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WATER-ENERGY NEXUS OF WATER AND WASTEWATER SERVICES IN LEBANON

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RENEWABLE ENERGY POTENTIAL AND MARKET ASSESSMENT

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WATER-ENERGY NEXUS OF WATER AND WASTEWATER SERVICES IN LEBANON

This research report was produced through the combined efforts of the IFI team (Nadim Farajalla, Rana El Hajj, Marc Ayoub, Lea Zgheib, Abed Hajj Chehadeh, Francis Hanna and Nay Karam) and the Oxfam team.

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List of Acronyms

AHP	Analytical Hierarchy Process
BMLWE	Beirut and Mount Lebanon Water Establishment
BWE	Bekaa Water Establishment
CEDRE	Conférence Economique pour le Développent par les Réformes et avec les Entreprises
CEDRO	Country Entrepreneurship for Distributed Renewables Opportunities
CDR	Council for Development and Reconstruction
CIP	Capital Investment Plan
COM	Council of Ministers
COP	Conference of Parties
DSP	Distribution Service Provider
EDL	Electricité du Liban
EE	Energy Efficiency
ESCO	Energy Service Company
GDHER	General Directorate of Hydraulic and Electric Resources
GIS	Geographic Information System
GVC	Gruppo di Volontario Civile
IWRM	Integrated Water Resource Management
IRENA	Joint Humanitarian Development Framework
JHDF	Joint Humanitarian Development Framework
LCEC	Lebanese Center for Energy Conservation
MoEW	Ministry of Energy and Water
MoF	Ministry of Finance
MoI	Ministry of Interior and Municipalities
MCA	Multi-Criteria Analysis
NERA	National Electricity Regulatory Authority
NEEREA	National Energy Efficiency and Renewable Energy Action
NRC	Norwegian Refugee Council
NRW	Non-Revenue Water
NWSS	National Water Sector Strategy

OMSAR	Office of the Minister of State for Administrative Reform
PV	Photovoltaic
RE	Renewable Energy
RWEs	Regional Water Establishments
SDG	Sustainable Development Goal
UNDP	United Nations Development Programme
VFD	Variable Frequency Drive
WaSH	Water Sanitation and Hygiene
WEF	Water Energy Food
WVI	World Vision International
WWTP	Wastewater Treatment Plant

Important Note

All field and desk work conducted for this study, Renewable Energy Potential and Market Assessment, was concluded before the severe economic downturn and the associated national currency devaluation that the country has experienced. All the currency and financial valuations and evaluations were conducted based on an exchange rate of $ 1 = LBP 1,500, and a pre-October 17 economy.

Executive Summary

This assessment posits that a market for renewable energy (RE) in Lebanon's water and wastewater services exists and is at an appropriate level of readiness. However, the potential of this market is constrained by some real challenges: absence of enabling legal framework, lack of financial incentive and performance-driven assessments, and the perpetual cycle of operating in a "crisis mode" on the centralized and utility levels, which impedes the uptake of energy and cost saving interventions.

Despite Lebanon being a small market for RE, technology know-how and a capable private sector exist and are waiting for an enabling environment to grow in different sectors, including water and wastewater. Although a few existing and pipeline projects do include RE systems, our analysis show that the true potential of RE in water and wastewater networks and facilities remains largely untapped.

Specifically, solar PV systems carry significant potential due to their scalability, current level of market readiness, and increasingly low costs. Our findings show that despite some varying potential among water and waste establishments, the sector can achieve substantial savings by adopting solar PV interventions. The suitability of these interventions should be determined on a case-by-case basis, and be based on the principle of economic efficiency, i.e. based on a realistic financial viability model that takes into account consumption levels, load profile, cost of service, and available space and its features (shading levels, orientation, land vs. rooftop, etc.).

A techno-economic modeling of solar PV systems feasibility in 19 water and wastewater facilities that has been conducted in this analysis suggests that solar PV systems can indeed be deployed, to meet at least part of their energy demand and provide costs savings. Some of these, such as Yanouh, Chamsine, and Jdita, can even generate a surplus and export onto the grid, or to other areas, through a power-wheeling arrangement in the future. In cases where utilities can generate power beyond their needs, energy storage solutions would be a major boost for the RE market in the water and wastewater sectors. However, and despite the impressive decline in the costs of energy-storage in recent years, our modeling did not support the inclusion of storage solution at this stage.

The exclusion of energy-storage solutions greatly limits the potential of solar energy, but even so, and under conservative assumptions, some water facilities can achieve up to 10% savings on their actual annual energy-costs when installing solar PV. Wastewater treatment plants can realize significant savings too. For example, both Iaat and Tripoli can achieve around 8% annual savings on USD spent per cubic meter of wastewater treated, and 16% on

EDL and diesel bills on average. As a result, installing RE can reduce the financial burden on water establishments, while promoting energy security.

Besides adopting the technical and economic assessment tools that can showcase how water and wastewater utilities benefit from RE solutions, the key to unlocking the RE market-potential is to enhance the water-energy nexus legal framework. This is best achieved through power-wheeling agreements, and mainstreaming RE in these services through policy, targeting design requirements and financing.

This section aims at understanding the applicability and feasibility of a key recommendation of this study: the incorporation of renewable energy (RE) technologies in the water and wastewater sector to ultimately reduce energy costs borne by the water establishments. It will examine the technological, legal, and socio-economic factors shaping the conditions of the Lebanese RE market, with focus on the readiness of the water and wastewater sectors. Specifically, it aims to achieve the following objectives:

- Assess the integration of RE in the water/wastewater sector by reviewing current legislation and local market dynamics.
- Demonstrate (and quantify) the potential of RE in the water/wastewater sector in terms of technological opportunities, operational flexibility, and cost savings.

Policy, Technical, and Market Landscape

The Policy and Legal Framework

Assessing the readiness of the water sector (which includes wastewater) to incorporate renewable energy (RE) is directly linked to the presence (or absence) of an enabling environment, including a legal framework that provides a platform based on which interventions and policies can be designed and implemented. On the policy level, Lebanon's earliest tangible commitment to RE was observed in 2009 when the government announced its first target of reaching 12% RE of the country's energy mix by 2020[1]. The Nationally Determined Contribution (NDC) for the 2015 Paris Agreement expanded this target further, aiming to reach 20% by 2030, and 30% conditional upon additional international support. The latest commitments to RE targets were announced in the Updated Policy Paper for the Electricity Sector in 2019. The paper briefly mentioned a commitment to more than 480 MW of solar PV, and that 600 MW of wind power-plants are planned for construction in the coming years (MoEW, 2019). The International Renewable Energy Agency (IRENA) has also issued in June 2020 its 2030 Renewable Energy Outlook for Lebanon, announcing in its Remap case that for Lebanon to reach its 30% target in 2030, it has to install 1000MW of wind, 601MW of hydro, 2,500MW of centralized solar PV, 500MW of decentralized solar PV and 13MW of biogas. Figure 1 summarizes the evolution of the Lebanese legal framework for renewable energy.

[1] *See the 2010 Policy Paper for the Electricity Sector.*

Figure 1. Lebanon's legal framework for renewable energy

Policy Plans

- **2010 Electricity Policy Paper:** Commitment to reach 12% RE of electric and thermal supply
- **2019 Updated Policy Paper for the Electricity Sector:** Aims at increasing the production power and reducing the sector's deficit. Commits to delivering around 1GW of electricity through wind and solar between 2020 and 2024.

Laws and Circulars

- **Circulars 184, 313, 318 and 346:** Issued by BDL in 2009 and 2013 to promote energy efficiency, RE and certified green buildings.
- **NEEREA Financing Initiative:** Provides subsidized green loans since 2010 for EE and RE projects by the private sector with low interest rates and a repayment period up to 14 years.
- **National Energy Efficiency Action Plan (NEEAP) 2011-2015:** 14 activities in EE and RE related to primary energy savings, decentralized power generation by PV, and more.
- **2nd National Energy Efficiency Action Plan (NEEAP) 2016-2020:** Suggests 26 EE initiatives to reduce electricity demand from 7% to 5.81% in 2020.
- **National Renewable Energy Action Plan (NREAP) 2016-2020:** Sets the national targets of each technology and a pathway to follow, and identifies the financial budget and discusses the policies and tools to reach set objectives.
- **Net Metering:** RE plant owners can transfer electricity surplus to the grid and gain energy credits in return, which are then deducted from the bill.
- **Law 462 (2002):** calls for the unbundling of the power sector and the establishment of an Electricity Regulatory Authority (ERA) to issue long-term licenses to independent power producers. This has not been achieved yet.
- **Law 288 (2014):** allows the government to grant temporary licenses for power purchase agreements (PPAs) till 2016.
- **Law 54 (2015):** The MoEW did not grant any permits under law 288. Law 54 therefore extends Law 288 till 2018 to continue allowing the private sector to generate electricity and sell it back to EDL via PPAs. This law was recently extended again till April 2022.

When considering the clauses in the legislative landscape that specifically account for the water-energy nexus, or that are at least relevant to water and wastewater services, it may be noted that although the link between water/wastewater services and energy is not explicit, the overall legislative framework mainly supports the deployment of RE in the private sector (residential and commercial). However, there are no policies that call for the installation of RE in specific sectors, such as water and wastewater services. A comparative case is Jordan. In its 2016 Energy Efficiency and Renewable Energy Policy for the Water Sector, Jordan called for the introduction of RE in the water sector, including PV implantation (where net-metering and power-wheeling can be used).

A framework enabling contractual agreements between water services, as a power producer, and EDL is still absent. Although net-metering was launched in 2011, it is still facing implementation challenges. The unstable grid suffers from technical and non-technical losses, preventing it from absorbing the power supplied from distributed generation.

Currently, there is a draft distributed renewable energy law, which sets the legal foundation for peer-to-peer distributed RE through direct onsite and offsite power purchase agreements (PPAs) and/or RE equipment leasing. If implemented, this law would pave the way for multi-site metering for all energy consumers, including public services like water and wastewater. This framework would not be complete without other RE integration mechanisms, namely power-wheeling. A wheeling agreement with the national electricity utility is required for offsite PPAs to take place. The European Bank for Reconstruction and Development (EBRD) is funding a study on the application of power-wheeling and net-metering, which could boost the deployment of decentralized RE, while benefiting the national utility (EBRD, 2019). Passing the distributed renewable energy law would incentivize water and wastewater services to incorporate RE in their processes.

In the long-term, and when the RE technologies mature enough in the Lebanese market, the introduction of new and innovative schemes, such as the Renewable Energy Credits (RECs)[2] would become a necessity. Electricity utilities can purchase such credits, to help meet requirements that they produce a certain percentage of electricity from renewable sources.

Overview of Technologies and Existing Projects

The following technologies are generally relevant when discussing the water-energy nexus in Lebanon: micro-hydro, bioenergy using anaerobic digestion of sludge, and solar PV. However, their applicability depends on the technical requirements that need to be met.

Micro-hydro

Water pumping facilities can benefit from elevated heads to generate electricity through a turbine. Similarly for wastewater treatment plants, a study by UNDP-CEDRO revealed that inlet and outfall pipes constitute a potential source for electricity generation which may be achieved either by installing a turbine at the inlet of the plant as untreated wastewater flows, or by making use of the treated wastewater before it is discharged. However, a major technical obstacle is the irregular flow in most plants with insufficient head (UNDP-CEDRO, 2013).

Bioenergy

Anaerobic sludge digestion in wastewater treatment plants offers potential for biogas production. Bioenergy is still a niche technology in Lebanon, and has yet to become a focus

[2] Renewable energy credits are certificates that represent the value of a specific amount of renewable electricity that has been generated, and are typically amassed in units that represent 1 MWh of electricity, equivalent to 1,000 kWh.

area in the government's long-term plans. The major study on the potential of biogas in Lebanon was done by CEDRO in 2013. The profile of WWTPs in Lebanon rarely fits the technical requirements for anaerobic sludge digestion (AD). Plant size is an important factor: large and medium plants (100,000 - 200,000 Population Equivalent) may consider AD after studying cost-effectiveness and sludge quality and quantity. This technology is less economically viable for smaller plants. In that case, it is recommended that the sludge undergoes AD in a nearby medium or large plant. The CEDRO report suggests that only six plants meet a set of technical criteria to implement anaerobic digestion (Sour, Abade, Majdal Anjar, Saida, Sarafand, and Tripoli). Moreover, WWTPs in Lebanon generally generate low-energy output from sludge and therefore must be supplemented by a co-substrate (like food or farming waste), or sludge from small or medium WWTPs in the area. Given the elevated capital costs of the technology (around 8,000,000 euros), potential projects cannot be considered without any financial incentive (UNDP-CEDRO, 2013). These technical and financial challenges make bioenergy less of a priority compared to other RE sources, like solar PV.

In practice, generation of biogas from anaerobic digestion of sludge was included in the design of two wastewater treatment plants—Sour and Tripoli; however, both plants are not fully operational. Sour WWTP was constructed in 2018 and is expected to start operation in mid-2020. It has a biogas generator of 500 kVA designed to generate electricity from anaerobic digestion of waste activated sludge (WAS). Tripoli WWTP was built in 2009 for primary and secondary treatment, followed by sludge incineration and biogas production. The design includes three biogas boilers of 1,600 kVA each. The plant began operation in 2014 and has only been performing pre-treatment since. The reason for partial operation is mainly rooted in cost-effectiveness issues, as the plant only receives a third of its designed inflow. Equipment not in use is being maintained as per an O&M service contract, and there is no indication as to when the plant would start full operation.

Solar Photovoltaic (PV)

Solar PV pumping systems consist of a direct connection to a Direct Current (DC) pump, or through an inverter to feed an Alternating Current (AC) pump. Wastewater treatment plants can also utilize available lands and rooftops to install solar panels, reducing the reliance on the utility or diesel generators for electricity. Although Lebanon does not create value from manufacturing solar cells, solar PV already has an established market in the country with over 60 companies competing in other parts of the value chain; mainly the installation and maintenance of solar panels for pumping, and tertiary uses, such as buildings' lighting and ventilation.

Solar PV pumping projects have begun picking up momentum in this sector, although slowly. The Decentralized Renewable Energy Generation (DREG) new Master Sheet 2018 for solar PV pumps recorded 76 projects, between 2013 and 2018, with a capacity of 3,357 kW, and a total annual electricity generation exceeding 4.7GkWh (LCEC, 2018). Total turnkey cost for the 76 projects (36 of which are NEEREA-funded) is around 5.8 million USD. Total annual cost savings during that period of time amounted to around 1.4 million USD. It should be noted though that these values cover all projects, not only those linked to public entities.

The LCEC recently devised a primary non-exclusive list upon request, which does not include all solar pumping projects as of May 2019. It counts 34 private projects undertaken and funded by NEEREA. Interestingly, 12 of them have been confirmed to be operational, while there is no information available on the operation status for the rest of them. Based on this list, 11 operational projects have been funded by the World Bank for the benefit of the Bekaa Water Establishment (Table 1). The LCEC suggested that there may be other existing solar pumping systems in other water establishments that have not been tracked and recorded. It appears that the potential for solar PV in this sector is still mostly untapped, despite the growing number of solar PV in the private sector.

Table 1 List of Solar Pumping Projects Funded by the World Bank (LCEC, 2019)

Site Location	Pump Size (hp)	PV Array Size (kWp)	Involved Parties	Opera-tional
Maqneh	125 + booster pump	163.84	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Maqneh	150 + booster pump	230.4	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Douris	75	122.88	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Younine	68	143.36	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Maslaha, Baalbeck	150	225.28	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Maslakh, Baalbeck	100	107.52	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Asayra	150	174.08	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Asayra	125	174.08	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Majdaloun	7.5	20.48	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Majdaloun	7.5	20.48	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes
Hosh Tal Safiyye	17.5	25.6	Funded by the World Bank, managed by CDR, initiated by the Union of Baalbeck Municipalities, and final owner Bekaa Water Establishment	Yes

Solar PV Market Perspective: Adoption and Barriers

Although other RE energy sources do carry a promising potential, as discussed in the previous section, solar PV systems have been chosen as a focus area for the rest of this assessment, given its maturity within the Lebanese context. An initial screening of RE suppliers revealed that 156 local companies entered the solar PV market in Lebanon between 1990 and 2018 (LCEC, 2019). In parallel, the DREG 2018 Solar PV Master Sheet accounted for 19 companies that carried solar pumping projects specifically in Lebanon between 2013 and 2017, representing only 12% of all solar PV suppliers in the field.

Exploratory interviews were then conducted with the managers of the following four companies: ASACO, Green Essence, ECOsys ITG Holding, and Phoenix. The aim was to gain their perspective on local RE market dynamics generally and in the water sector specifically in Lebanon and abroad for comparative purposes and lessons learned. These interviews focused on the engagement (or lack of activity) of these companies with renewable technologies in Lebanese water services, and addressed market trends, competition, and factors shaping the deployment of RE in this sector. Taking a step back and discussing policy and governance issues with these companies also provided insights on what the market needs to support further deployment of RE in the Lebanese water sector, and strengthen the readiness of the latter (questionnaire in Appendix A).

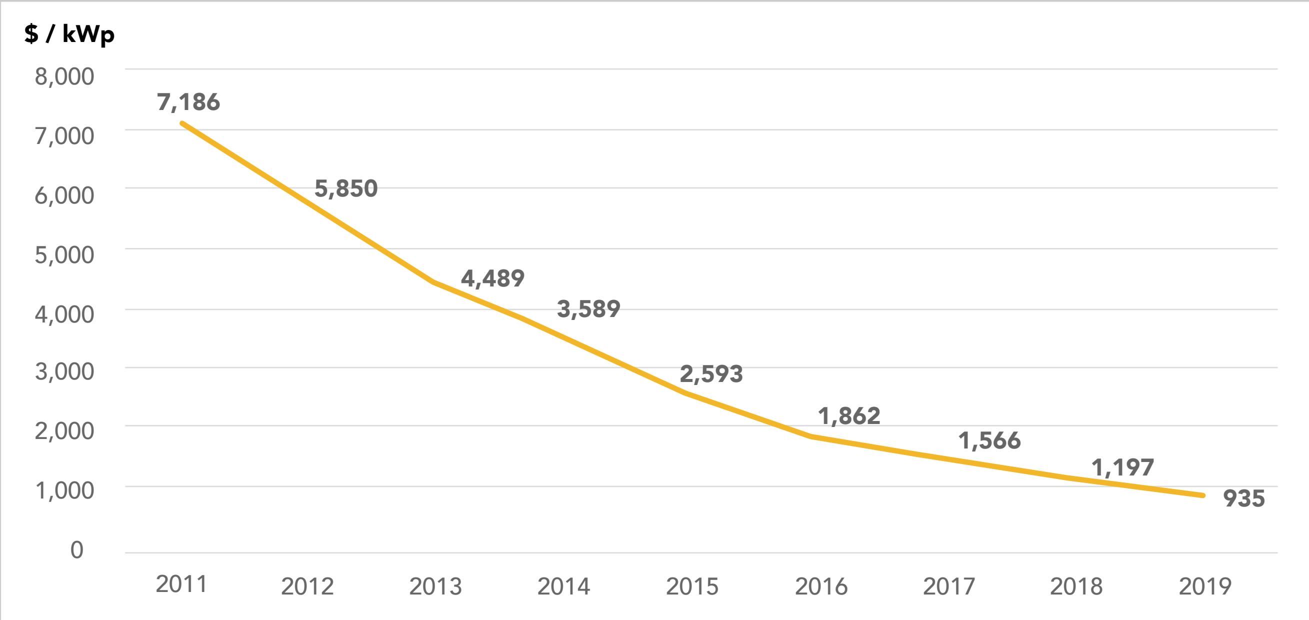
Market evolution

As shown by the statistics generated by the LCEC and DREG report, the Lebanese market gradually evolved from absence of competition, know-how, and awareness in solar PV over a decade ago to an established market today. The dynamics changed over the years because of the financial incentives and instruments supported by national commitments to RE as well as the market's improving technological maturity and feasibility.

Lebanon has been following the global trend in terms of declining costs of RE applications. The country relies on imports of modules, inverters, and controllers from many countries, often from China, Germany, and the USA (UNDP-CEDRO, 2015). The diversity of imports offers resilience to the sector as well as market competition. The average turnkey price for solar PV has declined by 83% in eight years, as displayed in Figure 2. This is mainly due to the drop in the cost of equipment and the financing mechanisms to incentivize technology deployment. Since 2018, global solar PV prices have dropped even below the USD 1,000/kWp limit, and until recently, this had generated a momentum within the Lebanese solar energy market, which was then dampened during 2019, due to the financial crisis and currency devaluation, that has deeply affected the industry, and forced a challenging costing environment.

The number of solar PV projects spiked from 25 projects in 2011, worth USD 3.3 million of investments (NEEREA and non-NEEREA), to 360 projects in 2019 worth USD 125.86 million of investments (LCEC, 2019). Zooming in on solar PV pumping, these systems also benefited from the price drop over the past ten years. Turnkey prices continued falling for this technology to reach an average drop of 42% between 2016 and 2017 (LCEC, 2017). Consequently, the number of PV companies has tripled between 2011 and 2018, resulting in more competition, which further drove prices down. This was further supported by policy incentives, such as the exemption of imported solar PV panels from customs duty, as of March 2018[3] (LSES, 2018). Today, what positions solar PV at the forefront of renewable technologies in Lebanon is its cost-effectiveness and bankability[4]. To put matters into perspective, a USD 100,000 investment in 2011 would have yielded a 14 kWp system; today, the same investment would produce 107 kWp (LCEC, 2019).

Figure 2. Yearly average solar PV turnkey price in USD/kWp (LCEC, 2019)



Declining prices of solar PV have been coupled with incremental innovation, and improved know-how and understanding of the technology itself across its value chain. This is critical to guarantee product quality and warranty, minimizing risks and raising confidence throughout the technology's value chain (from investors to end-users), and bankability of the supplier. The maturity of solar PV has also made it more accessible to the public, putting it at the forefront of renewable energy in a country like Lebanon, endowed with good solar irradiance. Other contributing factors include consumer awareness and scalability. Indeed, solar systems can be applied on the small, medium, and large scale, which in turn bring costs down due to economies of scale. Solar PV therefore remains the most mature RE technology thus far due to the alignment of economic, social, and technological factors.

[3] Taxes on panels comprise a VAT (10%), custom duties (5%), and others including a social security contribution, a property tax, and a corporate tax of 15% (LCEC, 2016; Repmann et al., 2017).

[4] In the current financial and banking crisis, the term "bankability" is more dependent on the Bank's liquidity as well as the project's financial merits.

Market challenges

The market continued growing until 2017 yet decelerated in 2018 and 2019 and is expected to slow down further in 2020 because of the crunching economic crisis. Moreover, the following events have also contributed to the slowdown of solar PV growth at the national level:

- Political instability and financing challenges: The current slowdown is related to the over-reliance on loan programs, such as GEFF and NEEREA. These incentives are now paused due to slowed activities of the banking sector amid the current political and financial instability.
- EDL's tariff is heavily subsidized and therefore does not offer the right price-signal that incentivizes the adoption of solar systems.[5]

On the water/wastewater establishments' level, other observed barriers to the deployment of RE include:

Lack of awareness on energy consumption and renewable energy potential

Water and wastewater utilities (apart from WWTPs under Tripoli) are not evaluated based on their energy and financial performances, i.e. regular energy audits to monitor key performance indicators are not a common practice among water establishments. Facilities are indeed operating on a day-by-day basis, facing the ongoing crisis, without any vision for improvement. When prompted about energy consumption, the utilities' answers were limited to generic responses, such as stating that pumps and blowers are usually energy intensive. Operators (and management in general) of water and wastewater facilities that were visited were not aware of how energy intensive their facilities are, and how much savings could be realized through energy efficiency measures and/or installation of RE systems. Ultimately, RE systems are a cost-saving measure but if costs are not part of the utility's management priorities (energy bills are not settled on an annual basis and therefore accumulate over the years), as opposed to service provision, adoption of these systems will remain modest and will only be pushed for by external players, who provide grants to cover the financing and technical support needed, or if EDL sets variable tariff schemes and gradually removes subsidies. This is further exemplified by the lack of request for feedback from preliminary assessments that have been made for the introduction of RE systems in water/wastewater facilities.

Silo sectoral governance system

Policies and projects are often conceived in a silo manner when it comes to the provision of water services, focusing on the water management aspect and ignoring the important role that energy plays; not only in the various processes but also its portion of the O&M costs. As such EE measures are often overlooked, and RE is absent from the strategic thinking of decision-makers and planners when conceiving water services projects. This has resulted in the underutilization of RE in the provision of water services. For instance, an initial solar PV

[5] *See Water supply facilities below for several pricing and tariff scenarios.*

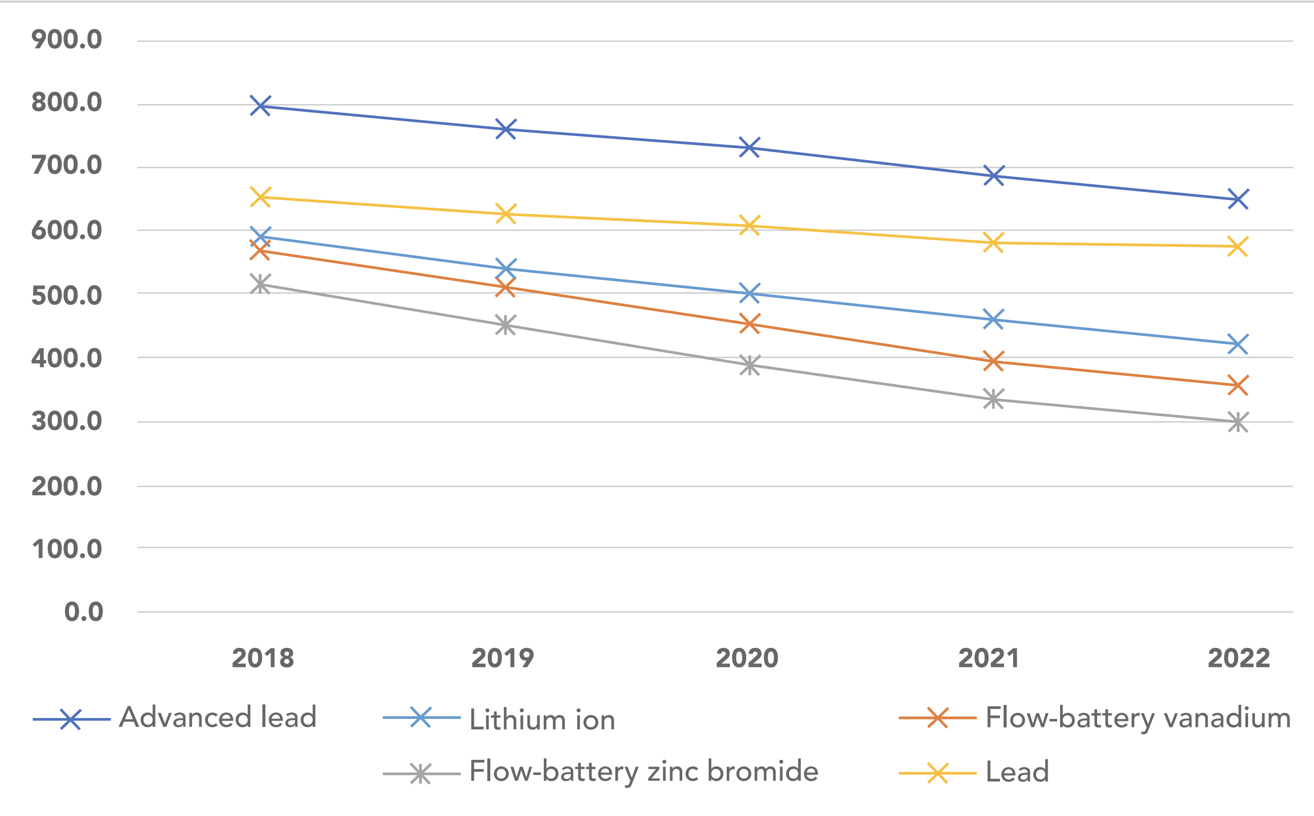
study was performed for the Selaata WWTP, but since the authorities provided no response or feedback to the study, the project never caught traction and the incorporation of PV systems was dropped due to a lack of follow-up.[6]

Lack of solar PV dispatchability

One key barrier to the adoption of solar PV is the lack of storage and hence the limited dispatchability of the system that can meet the water utilities' need to operate beyond daytime. Improved prospects of energy storage solutions would go a long way to increasing the adoption of solar PV systems.

Batteries for storage offer opportunities to increase the potential of solar PV beyond 27% of the utility's consumption (Appendix B). Although currently high, the capital cost of storage is expected to decline further by 6 to 7% a year, making it more affordable in the next five years (Finn-Foley, 2020). This is illustrated further in Figure 3, as the capital costs of various battery types continue to decline at a steady pace. Given these positive prospects, storage would offer more opportunities for savings. Assuming a full cost-recovery effective tariff (22 cents/kWh) and a discount rate of 8%, the levelized cost of storage must drop below 12.25 cents/kWh for the technology to be economically viable, based on the methodology used to assess economic feasibility of solar PV below.

Figure 3. Capital cost forecast of different types of storage batteries (USD/kWh) (Lazard, 2018)



[6] *Insight obtained from the operator during the primary energy audit at Selaata WWTP.*

One option to overcome the storage limitation of solar PV is to utilize the water reservoir itself rather than Battery Energy Systems (BES). This would allow for pumping water and storing it rather than storing energy to later spend it on pumping. In fact, although no projects with hydro-storage have yet been executed in Lebanon, pumped hydro-storage has been one of the better-recognized battery solutions that enable the storage of water when needed. Yet, those solutions are location-dependent and subject to the elevation and location of the pumping station. Additionally, there are costs involved in the building of, or increasing the capacity of existing, reservoirs; however, such an approach may present itself as a solution to a dual problem: lack of water storage capacity in the water supply system, and also lack of storage capacity in the electricity grid.

Assessment of Market Potential

As highlighted in the previous section, the market for RE generally and solar PV specifically in the water sector is ready, in terms of technology maturity, competition, and capabilities. However, despite some levels of adoption of solar PV solutions by the private sector, the Lebanese market is still modest and has not reached its potential yet, in terms of fast deployment and contribution to the national energy mix[7]. Solar PV applications for pumping or in wastewater treatment plants are not numerous due to the challenges described above. The current dependency on external grants and support has limited solar pumping projects to some municipalities, which were willing to select RE alternatives, such as Baakleen and Ghazze. There is still no substantial large-scale government-driven implementation of solar PV in the provision of water services, and this is directly related to a lack of targeted policies, which promote this aspect.

This section takes a forward-looking approach to highlight the market potential of RE in the water sector, and provides evidence that integrating RE into this sector ought to be a priority.

Future and Planned Projects

Future plans to integrate RE in the water sector seem to follow solar PV, micro-hydro, and bioenergy as the main technological trends. While some projects are still being studied under an exploratory or preliminary phase, few others have reached the tendering stage.

Solar PV for pumping projects

Oxfam submitted a tender in August 2019 for equipping three wells belonging to the Bekaa Water Establishment with solar water pumping systems in three facilities: Saghbine, Kfar Zabad, and Haour Taala (Oxfam, 2019)[8]. USAID,[9] through the LWP project, has also executed Ghazzeh a solar PV potable-water pumping station (176.8 kWp capacity), and has plans for several others in the tendering process, among which we can mention: Ras El Ain pumping station (Tyre), Araoun pumping station (Nabatiyeh), Joub Jennine/Aitanit WWTP (Bekaa), Baadaran WWTP (Chouf), Amatour WWTP (Chouf), and Maaser El Chouf WWTP (Chouf). In addition, World Vision[10] is currently executing two solar PV pumping stations in the villages of Baaloul and Ali El Nahri (Bekaa).

[7] The government is collaborating with IRENA to determine the optimal RE mix to achieve 30% of its consumed energy from renewables by 2030 (MoEW, 2019).
[8] Interview with Oxfam team in Beirut working on those projects.
[9] Interview with the USAID LWP team in Beirut.
[10] Interview with the World Vision team in Beirut.

Micro-hydro projects

The potential of micro-hydro power generation from unconventional sources[11] has been studied by UNDP-CEDRO (2014). These include power generation from water services, namely the Water Distribution Network (949kW), and water discharge from Zouk (2266kW), Jiyeh (988kW), Beddawi (1134kW), Zahrani (872kW), water treatment plants (123kW). As for wastewater services, the Tripoli wastewater treatment plant demonstrated a potential of 123kW. While these resources have presented some potential, no project has been planned yet.

Biogas from anaerobic digestion of sludge projects

The MoEW and CDR explored the generation of electricity from wastewater sludge via anaerobic digestion[12], as expressed in the Bioenergy Strategy for Lebanon (2012). The plants listed in Table 2 have the potential to generate power from sludge; this potential is listed as a percentage of the plant's power needs.

Table 2 Potential Energy Production from Anaerobic Digestion of Sludge in Wastewater Treatment Plants (UNDP-CEDRO, 2013)

WWTP	Primary Energy Requirement (kWh/year)	Potential Electricity Production (kWh/year)	Production Percentage of Plant Electricity Needs (%)
Tripoli	56,197,532	21,917,000	39.0
Sour	14,305,358	5,579,000	39.0
Aabde	10,585,965	4,129,000	39.0
Sarafand	18,596,966	7,253,000	39.0
Saida	22,316,359	8,703,000	38.9
Majdal Anjar	17,166,430	6,695,000	39.0
Total	139,168,610	54,276,000	39.0

While the potential from these plants has been studied, no project has been planned yet since technical challenges need to be overcome.

RE Potential in Water and Wastewater Services: Case Studies

Approach

This section aims to select facilities suitable for assessing the economic feasibility of deploying renewable energy in them. A preliminary matrix was built for water and wastewater facilities of all four water establishments, accounting for collected electricity data, and focusing on solar PV potential based on the reasons discussed above. The data collection effort, which

[11] Unconventional water resources refer to resources that do not originate from natural surface or groundwater bodies, require treatment before use, or that are generated as a by-product of a certain process. In the context of this study, water and wastewater treatment plants constitute unconventional water resources.

[12] Co-substrates (manure, agricultural residues, etc.) are not considered in these calculations.

formed the basis of a basic energy audit, through site visits and correspondence with water establishments, focused on acquiring information on EDL and diesel consumption and costs, diesel generator capacity and fuel volumes used annually, number of outages (hours/day), and total areas available for PV adoption. The latter information will be used to estimate the capacity to accommodate PV systems, and hence the power generation capability of the site.

Many facilities did not have the required data and thus were excluded from the database, which was then downsized to focus on the facilities with complete data and available land areas (Appendix B).

Preliminary review of land availability revealed the existence of substantial potential to incorporate solar PV systems in the South, North, Beirut Mount Lebanon (BML), and Bekaa regions. Economic modeling was performed to estimate the potential installed energy capacity (kWp) from solar PV in each of the selected facilities, the corresponding annual savings, and payback periods. The conventional way to compare the cost of electricity generated by different sources is to calculate the levelized cost of electricity (LCOE). It refers to the ratio of the total cost to the benefits (electricity produced), with all figures discounted to the same baseline year, 2019. This follows from the standard discounted cash flow methodology, which accounts for the time-value of money (Appendix C). This methodology is based on the following assumptions.

Table 3 Assumptions Used in Studying the Feasibility of Rooftop Solar PV Systems

Parameter	Value	Description
Discount Rate	Variable	The current discount rate is estimated at 8% based on the latest market trends in 2018, taking into consideration Lebanon's economic status and credit rate ranking (this discount rate could increase due to the current economic crisis since October 2019). A subsidized discount rate of 2% is considered for a scenario where the economy is stable and in continuous growth
EDL's tariff	Variable	9.3 c/kWh 22 c/kWh (post cost-recovery[13], i.e. when subsidies are lifted)
Capital cost (USD/kWp)	Variable	Estimated at 800 USD/kWp based on interviews with local solar PV companies
Specific yield	1500 kWh/kWp	
Area required per 1kWp	8m2	Estimated based on interviews with the private sector.
System lifetime	25 Years	

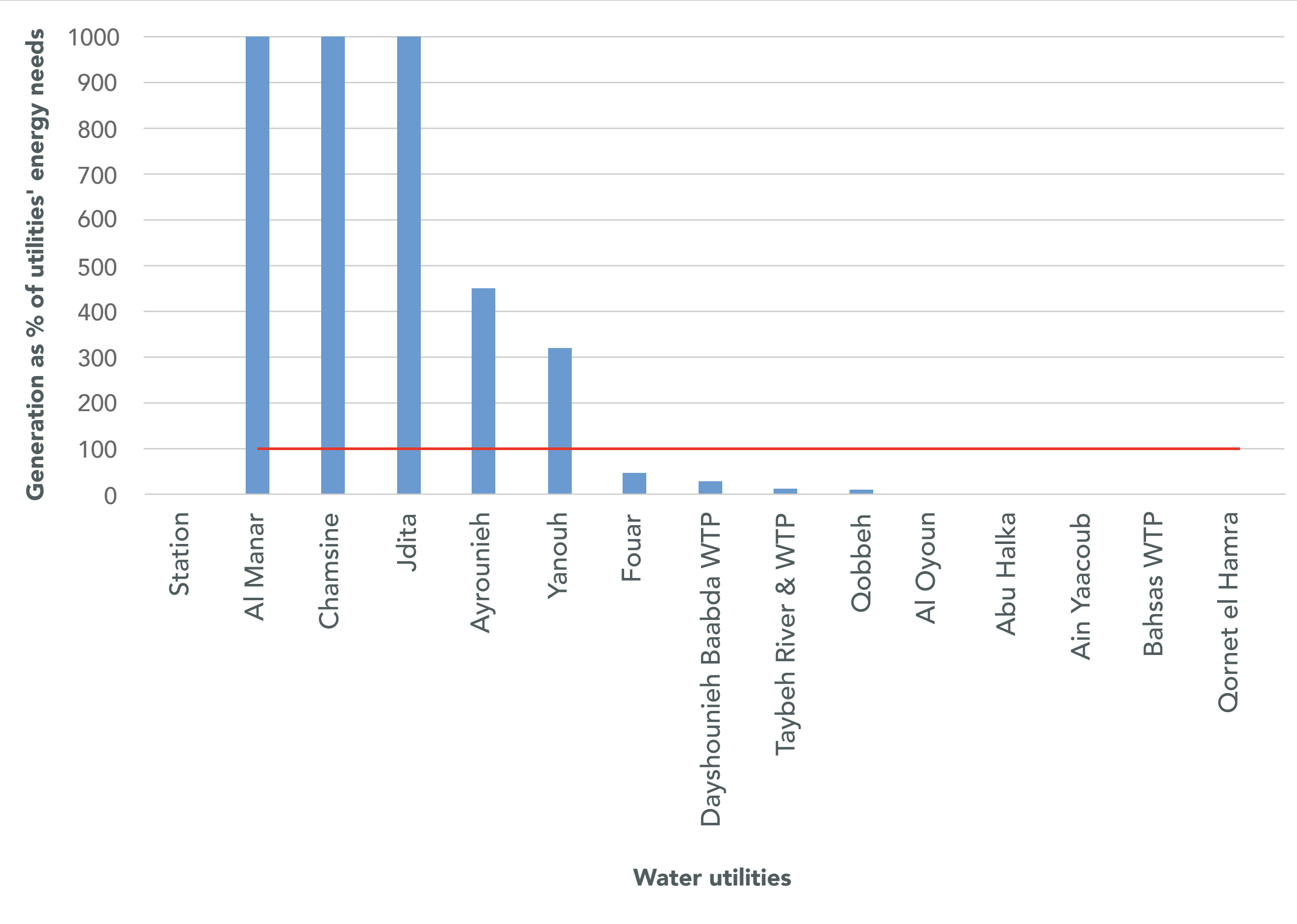
[13] *Post cost-recovery means when EDL Tariff subsidies are lifted/removed.*

Water supply facilities. An economic modeling of solar PV potential was performed for the following facilities:

- South: Fouar, Yanouh, and Taybeh River and WTP.
- Beirut Mount Lebanon: Dbayeh WTP, Qornet el Hamra, and Dayshounieh Baabda WTP.
- Bekaa: Chamsine and Jdita.
- North: Bahsas WTP, Qobbeh, Ayrouniyeh, Abu Halka, Al Manar, Al Oyoun, and Ain Yaacoub.

This assessment initially suggests that all facilities can rely partially on solar PV to meet at least part of their energy demand. Some facilities, namely Yanouh, Chamsine, Jdita, Ayrounieh, and Al Manar can even generate a surplus and export onto the grid, or to other areas, through power-wheeling arrangements in the future (Figure 4).

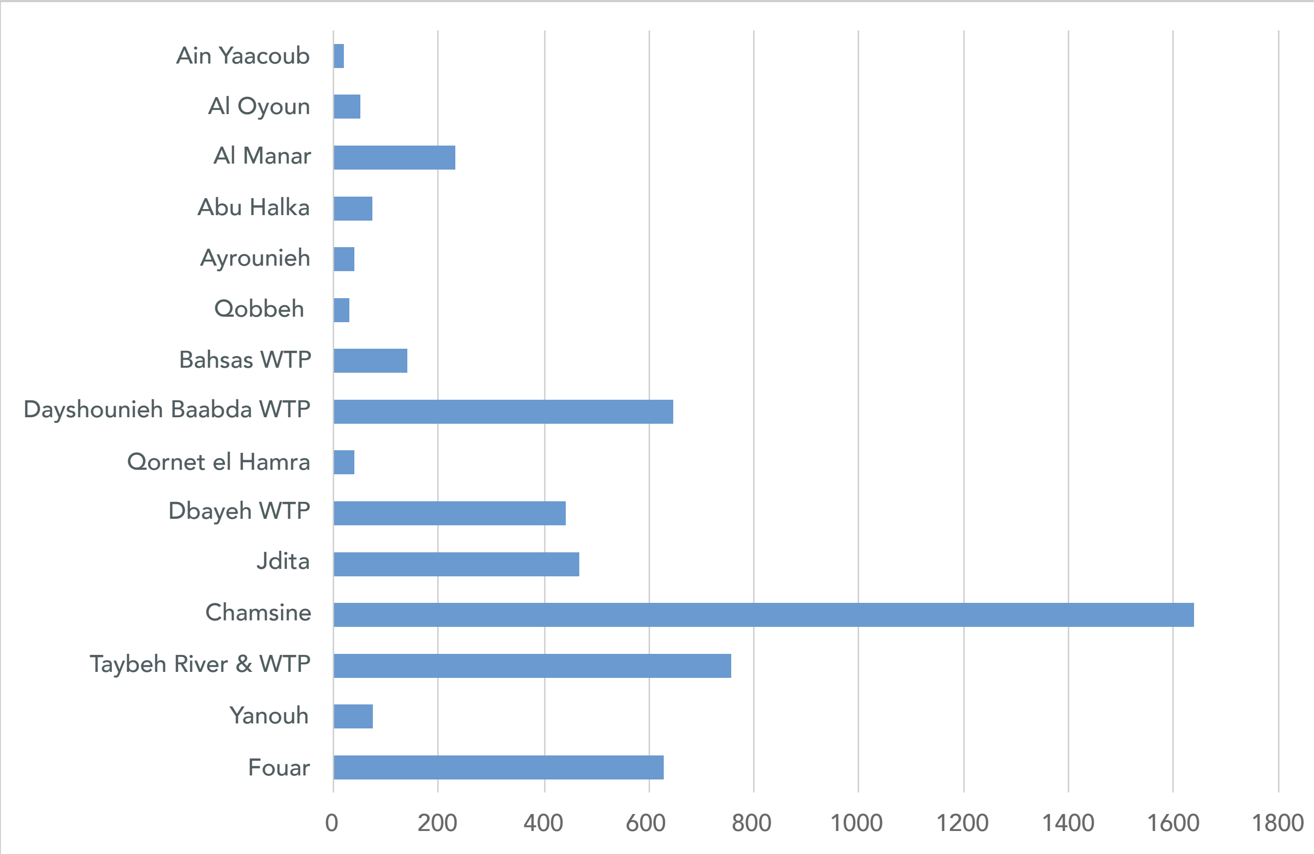
Figure 4. Surplus generated in water stations if storage is deployed



However, the potential of solar PV systems without storage is limited to 27% of the utilities' needs. This is based on the following assumptions: (a) utilities' energy consumption is uniform over 24 hours, (b) on average, eight hours of solar irradiance a day for 300 days a year are utilized with no storage, (c) no net-metering arrangement is utilized. Considering this dispatchability constraint, the recommended solar PV capacity[14] (kWp) for the selected facilities is as follow (Figure 5).

[14] *For more information, refer to the Methodology Note in Appendix C.*

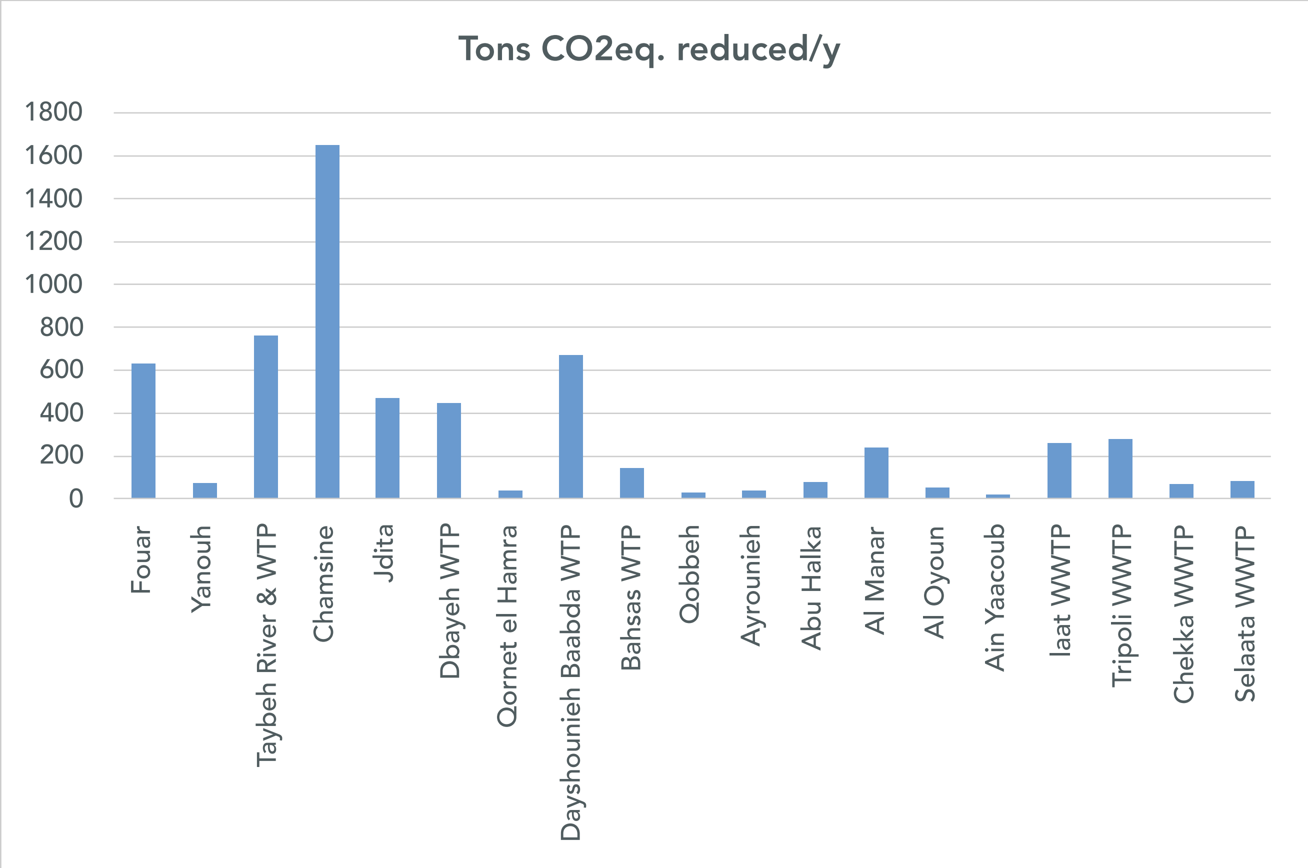
Figure 5. Recommended solar PV capacity without storage in water facilities (kWp)



The impacts of installing solar PV on climate change are demonstrated in Figure 6. Assuming an emission rate of 0.67 tCO2 eq. for EDL generation and 0.69 tCO2 eq. for private diesel generators, combined with EDL[15] utilities, can achieve significant reductions of greenhouse gas emissions (GHG). This impact is particularly more visible in stations with greater recommended capacities; namely Chamsine, Taybeh, Dayshounieh, Baabda, and Fouar, as these stations can reduce between 600 and 1,600 tons of CO2 eq. per year (or between 0.6 and 1.6 Gg CO2 eq./year), using the recommended solar PV capacities shown in Figure 5.

[15] *The latest emission factors were used, 2015, as calculated by the Ministry of Environment and adopted in the 2019 Third Biennial Update Report to the UNFCCC (p.204).*

Figure 6. Annual reduction of GHG emissions from solar PV installation in water and wastewater treatment plants (tons of CO2eq.)



The upfront capital cost would depend on sizing requirements (i.e. the recommended capacity in kWp obtained from the model). The current range of costs offered to customers for an on-grid 500 kWp project is USD 800 per kWp[16]. Given the recommended capacities in this case study, the upfront cost is therefore expected to range between USD 14,400 (Ain Yaacoub) and USD 1,311,200 (Chamsine). Further cost reductions are expected in the future, as prices of solar PV continue to decline. For a more comprehensive picture, the overall LCOE at the current 8% discount rate is 6.42 cents/kWh, and would decline to around 4 cents/kWh, at a subsidized discount rate of 2%.[17]

[16] *This cost is based on the latest 2019 numbers obtained from interviews with solar companies in the Lebanese market (Appendix C).*

[17] *The current 8% discount rate is obtained from financiers and bankers, based on their demand for a weighted average capital cost (WACC), given Lebanon's credit risk rates and fiscal challenges. This discount rate is expected to grow beyond 10% given the increased risk associated to the current crisis, making this financial incentive more appealing (Appendix C).*

Figure 7. Annual savings from the installation of solar PV without storage in water facilities (USD)

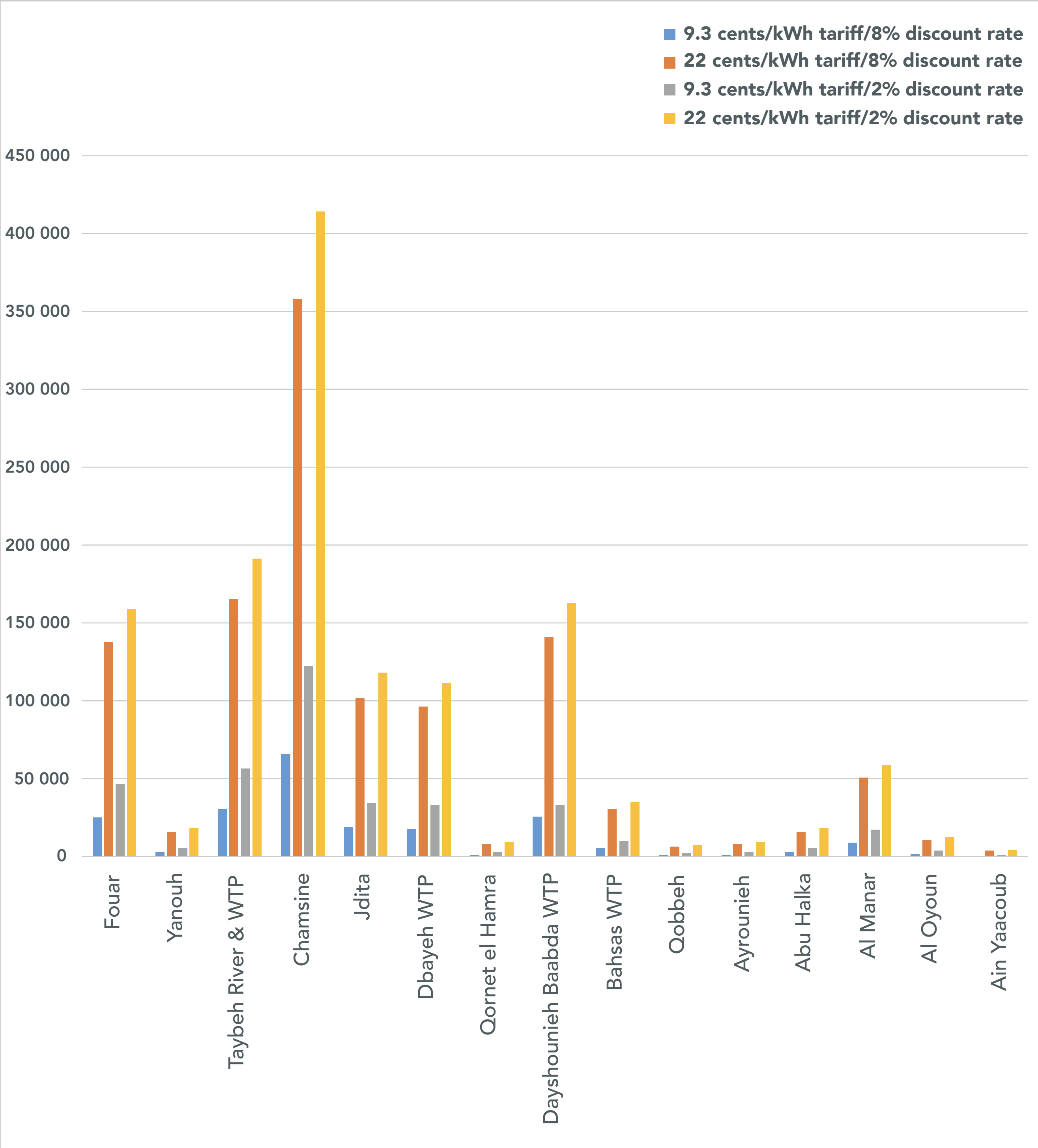


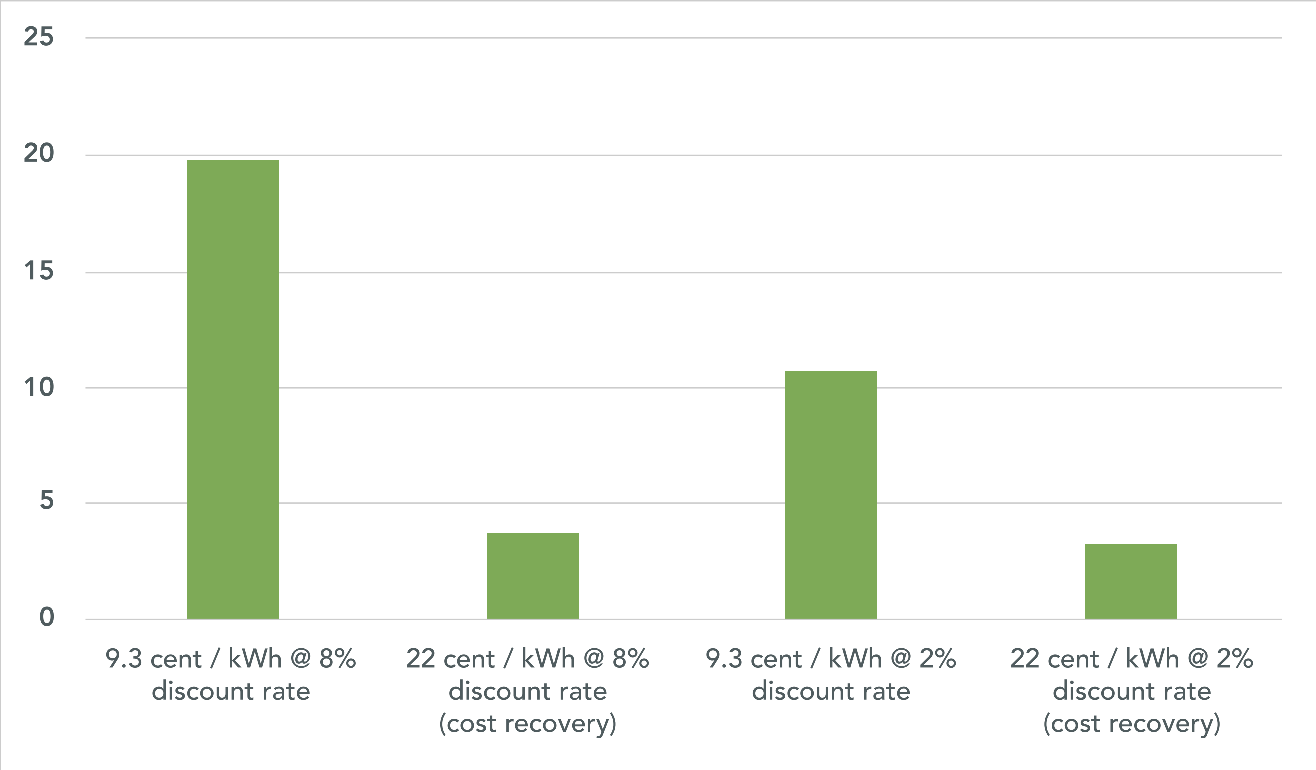
Figure 7 displays the dollars that can potentially be saved from installing solar PV in each station, according to varying EDL tariffs and discount rates. Significant annual savings can be achieved if these facilities invest in solar PV systems[18]. For instance, Chamsine can currently save around USD 65,000 annually. The magnitude of these savings, per kWh, depends on two variables: effective tariff[19] and discount rate. The most optimistic scenario would be based on a cost-recovery tariff of 22 cents/kWh and a subsidized discount rate of 2% (Appendix B),

[18] *Absolute savings refer to savings achieved, based on the full cost difference between the kWh produced by EDL and that produced by the solar PV system.*

[19] *The effective tariff refers the tariff paid by the consumer.*

where savings can reach up to 414,000 USD a year, in Chamsine's case, for a payback period of around three years (Figure 8). With a current tariff of 9.3 cents/kWh and the actual market-based discount rate of 8%, savings are considerable for some facilities, but expectedly, the payback period would extend significantly.

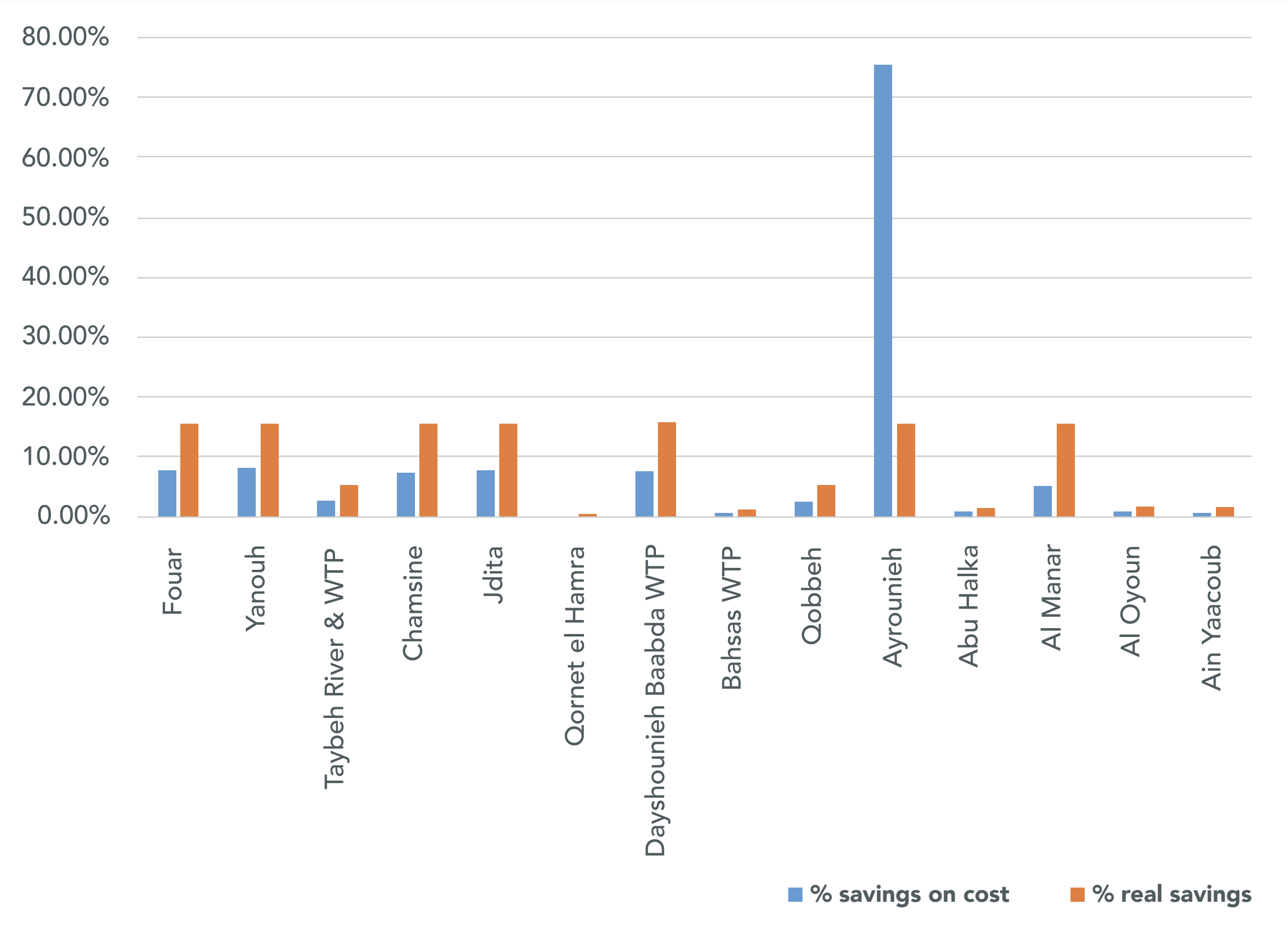
Figure 8. Payback period (years)



However, other indicators are needed to put these numbers into perspective. Figure 9 compares savings on cost to real savings. The former represents the amount of money saved (or its equivalent percentage) for each cubic meter of water pumped ($/m3), at 9.3 cents/kWh tariff and 8% discount rate. As for the real savings, they represent the percentage of USD saved from EDL and diesel generator bills[20]. Chamsine, among many other energy-intensive stations, can save up to 8% of the actual cost spent on each cubic meter of water pumped or treated (Figure 9). Other facilities, namely Ayrounieh, can even save up to 75% on such costs. In fact, Ayrounieh water pumping station does not consume much diesel or electricity from EDL, as it relies on two small pumps only (Appendix B). As for real savings on EDL and diesel fuel bills, they can reach 15% in many instances, which remain significant for water establishments and the government (Figure 8). It should be noted that in the current economic situation, with a chronic shortage of foreign currency, these savings are particularly important.

[20] *See Appendix C for details*

Figure 9. Percentage savings on the energy cost per station compared to real savings



Generalized Comparison between Operating a Station on Solar and Operating it on Diesel Generator

In order to quantify the amount of fuel saved when operating a water/wastewater station on solar PV, rather than on diesel, a base case scenario was developed as a guiding tool to generalize for all the other stations, where a 500 kVA diesel generator at 80% power factor is considered and therefore is able to generate 400 kW capacity.

Estimating the amounts saved when replacing this diesel generator with a 400 kWp solar system followed main assumptions below:

Parameter	Value
Capacity factor of solar system	16%
Specific Yield of solar system (kWh/year/kWp)	1,401.6
Energy conversion rate (L/kWh)	0.3125
Diesel Price ($/L)	0.59
Fueling Costs ($/kWh)	0.18
Discount Rate	10%

When operated at 40% capacity factor (around 10 hours/day), annual fuel costs (diesel costs) are estimated at 258,420 USD, while those costs can reach up to 581,445 USD when operated at 90% capacity factor (full operation on diesel generator).

On the other hand, a 400 kWp solar system will allow an annual energy production saving of 840,960 kWh, amounting to 155,052 USD.

Assuming no storage is implemented (8 hours of solar/day), up to 51,684 USD could be saved on annual fuel costs (diesel costs), and this could double to reach up to 103,368 USD with energy storage systems.

Wastewater treatment plants

Two case studies represent the manner in which RE may contribute to meeting the demands of wastewater treatment plants. The first is Iaat in the Bekaa, and the second is that of Tripoli.

Iaat WWTP

Iaat wastewater treatment plant was selected for this case study because it has 35,000 m2 of total available land and 600 m2 of rooftop space (see Figure 10). The plant relies on a 500 kVA diesel generator to make up for the six hours of daily electricity outages. With over 117,000 liters of diesel fuel used annually, in addition to its EDL subscription, Iaat WWTP consumes a total of 2,252,691 kWh, worth LBP 707,681,110 per year.

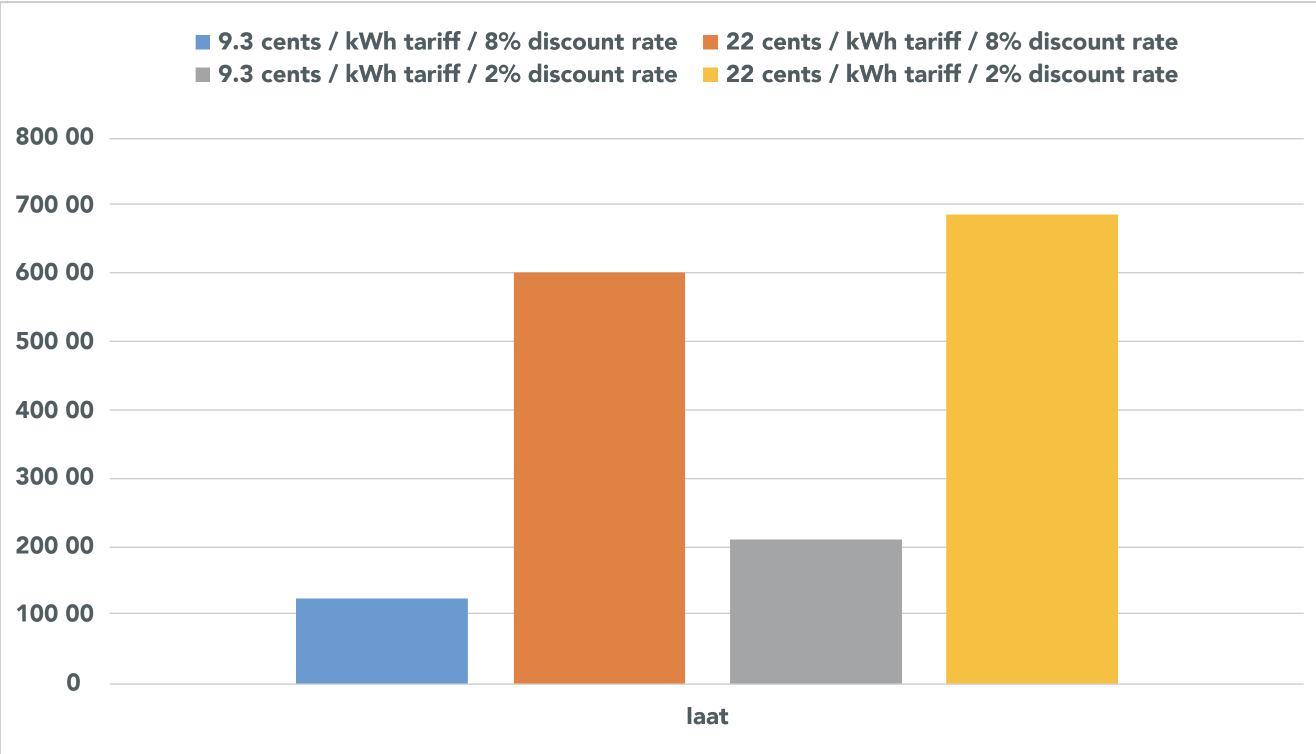
Figure 10. Available land and rooftop for solar PV installation in Iaat WWTP

The same methodology, described earlier, was used to model the potential of deploying solar PV at this plant. Results indicate that solar PV can meet 27% of the utility's consumption without storage, with a recommended capacity of 252 kWp. Ideally, Iaat could rely on storage and export its solar energy surplus, as solar would cover 381% of the plant's demand if all the available space is utilized (Appendix B). Since storage is not readily available and economically too costly, the analysis was conducted for PV systems without storage.

Bearing an upfront capital cost of USD 201,600, such a system would yield lucrative returns, even within the status quo scenario (effective tariff of 9.3 cents/kWh and 8% discount rate), as displayed in Figure 11.

The station can save USD 12,200 a year (or 7.5 % of its energy cost in terms of USD per cubic meter of wastewater treated, and 16% on EDL and diesel bills on average), and up to USD 68,500, if the discounted rate is subsidized (2%) and a cost-recovery tariff applied (22 cents/kWh). Although those savings do not seem very high when compared to the WEs' unsettled energy bills, real savings in the long-term are much bigger, especially when those projects are well operated and maintained. Similar to the water facilities, the payback period varies according to tariff and discount rate (Figure 8). As for the LCOE, it also ranges between 6.42 and 3.98 cents/kWh, depending on the discount rate (8 % and 2%, respectively).

Figure 11. Annual savings from the installation of solar PV in Iaat WWTP (USD)



Tripoli WWTP

Tripoli WWTP was selected for the second case study due to its direct relevance to policy. In this case, even though land is available to generate even more power than needed by the facility; however, dispatchability constraints of solar systems without storage have annulled the advantage of land availability. To compensate for the loss of advantage, due to technology availability (or lack of), policy and decision-makers must investigate options that are not necessarily tech-based but rather policy-centered.

The land covered by the Tripoli WWTP is extensive covering: area 1 (A1) 12,000 m2, area 2 (A2) 5,000 m2, rooftop 1 (R1) 700 m2, and rooftop 2 (R2) 500 m2 (Figure 12).

Figure 12. Available lands and rooftops for solar PV installation in Tripoli WWTP

Areas 1 and 2 were initially allocated for potential expansion of the WWTP. Yet, following interviews with operators and process engineers at the station, and given that the plant is only operating at 30% capacity, no expansions are foreseen in the near future. Therefore, these lands can be considered for solar PV.

The potential was assessed for both land areas with and without the rooftops. Results in Table 4 indicate that the maximum potential solar PV capacity is achieved when all areas are combined (1820 kWp). By comparison, relying solely on A2 would yield a capacity of 500 (kWp). In case storage is deployed, Tripoli WWTP can, in some instances (using all areas, A1 or A1+R), cover its entire consumption through solar, and generate surplus PV. However, given dispatchability constraints of solar systems without storage, the potential is limited to a maximum of 27% of the utility's consumption (270 kWp)—regardless of area sizes. In other words, Tripoli cannot leverage all or most of its available land and rooftops, in this case. This sheds light on the benefits of storage, and calls for incentivizing importing the technology as well as the need for power-wheeling agreements to avoid wasting the surplus.

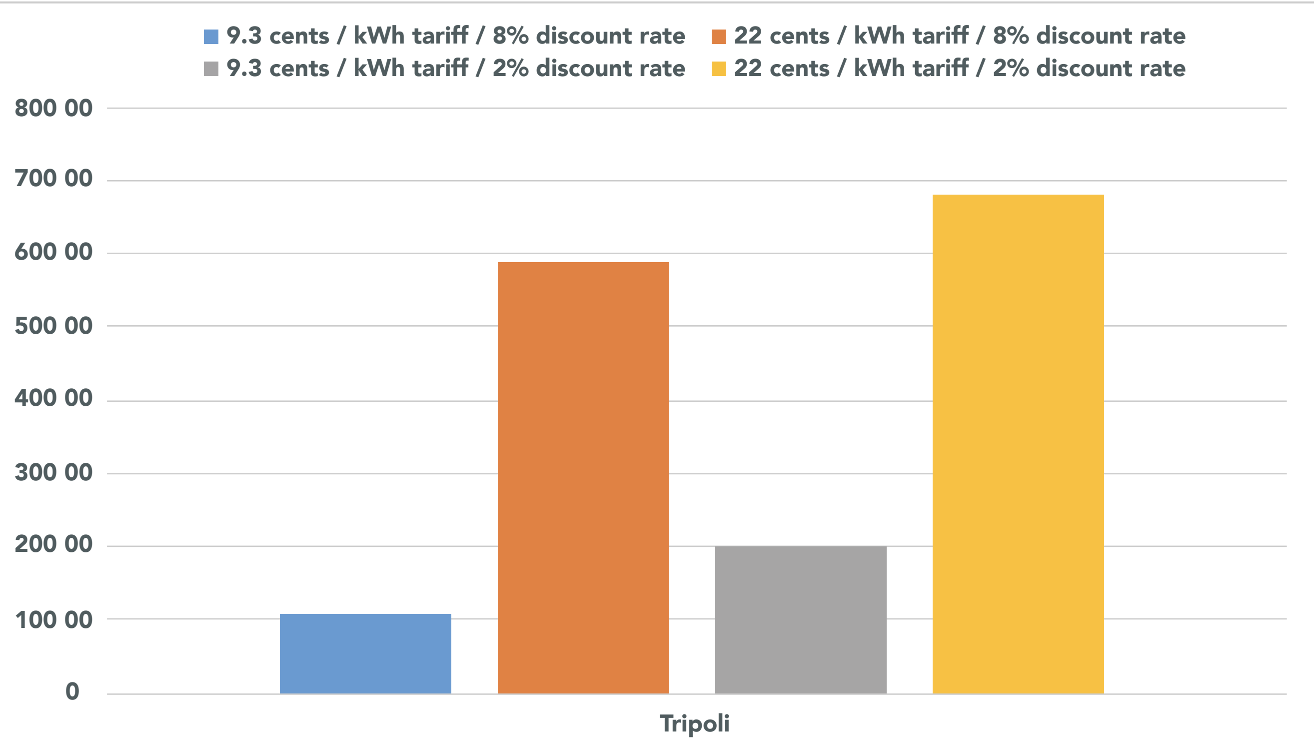
As for annual savings, the solar PV potential without storage is considered due to the affordability of the technology. With a capital cost of USD 216,000, current tariff, and discount rate, Tripoli WWTP can save up to USD 10,893 annually (Figure 13). This represents 7.91 % of its actual cost of energy, in terms of USD/m3 of wastewater treated, and saves 16% on average on its EDL and diesel bills. A cost-recovery tariff and subsidized discount rate would increase annual returns to USD 68,200 and reduce the payback period to around three years.

Assessments of contribution of RE in other WWTPs is included in Appendix B.

Table 4 Maximum Potential Solar PV Capacity in the Tripoli WWTP

Statio	Total consumption (kWh)	Total area approximation (m2)	Potential Solar PV Capacity (kWp)	Estimated kWh produced from solar PV	Solar PV potential with storage (% of utility consumption)	Solar PV potential without storage (% of utility consumption)	Recommended Solar PV capacity (kWp)
Tripoli A1	1,498,347	12,000	1200	1,800,000	120.13	27	270
Tripoli A1+R	1,498,347	13,200	1320	1,980,000	132.15	27	270
Tripoli A2	1,498,347	5000	500	750,000	50.06	27	270
Tripoli A2+R	1,498,347	6200	620	930,000	62.07	27	270
Tripoli all	1,498,347	18,200	1820	2,730,000	182.20	27	270

Figure 13. Annual savings from the installation of solar PV in Tripoli WWTP (USD)



Recommendations and The Way Forward

The case studies presented earlier are real examples of the potential of solar PV in the provision of water services. More importantly, the yearly monetary savings with the current conditions are over USD 25,000 per station, in some water facilities (Fouar, Taybeh, Chamsine, and Dayshounieh Baabda WTP), and over USD 10,000 per plant, in some WWTPs (Iaat and Tripoli). These numbers, which were generated using conservative assumptions, cannot be ignored, especially in times of economic crisis. Thus, it is apparent that the market for RE in water and wastewater services exists and is primed. The technology, know-how, and willing private sector are present, but a supportive environment to further enable market growth is still lacking.

Recommendations to improve the enabling environment for the adoption of RE in the provision of water services are suggested under two themes that complement one another: improving the energy resilience of water establishments on the one hand, and improving the integration of EDL and the establishments, on the other. These recommendations are made at four levels: policy, finance, design, and utility management.

Level	Theme 1: Improving Energy-Resilience of Water Establishments	Action Timeline
Policy	Develop a policy for RE integration in all water and wastewater facilities at the national level[21] as part of a Water Sector Strategy. All water and wastewater facilities, with significant potential from available lands and rooftops, should undertake a techno-economic analysis to assess the installation of solar PV to cover at least part of their energy consumption. This should consider future ramp-up of capacity and its impact on land requirements.	Medium - long term
Finance	Enhance RE affordability further by exempting RE components from import and other taxes, to reduce the initial cost of financing.	Medium - long term
Finance	Assess the possibility to revise the reallocation of international loans and funds to give priority to water and wastewater projects that incorporate RE and integrate energy efficiency measures.	Medium - long term
Design	Mainstream the deployment of solar PV in the design of water and wastewater facilities, whenever applicable. This should be a priority for the following water stations: Chamsine, Taybeh, Dayshounieh Baabda WTP, and Fouar; and the following WWTPs: Iaat and Tripoli.	Immediate
Design	Assess the techno-economic feasibility of hydro-storage solutions in facilities with elevated heads to generate electricity from hydro-power and/or extend the sizing of solar PV generation.	Medium - long term
Utility	Regularly monitor energy consumption and efficiency through scheduled energy and financial audits. Following such best-practice measures would allow establishments to explore RE alternatives and savings opportunities.	Immediate
Utility	Within the current economic situation, and knowing that a legal framework is already in place but is not yet applied (PPP Law 48/2017), seek Public Private Partnerships (PPPs) for solar PV installation and maintenance by ensuring the legal and policy environment enables investments to support such projects. This would also require coordination between the utility, the water establishment, the municipality, and the private sector.	Medium - long term

[21] *Refer to Energy Efficiency and Renewable Energy Policy for the Water Sector for lessons-learned from a neighboring country (Jordanian Ministry of Water and Irrigation, 2016).*

Level	Theme 2: Improving the Integration of EDL and Water Establishments	Action Timeline
Policy	Advocate for power-wheeling agreements to avoid wasting potential energy excess generated by solar PV. The draft distributed renewable energy law, which sets the legal foundation for peer-to-peer distributed RE, ought to be passed. Distributed RE would be supported further with the unbundling of the electricity sector, as per Law 462 (2002), which is yet to be implemented.	Immediate
Policy	Prioritize adequate implementation of multi-site net-metering by addressing technical challenges, such as the grid's instability.	Immediate
Policy	Increase synchronization between EDL and the facilities acting as decentralized producers generating solar PV surplus: Apply a smart rationing scheme, whereby EDL provides electricity when utilities generate excess to incentivize the installation of RE in facilities with large potential.	Medium – long term
Policy	Work towards eliminating EDL subsidies and increasing the electricity tariff, which would promote solar PV as a competitive, less expensive substitute. Concurrently, this would reduce the water establishments' electricity bills and their reliance on diesel powered generators.	Medium – long term
Finance	Rethink the relationship between EDL and the water establishments by proposing variable day/night tariffs to be reflective of cost-recovery at the level of connecting utilities to the grid, in such a way that incentivizes WEs to reduce costs or choose to operate during the least-cost available option.	Medium – long term
Utility	In the case of water pumping facilities, rescheduling the load to the eight hours covered by solar PV per day would reduce heavy reliance on EDL.	Medium – long term
Utility	Seek agreements with nearby municipalities for land utilization for power wheeling.	Medium – long term

Level	Theme 3: Involving water establishments in climate action	Action Timeline
Policy	Monitor and report yearly GHG emissions to set mitigation action plans. Given the demonstrated reductions in GHG emissions from water and wastewater treatment plants, solar PV should be considered as a main mitigation action in that area.	Immediate

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Appendix A
Interview Questions

Business

- Please describe your engagement with energy efficiency and renewable energy (RE) measures in water/wastewater services.
- What have been the positive and negative influences on your business model?

Market Trends

- How ready was the Lebanese market when you entered it? How has that changed over the years?
- How would you describe the current market demand for RE in Lebanon and in the water/wastewater sector specifically?
- How would you describe the market competition for RE in Lebanon, and for the water sector specifically?
- In your opinion, what are key factors to boost the deployment of RE in Lebanon and particularly the water/WW sector? Any other market barriers?
- How do you foresee the future of RE in the Lebanese water sector in terms of technology type and market dynamics?

Policy and Governance

- With the installation of RE comes other considerations like maintenance, quality control, and capabilities. Is the water/wastewater sector ready to accommodate renewables?
- What policies do you think are missing to boost the deployment of RE in Lebanon, particularly in the water/wastewater sector?
- Any lessons-learned from your experiences in Lebanon or abroad you would like to share to enhance the RE deployment in the water/wastewater sector?

Appendix B
Economic Modeling Results

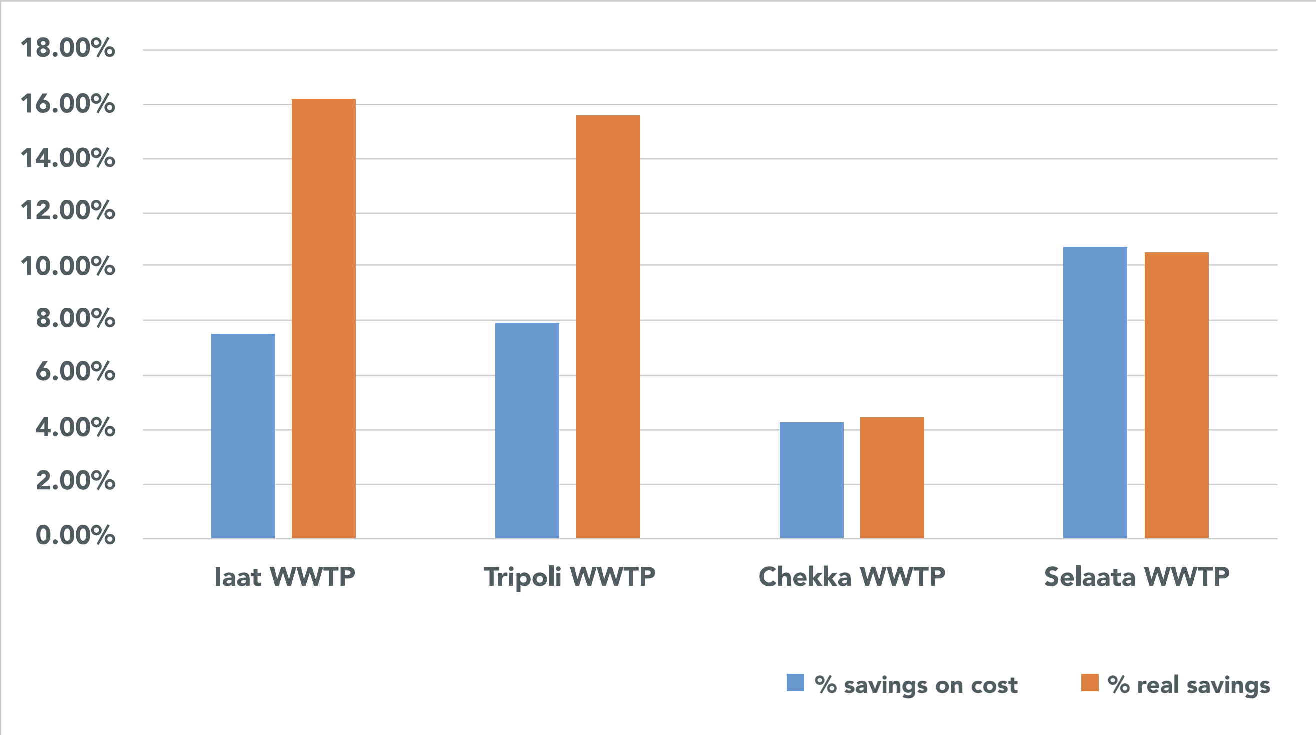
Figure B1

	Station	Region	Total consumption (kWh)	Total area approximation (m2)	Potential Solar PV Capacity (kWp)	Estimated kWh produced from solar PV	Solar PV potential with storage (% of utility consumption)	Solar PV potential without storage (% of utility consumption)	Recommended Solar PV capacity (kWp)
WATER	Fouar	South	3496271.4	10497	1050	1574550	45.04	27	629
	Yanouh	South	405171.43	8558	856	1283700	316.83	27	73
	Taybeh River & WTP	South	12609392.8	7735	774	1160250	9.20	9	757
	Chamsine	Bekaa	9107792.857	3142602	314260	471390300	5175.68	27	1639
	Jdita	Bekaa	2592292.857	295893	29589	44383950	1712.15	27	467
	Dbayeh WTP	BML	26765338.1	4410	441	661500	2.47	2.47	441
	Qornet el Hamra	BML	8472673.81	380	38	57000	0.67	0.68	38
	Dayshounieh Baabda WTP	BML	3771480.9	6464	646	969600	25.71	25.71	646
	Bahsas WTP	North	10494149.97	1400	140	210000	2.00	1.99	139
	Qobbeh	North	512830.9667	290	29	43500	8.48	8.48	29
	Ayrounieh	North	210996.6	6300	630	945000	447.87	27	38
	Abu Halka	North	4285044.733	732	73	109800	2.56	2.56	73
	Al Manar	North	1287933.333	4389608	438961	658441200	51123.86	27	232
	Al Oyoun	North	2774178.5	500	50	75000	2.70	2.7	50
	Ain Yaacoub	North	1104211.05	180	18	27000	2.45	2.45	18
WASTEWATER	laat	Bekaa	1,388,155.40	35600	3560	5340000	384.68	27	250
	Tripoli Al	North	1498346.9	12000	1200	1800000	120.13	27	270
	Tripoli Al+R	North	1498346.9	13200	1320	1980000	132.15	27	270
	Tripoli A2	North	1498346.9	5000	500	750000	50.06	27	270
	Tripoli A2+R	North	1498346.9	6200	620	930000	62.07	27	270
	Tripoli all	North	1498346.9	18200	1820	2730000	182.20	27	270
	Chekka	North	1276745.4	650	65	97500	7.64	7.64	65
	Selaata	North	693609.6	780	78	117000	16.87	16.87	78

Figure B2

	Station	Recommended Solar PV capacity (kWp)	Upront Capital Cost	Annual Savings (@ 9.3 cents/kWh tariff / 8% discount rate)	Annual Savings (@ 22 cents /kWh tariff /8% discount rate)	Annual Savings (@ 9.3 cents/kWh tariff /2% discount rate)	Annual Savings (@ 22 cents /kWh tariff / 2% discount rate)
WATER	Fouar	629	503200	25376	137340	46917	158881
	Yanouh	73	58400	2945	15939	5445	18439
	Taybeh River & WTP	757	605600	30540	165288	56464	191213
	Chamsine	1639	1311200	66122	357870	122252	413999
	Jdita	467	373600	18840	101968	34833	117961
	Dbayeh WTP	441	352800	17791	96291	32894	111393
	Qornet el Hamra	38	30400	1533	8297	2834	9599
	Dayshounieh Baabda WTP	646	516800	26062	141052	48185	163175
	Bahsas WTP	140	112000	5648	30568	10443	35363
	Qobbeh	29	23200	1170	6332	2163	7325
	Ayrounieh	38	30400	1533	8297	2834	9599
	Abu Halka	73	58400	2945	15939	5445	18439
	Al Manar	232	185600	9360	50656	17305	58601
	Al Oyoun	50	40000	2017	10917	3729	12630
	Ain Yaacoub	18	14400	726	3930	1343	4547
WASTEWATER	laat	252	201600	12219	59880	20850	68510
	Tripoli Al	270	216000	10893	58954	20139	68200
	Tripoli Al+R	270	216000	10893	58954	20139	68200
	Tripoli A2	270	216000	10893	58954	20139	68200
	Tripoli A2+R	270	216000	10893	58954	20139	68200
	Tripoli all	270	216000	10893	58954	20139	68200
	Chekka	65	52000	2622	14193	4848	16419
	Selaata	78	62400	3147	17031	5818	19702

Figure B3



Percentage savings on actual energy costs in wastewater treatment plants compared to real savings

Appendix C
Economic Modeling Methodology

Levelized Cost of Electricity

The conventional way to compare the cost of electricity generated by different sources is to calculate the levelized cost of electricity (LCOE). This follows from the standard discounted cash flow methodology, which accounts for the time-value of money (Brealey and Myers, 2000). This methodology is used in this analysis to calculate the life-cycle cost of producing distributed electricity from solar PV, solar PV plus storage, and diesel generators. The levelized cost is the ratio of the total cost to the benefits (in this case the electricity produced), with all figures being discounted to the same baseline year, 2019. In a way, the LCOE is the break-even price at which electricity must be sold to yield a zero net present value (NPV), and can be expressed as:

$$LCOE = k + f + v\,.$$

Where k, f, and v are the time-discounted (per kWh) capital, fixed, and variable costs, respectively. These three parameters can be expressed as follows:

$$k = \frac{K}{\sum_i^T E_i \times \alpha_i}\,.$$

$$f = \frac{\sum_i^T F_i \times \alpha_i}{\sum_i^T E_i \times \alpha_i}\,.$$

$$v = \sum_i^T V_i \times E_i \times \alpha_i\,.$$

Where: i denotes the year, T is the lifetime of the project, K is the overnight capital-cost, E_i is the annual electricity produced, f is the annual fixed costs, and V is the annual variable cost. All these parameters are discounted by α_i, the discounting factor expressed as:

$$\alpha_i = \frac{1}{1 + r}\,.$$

Where r is the discount rate.

In such type of analyses, an important factor is the discount rate. For the base case, a discount rate of 8% is assumed. This number is obtained from interviews with financiers and bankers, based on their demand for a weighted average cost of capital (WACC), given Lebanon's credit risk rates and fiscal challenges. Also, it should be noted that this is a real discount rate, and inflation is implicitly taken into account. Other (subsidized) scenarios studied below use lower interest rates.

Another factor that strongly affects the economics of the different energy systems examined is the capacity factor, which is the ratio of the energy produced in a given year to the amount that could have been produced if the system were to operate at full power all the time. Based on interviews with solar PV companies in Lebanon, the availability factor is somewhere between 16-17%, leading to a specific yield of around 1,500 kWh/kWp.

For capital costs, the numbers used were based on the latest 2019 numbers obtained from interviews with solar PV companies working in the Lebanese market. The current range of costs offered to customers for an on-grid, 500 kWp project is USD 800 kWp.

The ratios of fixed O&M costs were also obtained through a combination of interviews with solar companies and the literature. For on-grid systems, solar companies estimate that the fixed annual costs are at 2% of a project's capital costs. Finally, the economic lifetime of the solar system is 25 years.

Estimating Solar PV potential

The assessment of the solar resources available for utility j is based on the following formulas:

$$Available\ Space\ (S_j^{av}) = \beta_j \times A_j\ .$$

Where S_j^{av} is the available space for solar panels in m², β is the occupancy factor and ^ is the area available. Therefore, the available solar resource for a utility can be expressed a A

$$E_j^{PV} = S_j^{av} \times \left(\frac{1}{a}\right) \times \varepsilon\ .$$

Where E_j^{PV} is the annual generated solar energy in utility j, a is the area required to install one kWp (8 m²), and ε is specific yield, which is currently estimated at 1,500 kWh/kWp, based on data collected from Lebanese solar companies and on a conservative assumption for yield estimation.

As for the capital cost of the solar PV system in building j, K_j^{PV} can be estimated using the following:

$$K_j^{PV} = \frac{S_j^{av}}{A_{kWp}} \times k \ .$$

Where A_{kWp} is the area required for one kWp, and k is the capital cost in USD/kWp.

The annual savings that result from installing solar PV panels, Φ_j, can be then estimated using the following equation:

$$\Phi_j = E_j^{PV} \times T_{eff} \ .$$

Where T_{eff} is the effective tariff paid by the consumer.

Estimating Real Savings on EDL and Diesel Bills

- **% EDL savings** $= \frac{\text{\#of solar kWh (EDL cost} - \text{Solar cost)}}{\text{total \# kWh x EDL cost}}.$

  Where EDL cost is 22 cents/kWh and the solar cost is 9.3 cents/kWh

- **% Diesel savings** $= \frac{\#\ of\ solar\ kWh\ (generation\ cost - solar\ cost)}{total\ \#\ kWh\ x\ generation\ cost}.$

  Where the generation cost is 0.3 cents /kWh and the solar cost is 9.3 cents/kWh

- **Average % savings** = W x f(1) + W x f(2) .

  Where W is the coefficient representing hours of EDL or diesel consumption during a day (e.g. W = 0.5 for 12 hours EDL consumption per day).

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