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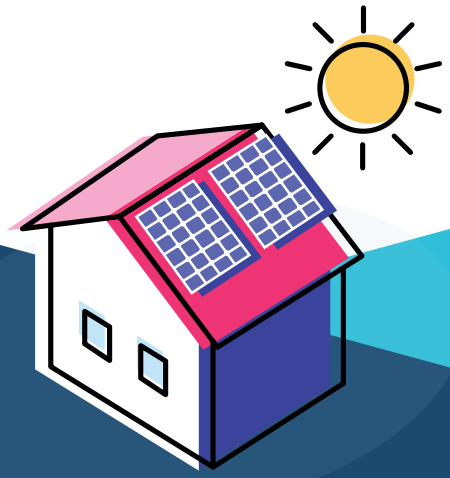
SOLAR PHOTOVOLTAIC SYSTEMS FOR RESIDENTIAL HOMEOWNERS:

A Guide to Selecting your Solar System with Battery Storage



September 2021

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01.

PURPOSE AND BENEFITS OF SOLAR PHOTOVOLTAIC (PV) SYSTEMS

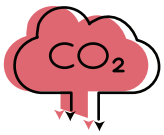
Investing in a solar PV system provides an alternative source of electricity that can reduce the burden of the extended hours of blackouts that Lebanon is currenty facing (as of September 2021) from either the national grid or due to the shortages and costs of diesel for backup generators.

The benefits of solar photovoltaic systems are as follows:

- Can be designed for a variety of applications and operational requirements, and can, therefore, be adapted to the user's preferences.
- Once the solar PV system is properly installed, it will only require minimal maintenance. Solar PV systems offer sustainable electricity generation, as they rely on a natural resource (sunlight), and their operations doesn't create any noise or pollution.
- Since photovoltaic systems are modular, it is easy to expand them or, even, if required, relocate them.
- Although the solar PV system upfront supply and installation costs are relatively high, it is important to keep in mind that a solar PV system will reduce your electricity bills will reduce your electricity bills annually over 20+ years.

All the above can be achieved while:

Increasing the home's value due to the addition of the solar system and corresponding equipment.



Helping the environment and improving public health, by reducing greenhouse gas emissions and thus your carbon footprint.

02.

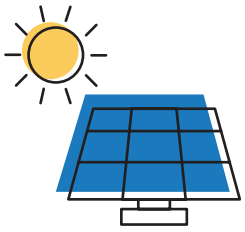
Solar PV Systems – Components

A solar PV system has three main components:

1. Solar Panels (i.e. the generator)
2. Inverter and controller, the latter is used in systems with battery storage only
3. Batteries (i.e. the storage)
4. Solar structure
5. Types of solar PV systems

2.1 Solar Panels

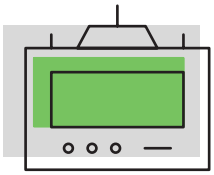
Solar panels use sunlight as a source of energy to generate direct current (DC) electricity. The size and number of PV panels will define the capacity of the PV system. PV capacities are commonly referred to in kWp.



2.2 Inverter and Controller

INVERTERS

A solar inverter is a type of electrical converter which converts the variable direct current (DC) output of a photovoltaic (PV) solar panel into the utility frequency alternating current (AC) that can be fed into the electrical grid or used at home or in your business. Solar inverters have embedded charge controllers to charge batteries from the sun and from the existing grid (if need be). These inverters are called Hybrid Inverters or Battery Inverters.



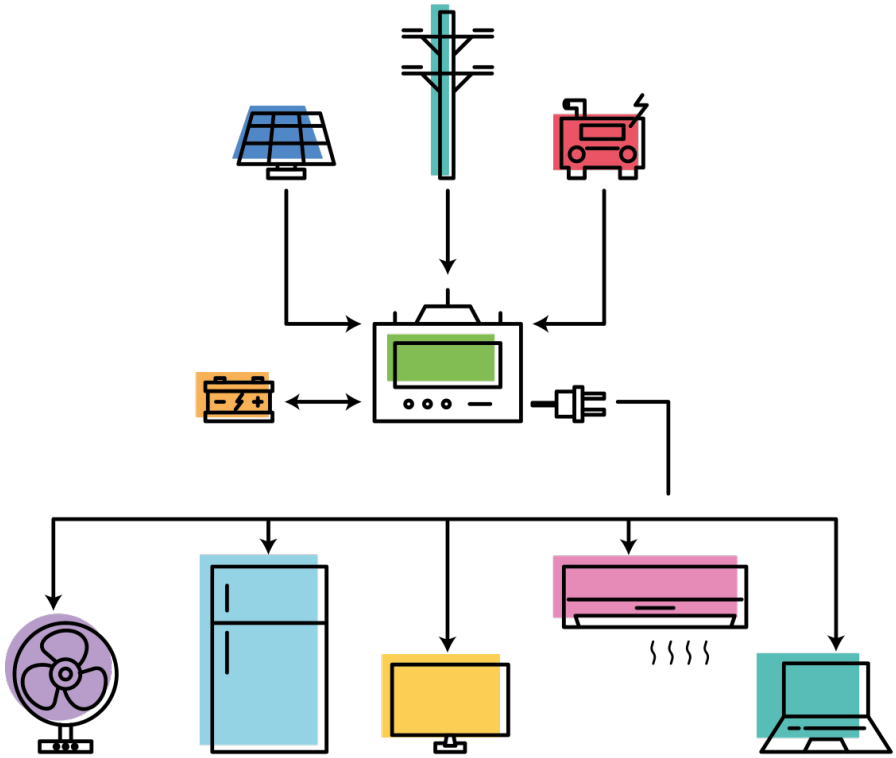
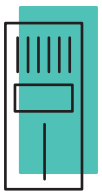


FIGURE 1: PV SYSTEM WITH HYBRID INVERTER

CONTROLLER

Charge controllers regulate the DC from the solar panels to make sure that the batteries don't overcharge. A charge controller can measure whether the batteries are fully charged, and can stop the current from flowing in order to prevent the batteries from being damaged.

All battery inverters have the option to autostart the standby diesel generator in case it is present, to charge themselves if needed.



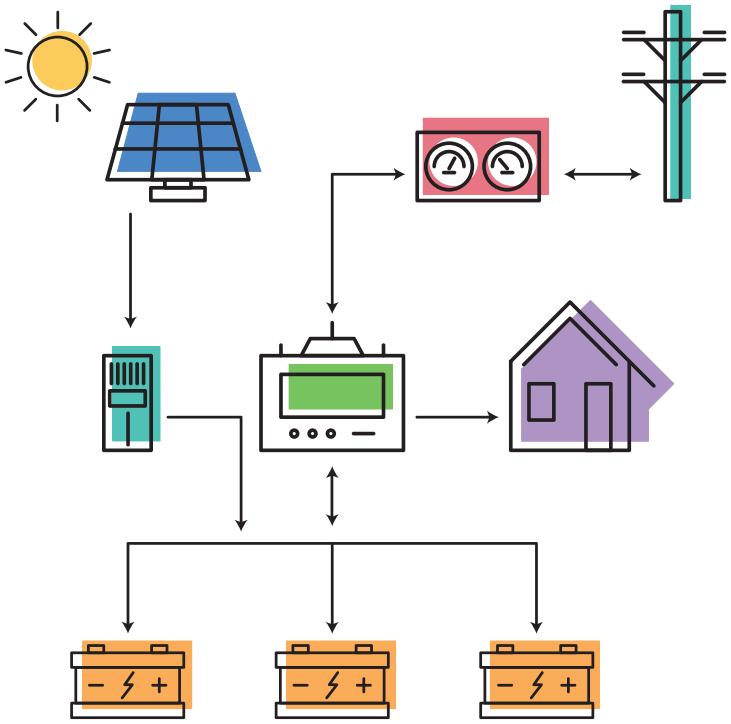
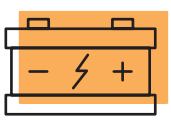


FIGURE 2: PV SYSTEM WITH CHARGE CONTROLLER AND BATTERY INVERTER

2.3 Batteries

Batteries accumulate excess energy created by your PV system and store it to be used at night or when there is no usable solar energy (such as on cloudy days). The performance of your battery depends on climate, location, and usage patterns (charge/discharge of battery, cycle history in cases of lead acid batteries). Battery capacity is commonly referred to in kilowatt hour (kWh) or Ampere hour (Ah).

Below is a comparison between the 2 commonly found types of batteries in the market (Lead Acid vs Lithium-Ion):



DESCRIPTION	LEAD ACID	LITHIUM-ION
Availability	It has been used for several years and is widely available.	Relatively new technology that is in high demand in new applications, especially for electric vehicles and renewable energy
Compatibility with Inverters	Compatible with most inverters and charge controllers	Not all inverters accept lithium-ion batteries, but new inverters should be
Cost	Cheaper than lithium-ion and local prices range between 135$/kWh to 160$/kWh depending on the origin &quality	More expensive - Local prices range between 260$/kWh to 430$/kWh depending on quality and origin
Lifetime	Depends on the cycles and the depth of discharge history. Average 1,500 cycles in a lifetime	Longer lifetime and depends on the cycles. Average 5,000 cycles in a lifetime. Not affected by depth of discharge history
Deep of Discharge (how much we can discharge the battery)	battery, the usable capacity is 50Ah60-Ah. More batteries will need to reach the desired capacity and more cables and space	Up to %90: Most of the battery rated capacity can be used and few numbers of batteries are needed when sizing the system
Charging time	Requires longer charging time due to limitations on charging current	Requires temperature monitoring and typical protection equipment (fuses, breakers)
Protection	Requires temperature monitoring and typical protection equipment (fuses, breakers)	Requires battery management system (built-in) which protects the battery from high temperatures, overcharge/ discharge, short circuits and regulates the charging process of the battery
Space requirements or volume	Needs larger space since lead-acid has a lower energy density, between 90-50Wh/L. Lead acid batteries are heavier	Requires less volume due to higher energy density that is between 600-125Wh/L. This is an advantage when space is a constraint

TABLE 1. COMPARISON BETWEEN LEAD ACID VS LITHIUM-ION STORAGE

2.4 Solar Structure

The structure is an additional component to any system to be installed that affects the cost of the system and its aesthetics. Mounting structures provide support to the PV modules with a specified orientation and tilt angle. The tilt angle depends on the location's geographical coordinates. The tilt angle should be adjusted to have the solar panels capture perpendicular sunlight for best output. Optimum tilt angle doesn't only depend on the location but it differs between summer and winter. For Lebanon, 25-30 degrees are the optimum tilt angles for best PV production. Solar panels connected in series or parallel must have the same tilt angle and orientation and should be of the same electrical specifications (same voltage and current).

Some examples for fitting solar systems to buildings are shown in Figure 3.

Installation on flat concrete slab with counter-weight ballasts

Installation integrated in the facade of the building

Installation is ground mounted

Installation on elevated structure on roof

Installation directly on tiled roof

Installation on car port / elevated structure

FIGURE 3. SOME EXAMPLES OF SOLAR PV PANEL INSTALLATIONS

2.5 Types of solar PV systems

Grid-tied systems

Grid-tied configurations consist of connecting the PV module to the grid with no battery backup. This means that if the grid goes off, the PV system goes off as well. The payback period of such system ranges from three to five years.

Off-grid systems

Offgrid systems consist of connecting the photovoltaic (PV) panels to a battery storage system that would provide electricity in situations where utility power is not available. The payback period of such systems ranges between five to eight years.

Hybrid Systems

Hybrid systems are systems that would be connected to the grid, but would still include a battery bank that allows the system to store energy and supply it when needed. Therefore, the main difference between grid-tied and hybrid systems lies in the availability of providing power during blackouts and the possibility to back up a specified power load with a particular autonomy.

In hybrid systems there are two types of loads:

CRITICAL LOADS

Electrical devices that require back up when the power grid fails.
These loads need to be separated from other loads and connected to a different sub-panel.

NON-CRITICAL LOADS

Electrical devices connected to the main panel that will not be backed up during the grid failure.

03.

PLANNING YOUR OWN SOLAR PV SYSTEM; DEMAND, SOLAR CAPACITY, COST

For home owners wishing to purchase a solar system, the size and options available are contingent on their energy needs and on the non-shaded roof area available, subject to the home-owner's budget constraint. Accompanying this Technology Brief is an excel sheet that you can download to input the power consumption demand that you require at your residence (kindly check the www.cedro-undp.org).

Table 2 provides you with an example.

Necessary Daily Use of Energy During Utility and/or Generator Blackout				
APPLIANCE	QTY.	POWER RATING [Watt]	RUNNING TIME [hrs.]	ENERGY CONSUMPTION [kWh]
LED lighting	10	9	9	0.81
Air conditions (9000 BTU)	1	850	8	6.8
Internet Router	1	20	8	0.16
LED TV	1	150	3	0.45
Laptop	2	120	5	1.2
Fridge	1	350	5	1.75
Water Dispenser	1	200	3	0.6
Other Appliances	1	400	4	1.6
		Total of Energy Consumption		13.37 kWh

TABLE 2. PRIORITY APPLIANCES DAILY ENERGY USE CALCULATION

Different homes and preferences will lead to different power requirements for the sizing of the solar PV system. Table 3 outlines the options available in terms of solar PV capacities that can be found in the market in order to satisfy different demand or power loads. Other options, particularly larger systems, can also be designed and installed. The household example in Table 2 will thus require a solution found in either Option 3, conservatively, or Option 4.

UNIT	DESCRIPTION	OPTION 1	OPTION 2	OPTION 3	OPTION 4	OPTION 5	OPTION 6
kWh	Load in kWh	5.94	7.92	11.88	15.84	23.76	31.68
Ah	Equivalent loads in Ampere hours	30	40	60	80	120	160
Amperes	Approximate required Amp Capacity	5	5	10	10	15	20
kWp	Required PV Capacity	2	3	4	5	8	10
kWh	Required Battery Capacity	7.7	9.6	15.4	19.2	28.8	33.6
Ah	Required Battery Capacity Complere System)	160.42	200.00	320.83	400	600	700
Ah	Required Battery capacity (per Battery)	2* (80Ah - 48V)	2* (100Ah - 48V)	2* (160Ah - 48V)	4* (100Ah - 48V)	6* (100Ah - 48V)	7* (100Ah - 48V)
Hours	Assumed Battery autonomy	6	8	6	8	8	8
m^2	Required surface area	10	18	20	24	40	50

TABLE 3. SOLAR PV OPTIONS ASSOCIATED WITH DIFFERENT LOADS

It is to be noted that the above capacities / values are based on lithium – ion batteries and the system configuration.

A fully charged medium-sized battery system could store sufficient energy to power during the night appliances and energy uses such as lighting, fridge and lower-powered items (TV, phone, and laptops). However, the batteries will quickly run out if you put on heavy energy users like the following:

- Electric Water Heater
  (we highly recommend you install a solar hot water system for hot water!)
- Washing machine
- Tumble-dryer
- Electric Oven
- Steam iron

It is recommended to use the above equipment during the day when the sun is shining, to ensure a longer battery life. It is important to mention that the inverter capacity will determine the loads that can run simultaneously (kW) while the battery bank size will determine how long the loads could be used (hours of operation).

Financial Analysis of the solar sytems

Options for solar PV installations will be subject to the budget requirement for different systems, depending on their capacity and the required battery autonomy.

In this assessment, we focus only on lithium-ion storage, given the benefits outlined in Table 1. Table 4 indicate the costs and benefits of the same options identified in Table 3.

PV SYSTEM	OPTION 1 5A6-hr.	OPTION 2 5A8-hr.	OPTION 3 10A6-hr.	OPTION 4 10A8-hr.	OPTION 5 15A8-hr.	OPTION 6 20A8-hr.
PV System Size [kWh]	2	3	4	5	8	10
Average System Cost in USD*	5,000*	6,000*	11,000*	13,000*	20,000*	24,000*
Yearly Energy Savings [kWh]	3,400	5,100	6,800	8,400	13,500	16,900
Annual Savings with an average of $0.17/kWh	578	867	1,156	1,428	2,295	2,873
Savings of CO_2 in Kg	136	204	272	336	540	676

** Average values based on Lebanese market assessment undertaken by UNDP CEDRO team in August 2021. Actual costs may differ between different suppliers and installers depending on product quality, system design and site specific characteristics, warranties provided, and other parameters.*

TABLE 4. FINANCIAL ASSESSMENT OF SOLAR PV WITH STORAGE OPTIONS

Important factors to consider when installing a solar PV system

Available Space at the house and roof inclination

For the PV system to optimally perform, the PV panels should receive adequate solar radiation, as they work well in areas with sunlight coverage. It is recommended to avoid shaded areas where the efficiency will decrease drastically. The available space is critical to define the PV capacity that could be installed.

The energy requirement of the property/home

The energy needed determines the types of solar systems that can adequately meet the power demands of a home. There are several types of solar systems, depending on the manufacturing company, which designs them in different sizes and capacities of performance (see Tables 2 and 3).

The contracting company

Picking a solar company with a solid track record has a myriad of advantages. Suppliers dealing with quality equipment will probably provide warranties and at least regular servicing and maintenance of the systems. They can provide longer warranty periods, some as long as 10 years. Moreover, they have the capacity to implement an expert installation of the systems. It is vital to research the best companies for the contract. A reference by a previous client can be of vital help.

Operation & Maintenance – Solar PV System

Operation & Maintenance (O&M) is one of the most critical ways to ensure that the solar power system gives the best possible generation. As solar panels have no moving parts, very little service and maintenance is required.

To keep the solar panels generating efficiently, an annual service is recommended to ensure your system is kept in full working order, and any fault or drop in generation is flagged immediately and resolved.

Maintenance recommendations on key parts of the solar systems are indicate below:

Modules

To clean the PV modules, just remove a layer of dust and dirt from the modules by washing the panel with cold water. If the module has thick dirt or grime and bird droppings, which are harder to remove, wash with cold water and rub the panel surface with a sponge. Do not use a metal brush to clean solar panel surface. The optimum time for washing the panels are early mornings or late afternoon at least once during Spring, Autumn, and Summer seasons unless unusual events occur (such as dust from a nearby construction site). On higher altitudes, solar systems may be covered by snow in winter and will thereby require the clearing of snow on a needs basis.

Studies show that cleaning improves output on average by 6%. For PV modules that have been neglected, the output might decrease beyond 30%.

FIGURE 4. SOLAR PANEL CLEANING WITH WATER

Batteries

- Lead-Acid Batteries (flooded type and vented battery): Check the liquid level for batteries every 3 months. In case it is under the marked level, distilled water needs to be added until reaching the marked level.
- Lithium-ion Batteries: Monitor the battery voltage on the Battery Management System (BMS) Screen regularly.
- Ensure proper ventilation of battery room to keep battery temperature low (temperature > 30°C will cause a substantial reduction of a battery lifetime.

Other components and general maintenance procedures

- Inverter: manufacturers recommend servicing it yearly, ventilation filter needs to be frequently cleaner
- Tighten cables on each junction and protection device (Circuit breakers, inverter connections, distribution boards). Loose connections can cause fire!
- Cabling connectors: ensure that there is no gap between the male and female connector pipes
- Protection from external elements:
  To ensure that the plant is working smoothly, the cables must be sealed properly
- General Maintenance Procedures:

1. Ensure roof drainage is adequate, roof drains are not clogged, and confirm that there are no signs of water pooling near the array
2. Check for corrosion on the outside of enclosures and the racking system
3. Check for loose hanging wires in the array

- Warranty: Complete systems are often only warranted by the installer for one or two year(s). However, the manufacturer‘s warranty will apply for the respective components. Typically, up to 25 years warranty are provided for PV modules, two years warranty for inverters and 1 year warranty for batteries. It is vital that you ask your suppliers on the warranty of the system as a whole and of the components.

04.

NET METERING

When you install your solar PV system, make sure you tell the contractor that you would like to submit an application to EDL's net metering program. Net metering is a process under which power generated by your solar system (or any other type of distributed renewable electricity-generating source) may be exported to the national grid and used to offset electricity imported from the national grid. As an example, if you are out on Sunday and the sun shining, your solar PV system will be generating power that you may not use. This power will then be exported to the national grid. EDL will apply net metering in this case and measure this exported power over each billing cycle. EDL will then bill you only for the net amount you used from EDL, i.e., the EDL electricity imports you used minus your solar electricity exports to EDL. Find out more and how to apply to net metering on the following link http://www.edlnetmetering.com/.