

Best Practices and Constraints in Installation and Maintenance of Solar and Wind Power: Lebanon Case Study

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ABSTRACT: This paper reviews best practices and constraints in the installation and maintenance of solar and wind power, laws and regulations that govern these systems in Lebanon, as well as an economic comparison of the cost of solar Photovoltaic (PV) systems compared to power from diesel generators. This paper examines the individual decentralized initiatives to shift from reliance on the national energy grid and diesel generators towards renewable energy sources as a way to achieve energy independence, triggered by the electricity situation in Lebanon, primarily after the country's 2019 financial crisis that led to widespread electricity interruptions and total collapse of the national electricity supply. This paper also highlights the importance of proper implementation of regulations that govern the installation of solar panels, which can be achieved through adequate and enforceable inspections.

KEYWORDS: Energy, Solar and Wind Power Generation, Installation and Maintenance, Best Practices, Lebanon Case Study.

■ Introduction

Lebanon has witnessed major electricity disruptions that have led to the reliance on diesel generators to power homes and businesses. The number of daily hours of electricity provided by Electricité du Liban (EdL) has witnessed a steady decrease to reach only 2-3 hours per day in mid 2021 onward, down from 11 hours in 2020. Diesel generators serve to fill the gap in electricity interruptions and provided in 2022 around 9 hours of electricity per day.¹

The large reliance on diesel generators comes at a great cost, stemming from the economic, environmental, and health ramifications, because these generators are installed in highly populated areas.

Lebanon has strong potential for solar renewable energy with an average of 300 sunny days per year,² and potential for wind energy with average wind speeds in some areas reaching 7 m/s, particularly in the Akkar region and some coastal and mountain areas.³

Individuals and businesses have started tapping into this potential, especially in the absence of country-wide government initiatives to capitalize on renewable energy. Solar panel installation projects witnessed considerable growth between 2020 and 2023, with 15% of the country's total electricity generation in 2023 stemming from solar panels compared with only 2.2% in 2020.⁴

Although Lebanon issued in 2020 Decree No 6997 on the national standards relating to solar energy and photovoltaic systems and mandated the compliance with the standards that are issued by the Lebanese Standards Institution (LIBNOR), the current state of solar panel installations in Lebanon, as witnessed and documented firsthand following over 50 different rooftop site visits, reflects the lack of and disregard to proper installation guidelines, and the safety concerns that arise from lack of safeguards and inspection measures. Current solar panel

installations also shed light on the lack of equity and fairness in accessibility to solar power.

Given Lebanon's current economic environment and the need to shift to a more reliable source of energy, Lebanon has great potential to capitalize on both solar and wind power, and can achieve this through the effective enforcement of its laws and regulations governing the usage and installation of solar panels, encouraging public-private partnerships to deploy solar and wind farm projects to help decrease the widespread chaos in the individual initiatives taking place and to reduce reliance on costly diesel generators, and employing AI tools for enhanced maintenance of both solar and wind power systems.

This paper reviews best practices for solar and wind energy installations and maintenance, and provides a look at Lebanon's potential and current challenges in implementing these renewable energy technologies. It also assesses the economic feasibility of transitioning to renewable energy as a pathway toward improved energy security through a cost comparison of diesel generators vs. solar and wind power.

■ Methodology

This paper combines a literature review with field observations and cost analysis. Primary literature and articles for this paper were retrieved from databases such as ScienceDirect and ResearchGate, and from institutional, governmental, and industry webpages. Field observations were conducted by the researcher, and digital photographs were taken to document findings. The cost data used in the economic comparison were derived primarily from IRENA and World Bank reports.

■ Discussion

Solar and Wind Energy Best Practices:

Solar Panels Installation:

The solar panel system is composed of several elements

and includes solar panels, a battery, an inverter, connecting wires, a grounding/earthing appliance, a mounting system, and any other components needed for proper functioning and harvesting of solar power. Figure 1 is a simple illustration of a residential solar panel system.

The most important step in adopting solar panels is a proper and safe installation method. Installation of solar panels on residential buildings, primarily on flat rooftops, requires careful planning, consideration, and assessment to evaluate the weight-bearing limit of these rooftops and to ensure that they offer sufficient structural stability and load-bearing capacity. The use of different anchoring techniques should not compromise the structural integrity of the rooftops and should take into consideration the impact of roof loading, weather elements, and wind resistance. A wind pressure coefficient based on the roof height and orientation needs to be accounted for when deciding on the optimal anchoring technique that will be used.⁵

One method of anchoring solar panels on rooftops is using a ballasted system, which is a noninvasive, nonpenetrative installation method that uses the heavy weight of concrete blocks as a way to secure the solar panels in place. These blocks are ideal for flat or low-slope rooftops (less than 5-degree slope), and are not fixed into the roof structure. The downside of using these concrete blocks is the potential cracking and corrosion that they can face due to their exposure to weather elements in Lebanon, including wind and rain.

The use of these concrete blocks necessitates a structural analysis of the rooftop to ensure sufficient structural capacity and support, and must account for high wind speeds, which would require additional anchoring in high wind areas, as these blocks might move and shift, which can damage the roof as well as expose the blocks to cracking.

The structural analysis needs to be done by a qualified team of professionals and needs to follow the proper structural codes.

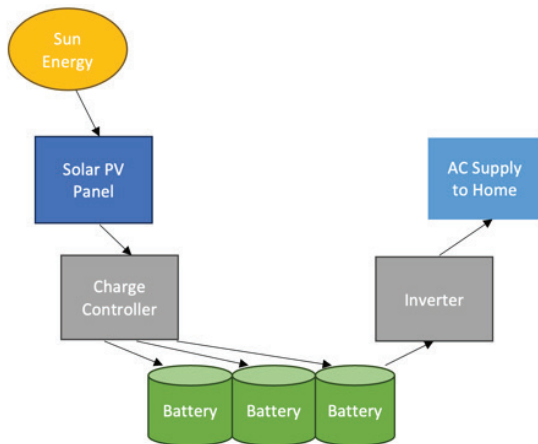


Figure 1: Solar panel system components.⁶ The diagram illustrates the components needed for setting up a residential solar panel system, which includes the solar PV panel, which receives solar energy; the charge controller; the battery bank; and the inverter, which supplies AC power.

New technologies have emerged in the use of concrete blocks that add wind deflectors to reduce the risk of uplift. This aerodynamic feature aims at decreasing the amount of concrete used, in turn reducing the weight load on the building

structure.⁷ This new technology, if adopted in Lebanon, can help minimize the risk of adding heavy loads to aging rooftops.

Use of concrete blocks also needs to ensure equal weight distribution, as localized weight can have a long-term damaging effect on the structure of the roof. The use of these concrete blocks is low in cost as it is not highly labor-intensive.

Another method of anchoring solar panels is mechanically penetrating the roof and firmly securing the solar panels into the roof structure, which anchors them in place and offers a defense against strong winds in high wind areas. Depending on the roofing material used, mechanical anchoring requires different attachment techniques and waterproofing, as improper sealing can risk leaking into the roof structure through the holes in the roof. Special care and consideration need to be given to side building tiling when anchoring solar panels to the edge of the rooftop, as these tiles might come loose and require refixing.

The selection of material used in the mounting structure depends on the environmental conditions. Coastal areas in Lebanon with high humidity and salinity expose the structure to corrosion and rusting. While a steel structure might be considered a strong, cost-effective base, aluminum offers a lightweight alternative that has a high strength-to-weight ratio, given that its density is a third that of steel,⁸ and is resistant to corrosion, rust, and other environmental factors. Use of aluminum would therefore give the structure a longer life cycle and would bring down the total cost of maintenance and replacement.

The mounting material and technique play an important role as well in ensuring that the entire solar panel structure is well anchored and that it can withstand high winds and not compromise the safety and security of passersby.

The efficiency of solar panels varies depending on the type of solar panel material used. Monocrystalline panels have an efficiency of 15-20% and use pure silicon crystals, whereas polycrystalline panels have an efficiency of 13-16% and use melted silicon crystals. In addition, monocrystalline solar cells have a lower temperature coefficient than polycrystalline cells, meaning that when the temperature rises, monocrystalline cells have a lower loss of efficiency compared to polycrystalline cells. As a result, monocrystalline cells are a better fit to serve hotter regions. The downside to monocrystalline cells is their high cost due to the price of the pure silicon crystals used in their production.⁹ Given Lebanon's climate and the restrictive space on rooftops, monocrystalline cells prove to be the better option to maximize efficiency and minimize energy loss.

Monocrystalline cells are darker in color with round edges, which creates empty spacing between solar cells and would result in larger panels, whereas polycrystalline cells are blue in color with straight edges, as shown in Figure 2.

Use of high-quality materials during installation helps prolong the life of the panel system. The best approach to selecting batteries and inverters would be to prioritize using the same brand if feasible for easier installation and communication between components. Proper ventilation for batteries and inverters is crucial, as well as the use of DC wiring with proper grounding and cable protection against UV and moisture

damage. These measures help prevent fires or electrocution during maintenance and installation.

The physical placement of solar panels should aim for space optimization on rooftops to maximize energy generation, taking into consideration the required access space for cleaning and maintenance. Solar panels should be installed in areas with maximum sunlight exposure, avoiding shaded areas, which might be a problem in densely populated areas in cities in Lebanon, and areas with poor urban design where tall buildings obscure sunlight from surrounding shorter ones.

Different types of battery options can be used for energy storage, with Lithium-Ion batteries being the most widely used option due to their long life span, low lifetime cost, and low fire risk. Lead-Acid batteries have a low initial cost, but require frequent maintenance and more ventilation, and have a shorter cycle life. Large-scale installations rely primarily on flow batteries. A new emerging technology replaces liquid electrolytes used in lithium batteries with solid materials such as ceramics or sulfides, increasing energy density and eliminating liquid leaks. These solid-state batteries remain expensive due to the cost of materials. Table 1 summarizes the efficiency, energy density, cost, and cycle life of different types of batteries.

Table 1: AC power. Batteries are used in the storage of solar energy.¹⁰

Type of Battery	Efficiency	Energy Density	Cost \$/kWh	Cycle life
Lithium Ion Battery	90%-95%	150-250 Wh/kg	Moderate: 250-500	2,000-5,000 cycles
Lead-Acid Battery	75%-85%	30-50 Wh/kg	Low: 100-200	500-1,000 cycles
Flow Battery	75%-85%	15-30 Wh/L	High: 500-1000	10,000 cycles

The capacity of the system is dictated by the number of solar panels used and is measured in kWp (kW peak), which represents the maximum power output under ideal conditions. The capacity is calculated using the power rating of each panel multiplied by the number of panels used. The solar panels are installed in series (string) and/or in parallel (array).

The simplest way to calculate the number of panels needed is to determine the daily energy needs based on historical energy data and the number of peak sun hours in the specific location.

Given that the rooftop areas in Lebanon are shared among residents of the building, another method of calculating the number of panels would be to determine the number of panels a rooftop can handle based on the available usable roof space. This method accounts for total roof area, safety clearance from the edge for maintenance and access, and space for other components installed on roofs such as vents, satellite systems, and water tanks.

It is recommended that the solar panel system produce 20% more power than the average energy needs to serve as a buffer for factors like energy loss during conversion, external parameters including cloud cover, and any energy usage spikes.

In setting up the solar panels, the ideal direction of the system is always in the direction of the equator, meaning towards the south in the northern hemisphere and towards the north in the southern hemisphere. The parameters needed to calculate the optimal tilt include latitude, time, day, and orientation (north/south).

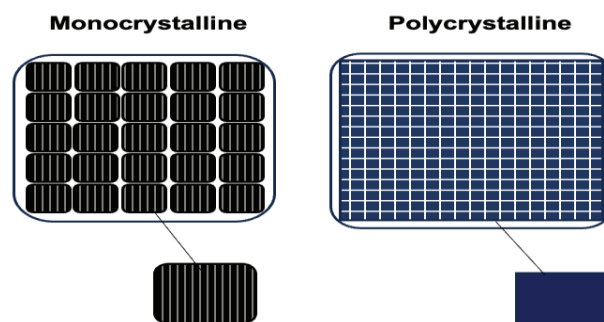


Figure 1: Different types of solar panels.¹¹ Illustration of monocrystalline panels, which are darker in color with round edges and formed from silicon, and polycrystalline panels, which are blue in color with straight edges and formed from fragments of silicon.

Various analytical formulas have been developed to calculate the optimal tilt position of the solar panels, and many have concluded that the annual optimal position is equal to the latitude of the location of the panels. The tilt of the panels can be adjusted monthly or seasonally to achieve higher performance, as some studies have concluded that adjusting the tilt 6 times per year led to 99.5% of performance and energy yield.¹²

The optimal solar panel tilt should be based on the solar elevation angle and should match the zenith angle. The Zenith angle is smaller in the summer months when the sun has a higher elevation and is larger in winter months when the sun is at a lower elevation. The azimuth angle represents the optimal horizontal direction of a solar panel (Figure 3).

A study done on Lebanon calculated the optimal annual tilt position to be averaging between 31.25 and 32.67 degrees for Beirut, between 30.91 and 32.16 degrees for Tyre, and between 31.58 and 33.15 degrees for Tripoli. The optimal tilt went up to the 60-degree range in winter months and down to the single-digit range in summer months.¹³ The tilt should, in any case, exceed 10 degrees to create a slope for precipitation to flow, therefore limiting the accumulation of rain, snow, dirt, and dust on the panels.

The efficiency of solar panels is influenced by several external factors and parameters, including solar intensity, temperature, wind speed, cloud coverage, and humidity. A study done on the correlation between external parameters and the efficiency of the solar panels using linear regression concluded that a positive correlation exists between solar intensity and output power, whereas a negative correlation exists when it comes to temperature, cloud coverage, and humidity and their effect on output power.¹⁴ With its high solar intensity, Lebanon can benefit from highly efficient solar energy if solar panel systems are correctly installed.

To increase the efficiency of systems and limit the effect of environmental factors, new technologies have emerged, including solar tracking systems that use a variable tracking device that sits on an axis to automatically change the tilt position of the panels. These tracking devices are costly compared to the fixed system that is manually adjusted to achieve the optimal tilt. This high initial cost, coupled with continuous upkeep, outweighs the added energy yield of the solar panel system.

Solar Panels Maintenance:

Proper maintenance of solar panel systems is a crucial aspect of achieving high efficiency and maximizing the life cycle. Maintenance includes regular cleaning for dust, bird droppings, and pollutants, inspection and testing of batteries, inverters, and wiring.¹⁵ Maintenance also includes repairing any roof leaks and checking for corrosion or cracks in the mounting structure.

Maintenance is a crucial element in Lebanon, given its high humidity, dust, pollution levels, as well as diesel smog and black carbon that accumulate on solar panels and severely impact their efficiency, the severity of which was witnessed and confirmed during rooftop site visits.

Cleaning panels starts with removing any particles and then spraying the panels with water to ensure proper cleaning. Regular cleaning and testing ensure optimal efficiency and limit energy loss. The optimal time for manual cleaning of solar panels is early morning or late afternoon when the system is not actively storing energy.

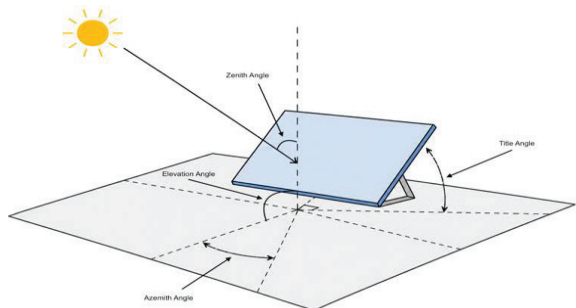


Figure 3: Optimal solar panel angles.¹⁶ Relationship between the zenith angle and the optimal tilt of a solar panel, where the zenith angle is calculated relative to the vertical axis, and the tilt is measured relative to the horizontal axis.

Optimal maintenance of solar panels should rely on both passive and active cleaning. New innovative solutions are being deployed to optimize the efficiency of panels and reduce the need for manual intervention. Figure 4 lists the various types of mitigation techniques to decrease dust, pollutants, and buildup on solar panels, and to provide optimal conditions for solar panel performance.

Passive maintenance relies on environmental factors such as rain, wind, and gravity that help eliminate particles and decrease their adherence to the solar panels, and on the tilt of the solar panels, which helps these particles slide off the panels and limits their accumulation.

In contrast, active mitigation methods rely on intervening either through manual cleaning or through setting up automated systems to help with irrigation and cleaning. Manual cleaning should follow a specific schedule based on seasonal humidity, rainfall, and droppings in the area. AI tools can help with the scheduling of maintenance and cleaning of solar panels by gathering historical data on cleaning and maintenance of panels in specific areas, and proposing a cleaning and maintenance schedule.¹⁷

The incorporation of water-based systems is another method of active maintenance that does not require manual intervention. These systems are ideally used in dusty environments and

areas with heavy bird droppings. These systems are installed on the panels and use a combination of automatic sprays and/or high-pressure water to remove dust and dislodge particles stuck on the surface of the panels. These water-based systems follow a preset daily or weekly schedule to optimize the efficiency of the solar panels. To reduce the amount of water used in the cleaning of solar panels, these water-based systems rely on recycling rainfall or water previously used for cleaning the panels, filtering it, and reusing it in the water-based system for panel cleaning.

Another method for active cleaning is the use of automated waterless techniques that involve the installation of small brushes that are deployed based on a specific schedule, which help remove dirt and dust particles and prevent them from sticking to panel arrays in humid climates. Another emerging technique involves the automated use of ultrasonic or acoustic waves that shake the dirt and dust particles off the panels.¹⁸

Use of remotely deployed robots in the cleaning of solar panels is gaining popularity, particularly for large solar panel systems, as they can assist manual cleaners and reduce the time required to complete the cleaning process.

Generative AI is shaping the future of solar panel maintenance by focusing on anticipatory and predictive vs. reactive maintenance to increase efficiency and reduce downtime, and is best used in large solar installations as opposed to residential areas. These systems are trained through the use of historical data and are fed with real-time data such as irradiance meters, thermal cameras, and inverter error logs to generate maintenance forecasting.¹⁹ They also rely on satellite imagery and weather prediction data, including global horizontal irradiance, temperature, and humidity, to generate power forecasting for solar panels, and on drone thermal infrared footage and voltage readings to locate any potential problems and generate panel health reports and alerts for preventive maintenance.

Mitigation Methods						
Passive			Active			
Natural Mitigation	Coated Surfaces	Architectural and Design Solutions	Manual Cleaning	Water-Based Systems	Electro-mechanical Systems	Robotic Cleaning systems
-Rain -Wind -Gravity	-Hydrophobic -Hydrophilic -Emerging Technologies	-Tilt Optimization -Surface Microstructures		-Pressurized Water -Recycled Water -Surfactant Assisted Cleaning	-Brush Cleaning -Surface Acoustic Wave -Ultrasonic Cleaning -Electrodynamic Screens	-Autonomous -Semi Autonomous

Figure 4: Various methods of cleaning solar panels.²⁰ The chart lists the various mitigation methods used in cleaning and maintenance of solar panels and includes both passive and active mitigation methods.

These systems can be beneficial for Lebanon, given the limited access space to conduct manual maintenance, and would therefore limit any risk of injury to the maintenance crew, and increase efficiency and energy output of the solar panel systems.

Wind Turbines:

While Lebanon can benefit greatly from a large-scale implementation of solar panels, wind proves to be another source of renewable energy that Lebanon can benefit from due to its high wind profile in a number of its areas. Wind turbines harvest energy from wind and convert the kinetic energy of

the wind into mechanical energy and ultimately into electrical energy.

The global reliance on wind energy has significantly increased in the last decade due to its efficiency and reliability as a source of sustainable energy. Many countries have expanded their use of wind energy, with Asia being at the forefront of this development. Figure 5 highlights the steady growth in installed wind power between 2011 and 2020, which reached over 700GW in global installed wind power.

Wind turbine installation takes place either offshore or on-shore through what is referred to as wind farms. The taller the wind turbines, the higher the amount of energy generated, as these tall turbines access the stronger winds. Wind turbines include several components, starting with the blades and rotor, the hub, the nacelle, the generator, and the tower. Figure 6 provides a detailed view of the various components.

Wind turbines are classified as either horizontal or vertical based on their rotating axis. Horizontal wind turbines have their rotating axis parallel to the ground, whereas vertical turbines have their rotating axis perpendicular to the ground. Most wind turbines rely on the horizontal rotating axis, with the vertical ones primarily used in smaller spaces and residential areas. Figure 7 shows the difference between the two types.

The installation of onshore wind turbines requires careful planning and proper resources to ensure a smooth and safe installation and functioning of the wind turbines.

The site for installation of wind turbines is selected based on terrain and soil, wind quality and strength, as well as environmental factors. Onshore wind turbine installation requires logistical planning for the transportation of the large components of the wind turbines to the site, and resourcing large enough cranes for lifting the components to the desired height.

The tower is secured to the ground by the use of long bolts to anchor the structure into a cylindrical pedestal that is attached to a block of reinforced concrete. The Cylindrical pedestal has a diameter of 4 to 5 meters, typically, whereas the concrete base has a diameter of 15 to 20 meters and has a thickness of around 4 to 5 meters to allow anchoring deep into the ground. Figure 8 shows the different shapes of foundations that are used in securing wind turbines.

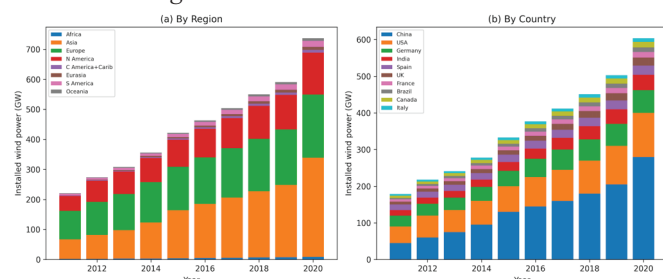


Figure 5: Global growth in wind turbines.²¹ Charts illustrate the growth in installed wind power by continent and by country between 2011 and 2020, with Asia and China having the highest.

The bolts used in securing the tower to the cylindrical base are long anchor rods with lengths of around 6 meters that are placed into the reinforced foundation before the concrete sets. The tower of wind turbines is then attached and secured to these bolts, as shown in Figure 9.

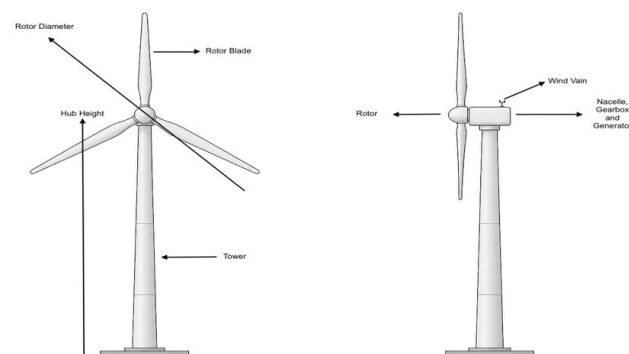


Figure 6: Components of wind turbines.²² Representation of the main components of a wind turbine, which include the tower, rotor, and nacelle with gearbox and generator.

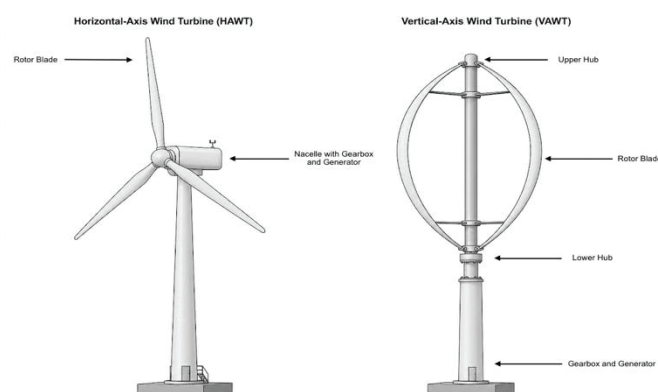


Figure 7: Horizontal vs. vertical axis of wind turbines.²³ Representation of a horizontal wind turbine with a rotating axis parallel to the ground versus the vertical wind turbine with a rotating axis perpendicular to the ground.

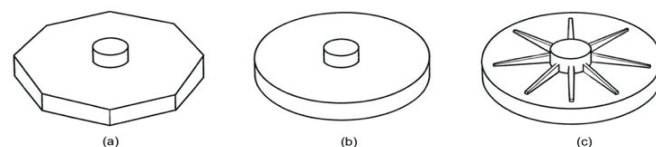


Figure 8: Typical wind turbine foundation configurations: (a) octagonal; (b) circular; (c) circular modular/segmented.²⁴

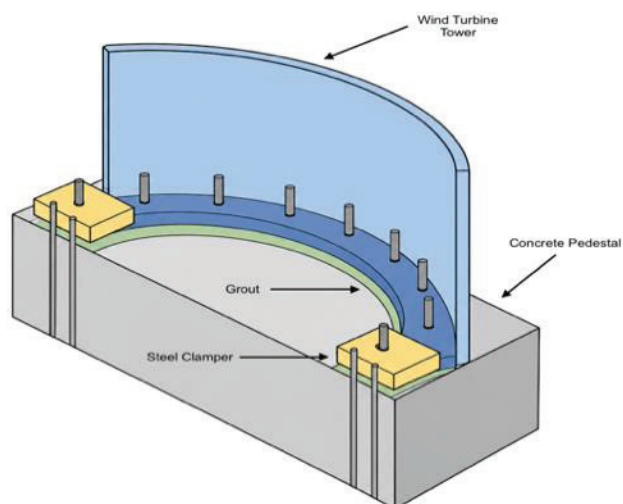


Figure 9: Representation of bolts used in the installation of wind turbines.²⁵ The illustration shows the long bolts used in securing the wind turbine tower into the concrete pedestal.

The weight of the concrete foundation represents around 75% of the weight of the wind turbine system as a whole, and it offers stability to the system against wind and environmental factors. Figure 10 shows the massive size of the reinforced concrete.

The cost of operating and maintaining onshore wind turbines is fairly low and accounts for only 5% of their total cost,²⁶ where maintenance operations include servicing power and electrical wiring and systems, as well as maintenance of the main components, such as the blade and gearbox.

When it comes to undertaking an offshore wind farm initiative, the installation of turbines proves to be the most critical phase due to the cost as well as logistical and environmental constraints. Lebanon has yet to take on such an initiative, primarily due to its high cost and potential maritime border issues.

Installations of offshore wind turbines consist of different types of foundations, based on the size of the structure, the depth of the seabed, wind and wave intensity, as well as the cost and complexity of installation.

The majority of offshore wind turbines are bottom-fixed (Figure 11). These turbines can be fixed by either using a monopile foundation (a), which is suitable for depths of up to 40 meters, a gravity base foundation (b), suitable for water depths of up to 10 meters, or jacket-supported turbines, which are suitable for depths of up to 70 meters (c). For wind turbines installed in deeper water, floating wind turbines serve as the optimal solution and can be supported by anchors reaching the seabed (e). Lebanon's deep-sea floor requires it to use floating wind turbines, which are more complex and costly to install.

Installations are generally affected by weather and wind constraints, and require the use of vessels, ships, as well as cranes suitable for the transport and installation of the large tower and blades. Installation typically begins with laying the foundation, securing the tower, placing the nacelle and blades, and then securing the electrical wiring and connection.

Given Lebanon's location and high probability of seismic tremors, special consideration would need to be given in Lebanon to any potential seismic activity on the sea floor and its impact on the future of the wind turbines installed, as well as disturbing the marine ecosystems present in the selected location.

Several international standards and guidelines issued by DNV govern the installation of offshore wind turbines (Table 2). These industry standards include technical criteria and aim at ensuring the safety of the wind power structures, as well as the integrity of the structure.

New technologies in wind energy are emerging, some with the concept of including high-rise building- integrated wind turbines either on a horizontal or vertical axis, others with installing smaller appliance-sized wind turbines to generate an acceptable amount of energy, and are being used to power homes.²⁷ Another new technology in wind turbines revolves around harvesting energy from bladeless systems that rely on vibrations of cylindrical turbines. These new bladeless turbines offer great advantages relating to size, weight, and cost of harvesting energy, and can generate higher amounts of energy due

to their ability to capture the vortex-induced vibrations from the wind flowing around a circular object.



Figure 10: Example wind turbine foundation.²⁵ The picture shows the size of the concrete foundation used in installing a wind turbine.

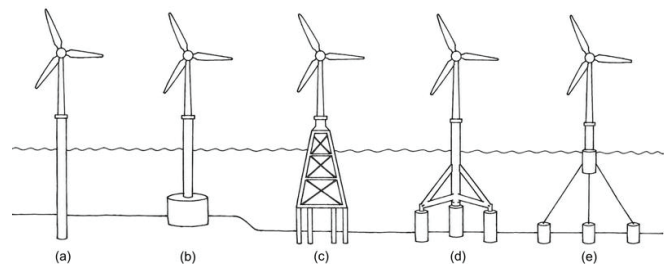


Figure 11: Types of offshore wind turbine installations.²⁸ Illustration shows different types of wind turbine foundations: (a) monopile foundation, (b) gravity base foundation, (c) jacket-supported foundation, (d) tripod foundation, (e) floating.

The new technological advances aim at reducing the cost of wind energy to achieve economies of scale and increase the total number of onshore and offshore wind turbines installed. Average costs of wind energy have been continuously decreasing and are expected to decline by up to 35% by 2035 and by up to 49% by 2050. These new cost levels are attributed to a larger turbine size that produces higher energy levels and lower operating costs. The following image portrays the expected increase in onshore and offshore wind turbine size and their corresponding power generation by 2035 (Figure 12).

Wind Turbine Maintenance:

Maintenance of offshore wind turbines poses great financial cost and risk, due in large part to the cost of acquiring the necessary equipment and logistical needs to carry out the maintenance operations, and the safety of staff involved in these operations. Operating and maintaining offshore wind turbines amounts to 23% of their total cost, making the maintenance of these wind turbines an essential phase of their life cycle.²⁶

These maintenance operations can be categorized into three types of initiatives. Corrective maintenance takes place after a technical issue or failure is detected, which requires immediate remediation since it directly affects the level and amount of energy produced by the wind turbines. Preventive maintenance

relies on regular and frequent visits to prevent failures from happening in the first place. Opportunistic maintenance relies on performing maintenance whenever weather and other environmental and marine factors permit, regardless of the state of the wind turbines and the need for their maintenance.

Failure can take place in any part of the wind turbine system, with the tower and the blades accounting for the largest percentage of failures, as shown in Figure 13.

Table 2: Standards for installing offshore wind turbines.²⁹

Standards	Title
DNVGL-ST-N001	Marine operations and marine warranty
ISO 29400:2015	Ships and marine technology – Offshore wind energy – Port and marine operations
DNV-RP-H103	Modeling and analysis of marine operations
DNVGL-ST-0378	Standard for offshore and platform lifting appliances
DNVGL-ST-0054	Transportation and installation of wind power plants
DNVGL-ST-0437	Loads and site conditions for wind turbine

Characteristics	Onshore Wind Turbines	Offshore
Wind Speed	7.5 m/s	9.5 m/s
Specific Power	231 W/m ²	346 W/m ²
Capacity	5.5 MW	17 MW
Rotor Diameter	174 m	250 m
Hub Height	151 m	151 m
Plant Size	-	600-1299 MW (fixed), 500-699 km (floating)
Distance to Shore	Land-based	70 km (fixed), 100 km (floating)
Water Depth	-	Up to 42 m (fixed), 100-199 m (floating)
Key Value Enhancements	Large rotors, storage hybrids, self-curtailment	Large rotors, balancing services, access to high-price and low-curtailment grid points
Main Barriers	Permitting, transportation, community concerns	Vessels, cranes, ports
Fixed-to-Floating Crossover	-	>60 m water depth
Use of Floating	-	11-25% of projects

Figure 12: Characteristics of wind turbines in 2035.³⁰ Comparison shows the expected characteristics of onshore and offshore wind turbines by 2035, including the increase in rotor diameter and hub height, with offshore wind turbines representing 11% to 25% of projects.

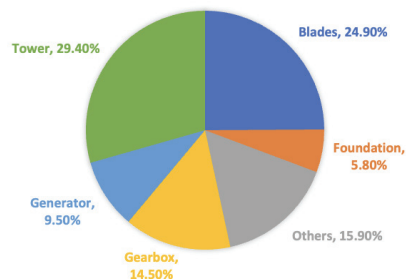


Figure 13: Percentage failures by system part.³¹ The chart shows the failures wind turbines can face, with the highest failures affecting the tower and the blades.

Recent technological advances aim at maximizing the efficiency of maintenance operations and reducing costs by employing AI tools and monitoring systems to analyze environmental factors that might affect the offshore wind turbines and conduct fault diagnoses to ensure their efficiency and schedule maintenance accordingly. Current advances in AI models use data on mechanical stresses of the gearbox and the blade, including data on oil temperature and vibration of the gearbox, to generate early warning reports for parts replacement. AI models also rely on information on historical and current wind speed and wind flow to select optimal turbine placement and aerodynamic efficiency.

While advancements in the maintenance of wind turbines are paving the way for higher efficiency and more energy generation, high costs and financial constraints still pose implementation challenges, particularly in markets and regions like Lebanon, where the adoption of wind power is still underdeveloped. Nonetheless, these technological advances, if adopted, can provide long-term cost savings and can improve consistency and reliability.

Lebanon's Potential in Solar Power:

With many advancements in renewable energy driving costs of installation and maintenance down, Lebanon can greatly benefit from its location to implement these reliable sources of energy. Lebanon's Mediterranean climate allows it to benefit from year-round sunny weather, with a total of 300 sunny days, amounting to roughly 3000 hours of sunshine annually. This level of sunshine provides a solar irradiation level of approximately 1900 kWh/m² per year, making it an ideal location to benefit from solar energy for both residential and commercial uses.³² Figure 14, given by the World Atlas, represents the average photovoltaic power generation potential by area in Lebanon.

Laws Governing Solar Power in Lebanon:

Decree No 6997 on the national standards relating to solar energy and photovoltaic systems was issued in Lebanon on October 8, 2020, and mandates the use of the standards that are issued by the Lebanese Standards Institution (LIBNOR). These standards are based on international standards and cover areas from components of PV systems to installation and safety. The decree designates the Industrial Research Institutes (IRI) or any other internationally accredited laboratory as the party responsible for ensuring adherence and compliance with these standards (Figures 15 and 16).

In December 2023, the Lebanese Parliament ratified the Decentralized Renewable Energy Production Law No. 318/2023, which provides the legal framework for decentralized renewable energy production and sets the ground rules for the exchange of electricity (net-metering) with the national grid through Electricité du Liban (EDL) up to a maximum of 10 Mega-Watts (MW).³³ The implementation of this law is pending the establishment of the Electricity Regulatory Authority (ERA).

The concept of net metering allows owners of solar panels to share excess energy generated with EDL, with net metering calculated on a monthly basis by offsetting the amounts of energy provided to EDL with the amount of energy consumed.

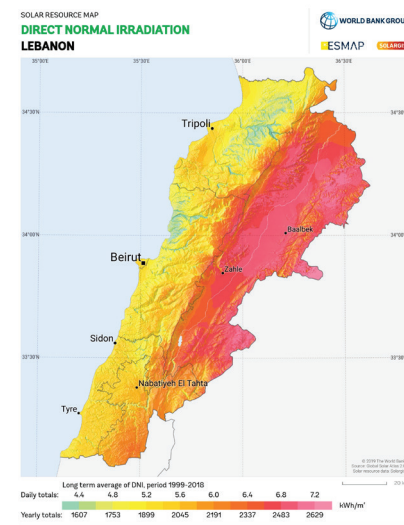


Figure 14: Photovoltaic potential by area in Lebanon.³⁴ The map shows the photovoltaic potential of different areas in Lebanon, with the highest potential in parts of the Beqaa Valley.

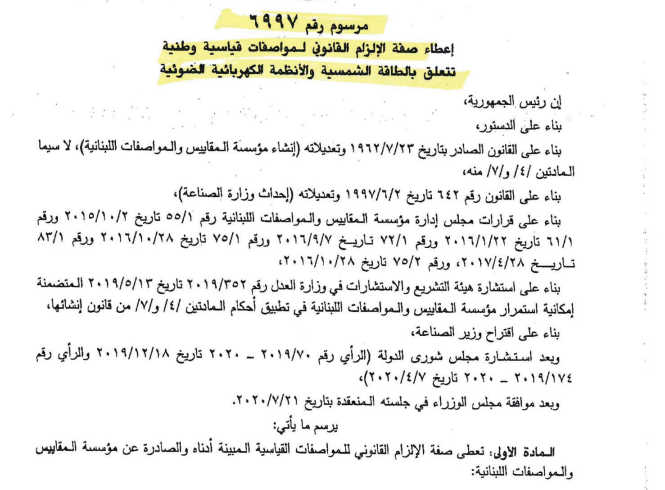


Figure 15: Decree No 6997 (Arabic) – introduction.³⁵ The introduction section of the decree lays the legal obligation to comply with the standards issued by the Lebanese Standards Institution (LIBNOR).

١٥٩٦ الجريدة الرسمية – العدد ٣٩ – ٢٠٢٠/١٠/٨

عنوان المواصفة	الرقم
Photovoltaic devices - Part 1: Measurement of photovoltaic current-voltage characteristics	NL EN 60904-1:2015
Thermal solar systems and components - Solar collectors- Part 1: General requirements	NL EN 12975-1:2015
Solar energy.- Vocabulary	NL ISO 9488:2015
Solar Heating - Domestic Water Heating Systems - Part 2: Outdoor Test Methods for System Performance Characterization and Yearly Performance Prediction of Solar-only Systems	NL ISO 9459-2:2015
Solar Heating - Domestic Water Heating Systems - Part 5: System Performance Characterization by Means of Whole-System Tests and Computer Simulation	NL ISO 9459-5:2015
Balance-of-system components for photovoltaic systems- Design qualification natural environments (IEC 62093:2005)	NL EN 62093:2017
Safety of power converters for use in photovoltaic power systems - Part 1: General requirements (IEC 62109-1:2010)	NL EN 62109-1:2016
Safety of power converters for use in photovoltaic power systems - Part 2: Particular requirements for inverters (IEC 62109-2:2011)	NL EN 62109-2:2016
Utility-interconnected photovoltaic inverters-Test procedure of islanding prevention measures (IEC 62116:2014)	NL EN 62116:2016
Photovoltaic systems - Power conditioners - Procedure for measuring efficiency (IEC 61683:1999)	NL EN 61683:2016
Battery charge controllers for photovoltaic systems - Performance and functioning (IEC 62509:2010)	NL EN 62509:2016
Solar photovoltaic energy systems - Terms, definitions and symbols	NL CLC/TS 61836:2015

المادة الثانية: تعتمد نتائج التحاليل والاختبارات الصادرة عن مختبرات معهد البحوث الصناعية أو أي مختبر آخر حاصل على الاعتماد الدولي للاختبارات المطلوبة، للتحقق من مطابقة المنتجات المعنية بهذا المرسوم للمواصفات المحددة في المادة الأولى أعلاه.

المادة الثالثة: تعتبر المنتجات المصنعة محلياً الحاصلة على شارة المطابقة من مؤسسة المعايير والمواصفات اللبنانية لإحدى المواصفات القياسية الواردة في المادة الأولى أعلاه، مطابقة حكماً لمطابقات المواصفة المعنية، مع مراعاة أحكام المادة الثانية أعلاه عندما تعدد المؤسسة حاجتها للقيام بذلك.

المادة الرابعة: تلغى جميع النصوص والأحكام المتعارضة مع أحكام هذا المرسوم.

المادة الخامسة: يعمل بهذا المرسوم فور نشره في الجريدة الرسمية ويبلغ حيث تدعو الحاجة.

بعبدا في ٢٩ ايلول ٢٠٢٠

الامضاء: ميشال عون

صدر عن رئيس الجمهورية

رئيس مجلس الوزراء

الامضاء: حسان دياب

وزير الصناعة

الامضاء: عماد حب الله

Figure 16: Decree No 6997- specifications.³⁵ This section includes the standards governing the PV solar devices, systems, terms, definitions, and symbols.

This law also allows for the exchange of electricity between residents of neighborhoods within a specific geographical area, as well as for municipalities to sell solar energy to their residents, without the need to go through EDL.

The transition to decentralized solar energy in Lebanon has emerged in response to the inability of the national electricity system to provide reliable power. The solar energy boom and transformation in Lebanon stems from an energy crisis that was intensified by the financial and energy system collapse of October 2019. However, the decentralized current state of adoption of solar technology and installations in Lebanon shows the amount of chaos, injustice, and lack of safety in the installation of solar systems on residential rooftops.

Many installations of solar panels in Lebanon are performed by unqualified individuals who do not account for wind load in high wind areas. The installation of solar panels in Lebanon for personal use of up to 1.5 Mega-Watts does not require approval from the Ministry of Energy and Water. The installation of the metal structures, however, is under the Directorate General of Urban Planning and requires the acquisition of the appropriate permits.³⁶

A study done in 2022 by the Lebanese Center for Energy Conservation (LCEC) on the state of solar panel installation in Lebanon shows that in 2020, residential solar panel installation in Lebanon, in terms of kWp (kW peak), had increased by 93% year on year, with an investment of 26.6 million USD in the residential sector.³⁷ The most used mounting system type according to the study is the railed mount, followed by the foundation mount, and then the ballasted mounting system.

Site Visits and Observations:

Several site visits were conducted in the last quarter of 2025 in Beirut and neighboring areas to observe and document firsthand the current state of implementations of solar panels on rooftops. Sites were selected in areas with older buildings, newer buildings, and highly condensed areas. Observations focused on several criteria, including the mounting structure and foundation of the system, wiring, service clearance, corrosion, and dust accumulation. The observations did not address the amount of energy generated by the system, but focused primarily on installation. Digital photographs were taken of installations in 50 different sites. Photographs taken highlighted several issues regarding structural integrity, electrical safety, accessibility, corrosion, and the lack of cleaning of panels. Table 3 summarizes the main issues observed in solar installations and the frequency of these issues.

Table 3: Decree No 6997- specifications.³⁵ This section includes the standards governing the PV solar devices, systems, terms, definitions, and symbols.

Issue	Frequency
Structural Issues	17 out of 50 sites had structural issues
Electrical Safety	35 out of 50 sites had wiring exposed to weather elements
Service Clearance	32 out of 50 sites had limited access for maintenance
Corrosion	27 out of 50 sites had signs of rusting and corrosion
Dust Accumulation	41 out of 50 sites had dust accumulation

These field observations revealed the need to implement specific protocols with annual inspections to mitigate the risks, vulnerabilities, and hazards. Protocols need to address at a minimum the following needs to ensure safe and proper functioning of installed systems:

- Certified installers
- Load calculation protocols
- Approvals from structural engineers
- Anchoring and mounting protocols

- Electrical code for grounding and electrical testing
- Mandatory maintenance access
- Mandatory spacing from other utilities on the rooftop
- Use of anti-corrosion metal, such as aluminum, for the frames and mounting structure

A sample of these photographs is included in figures 17-30. Rust on the steel mounting structure, as shown in Figures 17 and 18, poses risks to the integrity of the system. This confirms aluminum as the better material of choice in installing solar panels in Lebanon due to its resistance to weather and environmental elements. Lack of space around the solar panel system, as seen in Figures 19, 20, and 21, renders the maintenance, cleaning, and inspection of solar panels both unsafe and ineffective. Wiring exposed to weather and environmental elements in Figure 22, compared to cable protection used in Figures 23 and 24. No adherence to regulations in the use of space on rooftops, as solar panels are installed over water tanks, as seen in Figure 25. Figure 26 shows the effect of high wind on a poorly installed solar panel, which raises concerns about the safety of passersby, an issue raised by YASA (Youth Association for Social Awareness).³⁸

Given the current political and economic environment in Lebanon, and the lack of equity and fairness in the current state of solar panels in residential buildings, community solar builds on previous experiences of resorting to neighborhood public generators to power homes, and has emerged as a viable solution to improve access to electricity and decrease costs. By aggregating resources, participants in community solar can benefit from shared installation, making access to generated energy more affordable and efficient.

Access to empty pieces of land poses the main challenge in implementing community solar. Covering parking lots with solar panels can serve as one solution to the limited available space in cities. Figures 27-30 are taken from a current community solar park being built. Given the size of the project and the monetary investment allocated, these figures show more adherence to safety rules and regulations, primarily with no exposed wiring.



Figure 17: Rust on the steel structure of a solar panel. The image shows the negative impact of using a steel structure in an environment with high humidity.



Figure 18: Rust on the anchoring connection of a solar panel installation. The image shows the impact of rust on the integrity of the anchoring system.

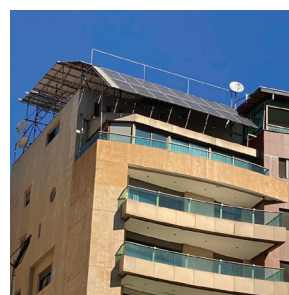


Figure 19: Solar panel installation. The image shows the installation of solar panels on rooftops with no spacing for maintenance work.

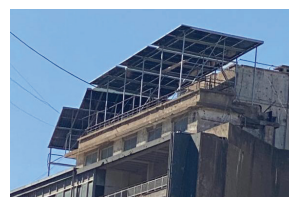


Figure 21: Anchoring of the solar panel on the edge of the building. Image shows the lack of planning and safety measures, as solar panels are anchored on the edge of the building, which allows for minimal space for maintenance.



Figure 23: Covered wiring of a solar panel installation. The image shows the use of covered wiring in the installation of solar panels.



Figure 25: Solar panel installation over water tanks. The image shows the lack of planning in space use on rooftops and the installation of solar panels and wiring over preexisting water tanks.



Figure 20: Solar panel installation on the edge of the rooftop. The image shows the installation of solar panels extending beyond the rooftop, which poses safety issues.



Figure 22: Exposed wiring of a solar panel installation. Image shows the lack of safety measures as wiring used is exposed to weather elements.



Figure 24: Wiring placement on rooftop installation. The image shows the placement of the wiring of solar panels.

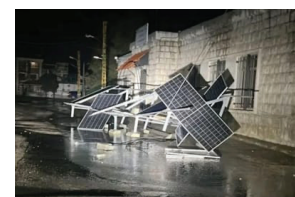


Figure 26: Effect of high wind on solar panels.³⁸ The image shows the collapse of solar panels on a road following a gust of high winds.



Figure 27: Solar Park installation. The image shows an example of an installed solar park.



Figure 28: Site preparation for solar park. The image shows the extensive work needed for site preparation for the installation of solar panels in a solar park.



Figure 29: Anchoring is used in a solar park. The image shows the use of aluminum for the structure and anchoring of solar panels.



Figure 30: Battery installation in a solar park. The image shows an installation of a battery with covered wiring.

Lebanon's Potential in Wind Power:

Lebanon's wind power potential is substantial and can provide the country with the much-needed relief in terms of electricity shortages. Figure 31 shows the wind speed in different locations in Lebanon at an 80-meter height.

As part of its national strategy of increasing its reliance on renewable energy sources and reducing its greenhouse footprint, Lebanon has started to tap into its onshore wind farm potential by signing during the year 2018 three onshore wind farm projects located in North Lebanon in the Akkar region under the names Lebanon Wind Power (LWP), Hawa Akkar Wind Farm, and Sustainable Akkar Wind Farm, to install a total of 54 turbines generating a total of 219 megawatts (MW). These projects have yet to be completed and made fully operational.³⁹

Once operational, these projects will face some challenges primarily due to Lebanon's, particularly Northern Lebanon's, location in the migratory route of hundreds of millions of protected birds flying from Africa to Europe in the Spring, and from Europe to Africa in the Fall. Wind turbines operate at the same height and corridor that birds fly into. Measures would need to be taken to protect the safe passage of these birds, such as shutting off or slowing down the wind turbines during the migratory period. AI tools can also be used that can monitor and detect birds flying into the wind turbine region, and signal

automatic shutdown of the blades until safe passage is completed.

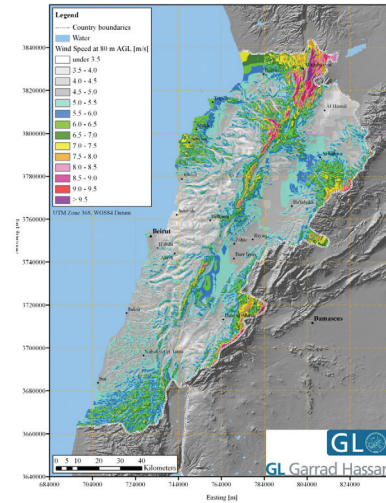


Figure 31: Wind speed in different areas in Lebanon.⁴⁰ The map shows the different wind speeds for different areas in Lebanon, with the highest wind speed in the Akkar region.

When it comes to offshore wind farms, Lebanon's offshore potential is largely affected by the high costs of such initiatives, its technical complexity, and the logistical implications of installing the foundational structures of wind turbines in the deep Mediterranean Sea.

Economic Comparison of Diesel Generators vs. Solar and Wind Power:

The cost of diesel per kWh has been increasing in the last few years and has reached a level of 55 cents per kWh in May 2026 due to the ongoing conflict in the region and its effect on fuel prices.

In contrast, technological advances have driven down the upfront costs of solar and wind power systems, with a 90% decrease in the cost of Photovoltaic systems (PV) between 2010 and 2023, putting these renewable energy sources at the lowest levelized cost of energy LCOE. The average LCOE in 2023 of wind power systems is the lowest at 0.03 USD/kWh, followed by solar power with 0.04 USD/kWh, and diesel generators with 0.44 USD/kWh. By combining the three sources of energy, where diesel generators are used to cover the gap in solar and wind energy produced, the LCOE of a hybrid system amounts to an average of 0.28 USD/kWh.⁴¹

The initial capital expenditures (CAPEX) for solar and wind energy are high compared to diesel generators. In return, diesel generators have high fuel and other operational expenditures (OPEX), which make up about 80% of their LCOE. Despite having higher initial costs than diesel generators, both solar and wind power are economically more beneficial over the lifetime of the system. In contrast, EdL's reforms aim to set the cost of electricity at \$0.27/kWh. Table 4 provides a look at these costs for the different types of energy sources in Lebanon, and the LCOE after accounting for maintenance and fuel price at \$0.93/L for diesel generators.

Table 4: Cost comparison of kWh per source and cost of the system to generate 10 kW in Lebanon.^{4, 42, 43}

Type of Energy Sources	CAPEX (Materials & Installation)	Cost for 10kW	Fuel	OPEX	LCOE
Solar	~\$1000/kW	~\$10,000	None	Low- 1%-2% of CAPEX	\$0.08/kWh
Wind	~\$1,600/kW	~\$16,000	None	Low-Moderate	\$0.06/kWh
Diesel Generator	~\$200/kW	~\$2,000	~\$0.279/kWh	Moderate- Fuel dependent	\$0.4/kWh
EdL Tariffs			\$0.27/kWh		

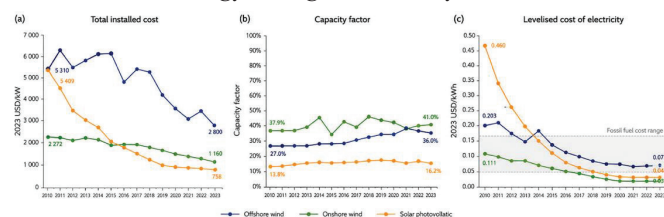
■ Conclusion

In this paper, best practices for installation and maintenance of PV and wind power systems were explored, as well as developments in AI and machine learning to improve cleaning and maintenance of these systems and increase their efficiency and output power, and should serve as the foundation for the development and the regulation of this sector in Lebanon.

This paper also looked at Lebanon's potential in the solar and wind energy sectors. Lebanon's persistent electricity problems were aggravated by the country's financial crisis and the total collapse of EdL. Lebanon's target of reaching 30% reliance on renewable energy by 2030 puts the country at a major crossroads for the need for immediate adoption of both solar and wind energy. Political, legislative, and financial accord needs to take place to lay the foundation for public and private initiatives to transpire.

A look at the economic comparison of the cost of power obtained from diesel generators compared with solar and wind power shows the lower LCOE of renewable power sources, and the need to quickly adopt widespread government measures to move towards these renewable sources.

Figure 32 shows the decrease in cost per kW for solar and wind energy between 2010 and 2023, with the LCOE for both solar and wind energy falling dramatically.

**Figure 32:** Cost, capacity, and LCOE of renewable energy from 2010 to 2023.⁴¹ Graphs show the change in cost, capacity, and levelized cost of electricity per type of energy between 2010 and 2023.

Lebanon's current economic instability and financial paralysis, worsened by the prevailing security situation, hinder the progress of any sizable transformative renewable energy projects and impede further development of this sector. Regulations have been put in place, but not yet made effective, awaiting the establishment of the Electricity Regulatory Authority (ERA).

The significant growth in recent years in the large number of decentralized PV solar system initiatives in Lebanon, primarily in residential buildings, aims at mitigating the lack of electricity by EdL and to offset the large cost of electricity obtained through private and neighborhood diesel generators, and reveals the lack of application of best practices for installations and maintenance of PV systems, safety concerns, as well as the lack of inclusivity and the inequity in the access to these PV systems. The installation of solar panels on residential build-

ings in Lebanon during the growth period relied partly on previously used or low-quality components, and/or damaged batteries. These components do not meet safety regulations and were prohibited by Decree 6997. The lack of inspectors in Lebanon to examine the installation of solar panels and the structural integrity of the rooftops led to widespread chaos in the installations of these systems and safety concerns, observed firsthand during rooftop visits in Beirut and surrounding areas.

Lebanon needs to adopt a centralized initiative to fix its ongoing electricity problem. Based on the LCOE of each of the energy sources available for Lebanon to take advantage of, which include EdL, solar power, wind power, and diesel generators, and taking into account the economic, political and financial environment that Lebanon is currently witnessing, the optimal solution for Lebanon is to implement a hybrid system that focuses on addressing the challenges of EdL, adopting wide scale solar energy projects, putting into motion its wind power initiatives, and relying on diesel generators to cover the remaining gap in electricity supply. By doing so, Lebanon can benefit from uninterrupted electricity, decrease the chaos in installations of PV solar systems, lessen dependence on polluting diesel generators, and attract investors.

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During the preparation of this work, the author used Google Gemini to research industry publications and acronyms. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

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