down the LCOE.[37]

  The GCC's first large-scale wind power project, the 50 MW Dhofar Wind Power Project located in the Dhofar Governorate of Oman—started to generate power in 2019. The facility is equipped with 13 GE wind turbines that have been customized to desert conditions specific to the GCC and can power up to 16,000 homes in the south of Oman. As the technology matures further, interest in wind power is likely to keep increasing across the region in the years ahead.

FIGURE 7: Evolution of LCOE (2018 US$/kWh) across solar PV and CSP projects globally[34]

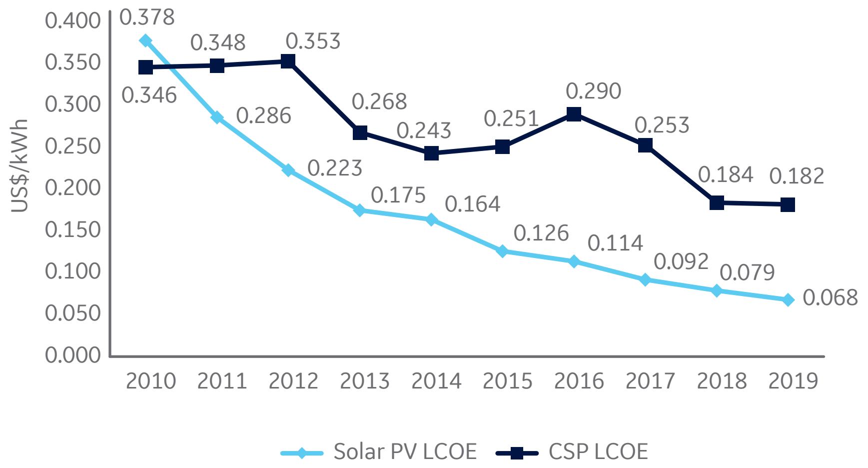
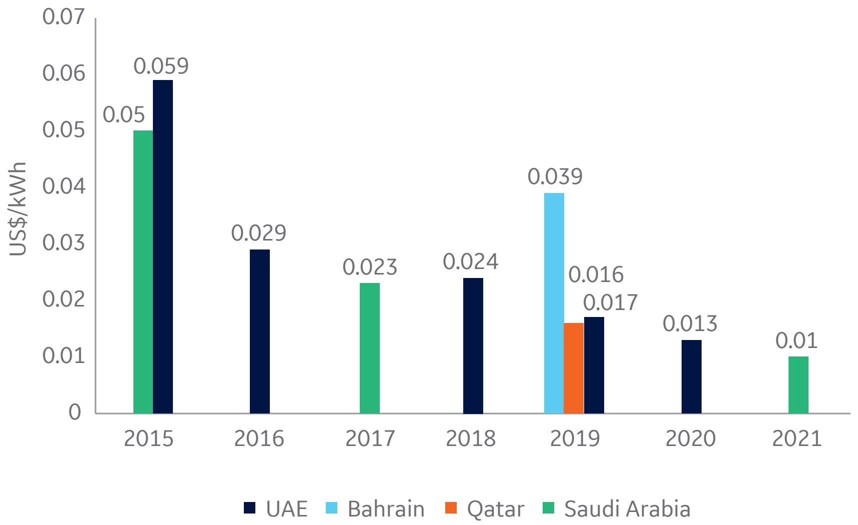


FIGURE 8: Evolution of on grid tendered solar PV tariffs in the GCC, 2015 to 2021[36]



INTEGRATING RENEWABLES INTO GRIDS CAN CHALLENGE STABILITY AND REQUIRES BALANCING

This increased adoption of renewables is, however, creating certain challenges—the variable nature of solar and wind have resulted in system instability and reduction in system inertia when not accompanied by incremental investments in the grid and in critical enablers like advanced forecasting, flexible generation, fast dispatch, reserves management, demand response, and demand side flexibility. Extreme weather events and the unavailability of solar or wind resources require greater emphasis on developing a resilient electricity system that can ensure reliable and quality supply at all times.

Power generation based on solar and wind is dependent on the adequate availability of these natural resources—which limits the extent to which they can be scaled to meet variances in demand—since the availability of these resources does not necessarily coincide with demand.

Conventional fossil fuel power plants can be ramped up and down on command and are dispatchable. Renewable power on the other hand is not fully dispatchable by the electricity grid and is often accommodated in the demand-supply curve, requiring agility. This is what South Australia opted for, running gas power plants to provide stability to the grid, even after having capacity to achieve 99%+ demand fulfillment from renewables.

The GCC can draw on the experiences of successful renewables adopters and structure a balance in the energy mix that incorporates various commercially viable technologies to meet its decarbonization goals.

Gas Power Technologies can Support Decarbonization of the GCC's Power Sector

Gas can be a force multiplier for renewables, helping to provide cost-effective, flexible, reliable power with lower emissions than any other fossil fuel based generation today, while progressing towards carbon neutral generation through the decarbonization of fuels and facilities in the future.

FIGURE 9: Average dependable capacity of various generation technologies[38]

Nuclear	92%
Gas	84%
HFO/Fuel Oil	80%
Coal	78%
Hydro	63%
Solar	20–40%
Wind	14% onshore, 27% offshore

FIGURE 10: Global typical CAPEX cost (US$/kW) for different power generation technologies[39, 40]

Gas Combined Cycle	500–600
Wind Onshore	1,050–1,450
4 Hour Battery Storage	1,165
Utility Scale Solar PV with Tracking	1,248
Gas Combined Cycle with Carbon Capture and Storage	1,500–1,800
Residential Solar PV	2,525–2,825
Hydropower	2,769
Wind Offshore	3,138
Coal (Ultra Super Critical)	3,672
Biopower/Biomass	4,078
Coal – IGCC	4,656
Concentrating Solar Power	7,116

Gas turbine technology is necessary to help accelerate decarbonization efforts in the GCC.

Gas power presents a dependable and commercially viable solution. Natural gas-fired combined cycle power plants have the lowest emissions intensity among fossil fuel-fired power plants, able to reach below 310 gCO_2/kWh. Gas power plants also typically have very high availability, second only to nuclear power across all power generation sources. Moreover, despite the falling costs of renewables, gas power still offers the lowest capital expenditures (CAPEX) on a $/kW basis across all power generation technologies.

Additionally, given the abundance of gas reserves, the International Energy Agency (IEA) projects that global natural gas production could increase nearly 30% by 2040 from 2019 levels, making it increasingly accessible. The complementary nature of renewables and gas, the significant investments in existing gas power infrastructure in the GCC, the advances in technology that are unlocking record-setting gas turbine efficiency levels, and long-term pathways to lower carbon gas power generation through a mix of hydrogen and CCS solutions, mean that gas power technologies can enable significant immediate reductions in emissions today, with more ambitious decreases in the future.

Renewables and gas are complementary, not competing forces.

Combined cycle gas technology provides a cost-attractive, resilient, and scalable infrastructure for base load power that can be effectively transitioned to complement the future integration of renewables.

- **Dependable capacity:** Gas provides dependable, dispatchable capacity that is available regardless of the time of day, season, or weather. Utilities and operators have been evaluating battery energy storage systems (BESS), especially lithium-ion (Li-ion) technologies, as a solution for improving the dispatchability of solar and wind power generation. This is driven by a considerable decline in costs for battery storage technologies—the current total system cost is now at US$ 380/kWh for 4-hour duration projects.[41] Additionally, there has been an increase in average storage duration capability, increasing to 2.2 hours in 2020, up 47% over 2015 and the CAPEX of a 4-hour BESS is expected to drop to a median value of US$ 156/kWh in 2050.[42, 43]

  However, battery storage will not be competitive on a levelized cost of storage basis for durations greater than 8 hours until there is a significant technology breakthrough resulting in a reduction in cost. Until then, gas power remains the most cost-effective backup for large, multi-day shortfalls in the supply of renewable energy.

- **The land advantage:** It is getting costlier to attain developed land in the GCC—especially land with proximity to high density population areas. Typically, solar and wind power are less power dense than thermal power generation resources, requiring more land per unit of installed generation capacity and electricity produced. For example, a 1,000 MW natural gas combined cycle plant requires 13 acres of land, while a solar farm requires 5,000 to 6,000 acres.[44, 45] The location factor also needs to be considered—renewable plants are typically constructed further away from demand zones, often requiring an increased investment in transmission infrastructure. Gas power plants can be constructed nearer to demand, allowing for reduced transmission costs.

- **The time element:** Renewables and gas power can also both be deployed quickly. A trailer mounted TM2500* aeroderivative gas power plant rated at 34 MW can be deployed anywhere in the world in a manner of weeks to months to address emergency needs. Simple cycle gas power plants can be in commercial operation 6–12 months after notice to proceed is received. Combined cycle power plants rated at 1 GW or more usually take 24–36 months to be brought into commercial operation. Wind and solar power can also be deployed quickly, typically generating power in as little as 6–12 months from notice to proceed. Switching over from liquid fuels to a combination of renewables and gas, as opposed to either alone, or to other power sources where the gestation period of the projects is longer, presents an immediate opportunity for deeper emissions reductions, while ensuring firm capacity.

**Trademark of General Electric company*

FIGURE 11: The complementary attributes of renewables and gas power

	WIND, SOLAR, AND STORAGE	GAS POWER
FUEL	Limitless, free fuel that is variable	Flexible, dispatchable power whenever needed, utilizing abundant and affordable natural gas or LNG
CO_2	Carbon-free	Less than half the CO_2 of coal with a pathway to future conversion to near-zero carbon with hydrogen and CCS
COST	Competitive LCOE when available, with no lifecycle uncertainty (mostly CAPEX)	Competitive LCOE with lowest CAPEX, providing affordable, dependable capacity
DISPATCH	Dispatches first in merit order... extremely low variable cost	Most affordable, dispatchable technology... fills supply/demand gap
PEAKING	Battery storage economical for short duration peaking needs (<8 hours, intraday shifting)	Gas economical for longer-duration peaking needs (day-to-day and weather-related extended periods)
CAPACITY FACTORS	25%–55% capacity factors based on resources (wind and solar often complementary)	Capable of >90% capacity factors when needed, runs less based on variable costs and renewables
LAND	Utilizes abundant land with good renewable resources (multi-purpose land use)	Very small physical footprint for dense urban areas with space constraints
HYBRID SOLUTIONS	Extends renewable energy to align with peak demand	Carbon-free spinning reserve peaking plants

SOLUTIONS EXIST TO REDUCE THE CARBON INTENSITY OF EXISTING GAS POWER INFRASTRUCTURE

The GCC has invested significant resources in its existing gas power infrastructure. With gas power plant lifespans typically running 20–40 years, it is not economically feasible to retire these assets. However, many of these facilities can be enhanced for better performance and lower carbon emissions with solutions that pay for themselves over time.

- **Upgrades:** In the more immediate to short term, upgrade solutions can be deployed to increase the output, efficiency, flexibility, lifespan, and availability of gas turbines, while reducing fuel consumption and environmental impact. For example, an organization in Qatar is using GE's Advanced Gas Path (AGP) upgrade solution on four 9F gas turbines. The technology is expected to help enhance power output by up to 96.7 MW with improved plant efficiency and to reduce carbon dioxide emissions for the same level of power output by up to 67,000 tons annually—the equivalent of taking up to 14,000 cars off Qatar's roads.

- **Simple to combined cycle conversion:** Today, many power plants in the GCC still use gas turbines that were installed in the 1980s and continue to operate in simple cycle mode at efficiency percentages around the mid-thirties. Modern combined cycle technologies offer efficiency levels as high as 64%. Converting simple cycle facilities to combined cycle—something that can be accomplished in as little as 16 months—can enable them to produce up to 50% more electricity using the same amount of fuel with significant CO_2 emissions reductions per megawatt hour of power generated.

The development of advanced technologies is helping to make gas power generation cleaner than ever before and offering possible pathways to near-zero carbon emissions in the years ahead.

- **Gas turbines with record-setting efficiency levels:** Gas turbine technology is becoming increasingly efficient, which immediately translates into lower emissions. For example, GE's HA gas turbine technology, which has helped to set two world records for efficiency, is now available at over 64% combined cycle efficiency and is closing in on 65%—a feat once considered to be almost impossible. Three GE 9HA units will be used at the 1.8 GW Hamriyah Independent Power Plant in Sharjah, UAE. The units are expected to be able to help Sharjah Electricity, Water and Gas Authority (SEWA) to reduce carbon dioxide emissions by up to 4 million tons per year compared to current levels—the equivalent of taking 1 million cars off the UAE's roads.

  As the GCC continues to decarbonize the power sector, efforts should be made to adopt proven, robust, highest efficiency turbines for upcoming gas power projects.

- **CCS:** CCS has the potential to significantly reduce CO_2 emissions from all fossil fuel burning power generation and industrial processes. Drawbacks include a near doubling of the upfront CAPEX of a power plant, additional space requirements, and a reduction in generation efficiency of up to almost 10 percentage points. Factoring in the additional cost and reduced efficiency results in an increase in LCOE of 30% to 50%.[46] Efforts are underway to optimize the power plant and CCS thermal needs such that the impact on efficiency is reduced, and a price on carbon could make CCS an economic option even with the increase in LCOE. GE believes in the mid-term to long-term benefits of CCS and is planning to invest in research and development (R&D) activities to make CCS a more affordable and efficient technology to reduce over 90% of the carbon footprint in existing and new combined cycle power plants.

  Merely separating CO_2 is insufficient to reach deep decarbonization goals, though. It must be either used or stored safely and permanently. Based on parallels to fossil fuel extraction technologies there is a strong technical basis that the Earth, and in particular, the oil and gas-rich GCC countries, has the capacity to store more CO_2 than humans can produce, and there is very strong evidence that we can safely store the CO_2 underground for hundreds of millions of years. All CO_2 molecules emitted began their journey underground, so the challenge is to put them back when we are done.

  CCS solutions are already deployed in the GCC and there is increasing interest in the technology across the region. For example, an ongoing CCS project in the UAE has the capacity to capture 800,000 tons of CO_2 per year. In addition, we have seen commitments by organizations in the UAE and Saudi Arabia to produce and export large commercial amounts of blue hydrogen/ammonia, which require significant investments in CCS.

- **Hydrogen:** The GCC is starting to look at hydrogen as an important fuel in a future where only low-carbon fuels will be allowed to burn. The region has many of the ingredients needed to produce both green and blue hydrogen cost-effectively in the long run—enormous renewable energy potential, large reserves of hydrocarbons, access to sea water, and depleted oil and gas reservoirs to safely store carbon dioxide—and is investing in blue hydrogen (produced through steam methane reforming with CCS) and green hydrogen (produced through the electrolysis of water using renewable power). In terms of power generation, what is important to note is that the source of the hydrogen doesn't matter—once it is produced, any given volume can be burned in a gas turbine to generate the same amount of power, regardless of what means it was produced by.

  A potential benefit of using hydrogen as a fuel in gas turbines, either as a blend with natural gas or at 100% hydrogen, is that it can be accomplished either as a new build or on a retrofit basis, with relatively minor changes to the gas turbine and plant auxiliary equipment.

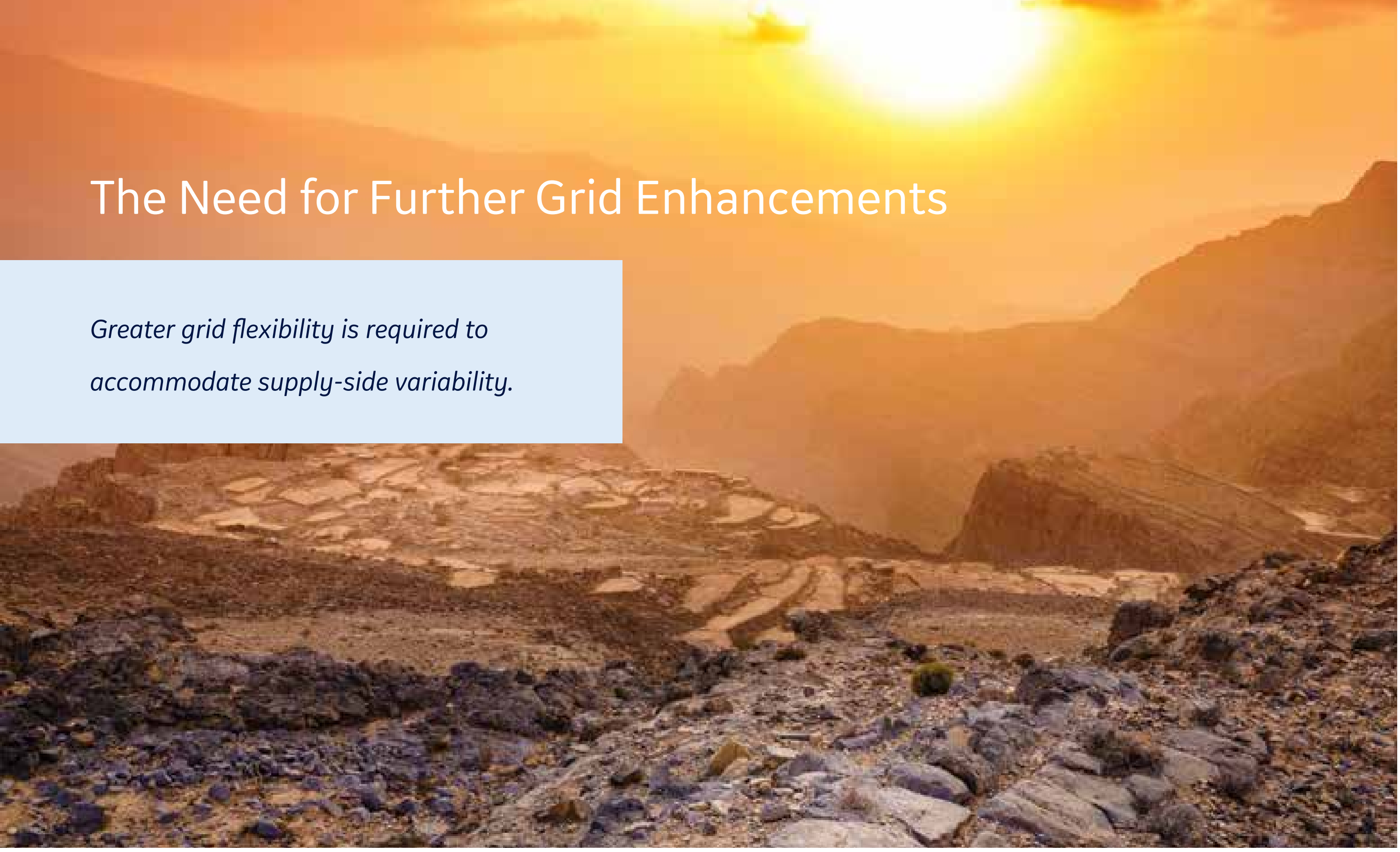
  Therefore, the decision to build a gas power plant today does not necessarily lock in CO_2 emissions at the original level for the entire life of the power plant.

  Hydrogen is already being used for power generation. GE gas turbines have been operating with hydrogen fuel blends in a variety of industrial applications, including steel mills, refineries, and petrochemical plants; we are a world leader in gas turbine fuel flexibility, including more than 100 gas turbines that have operated (or continue to operate) on fuels that contain hydrogen and have accumulated more than 8 million operating hours.

- **Hybrid technologies:** Hybrid solutions can provide vital grid stability services such as frequency regulation, spinning reserve capacity, or black start capability, and several hybrid systems are already in operation today. For example, GE integrated energy battery storage technology has been deployed to black start a 7F gas turbine at Entergy Louisiana's Perryville Power Station in the USA. The term 'black start' refers to the rebooting of an idle power plant without support from the grid in the event of a major system disruption or a system-wide blackout. To provide a black start, traditionally some power stations have small diesel generators—normally called black start diesel generator (BSDG)—which can be used to start larger generators, which in turn can be used to start the main power station generators. Today, the Perryville Power Station is supported by GE's 7.4 MW battery-based energy storage system paired with the plant's simple cycle gas turbine. The project demonstrates the complementary nature of gas-powered energy and battery storage.

The Need for Further Grid Enhancements

Greater grid flexibility is required to accommodate supply-side variability.



The full potential of renewable energy to decarbonize the power sector cannot be unlocked without the right investments in transmission and distribution systems. Grid operators need to ensure the availability of sufficient resources to account for the considerable variation in renewable generation, while avoiding cycling or curtailment strategies that can result in reduced efficiencies and a need for increased maintenance due to the thermal stresses on equipment.

A range of solutions are available to secure and stabilize the grid. Their selection depends on the cost-effectiveness of the method and the characteristics of the existing grid system.[47]

- **Advanced forecasting:** Techniques and models that can help provide reliable predictions of load demand and the availability of various renewable and conventional energy supplies are critical for grid management. Forecasts can help grid operators better accommodate fluctuations in wind and solar power supplies and prepare for extreme events in which renewable generation is unusually high or low. Forecasts can also help to lower the operating reserves required, decreasing the overall costs of balancing the system.

- **Fast dispatch and fast frequency response (FFR):** As penetration of renewable energy increases, the need to maintain a demand-supply balance on the grid at very short intervals increases, too. Fast dispatch technologies like gas generation and battery storage provide access to a wider set of flexible resources to balance the system. FFR strategies refer to the delivery or removal of active power from the grid at very short time intervals to correct any supply demand imbalance and assist in managing power system frequency.

- **Reserves management:** Modifying existing reserves management practices to reduce the overall need for balancing reserves can lead to significant cost reductions. As increasing amounts of variable renewable power supplies come online, one such tool is to introduce ramp rate controls that limit the extent to which wind or solar generation from a particular facility can ramp down during extreme weather events. This could be achieved, for example, through the integration of a smoothing BESS that can enable power supply to remain within the required ramp rate limitations.

- **Two-way power flow:** Distributed power generated from residential, industrial, and commercial sources can be connected to the grid to help balance electricity demand with supply and provide ancillary services such as frequency regulation, voltage control, etc. This reduces the amount of large spinning reserves that utilities need to maintain to respond to possible fluctuations in renewable energy supplies.

- **Flexible market design and mechanisms:** Generators can be provided incentives to perform in a flexible manner through the right market design and mechanisms. Learnings are available from Germany, where short-term variability in electricity supply due to renewables resulted in costly disruptions at industrial facilities. The country went on to establish a balancing market auction where market participants provide power or cut outputs, earning fees whether their services are needed or not.

- **Cross-border grid interconnectivity:** Cross-border grid interconnectivity, such as the GCC Interconnection Grid, can help enable electricity exchange and emergency support, creating more robust and dependable power systems.

Beyond Power Supply: Demand Side Management and Digital Solutions

A system-wide approach is needed to decarbonize the GCC's power sector faster, at scale.

Opportunities for decarbonization are not restricted to the power supply side alone. Improvements in consumption behaviour and technology have an equally important role to play in achieving emissions reductions across the value chain.

DEMAND SIDE ENERGY EFFICIENCY AND MANAGEMENT

> *Energy efficiency is the first fuel of a sustainable global energy system.*
>
> — IEA

Demand side energy efficiency and management, focuses on a set of interventions designed to efficiently manage energy consumption across end use sectors, reducing energy consumption, wastage, emissions, and costs (associated with electricity supply and demand).

The GCC countries are among the highest per capita consumers of electricity in the world, ranging from 103% to 430% above the global average (3.5 MWh/capita),[48] with consumption increasing at 4.8%[49] annually between 2010 and 2018, higher than the global average of 3.1%.[50] This increase in electricity demand has necessitated the need for additional investments in generation capacities, which grew by 8% between 2015 and 2019.[51] Consumption, if left unaddressed, is expected to continue increasing, spurred by accelerated economic development and population growth, and peak electricity demand is expected to increase by 7.5% CAGR, from the current 122 GW to over 250 GW in 2030.[52]

To complete the loop, the GCC needs to go beyond the supply side, and focus on addressing the demand for electricity. The region has previously grappled with the challenge of variability in peak loads, and energy efficiency and peak-demand management strategies can reduce the demand for power, leading to fewer emissions.

The GCC countries have recognized the role of energy efficiency in building a sustainable and carbon-neutral energy system. The UAE's Energy Strategy 2050, for example, seeks to increase the consumption efficiency of individuals and corporates by 40%. Subsidies on electricity and water tariffs that were in place in many countries of the GCC are gradually being reduced and phased out in much of the region.

Mandates and mechanisms for improvement in energy efficiency are expected to result in substantial reductions in CO_2 emissions across the entire energy value chain. Energy labeling of consumer appliances, built-in energy efficiency through integration of technology and innovative materials, water desalination, and improved heating and cooling systems have emerged as key focus areas for interventions for governments and energy service companies (ESCOs).

Digital technologies can enable generation optimization to be coupled with grid optimization and a real-time understanding of demand to enable a system that works seamlessly across multiple generation sources, an intelligent grid, and varying demand, to maximize system efficiency, minimize CO_2 emissions, and ensure reliability.

DIGITAL SOLUTIONS

Integration of assets is a critical enabler for decarbonizing the power sector—to optimize the system, by pulling together generating assets, the electricity grid, and loads. As the region adds more renewable capacity, system operators will need to integrate and optimize the dispatch of assets after considering availability of resources, while factoring in the actual cost associated with the operation of each generation technology. Utilities across developed and developing economies have witnessed improved production efficiency and reliability, reduced generation costs, and lower carbon emissions through the implementation of digital solutions that enable real time asset and system visibility, predictive diagnostics, troubleshooting, and more. It is anticipated that by 2025, digitized plants will result in up to 4.7% reduction in emissions from power stations.[53]

The Role of Finance in Accelerating the Decarbonization of Power in the GCC

Creating a realistic path to net zero in the GCC requires the right investments. It is well understood this includes investing in renewable energy to the maximum extent feasible.

To succeed in reducing emissions as quickly and effectively as possible, it is necessary to also make smart investments in natural gas. Gas facilitates the fast deployment of renewables, rapidly reduces emissions by accelerating the retirement of liquid fuel power projects, and can avoid carbon lock-in through the ability to deploy carbon capture and hydrogen generation technology over time.

The IEA recognizes the role of gas in both reducing emissions and growing renewables, and estimates that US$ 1.4–US$ 2 trillion is required to support current 2050 global gas capacity projections, and an additional approximately US$ 400 billion for new gas capacity with CCS. The continued appropriate support and financing of gas projects is necessary to help the GCC countries achieve their ambitious decarbonization goals, build infrastructure to support renewable energy, and deliver reliable, affordable, and sustainable access to their growing demand for energy.

Adequate financing is required to upgrade the existing, vast infrastructure and accelerate decarbonization in the GCC. With the growing need for electricity, fluctuating oil and gas prices straining national finances, and COVID-19 recovery, there has been significant unplanned spending in the GCC. Consequently, the region will need to look beyond traditional models of government-backed projects to more innovative, collaborative models involving multiple parties.

- **Public-private partnerships (PPPs)** are one such example and already have a successful track record in the region. For example, in 2019, GE and Japan's Sumitomo Corporation ("Sumitomo") along with Shikoku Electric Power Company and Sharjah Asset Management ("SAM"), the investment arm of the Government of Sharjah, closed financing from leading private financial institutions and the Japan Bank for International Cooperation ("JBIC"), Japan's export credit agency (ECA), for GE's flagship 1.8 gigawatts (GW) power project, Hamriyah Independent Power Company ("Project"), in Sharjah, United Arab Emirates (UAE). This is the first independent combined cycle power plant in Sharjah, which demonstrates the strength of the emirate's economy and its attractiveness for foreign direct investment (FDI). The project is expected to be the most efficient power plant in the Middle East's utilities sector on completion.

- **Sukuk,** sharia-compliant, fixed-income capital markets instruments, have steadily increased their share of global markets over the past decade.[54] Sukuk represent aggregate and undivided shares of ownership in a tangible asset as it relates to a specific project or investment activity.[55] In the GCC, Saudi Arabia has led the development of Islamic finance markets, with its corporates issuing around US$ 13 billion of sukuk in 2020,[56] including for projects related to the decarbonization of the power sector. In May 2019, a Dubai-based organization issued the GCC's first green sukuk to finance and refinance green building and energy efficiency investments.[57] As understanding of and familiarity with the instrument grows, it could play an increasingly important role in financing the development of the region's power sector.

- **Export credit agencies (ECAs)** play an increasingly important role as financing partners for the GCC power sector. While private financing can and should deliver the largest share of investments in decarbonization, ECAs are critical in supporting nascent technologies and complementing private sector investments where market forces are not sufficient. Without support from ECAs and other public institutions such as development finance institutions (DFI), there is a risk that emerging market countries continue to operate and invest in new build oil-fired projects. Furthermore, support and financing of gas provides economic opportunities and enhanced global competitiveness, particularly because of gas import and export capacity.

  Policymakers and financing institutions can help achieve Paris Agreement goals and reduce global emissions, enabling gas to be an accessible, viable option to reduce emissions and build the foundation for reliable renewable energy infrastructure. Longer term, gas investments can be decarbonized through CCS and hydrogen, further contributing to addressing climate change globally.

Appropriate policy support and financing of gas and CCS will enable emerging economies to build a resilient renewable energy infrastructure and invest in technology choices that rapidly reduce emissions and expand affordable access to electricity, while raising standards of living.

Conclusion and Recommendations

Capitalizing on the complementary attributes of gas and renewables can help the GCC to address the imperatives of climate change and presents the most viable pathway to deeper, faster decarbonization of the region's power sector at scale.

Gas and renewables alone may not offer the sole means to decarbonize the GCC's power sector, however, they are low hanging fruits that together, can drive significant carbon reductions in the near-term, with more ambitious decreases in the future, while maintaining system reliability.

No single technology, solution, or stakeholder can singularly address the complex requirements for resolving the energy trilemma of securing more reliable, affordable, and sustainable power. With the right mix of stakeholder participation, technology adoption, and market play, the GCC countries can position themselves as leaders in the decarbonization of power, while operating to their strength and experience in the energy sector.

Addressing climate change will require government, private sector, and consumer action. GE is well positioned to support the decarbonization of the GCC's power sector, through its local presence and knowledge, scale, breadth, and technological depth. We have been a key player in the GCC's energy sector for more than 80 years. With investments in local facilities and talent, global expertise, and a suite of industry-leading, complementary technologies including gas-fired power, onshore and offshore wind, hydro, nuclear, battery storage, hybrids, grid solutions, and digital applications, we are committed to accelerating the region's transition towards a more decarbonized energy future.

RECOMMENDATIONS

A successful roadmap to decarbonize the GCC's power sector must include:

- **Investment in a mix of renewables, gas, nuclear, hydrogen, CCS, hybrid solutions, battery energy storage solutions,** and other low and near-zero power sources urgently and at scale.
- **Leveraging abundant gas supplies in the region,** as a strategic resource, to provide dependable support and to complement renewables.
- **Replacing liquid fuels** with a combination of lower or near-zero carbon resources.
- **Enhancing existing gas power generation facilities** to improve their operational performance through the conversion of simple cycle power plants to combined cycle, upgrades, digital solutions, and other technologies.
- **Adapting existing, and constructing new gas power generation facilities to transition to near-zero carbon emissions** by operating on low carbon hydrogen or hydrogen blended fuels and/or integrating carbon capture solutions.
- **Upgrading transmission and distribution infrastructure** to seamlessly integrate variable power generation sources into the grid.
- **Continued focus on demand side energy efficiency** to curtail the wasteful consumption of energy—for example, by developing a unified country-wide mandate for reduced energy consumption, with specific targets for regions/sectors, creating consumer awareness, as well as structured investment in R&D capabilities, technology development, and implementation.
- **An inclusive framework** that does not depend on government action alone but facilitates active participation from the industry to ensure a balanced and sustainable growth path.
- **New business models** that encourage competition and the development and adoption of new technologies.
- **Market mechanisms and policies** that incentivize reductions in power sector carbon intensity, are transparent and predictable, allow lifecycle economics to drive investment decisions, and enable the market to define the optimal mix of solutions and technologies to secure access to reliable, affordable, and sustainable power.

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