Electricity Generation in Kuwait using Sustainable Energy Sources – A Focus on Solar Photovoltaic Systems

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Abstract:

To overcome its reliance on burning fossil fuels for energy generation and water desalination, Kuwait has pioneered research and cutting-edge projects in renewable energy since the 1980s. This paper examines the power sector in Kuwait and emphasizes the government's keenness to diversify the country's electric power supply. It provides a comprehensive overview of Kuwait's efforts, to emerge as a leading example in the region, fostering collaboration and matchmaking within renewable energy industries. The country's goal is to meet 15% of the demand for power from renewable energy by 2030, including a reduction in energy use in the building sector by 12% and a decrease in CO_2 emissions by 33%. The country's initiatives revolve around harnessing renewable sources, particularly emphasizing the exploration of solar photovoltaic (PV) systems. Challenges and opportunities are presented to provide information for international institutions, technology companies, designers, researchers, and decision makers, aiming to increase the effectiveness and efficiency of PV project implementation in the country and the region.

Keywords: Renewable energy, Kuwait power grid, solar photovoltaic system, environmental impact.

1. INTRODUCTION

Kuwait has high solar energy potential, with 2500–3000 sun hours per year and average daily solar radiation of 5.5 kWh/m^2/day. This amount is considered to be one of the highest in the world; it could be exploited for several applications, especially solar photovoltaic (PV) usage. According to [1], power production in Kuwait still depends heavily on crude oil, petroleum products, and natural gas. In fact, the main sources of the national income are oil and natural gas. The government owns and operates power generation, transmission, and distribution. It is mentioned in [2] that Kuwait's development plan for 2015–2020 (DP15-20) is paving the way for the private sector to have direct ownership over power production and management involvement.
This culminated recently with the ongoing effort to finalize a new decision regulating the renewable energy sector, allowing purchasing renewable energy from third parties as of 2023, according to the Kuwaiti Council of Ministers decree No. 57 [3].
This involvement has been introduced to meet the fast-growing demand for electricity from the residential, industrial, and commercial sectors, in addition to establishing a competitive market for power generation. Fig.1 shows an estimate of future expected power generation and anticipated peak load.

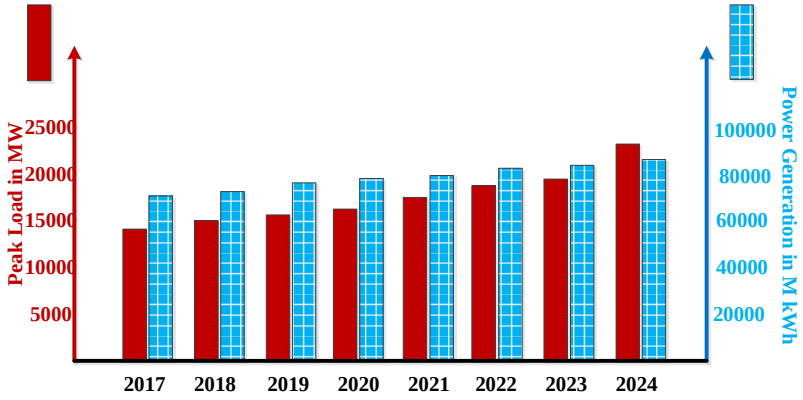

Fig.1. Future estimates of power peak demand and generation.

It is well known that burning fossil fuels (coal, oil, and natural gas) generates pollutants and harmful gases that cause environmental problems [4]. Although they are considered the world's primary energy source, fossil fuel reserves are limited and their large-scale use is associated with environmental deterioration [4]-[5]. For these reasons, Kuwait has paid great attention to renewable energy sources and committed itself to a renewable energy strategy [6].
Kuwait is considered among the highest per capita energy consumers and CO_2 emitters in the world [7]; as a consequence, the country has found itself called toward adapting a sustainable energy strategy.
The primary contribution of this paper is to present a comprehensive overview of Kuwait's efforts to become a leading example in the renewable energy realm and to highlight important related projects and their challenges for international institutions, technology companies, designers, and decision makers. A Geographical Information System (GIS) that includes the related projects' details is constructed in ArcGIS online as the first step toward dedicating a shared database of all renewable energy projects in the country.

2. ENERGY SECTOR IN KUWAIT

Energy pricing is considered one of the main factors that influences the deployment of various power technologies [8]. The tariff in Kuwait is 2 fils per KWh (0.66 ¢/KWh), which is a fraction of the cost. The Ministry of Electricity, Water, and Renewable Energy (MEWR) in Kuwait is the sole supplier of electricity and water resources in Kuwait [9]. It is also the central regulatory body that manages the supply/demand of electricity as well as water. Table I depicts the latest approved electricity tariffs according to the MEWR.

TABLE I: ELECTRICITY TARIFFS IN KUWAIT

Sector	Electricity Tariffs (¢/KWh)
Government	8.25
Commercial	1.65
Industrial and agricultural	1.65
Industrial/agricultural (production)	0.99
Residential	0.66
Others	3.96

Kuwait is also a member of the GCC Interconnection Authority (GCCIA), which links the power systems of the Arabian Gulf states. GCCIA was established to improve electricity ties among gulf countries, along with better management of shortage/excess of electricity. Although the market for renewable energy sources in Kuwait is still in its early stages, it is currently a high-focus area of interest on the government's development agenda [10]. The government plan is to transform Kuwait into a country dependent on alternative power, with the help of the private sector. Both the government and the oil sector are the leading investors in renewable energy resources; however, there has been rising interest in involving the private sector. As stated in [11], the government of Kuwait has adapted a public–private partnership (PPP) program, which promotes collaboration between the public and the private sectors to develop quality infrastructure and services. The program falls under the auspices of the Kuwait Authority for Partnership Projects (KAPP), which was established in 2008. The program is designed to create a framework for increased foreign direct investment (FDI) in Kuwait by facilitating the PPP model.

The program paved the way for two major power and desalination projects (Az-Zour and AlKhairan) in the south of Kuwait. Similarly, Phase III of the largest renewable energy project in Kuwait, Shagaya Renewable Energy Park, is slated to be completed via KAPP and successful bidders by 2030.

Table II shows the type of technology applied in the three phases of the Shagaya Renewable Energy Park. The purpose of phase I is to assess the technical and economic performance of renewable energy technologies, support the development of a regulatory framework with respect to power purchasing and dispatching, and provide performance data to the private sector for the development of phases II and III. More information about the project will be provided in the next section.

TABLE II: SHAGAYA RENEWABLE ENERGY PARK

Phase I	Phase II	Phase III
CSP/Wind/PV	PV	TBD
50 MW + 10 MW + 10 MW	3150 GWh/yr	3.2 GW

CSP: Concentrating Solar Power; **TBD**: To Be Declared

3. SUSTAINABLE ENERGY PROJECTS

Kuwait has pledged to address global warming and has taken responsibility among the nations of the world to serve as a learning ground for the implementation of renewable and solar PV projects. Because of this greater cause and global benefit, there will be no economic evaluation or assessment in our coverage of the related projects.

Photovoltaic projects in Kuwait date back to the 1980s. Reference [12] discusses the installation of a 24.2 kW_P PV system that was commenced and completed in 1985 for the Kuwait Institute for Scientific Research (KISR). The project was jointly funded by KISR and German parties to be installed at the Kuwait English School.

The main entities that have the largest contribution to the currently installed solar PV projects in Kuwait are MEWR and the oil sector. Other ministries have invested in PV projects as well, such as the Ministry of Public Works (MPW), the Ministry of Education, the Ministry of Social Affairs (the Union of Cooperative Societies), the Ministry of Health, and the Ministry of Finance, among others.

The educational and research bodies and centers, such as KISR, Kuwait University, the Kuwait Scientific Club, the Kuwait Foundation for the Advancement of Sciences (KFAS), and the Public Authority for Applied Education and Training (PAAET), have all aided the development of a solid ground for the application of renewable energy in the country.

KISR provides consultative advice and technical assistance for PV system implementation for most of the PV projects in the country. The institute is responsible for the emergence of the crowning achievement of renewable energy projects in Kuwait, viz., the Shagaya Renewable Energy Park. The maximum PV system installed at the time of writing this paper is 10 MW_P. It is part of the first PV system described in this study. The following list provides insights on the key PV projects that have been completed or are currently open for tender.

A. Project: Shagaya Renewable Energy Park

The project comprises three major phases of an ambitious master plan (2014–2030). It includes Research and Development (R&D) village, Operations and Maintenance (O&M) housing community (1200 persons), and four substations integrated into the national grid. Phase I was designed and developed by MEWR and KISR. Reference [13] states that Kuwait Petroleum Corporation and its subsidiaries will contribute to achieving Kuwait's renewable energy goal by building the Dibdibah project (Phase II of the Al-Shagaya Renewable Energy Park).

The Dibdibah project involves the construction of a PV solar plant that is expected to generate 3.150 GWh/year throughout the complete 25-year project lifetime. Upon the park's full entry to the national grid, the project will slow the growth of high demand for energy and promote clean economic development. Fig.2 illustrates the park's overall layout, including all three phases. The park's development is ongoing and will continue to evolve until 2030. The entire project serves as a technology test and regulatory

benchmark in the country for renewable technologies, including the development of interconnection protocols and grid support for the various technologies [13].

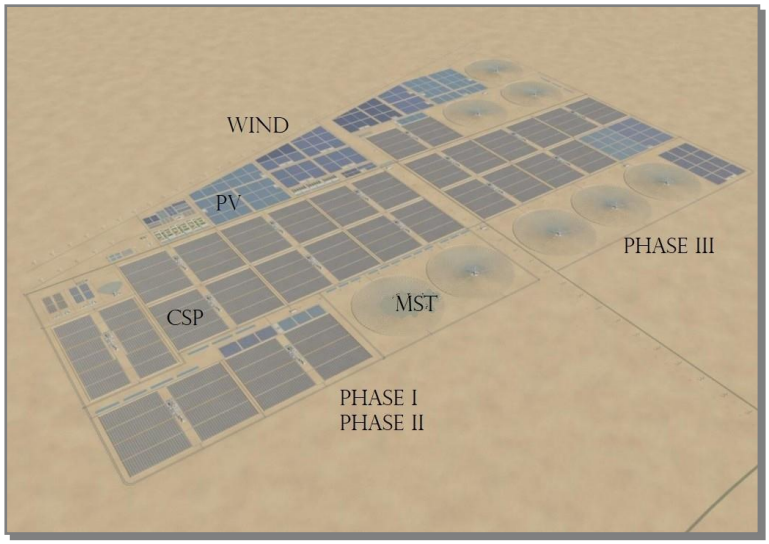

Fig.2. Shagaya Renewable Energy Park master plan layout. (PV: photovoltaic. CSP: concentrated solar power. MST: molten salt towers)

Phase I was completed and officially commissioned in 2018 [14]. The total installed capacity of PV technology in phase I is 10 MW. The PV plant is divided into two parts, each having a capacity of 5 MW. Each part uses a different technology (thin-film and polycrystalline PV technologies), to enable developing an understanding of PV performance under Kuwait's specific geographical and weather conditions. Three central inverters are installed for each technology. Fig.3 demonstrates the PV plant diagram, starting from the PV modules (source) to the 132 kV cable (underground) and the 132 kV overhead power line (OHL). The Shagaya substation subsequently transmits electricity to the national grid. The three-phase DC/AC medium voltage inverter is designed for solar application. It converts the DC power output into AC power that can be fed into the public grid. The output power for the inverter is 2200 kVA. This type of inverter continues running, even under extreme ambient temperature and harsh weather conditions.

The temperature coefficient of thin-film PV is less than that of polycrystalline PV, which makes it more tolerant to higher temperatures, but the tradeoff is the PV system area size per watt capacity. Although it is not the main focus of this work, a related sustainable energy source to consider from this project is Concentrating Solar Power (CSP). Given the extreme high temperature in Kuwait during the summer, when the average daily temperature ranges from 42 to 50 ℃ (108 to 122 ℉), CSP is suitable because it reflects and concentrates sunlight to generate heat, which in turn is used to generate electricity.

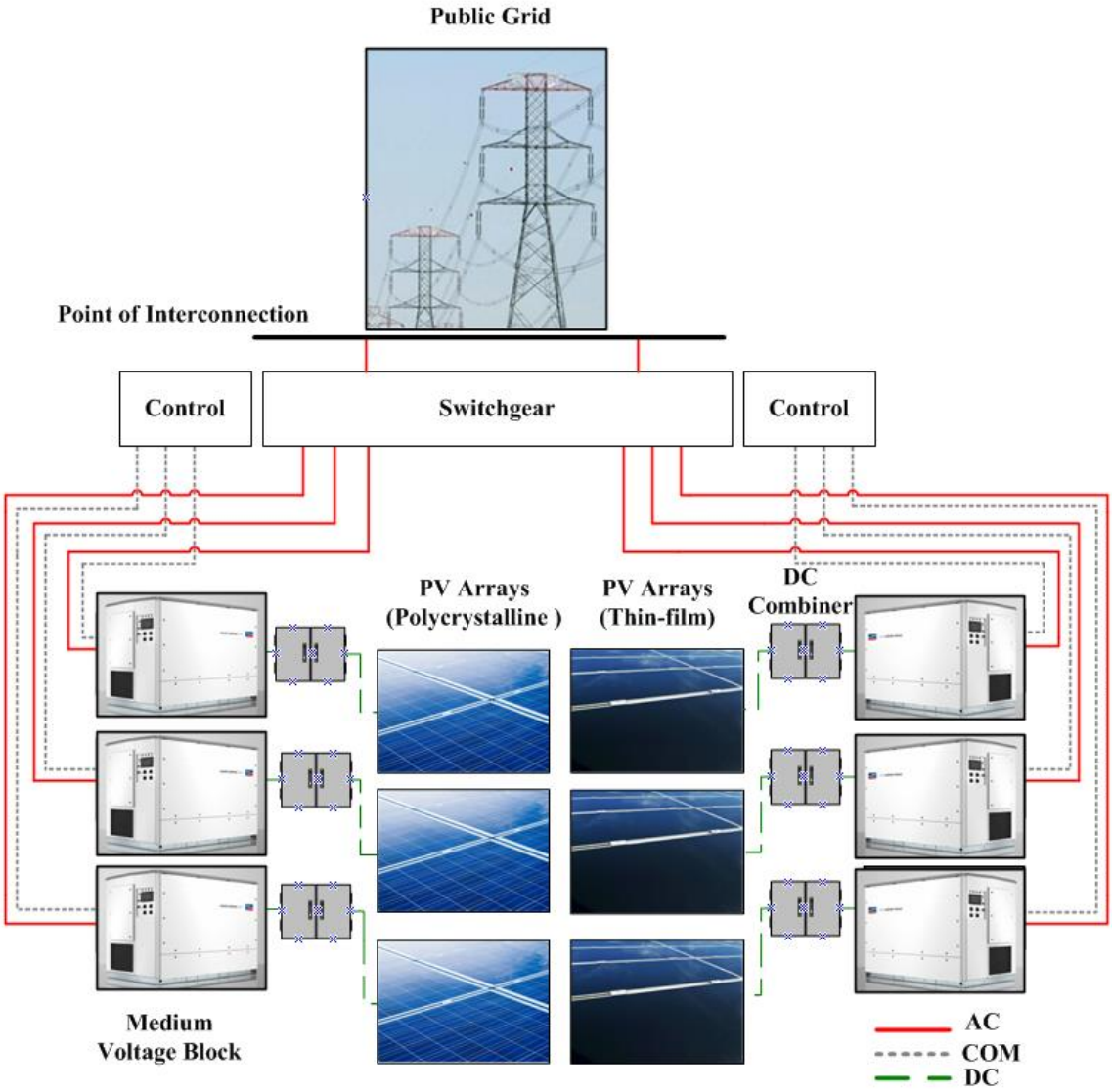

Fig.3. The Shagaya Renewable Energy Park PV plant in Phase I.

It is important to emphasize that solar CSP is often confused with solar PV by decision-makers and among the public. Not only are the two technologies technically different, but also the cost and performance are significant for each. Phase I also includes a 10 MW wind farm comprising five wind turbines of 2 MW each. The 10 MW is part of the projected 142 MW wind farm distributed over the three phases. Fig.4 depicts the first few wind turbine generators, which required an installation period of only three weeks.

Fig.4. Wind turbine generators for Shagaya phase I.

B. Project: Sidra 500

The Sidra 500 project is considered to be the first solar PV plant to power oil pumps. The peak half of 10 MW supplies the national grid and the other half supplies the Umm Gudair oilfield. The project used 32,450 polycrystalline modules over an area of 36 km^2 mounted on single-axis trackers [15]. The project is a PV grid-connected system integrated and synchronized continuously to an existing Kuwait Oil Company (KOC) substation simultaneously with the national grid. Fig.5 gives a view of the Sidra 500 PV project.

Fig.5. View of the Sidra 500 PV project.

The PV system feeds electricity to electrical submersible pumps (ESPs), which are used to extract oil from under the ground. The PV plant is used to operate submersible pumps in approximately 29 oil wells belonging to KOC [16]. It comprises six PV blocks, each of which is connected to two DC/AC inverters and one step-up transformer. The transformer is a three-winding transformer [17].

Fig.6 details the overall diagram of the Sidra 500 project. The main objective of connecting the PV system is to contribute to the reduction of summer peak demands. The project earned its name, Sidra 500, because it refers to planting 500,000 Sidra trees to reflect its environmental benefits. The modules are installed on a single-axis (east-west) tracker that compensates for the sun's movement, with an orientation of 0–55 degrees. The transformer is rated 1600 KVA. Every two inverters are connected to a transformer to step up its output from 0.324 kV to 11 kV. The six PV blocks are connected to an 11 kV medium-voltage substation (distribution center). The connection is via two runs of 300 m^2 multicore underground buried cables. The connection is at the 11 kV voltage level. The distance from the distribution center to the KOC substation is 5 km. Table III provides some technical details about the electrical equipment.

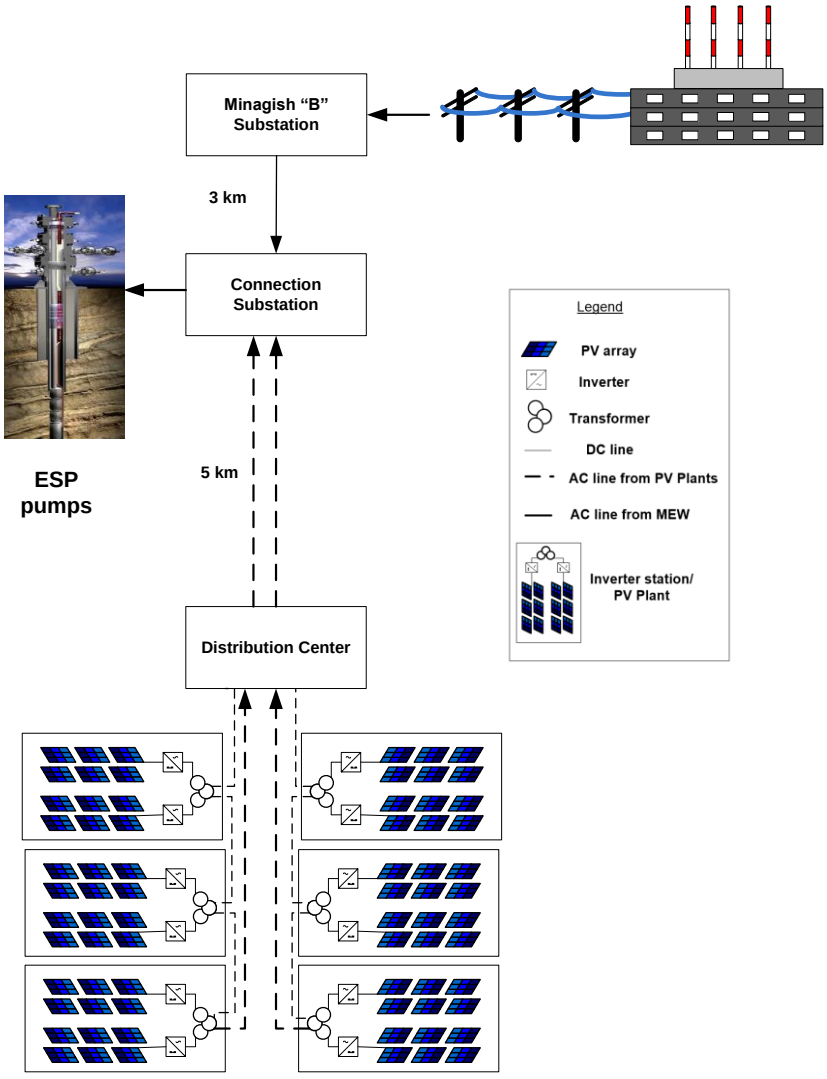

Fig. 6. Schematic diagram of the Sidra 500 project connection with the KOC substation.

TABLE III: TECHNICAL DETAILS OF SIDRA 500 PV PROJECT

Electrical Equipment	Model	Rating
PV module	TSM-310PC14	310W
Inverter	Sunny Central 720 CP XT	792kVA/720kVA
Transformer	SMA-1600	2 × 800/1600
Tracker	HA-SS1E-1PV	Horiz. W/E ±55˚

C. Project: MEWR and MPW Head Office Buildings

The MERW has taken serious steps toward promoting investment in solar and renewable energy to participate in Kuwait's economic vision for 2035 and to meet global trends in environmental protection from pollution. There are currently a number of major solar projects planned or in progress, in coordination with the MEWR. The MEWR and Ministry of Public Works (MPW) have successfully installed two rooftop PV systems on their buildings. These systems were commissioned in 2014 and cover a total area of 17000 square meters. Together, they can generate 1MW of electricity. The expected yearly yield from this project is 1.9 GWh. The total power capacity of 1 MW is divided into two systems, 500 KW from the MEWR rooftop and 500 kW from the MPW rooftop. An aerial view of the plants is shown in Fig.7. The project electrical diagram is displayed in Fig.8.

Fig.7. An aerial view of the MEW and MPW rooftop PV systems.

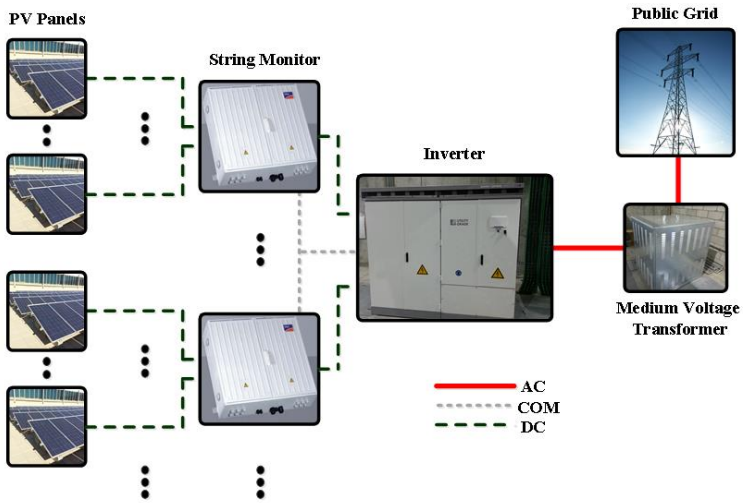

Fig.8. Main components of the PV system at the MEWR/MPW headquarters in Kuwait.

D. Project: PAAET

PAAET completed a solar PV energy station in 2017 across the rooftops of 25 distributed buildings at the College of Basic Education campus. The system is designed to generate approximately 2 MW of solar power, accommodating 20% of the power demand of the campus. The project was executed across the rooftops of the remaining buildings, according to space availability and site assessment. Furthermore, the project is intended to be of educational use to PAAET students. The PV systems throughout the campus can be a living laboratory. Students can compare real-time data on electricity production of the solar PV systems, view comparative analytics, and export data for various analysis projects. Fig.9 presents the Ardiya campus, where the installation of the PV systems enhances the aesthetic appeal of the building's rooftops.

Fig.9. An aerial view of PAAET College of Basic Education, Ardiya Campus.

E. Project: KFAS

KFAS plays a main role in stimulating science, technology, and innovation (STI) in the field of PV, where the foundation aims for a sustainable Kuwait [18]. The foundation has a commitment to enhance research and development by granting funds for selected research proposals and projects, addressing national priorities such as sustainable energy. One of the main projects funded by KFAS is installing PV systems for selected cooperative societies. Cooperative societies are large supermarkets with their subdivisions, put up by the Kuwaiti government and forming a grand distribution network for the retail trade in the local market.

The PV system structures utilize the enormous parking garages of chosen cooperative societies. The PV structures aim to improve energy efficiency during peak demand periods. So far, the project has served two cooperative societies, namely, Al-Zahra and Al-Adailiya. This is part of a plan in which KFAS has approached the Supreme Council for Planning and Development, to include the large-scale deployment of solar energy projects in ten cooperative societies and 1500 homes in the next development plan [19].

The other ambitious project aims to design, construct, operate, and monitor rooftop grid-connected PV systems for a total of 150 Kuwaiti homes, at a rate of 50 homes per year. The project is ongoing, and the selection criteria are as follows: reasonable available area; the house is owned by the resident; the homeowner has paid all electricity bills; the homeowner will be responsible for the system; and the homeowner deposits KD 1,000 ($3,290) as a guarantee for system maintenance. This will serve as a test case for future installations of residential PV systems.

It is also intended to develop policies and legislation for the dissemination of the use of these applications on the roofs of residential and commercial buildings in Kuwait. The policies and legislation should also provide incentives for citizens and building owners to participate through sharing the returns from the savings, especially with the expected continued decline in the cost of solar energy systems as a result of technical developments in this area.

F. Project: MEWR Renewable Energy Plan

In 2019, the ministry issued a ministerial decree mandating government buildings to produce at least 10% of the building's peak power consumption from renewable sources. The MEWR itself has upcoming projects under tender that will utilize solar energy in various locations in the country. The projects are divided into four stages. The first is to install PV modules in the technical services and main workshops sector with a production capacity of 2.7 MW. The second phase is to install 3 MW of PV next to power generation and water distillation plants. The third stage is a project in the diesel emergency department to produce 3 MW. The fourth stage includes projects in the warehouses of the power stations at the Doha and Al Zour stations.

Two other projects to be launched in the near future will apply solar PV to twenty-five sites of the Ministry's ground water tanks to generate 300 MW, and on the roofs of six MEWR storehouses in Sabhan area.

G. Project: Ministry of Education

The Ministry of Education has two pilot projects in the field of renewable energy, which include PV rooftop grid-connected systems to benefit from the sun's energy in producing electricity to operate its schools. This is a preparatory stage for other PV projects to be built on school rooftops in the future. This project enjoyed the cooperation of KISR and the MEWR.

Two schools from Mubarak Al-Kabeer educational district were chosen for the pilot project because the area is newly constructed and the schools there are somewhat newer than the other schools in Kuwait. The goal is to implement the project in 200 to 300 schools in the same way, according to the PPP program [20].

The project outcome leads to design and implementation of an integrated system for energy demand management and photovoltaic systems for schools in Kuwait. Its employment aims to rationalize the use of energy in schools through a central system to control the air conditioning and lighting. It operates the air conditioners at the beginning of the school day and turns off all air conditioners and lights at the end of the day. The electricity savings of the energy demand management system can save 30–40% of the electricity consumption of these schools. In addition, the project will help to reduce consumption at peak time [21].

The project will comprise three separate contracts, each of which will cover the installation, operation, and maintenance for two educational districts. Every educational district will have a total installation of 2 MW, leading to a total of 12 MW at the end of the overall project. This project is still under study for implementation by 2030.

H. Project: Ministry of Justice

The Ministry of Justice in Kuwait has joined the effort to implement renewable energy with the help of funding and supervision from Amiri Diwan (Presidential Executive Office). Two major governmental establishments were built with a PV solar system attached to them, namely, the Jahra and Farwaniya court complexes.

The Jahra court complex has a PV rooftop system with a capacity of 101.4 kW_P with an energy output of 156 MWh per year [22]. The court building's façades include building-integrated photovoltaic (BIPV) shades, installed to serve the synergized functions of providing effective shading to the exterior glazing, reducing solar glare, and generated energy from the sun. The capacity of the BIPV system is 100.4 kW_P. The parking garage uses a 36.4 kW_P PV façade system with an energy output of 54.1 MWh per year. The parking garage roof includes a 85.5 kW_P PV rooftop system with 131 MWh per year. The Hawally court complex exhibits a similar style and incorporates PV systems, just like the Farwaniya court complex, which has also been designed and executed in a similar manner recently.

I. Project: Gas Station Rooftops

The first gas stations in Kuwait to have installed rooftop PV modules were part of the Kuwait National Petroleum Company KNPC's initiative to study the issue and evaluate the application of PV implementation at a larger project scale in the future. Several solar technologies were used for this pilot project, to evaluate their performance. The

heterojunction technology with ultra-thin amorphous silicon was selected, since it has a high endurance to temperature to survive in the harsh conditions and extreme temperatures of Kuwait.

The KNPC installed 50 kW_P at the Al-Rigga gas station. The area was used to accommodate the 210 PV modules (240 W_P each). This system has micro inverters installed (total 52 KVA). Al-Zahra gas station has 70 kW_P of installed PV panels over an area of 373 m^2. The available area allowed for the installation of additional modules compared to the Al-Riqqa station totals 296 m^2 of the same model. The system has four central inverters (total 70 KVA). Both systems are grid-connected, where at peak hours, each system can handle the station's total load and additional power is injected back to the national grid [23].
The implementation of such projects is ongoing at seven existing gas stations, which are under renovation totaling 600 kW [24]. The KNPC announced that 19 new gas stations will have solar power generation, which are part of the 100 new gas stations that will all have solar power generation in a similar manner by 2030 [25]. Additionally, the KNPC has planned to implement more rooftop installations on their warehouse locations in Subhan and Al-Ahmadi, to reach 5 MW. The plans include having solar panels on warehouses for petroleum derivatives including the parking lots, internal squares, and street lighting [23]. Table III enumerates a tentative list of current, under construction, and future renewable energy projects in Kuwait.

TABLE III : LIST OF CURRENT, UNDER CONSTRUCTION, AND FUTURE RENEWABLE ENERGY PROJECTS

No.	Beneficiary	Area	Capacity kW_P	Type	Operation	Annotation
1	Touristic Enterprises Company	Kuwait	117	PV	2013	Kuwait Direct Investment Promotion Authority (KDIPA)
2	Ministry of Education	Adan	85 + 22	PV	2013	Supervision: KISR
3	MEW	S. Surra	500	PV	2014	Supervision: MEW
4	MPW	S. Surra	500	PV	2014	Supervision: MEW
5	Zahra Cooperative Society	Al-Zahra	750	PV	2014	Supervision: KFAS
6	KNPC	Al-Zahra	70	PV	2015	Supervision: KISR
7	KNPC	Al-Raqa	50	PV	2015	Supervision: KISR
8	KOTC	Shuaiba	80	PV	2015	Supervision: KISR
9	KOC	Oil fields	700	PV	2015	Supervision: KOC
10	KISR	Shuwaikh	25 + 75	PV	2015	Supervision: KISR
11	Kuwait Science Club (KSC)	S. Surra	45	PV	2016	Supervision: KFAS
12	Adailiya Cooperative Society	Adailiya	250	PV	2016	Supervision: KFAS
13	MEW	Bayan	120	PV	2016	Supervision: MEW
14	KOC	Ahmadi	5,000	PV	2016	Supervision: KOC
15	KFAS	Selected areas	500	PV	2016	Supervision: KFAS
16	Ministry of Justice	Riqai	403	PV	2016	Supervision: Al-Diwan Al-Amiri
17	KISR	Shagaya	10,000	PV	2016	Supervision: KISR
18	KISR	Shagaya	10,000	Wind	2016	Supervision: KISR
19	KOC	Umm Gudair	10,000	PV	2016	Supervision: KOC
20	PAAET	Ardiyah	2,000	PV	2017	Supervision: PAAET
21	Expropriation for Public Welfare Department	S. Surra	230	PV	2018	Supervision: MPW
22	EQUATE Petrochemical Company	Shuaiba	819	PV	2018	Petrochemical Industries Company
23	MEW	S. Surra	236	CIS thin film	2018	Direct Investment Promotion Authority

24	Kuwait University College of Medicine	Jabriyah	460	PV	2018	Under construction
25	KISR	Shagaya	50,000	CSP	2018	Supervision: KISR
26	KFAS	Selected areas	1,000	PV	2018	Supervision: KFAS
27	MEW	S. Surra	31	PV	2018	Under construction
28	Kuwait University – New Campus	Shedadeya	500	Thermal	2019	Under construction
29	Kuwait University – New Campus	Shedadeya	73	PV	2019	Under construction
30	MEW	Sabhan	3,700	PV	2019	Under construction
31	KNPC	Selected areas	1,194	PV	2020	19 gas stations (BIPV + PV)
32	KGOC	Ahmadi	793	PV	2020	Under construction
33	KPC	Shuwaikh	915	PV	2020	Put on hold – Supervision: KISR
34	Ministry of Education	Ahmadi	250	PV	2020	In progress – Bin Hayan
35	Ministry of Health	Shuwaikh	635	PV	2020	Under construction
36	MEW	Mitlaa area	700	PV	2020	Tendered
37	Ministry of Finance	Ministries complex	490	PV	2020	Under construction
38	Kuwait National Guard	Sabhan	400	PV	2021	Tendered
39	Ministry of Education	Sabah Alnaser	402+430	PV	2021	Under tendering
40	KNPC	Shagaya	1,500,000	PV	2022	Tendered
41	MPW	Sabhan	16,900	PV	2022	Under construction
42	Ministry of Education	Salwa	300+300	PV	2022	Design stage
43	Ministry of Interior	Sabhan	25	PV	2022	Supervision: MPW
44	PAAET	Sabah Alahmed	768	PV	2024	Bidding stage
45	Kuwait Municipality	Kabd	80,000	BIO	2025	Bidding stage
46	KNPC	Ahmadi	20,000	PV	2025	Bidding stage
47	KOC	North of Kuwait	52,000	PV	2025	Under study
48	KOC	West of Kuwait	20,000	PV	2025	Under study
49	KOC	N/E of Kuwait	73,000	PV	2025	Under study
50	MEW	Shawikh	17,000	PV	2025	Bidding stage
51	MEW	Hawally	10,000	PV	2025	Bidding stage
52	Public Authority For Housing Welfare	West Abdullah AlMubarak	400,000	PV	2025	Bidding stage
53	MEW	Shagaya	1,500,000	Mix	2030	Under study + MEW + KAPP
54	MEW	Selected areas	270,000	PV	2030	Planning stage

4. CHALLENGES AND OPPORTUNITIES

For Kuwait to achieve its renewable energy vision, the government needs to attract international expertise, create robust renewable energy policies, and enhance grid infrastructure. The conditions for connecting PV solar systems to the grid have a direct relationship with the duration of the pre-commissioning and commissioning process of the PV project, avoiding grid interface problems as much as possible. This is why MEWR has set preliminary conditions for connecting the PV panels to the grid. It is required that the following conditions be met for connecting solar power:

- The solar energy systems shall be designed by an international consulting firm that has a minimum of five years of experience in the relevant field and has designed not less than 10 MW of PV power systems in total in the last five years.

- The detailed design drawings for the solar energy systems for grid-connected systems shall be submitted for MEW approval.
- All solar energy generation calculations and other electrical design calculations, including calculations for the sizing of connecting cables for the solar energy systems, shall be submitted detailing different design parameters.
- A summary of the solar energy system shall be submitted with details specified, such as the number of solar PV modules, and the electrical and mechanical details of all electrical components with the system's available solar energy. These details shall all be submitted in Excel sheets, to obtain complete, clear information on the solar energy system.

With Regard to the technical conditions, the solar energy systems for grid-connected systems shall have the following specifications:

- The solar system shall be connected only at the low voltage side of the distribution system, transformer, or switch board.
- The inverters shall be located in the air-conditioned electrical rooms of the distribution substation, where small- sized series PV inverters are not acceptable.
- There shall be two circuits to disconnect the solar energy systems in case of grid power failure; One circuit with the inverter. A second circuit with a separate control to disconnect the breaker available at the connection point of the solar power to the MEW network. On availability of power supply, the circuit with the inverter shall be automatically connected with a time delay of two to three minutes and the breaker for the second circuit shall be automatically connected with a time delay of five minutes.
- The protection system shall include a power quality meter to monitor the quality of the power generated, as well as relays to disconnect the power supply in the event of : 1) Over voltage, when the operating voltage is greater than 260 V phase to neutral. 2) Under voltage, when the operating voltage is less than 220V phase to neutral. 3) Operating frequency is greater than 52 Hz. 4) Operating frequency is less than 48 Hz. 5) Total harmonic distortions exceeds 5%.

A. Regulatory policies and manpower

Despite the promising early steps in dealing with grid-connected solar PV systems, there are significant additional projects in the pipeline for Kuwait to be able to achieve its strategic target. A dedicated renewable energy agency has not yet been established. KISR and KFAS handle R&D and the talent pool; however, there is a noticeable shortage of qualified engineers and renewable energy companies [26]. The current regulatory framework lacks clear guidelines for payment structures concerning the power generated by future PPP projects. It is crucial to adopt a revised clear tariff structure, specifically addressing the sale and purchase of electricity between public and private sectors.

B. KAPP and PPP

The liberalization of rules governing PPP may speed up the development of renewable energy projects. The PPP program promotes calibration between the public and private sectors, and aims for the development of infrastructure and services for the citizens of Kuwait. This paper suggests introducing a body, e.g., the Renewable Energy Agency, to

be formed under the auspices of the Kuwait Cabinet. This body will be able to introduce a council that includes not only private and public entities but also other representatives, such as the educational sector, along with nongovernmental organizations.
All PV projects could be executed under the auspices of this agency. This body would not only offer an economic solution to PV projects but also work as a portal for exchanging experiences in the field. Therefore, this would enhance the calibration and strong support of the public authorities, the private investors, and small business partners as well as research organizations.
Individuals as well as private and public organizations can all participate in Clean Development Mechanism (CDM) projects defined in the Kyoto Protocol by the United Nations Framework [27]. This entity will act as a link between the project investors and the Environment Public Authority (EPA), which has a direct agent for the application of the CDM through the United Nations. Having the projects CDM-certified will allow investors from eligible donor countries to engage in these projects and receive certified emission reduction (CERs) in return [28].

C. PV projects geographic information system

To further enhance PV performance, data must be collected from the existing projects to identify the key factors that are both project- and site-specific. This paper proposes linking PV projects through a GIS that enables adding details of the project such as its power generation, performance ratio, etc. In doing so, a live database would be created and would allow the development and enhancement of PV projects in this region, thus obtaining optimum designs in the future. See Fig.10.

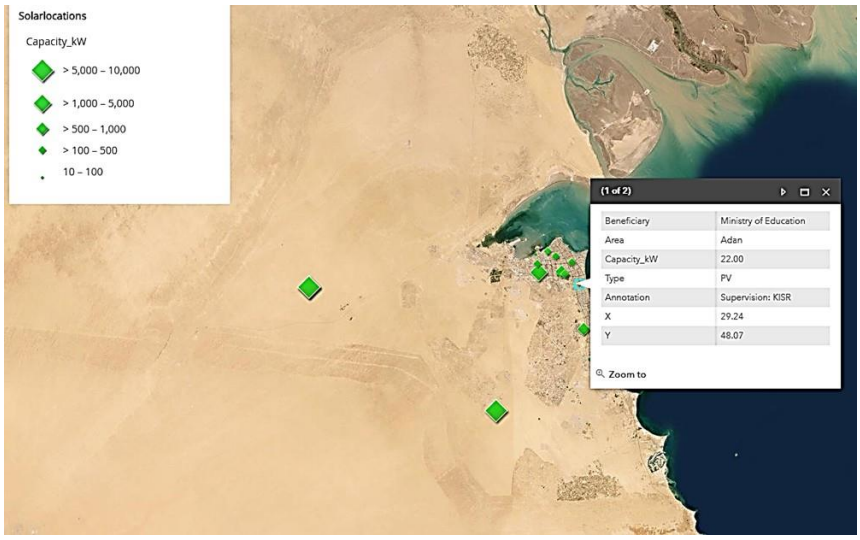

Fig. 10. A screen shot of the geo-information system for the existing PV projects in Kuwait by ArcGIS online (Link: https://arcg.is/89nzy).

5. CONCLUSIONS

Kuwait is increasing its efforts to reduce its fossil fuel emissions by implementing renewable energy projects. The current, ongoing, and future PV projects in Kuwait are highlighted in this paper. The greatest contribution in PV implementation is by the oil sector and KISR. Energy codes and regulations are under development to reach robust renewable policies, enhance grid infrastructure, and promote renewable energy projects. The noticeable shortage of qualified local renewable energy companies highlights the importance of having a dedicated renewable energy agency; to efficiently accomplish Kuwait's strategic targets. Kuwait's renewable energy vision requires creating strong renewable energy policies to guide and facilitate the implementation of such projects. This paper also suggests linking PV projects in a GIS, which would allow for the enhancement of PV implementation and optimum designs through performance analysis.

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