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Renewable Energy Development in Kuwait: Obstacles and Opportunities

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ABSTRACT: Kuwait is one of the highest carbon emitting countries per capita in the world with renewable energy resources severely underutilized in its energy portfolio. This paper examines the country's goals and progress towards meeting the standards set by the Paris Agreement, as well as provides a basic overview of some of the various opportunities and obstacles associated with further utilization of renewable technologies. The paper suggests that Kuwait's high incident irradiation and strong seasonal winds make for attractive resources to harvest. The technical challenges associated with generation uncertainty have been reported to be relatively minimal in the currently-operational plant in Shagaya, and are expected to be further minimized with recent innovations in the field. Economic and legislative obstacles that face renewable energy in Kuwait include the governments' heavy subsidization of energy and the absence of a government entity to oversee achieving renewable goals. The low cost of oil production in Kuwait hinders investment in renewables; however, as fuel prices grow and renewable energy costs drop, the economic scales are quickly shifting.

Keywords: Kuwait; Renewables; Energy; Policy

INTRODUCTION: Since 1960, Kuwait's electrical power demand has increased from around 380 GW.hrs [1] to 66,356 GW.hrs in 2020 [2]. Although this rise is mostly driven by population growth, the per capita consumption has also seen rapid growth until the stricter implementation of efficient building codes in 2005 caused it to moderately decline [3,4].

In 2015, local electricity consumption per capita was 14.95 MWh which was amongst the highest in the world [4]; almost double that of OECD countries (8 MWh) and considerably higher than the average in GCC countries (11 MWh, excluding Kuwait) [3].

Only 0.3% of the energy demand in Kuwait is being met through renewable energy resources [2] which, in combination with the high per capita demand, results in a substantial carbon footprint. Kuwait's emissions per capita in 2015 were 21.1 tonnes of CO_2-eq, which is tremendously higher than the average in the Middle East (8 tonnes of CO_2-eq) and the global average (4.5 tonnes of CO_2-eq) [3]. This situation necessitates a careful reevaluation of the country's energy policies.

Although Kuwait is only responsible for 0.23% of global carbon emissions (83 million tonnes of CO_2-eq emitted locally out of 35,000 million tonnes of CO_2-eq globally in 2015) [3,5-8], the country might be especially vulnerable to the perilous effects of global warming. Extended draughts, sea level rise, and average temperature increase are some of the adverse phenomena that have been linked to global warming [6] all of which could be exceptionally detrimental to an arid coastal country like Kuwait where over 90% of potable water demand is being met through seawater desalination [7].

Furthermore, the Intergovernmental Panel on Cli-mate Change (IPCC) forecasts global sea levels to rise by one to three meters during this century. This is catastrophic to Kuwait's low-lying coast of which 1.4%-3% could be inundated with a sea level rise of 0.5 m-2 m. This has the capacity to affect up to 5% of Kuwait's GDP and 174,000 individuals [8].

In 2016, The Paris Agreement urged the reduction of global carbon emissions by 50% in an effort to lower the average global temperature by 1.5°C-2°C. Kuwait signed this accord pledging to mitigate 7.4% of its projected carbon emissions in 2035 under "business-as-usual" parameters.

The country aims to achieve this goal through a number of projects that would reduce emissions as well as sequestrate and reuse carbon. These projects are shown below in Table 1 which is quoted directly from Kuwait's second "Nationally Determined Contributions" document submitted to the United Nations in ratification of the Paris Agreement in October 2021 [8].

Economic feasibility of utilizing renewables is directly dependent on the capital and operating costs of renewable technologies compared to fossil fuels. In the 1980s, renewables were considered unsuitable for Kuwait because of their high costs compared to the cost of using fossil fuels [9-28]. However, technological advancements have started shifting the balance with renewable energy costs rapidly declining over the past decade. Photovoltaics in particular have seen significant drops of 82% as seen in Table 2.

Table 1: Kuwait's plans against climate change [8].

Kuwait's	Kuwait's	Kuwait's	Kuwait's
Emission Reduction	Sidra project-renewable energy	2015	13,700
	Improving energy distribution efficiency-I	2015	134,949
	Improving energy distribution efficiency-II	2015	112,700
	Electricity production by renewable energy	2017	115,000
	Improving energy distribution efficiency-III	2019	219,700
	Improving energy distribution efficiency-IV	2020	351,800
	Production of 850 MW of combined cycle	2020	3,500,000
	Liquefied gas in energy production (70% gas, 30% fuel)	2022	3,000,000
	Production of 250 MW of combined cycle	2024	1,000,000
De-carbonization	Cultivating of Mangroves	2018	+50,000 (yearly)
Carbon Reuse	Industrial Application	2015	10,950
	Carbon capture and storage-I	2015	100,000
	Carbon capture and storage-II	2022	216,000
Percentage of total state emissions in 2035			7.4%

Table 2: Cost comparison between various renewable technologies [27].

	Total Installed Costs (2021 USD/kW)			**Capacity Factor (%)**			**Levelized Cost of Electricity (2021 USD/kWh)**		
	2010	2021	% Change	2010	2021	% Change	2010	2021	% Change
Bioenergy	2714	2353	-13%	72	68	-6%	0.078	0.067	-14%
Geothermal	2714	3991	47%	87	77	-11%	0.050	0.068	34%
Hydropower	1315	2135	62%	44	45	2%	0.039	0.048	24%
Solar PV	4808	857	-82%	14	17	25%	0.417	0.048	-88%
CSP	9422	9091	-4%	30	80	167%	0.358	0.114	-68%
Onshore Wind	2042	1325	-35%	27	39	44%	0.102	0.033	-68%
Offshore Wind	4876	2858	-41%	38	39	3%	0.188	0.075	-60%

Although the cost of oil production is low in Kuwait, its high selling price makes it more economically incentivizing to rely on energy generation methods that don't consume oil. Under this light, domestic oil consumption is associated with implicit losses in the form of foregone revenue from selling oil internationally. This consideration makes renewable energy technologies more economically competitive with conventional fossil fuels.

This paper aims to give a general overview of some of the potential opportunities available for Kuwait to utilize towards further incorporation of renewable energy within its energy portfolio, as well as some of the technical, economic, and legislative obstacles that could hinder such expansion. The paper also briefly mentions notable recent developments in the field that could aid in overcoming the technical obstacles. Specifically, the paper will focus on photovoltaic solar panels, concentrated solar power technology, and wind energy as some potential sources of renewable energy.

MATERIALS AND METHODS: Kuwait currently has a limited generation of renewable energy through three technologies: Solar photovoltaics, concentrated solar thermal power, and wind energy.

With the goal of assessing Kuwait's opportunities for renewable energy expansion and relevant challenges, research was conducted over existing material in the literature in order to obtain relevant data and formulate a concise elementary evaluation.

RESULTS AND DISCUSSION: Kuwait Electrical Energy Sector: Current energy production and consumption: In 2020, the total electricity demand in Kuwait was 66 TW.hrs with a peak load of 14,960 MW. With a population of more than 4.6 million this corresponds to a per capita consumption of 14,207 kWh/year or 38.8 kWh/day. This demand is amongst the highest in the world [9]. Furthermore, total demand is ex-pected to grow to 100 TW.hrs (around 50% increase) with a peak load of 20 GW in 2028 [2].

Kuwait's high electricity demand can be attributed to the extremely hot climate driving the use of energy-intensive HVAC applications which is estimated to account for 45% of the yearly demand of electricity and 70% of the electrical power peak load [3]. The correlation is evident from looking at the quarterly electricity generation in 2020 shown below in Table 3 and the dates and maximum temperatures of the annual peak loads in Table 4.

Table 3: National quarterly electrical energy generation in 2020 [2].

	1st Quarter	2nd Quarter	3rd Quarter	4th Quarter	Total
Elec. Energy Generation (GW.hr)	12,150	19,709	26,838	16,059	74,756

Table 4: Peak load v/s maximum temperature [2].

Year	Max. Load (MW)	Date	Max. Temperature at Peak Load (°C)
2015	12810	30/8/2015	49
2016	13390	15/8/2016	48
2017	13800	26/7/2017	49
2018	13910	10/7/2018	48
2019	14420	6/27/2019	50
2020	14960	30/7/2020	52

The third quarter (July-September) corresponds to the summer season where temperatures can reach an average of 44°C and maximums of above 50°C. Notably, on the 21st of July, 2016, a temperature of 54°C was recorded in northern Kuwait which was considered a historic high for the Eastern Hemisphere and Asia [10].

High temperatures have an additional role in driving electrical power consumption by lowering power plant efficiencies while they operate at their maximum loads which in turn increases the consumption of fuel and the emission of greenhouse gasses [4].

Kuwait's heavy energy subsidization might also be a factor that encourages extravagant consumption [9]. This is covered more thoroughly in the legislative obstacles section of the paper.

In order to meet recent spikes in power demand, Kuwait has been importing natural gas since 2009. In 2019, Kuwait's consumption of natural gas was 23BM3, of which 5.1BM3 (around 22%) were imported [14]. As for oil, Kuwait consumed 446 thousand barrels daily in 2019 out of its daily production of 2678 thousand barrels (around 16.6%) [14].

Given Kuwait's heavy economic dependence on oil and gas (91% of Kuwait's exports [15], 88% of governmental revenue [16], and 42.1% of GDP [17] in 2019) these losses, through importing natural gas and forgone oil sales, are especially costly and provide an economic motivation to transition to cleaner energy sources.

Additionally, the heavy dependence on fossil fuels as the primary source of income for the country makes it extremely vulnerable to oil price fluctuations. This was evident in 2020 when plummeting oil prices caused the governmental revenue to drop from 15.8 billion KWD in 2019 [23] to 7.5 billion KWD in 2020 [24].

Plans for economic diversification and product base expansion away from hydrocarbons could be supported with expanding investments in renewable energy. This could help create jobs, improve the participation of the private sector, and lead to expansions in industry, trade, and manufacturing [21].

Current energy policy and future plans: The total capacity of power plants in Kuwait as of 2021 is 20.2 GW of which only 70 MW are generated from renewable energy [2] which amounts to a miniscule 0.35% of the total electrical generation capacity. Although projections expect this share to increase to 16% by 2035 [3], Kuwait's vision isn't as clearly defined as its GCC counterparts [11]. It is worth noting that previously the country had set goals of 1% of renewable energy incorporation into its energy portfolio by 2015 and 10% incorporation by 2020 [11]. Both of these goals were never achieved.

Most power stations in Kuwait generate power using fossil fuels. Out of the total capacity of 20.2 GW, 8970 MW (44.4%) come from steam turbine units, 8151 MW (40.3%) come from gas turbine units, and 3032 MW (15%) come from combined cycle units.

These stations undergo annual maintenance during winter to be able to deliver high demand during summer. However, it is noteworthy that 6350 MW (17% of total capacity) are produced by old plants that would be retired over the next decade [18] to be replaced with more efficient combined cycle power plants in Al-Khairan, Al-Nuwaiseeb, through expansions in Az-Zour North [2], and conversions of existing open-cycle units (Table 5) [3].

Table 5: Kuwait's power plants in 2020 [2,18].

Power Plant	Technology	Capacity (MW)
Doha East	Steam Turbine [7] OCGT [4]	1,122
Doha West	Steam Turbine [8] OCGT [5]	2,541
Az-Zour South	Steam turbine [8] OCGT [4] CCGT [15] CCST [5]	6055.8
Az-Zour North	CCGT [5] CCST [2]	1,540
Sabiya	Steam turbine [8] OCGT [3] CCGT [10] CCST [5]	7046.7
Shuaiba South	Steam turbine [6]	720
Shuaiba North	CCGT [3] CCST [1]	875.5
Shuwaikh	OCGT [6]	252
Shagaya	PV, Wind, CSP	70
Umm Gudair	PV	10
Total Capacity		20,233
OCGT-Open-cycle gas turbine; CCGT-combined-cycle gas turbine; CCST-combined-cycle steam turbine; P-photovoltaic; CST-concentrated solar power. Table format adopted from [18] updated with information from [2].		

Additionally, in an effort to cut operational costs and reduce emissions, power plants are and will continue to phase out operating on oil in favor of natural gas. With that, production of natural gas is expected to increase in Kuwait to meet the projected growth in domestic demand and minimize the need to import natural gas. This is evident from examining recent trends in domestic fuel consumption, which is outlined in Figure 1 below. It can be seen that domestic consumption of natural gas has already overtaken that of oil in 2020.

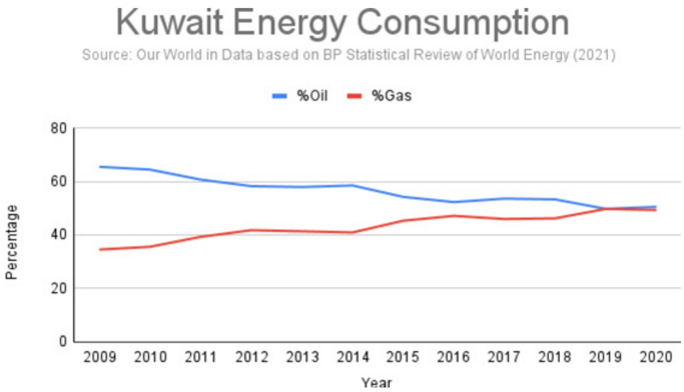


Figure 1: Kuwait energy consumption by source (coal & renewables omitted) [14].

As a result of the high consumption and overreliance on fossil fuels, Kuwait has a relatively massive carbon footprint. Kuwait's Institute of Scientific Research (KISR) assessed that the electricity sector was responsible for the emission of 44.6 million tonnes of CO2-eq out of 83 million tonnes of CO2-eq in 2015 [3]. Based on their analysis, this value is forecasted to experience a moderate decline to 41.4 million tonnes of CO2-eq out of 102 million tonnes of CO2-eq by 2035 through phasing out using oil for natural gas and the introduction of renewable energy technologies in the power sector [3].

However, bp's Statistical Review of World Energy issued in 2021 estimates that Kuwait's CO2 emis-sions in 2019 were 101.5 million tonnes [14]. It is worth nothing that bp's data doesn't account for carbon sequestration nor does it consider other greenhouse gas emissions.

Examining these values on a per capita basis gives a clearer understanding of the severity of the country's carbon footprint. Emissions per capita in 2015 were 21.1 tonnes of CO2-eq which was more than double the average in the Middle East (8 tonnes of CO2-eq) and almost 5 times the global average (4.5 tonnes of CO2-eq [3]).

The first large-scale renewable energy project to become operational in Kuwait was the off-grid Sidra 500 plant in Umm Gudair in Western Kuwait which was established in 2016 by Kuwait Oil Company with an installed capacity of 10 MW generated *via* photovoltaic solar panels.

In 2017, under the supervision of Kuwait Institute of Scientific Research, the first phase of Al Shagaya renewable energy park was connected to the grid with a combined capacity of around 70 MW. Three distinct power plants constitute the project: 10 MW of wind power, 11.15 MW of photovoltaic power, and 50 MW of parabolic-trough concentrated solar power.

The photovoltaic power plant is made of two systems: One where 5.53 MW is generated by thin-film photovoltaic technology, and another where 5.61 MW is generated by polycrystalline silicon technology [19]. The CSP plant also utilizes a molten salt thermal storage system capable of operating for ten hours. At its final stage, the plant is planned to reach a capacity of 4 GW. Such a massive project is intended to deliver 15% of the country's energy demand in order to realize the late Sheikh Sabah Al Ahmad Al Sabah's vision by 2030.

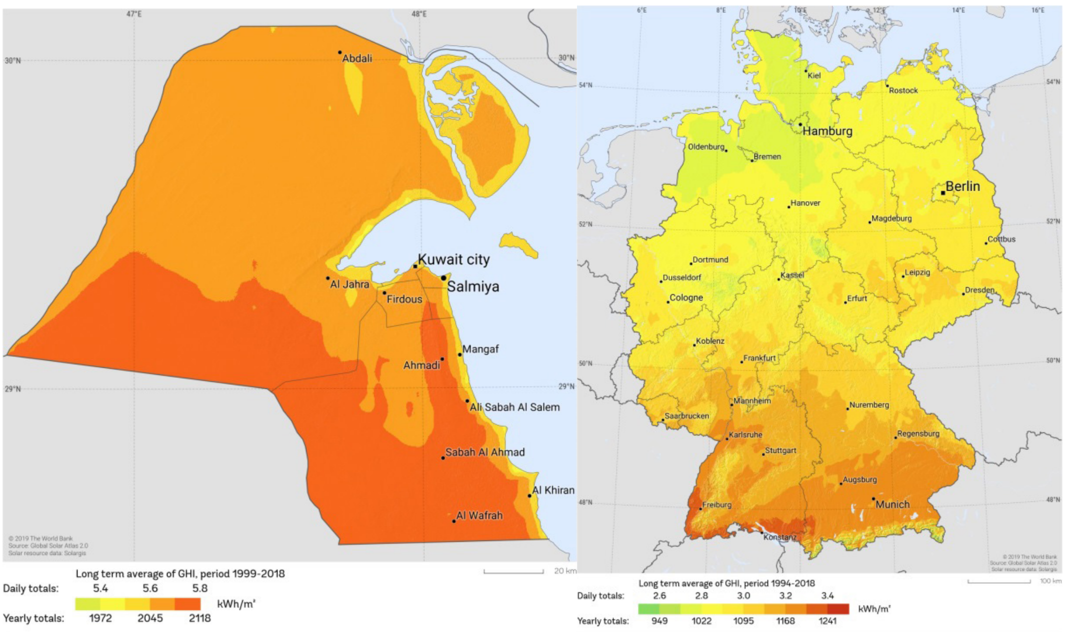
For the second phase an additional 1,500 MW of solar photovoltaic energy was scheduled to become operational in 2021 [3] but has been delayed. The third phase would incorporate another 1,500 MW of mixed technologies with photovoltaics likely dominating the composition. This third phase will be developed by a public-private partnership structured company. The last 1,000 MW would be added in the fourth and ultimate phase, and its layout is yet to be decided [18].

Off-grid photovoltaics are also expected to play a significant role in the realization of the 2030 goal of 15% renewable energy share of the energy portfolio. Several governmental buildings, parking shades, and water tanks have and will be equipped with Photovoltaic panels to contribute in delivering approximately 150 MW of the power demand [2].

Renewable energy supply: Photovoltaics (PV): Kuwait has ample solar resources that make it an ideal location for PV and CSP technologies. Yearly Global Horizontal Irradiance (GHI), useful for evaluating suitability for PV, was reported in some studies to be in the range of 1900 kWh/m^2-2200 kWh/m^2 [29-42].

Even if the lower value of this range was taken conservatively (to account for sandstorms, humidity, and cloud obscurement), it compares favorably with countries like Germany, where the GHI is estimated to be in the range of 1000 kWh/m^2-1150 kWh/m^2 [43] and where PV cells delivered 50.6TWh in 2020 (both utility-scale and residential systems) [44].

The number of sunshine hours per day ranges between 7 in December and 11 in August, with an annual average of 3347 sunshine hours [45]. The following solar resource maps (Figure 2) compare the long term average GHI in Kuwait to that of Germany [42].



Maps obtained from the "Global Solar Atlas 2.0, a free, web-based application is developed and operated by thecompany Solargis s.r.o. on behalf of the World Bank Group, utilizing Solargis data, with funding provided by the Energy Sector Management Assistance Program (ESMAP). For additional information: https://globalsolaratlas.info

Figure 2: GHI solar resource maps in Kuwait and Germany.

This high irradiance makes PV systems highly suitable for implementation in Kuwait either as utilityscale projects or off-grid residential systems. Computer simulations have shown that utilizing off-grid residential PV cells in Kuwait could aid in meeting 25%-50% of the electrical consumption [29].

Concentrated solar power (CSP): CSP systems are also very promising in Kuwait due to the country's high Direct Normal irradiance (DNI) which is estimated to be around 2100 kWh/m^2 [29]. Although this DNI is suitable for regular CSP plants, it has also attracted attention for other applications. For example, Al-Abdaliya, which had a measured DNI of 2033 kWh/m^2 [29], was selected as the site for an Integrated Solar Combined Cycle (ISCC). Simulations have shown that due to this high solar heat input, the efficiency of the ISCC plant could approach 66% [46]. Although PV technology is currently the cheaper, more widely-used solar technology, both technologies should be utilized for energy port-folio diversification.

Wind energy: Kuwait has substantial wind re-sources [3] that are categorized as "moderate" in the winter season and "good to excellent" in the summer season [47], especially in the northern part of the country. This variability follows the same trend as the demand fluctuation which also tends to increase rapidly during the summer season.

Alkhalidi, et al. in 2019 have identified three very promising offshore locations for windmill installation and three other possible locations [48]. Another study by Al-Nassar, et al. revealed that the highest wind power density in Kuwait was 583.2 W/m^2 during the summer season. Interestingly, they found out in their economic analysis that an offshore windmill in Kuwait is 30% cheaper than an oil-fueled combustion power plant [49].

Problems that Prevent the Growth of RE in Kuwait: Government related obstacles: There are many legislative and administrative obstacles hindering policy-makers from paving the way for renewable energy in Kuwait. Primarily, the absence of a dedicated government entity tasked with facilitating and overseeing the realization of renewable energy targets has been a big factor in delaying renewable energy development [29].

The energy sector is dominated by the Ministry of Oil, Ministry of Electricity and Water (MEW), and Supreme Petroleum Council while the development of renewable energy has been primarily supported and overseen by KISR, an independent research center.

This leads to delays in obtaining long-term licensing for projects as well as seemingly inconsistent national energy policies [21]. For example, in 2009, Kuwait established the National Nuclear Energy Committee (NNEC) with plans to erect four 1GW nuclear power plants [29].

However, the plans were quickly canceled in 2011 following the Fukushima Nuclear Power Plant in Japan [30]. Subsequently, NNEC was integrated into KISR while, paradoxically, MEW announced plans for 10% incorporation of renewables in the energy portfolio by 2020 [29].

Another example of policy inconsistency can be seen with Kuwait's largest solar power project: Shagaya Phase 2. Originally, the project was a standalone project called Al-Dibdibah, and was set to be a 1 GW PV power plant under the supervision of Kuwait Petroleum Corporation [50].

However, it was suddenly canceled amidst the COVID crisis only to be revived months later as a 1.5 GW PV-2 GW PV plant under the supervision of the Ministry of Electricity and Water and merged into the Shagaya Renewable Energy Park project [51].

Several studies suggested that Kuwait's high per capita energy consumption is in part driven by the high power subsidies [4,9]. In 2014, $ 3.5BN out of the government's budget was allocated to the utility subsidy bill [11]. This high value amounted to 11% of the GDP [3]. It was estimated that tariffs amounted to 1/15 of production costs (93% subsidization) [20].

In 2016, the Council of Ministers, in response to falling oil prices and in an attempt to rationalize consumption, reformed energy subsidies with increased tariffs for the governmental, commercial and industrial sectors and no changes for the residential sector (Table 6) [3].

Table 6: Current electricity tariff in Kuwait [3].

Sector	Tariff ($/kWh)
Residential villas and apartments	0.007 (unchanged)
Government and commercial	0.083
Industrial and agricultural	0.033
Others	0.067

The tariffs remain comparatively high even after the increase [9] as subsidies amounted to 8% of the GDP [3]. This is expected because 50% of the electrical consumption comes from the residential sector where subsidies were unchanged [22].

The average energy tariff for GCC countries is 0.07 $/kWh [3] which is around ten-fold higher than the tariff in the residential, governmental and commercial sectors in Kuwait, and around double that of the Kuwaiti industrial and agricultural sectors. The world average sale price of electricity in 2020 was 0.134 $/kWh for the residential sector and 0.103 $/kWh for the industry sector [12]. Figure 3 below shows the global distribution of residential and industrial electricity prices in 2020. It can be seen that:

a. For the residential sector, Kuwait's electricty retail price is amongst the lowest in the world.

b. For the industry sector, Kuwait's electricity retail price is still cheaper than the world average.

Reforms are needed to reduce electricity consumption and fiscal costs of subsidies. Assuming no reforms in residential power subsidization, a 26% increase in the associated costs of subsidization is expected by 2035 to reach a grand total cost of $ 3.9BN [18].

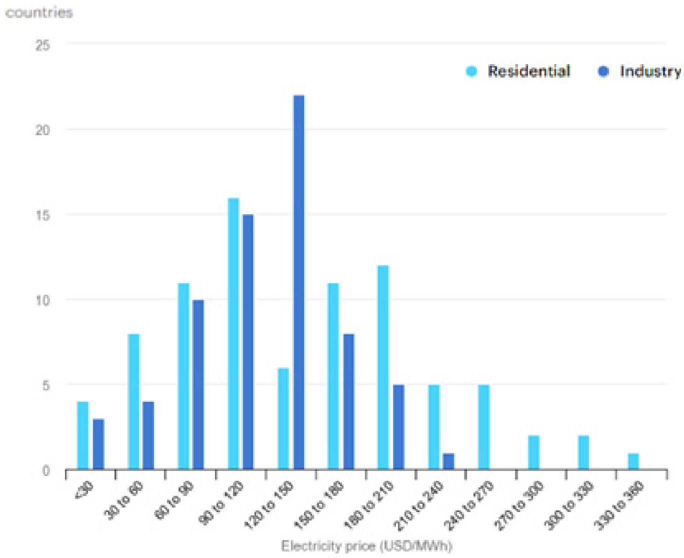


Figure 3: Global distribution of electricity retail prices in 2020 [12].

This generous level of subsidization also hinders many reforms that could mitigate a substantial portion of the carbon emissions. For example, although district cooling has seen very successful implementation in few government sectors in Kuwait, it remains underutilized in the residential sector. Over the past few decades, several studies have shown its financial unsuitability due to the generous level of subsidization [25] despite the high potential for power consumption reduction.

More recently, it has been suggested that the low retail price of electricity only misrepresents the view in a way that makes district cooling appear expensive. District cooling providers and consumers alike are hesitant because of the absence of government regulations and support [26].

Additionally, this artificially deflated retail price of electricity makes it difficult for off-grid PV installations to compete with cheap grid electricity. Even fiscal support mechanisms like feed-in tariffs, which would normally incentivize consumers to install solar panels, might be counterproductive under current electricity tariffs [11].

Despite popular opposition to the idea of lowering subsidies, the government was successful in lowering subsidization of gasoline and electricity in recent years. Further reductions would, expectedly, be faced with similar opposition. Therefore it is important to raise awareness within the general public regarding their energy consumption and how local energy subsidization compares globally.

Technical challenges: Energy dispatchability (ability to deliver energy in reaction to fluctuating demand) has been a big challenge for renewable technologies due to production variability and performance limitations within current energy storage technologies. Meteorological conditions such as dust and sandstorms [37], high ambient temperatures [38], and cloud obscurement can affect the production of a solar power plant.

Due to its geographical location between major regional deserts and marshes in Iran, Iraq, and Saudi Arabia [31], Kuwait has ample dust deposits especially during active sandstorm seasons with one of the highest dust precipitation rates in the world [32] and an average of 255 days of sandstorms and/or suspended dust [33].

High temperatures can also have a soiling effect on the performance of PV cells. Research has shown that a 0.5% drop in efficiency can be expected with each 1°C rise in temperature [34]. Therefore, with Kuwait's extreme temperatures in the summer, significant drops in performance can be expected.

Simulations for a 2 GW PV plant in Kuwait have shown a 13% reduction in output due to high temperature with significant fluctuations in output variability and generation certainty around the year due [35]. The soiling effect of sandstorms was shown to be limited to PM10 concentrations of 2700 ppb or greater as those could lead to reductions in daily total irradiance of 57% or higher.

However, actual monitoring data and perfor-mance analysis from the 11 MW PV plant in Shagaya over 25 months have reported more pos-itive results with 6%-8% drops in performance ratios under careful cleaning and maintenance [36]. Additionally, although significant water consumption was reported (3.35 Liter/MWh-4.61 Liter/MWh), the dry strong winds in Shagaya (11.3 m/s) resulted in a partial self-cleaning pro-cess [36].

Recent promising research shows that through advanced fabrication techniques and utilization of photonic structures and metamaterials, the soiling effect of temperature on PV cells can be greatly minimized [34]. Photonic structures are materials that are simultaneously and selectively transmissive and reflective for different wavelengths of electromagnetic waves.

This new coating material can protect the PV cell by reflecting solar radiation at wavelengths where radiation would normally be captured as harmful thermal energy while propagating solar radiation at wavelengths where radiation could be converted into useful electrical current. Furthermore, hybrid systems that combine PV and radiative cooling technologies can be manufactured to simultaneously produce cooling power and electrical current [34].

Along with frequent sandstorms and dust precipitation, Kuwait's water scarcity makes maintenance and cleaning for PV and CSP systems more challenging especially when these systems are deployed at large scale. However, latest advancements in nanotechnology have demonstrated the effectiveness of "self-cleaning" coating material that has low adhesive properties to combat dust accumulation while boosting high transmissive properties to allow the propagation of solar radiation [39].

To aid with generation uncertainty and variability, most PV and CSP power plants established recently were equipped with energy storage systems capable of delivering power for hours during periods of low radiation [40]. Furthermore, these storage systems, namely lithium batteries for PV plants and molten salt thermal storage tanks for CSP plants, have expe-rienced significant price drops and capacity im-provements all of which have substantially lowered their LCOE and performance.

For example, lithium batteries used both in utility-scale PV systems and rooftop installations, have experienced sharp price drops of 70% in Germany and the US [27]. Molten salt thermal storage systems have seen price drops of almost 20% while boosting capacity improvements of 84% for parabolic-troughs and 53% for solar towers [27].

Infrastructure planning and land availability, as well as access to the national electrical grid are another set of technical challenges facing renewables in Kuwait. Most renewable energy power plants require vast flat lands in close proximity to the electric grid which could be a challenge for Kuwait. Optimal locations for harvesting renewable resources are mostly remote and far from the national grid or coastal areas [21] leading to larger transmission losses and high connection costs.

DISCUSSION AND CONCLUSION: The average person in Kuwait consumes 14,207 kWh/year. This consumption is amongst the highest in the world, and leads to 21.1 million tonnes of CO2-eq emitted per capita into the atmosphere annually. The Paris agreement urged countries to reduce their carbon footprint in such a way that limits the annual rise of global average temperature to 2°C. Kuwait has pledged to reduce its carbon emissions by 7.4% and aims to do it *via* a number of projects that improve efficiency and lower consumption.

However, in order to meet the standards set by the Paris Agreement, Kuwait has to incorporate more renewable technologies into its energy portfolio. This paper drew information and data from the existing literature to offer an elementary assessment of Kuwait's opportunities for expansion in renewables as well as the most relevant obstacles hindering this expansion.

Solar photovoltaics have seen significant drops in cost over the past decade, and with Kuwait's high amount of incident irradiation and high number of sunny hours annually, this technology makes for an attractive opportunity for expansion into renewables.

Although Kuwait's high ambient temperatures and severe dust and sandstorms lead to considerable losses in PV efficiency, recent scientific and technological breakthroughs in the field of nanotechnology have the potential to protect PV cells against high temperatures.

Concentrated Solar Power is another technology that would make use of Kuwait's high irradiation without being negatively affected by its high temperature. It has also seen improvements in energy storage capacity and decent price drops. Wind energy is another potential candidate as research has demonstrated its suitability and identified several favorable on-shore and off-shore locations for constructing wind farms in Kuwait. Some of the locations that were identified have been associated with cheaper levelized costs of electricity than oil-fired power plants.

Renewables in Kuwait still have to compete with cheap fossil fuels in an environment where energy subsidies give fossil fuels a significant advantage. Kuwait's very general energy subsidies hinder the implementation of most forms of clean energy generation technologies or consumption reduction strategies. The administrative structure in the energy sector makes it difficult to expedite renewable energy projects, obtain licensing, and maintain a con-sistent energy policy due to the lack of an entity entrusted with overseeing the progression of renewable energy projects and meeting the country's targets.

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