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EXPECTATIONS AND DISAPPOINTMENTS OF SMALL AND MEDIUM-SIZED SOLAR PV POWER PLANT PROSUMERS

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Abstract

Many small investors are considering small and medium-sized photovoltaic (PV) plants as a solution for generating additional renewable energy and gaining quick and easy returns on the investment. However, relying solely on commercial data for investing in such PV plants is not advisable, as several factors may later, during the operation phase, negatively surprise those investors. This paper discusses potential obstacles these small investors may face while investing, operating, and selling electricity generated by such PV plants. The study shows the mismatch between expectations and disappointments regarding the outcomes of such PV plants, further reinforced by recent market analyses and studies in the USA and Spain.

Keywords*: Renewable energy sources (RES); Photovoltaics (PV); Prosumers; Economics; Return on investment.*

INTRODUCTION

The reduction of reserves in primary energy sources, especially fossil fuels, which are currently the dominant source for generating energy, has a strong negative impact on the environment and wildlife. This calls for emergency steps towards utilizing other energy sources and a global energy transition. The energy transition refers to a shift in how we obtain and use electricity, replacing fossil fuels with renewable energy sources (RES) such as solar and wind energy, tidal energy, biomass, biogas, and recently, energy derived from hydrogen and fuel cells. This shift provides significant benefits to various participants in the energy cycle, such as production companies increasing their equipment production volume and turnovers, investors improving their investment portfolio and return on investment, and energy consumers obtaining needed energy from technologically advanced, economically affordable, and environmentally friendly sources.

One of the biggest challenges facing the widespread use of RES is their unpredictable generation patterns, which can lead to issues with market balancing and integration into existing power grids. To address this, smaller RES power plants have been established that can generate electricity for their owners, but also sell excess power to the distribution network. These fresh players in the market are called *"prosumers,"* which is a combination of *"producer"* and *"consumer."*

Small and medium-sized power plants utilizing solar energy can be attractive investments for prosumers. However, several facts and issues can be problematic for any investor or prosumer interested in constructing and utilizing such power plants. Therefore, it is crucial that potential prosumers carefully investigate these potential drawbacks before making a final investment decision (Jahn, 2003; Mertens, 2014).

In this paper, the authors present several lesser-known facts about the energy production of a solar PV power plant (Jahn, 2003). We will demonstrate that the data presented to potential investors/prosumers about business and financial plans are not always precise and reliable for several reasons. Hence, the expected amount of electricity generated and the projected income from the investment should be taken cautiously.

SOLAR PV POWER PLANTS IN BRIEF

Solar photovoltaic (PV) power plants are electric energy (EE) generation facilities based on the photovoltaic effect. The photovoltaic effect does not need any conductor movement, because in this process certain chemical elements called semiconductors are bombarded by solar energy quanta called photons generating at their terminals a potential difference, i.e., an electric voltage. These energy quanta called photons are fast subatomic and energy-rich particles with no mass and no electric charge that originate from inside the Sun. Each photon contains energy inversely proportional to its wavelength – shorter wavelength, larger energy, and vice versa (Mertens, 2014).

Our planet is constantly bombarded with such photon particles whose total energy far exceeds the energy needs of our planet. Unfortunately, we can use only a few percent of that total energy that constantly falls on the Earth's surface. Using this energy, PV cells directly convert photon's energy into EE. It is important to mention that the PV effect could generate only direct currents (DC), thus it is considered only a DC energy source. Consequently, additional power switching equipment, such as DC/AC converters, inverters, or similar are essential for the PV plant to be commercially applicable.

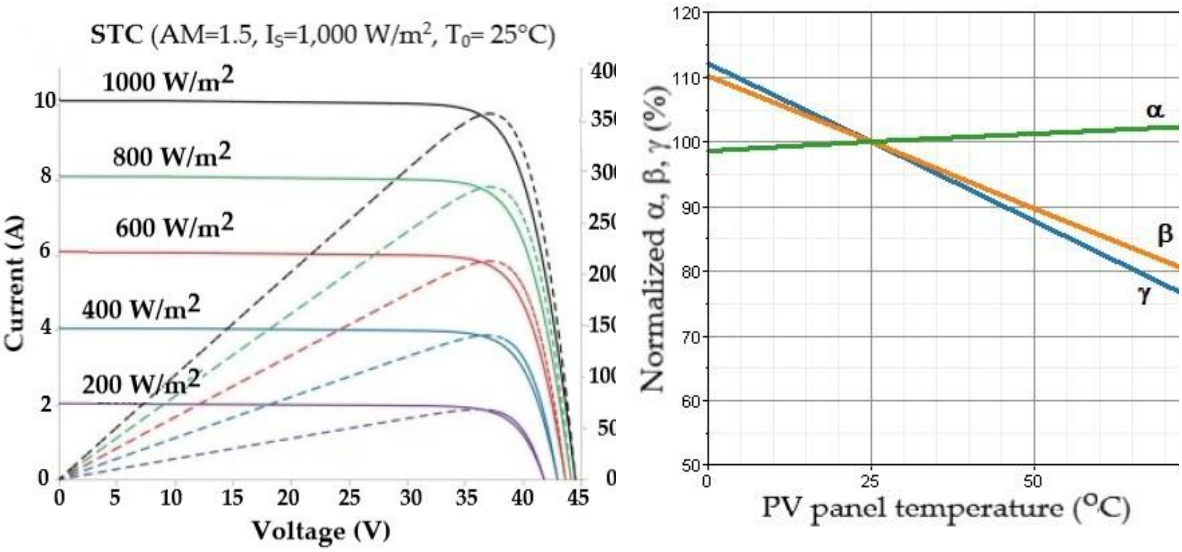
A single solar cell used in PV power generation has low energy density and generates only a small amount of energy, usually just a few watts. This is why they are typically grouped in modules, panels, and arrays, and then combined to form entire PV plants. As a result, PV power plants require large installation areas, ranging from hundreds to thousands of square meters, depending on their size.

MAIN CHARACTERISTICS OF SOLAR PV POWER PLANTS UNDER OPERATION

As a result of the so-called energy transition process, the need for additional EE, and limited so-called *"best-evaluated locations"* with the most favorable PV generation potentials, it is obvious that there is a huge *"hunger"* for easy and quick obtaining favorable locations and licenses for the installation and operation of new PV power plants. At the same time, prosumers who think that they can quickly, easily, and economically achieve production and consumption of EE for their personal needs or gain a quick return on the investment and financial profit by selling part or entire generated EE on the market, appear as the main license applicants. Simply, this *"photovoltaic fever"* included many subjects who do not know enough about the conditions in this extremely unpredictable sector.

One of the most crucial factors in setting up a PV power plant is choosing the right type and producer of PV panels, along with the corresponding DC/AC inverters that can convert the generated DC power into AC power that can be used by most consumers. There are several types of solar panels available in the market, including monocrystal or polycrystal type, monofacial or bifacial, one-piece, or half-cut type panels, agriculture-type panels, etc. Additionally, the same type of PV panel may come with different installed capacities and connections of PV modules within the panel. When selecting PV panels, investors should consider the installation location, their personal preferences, and available investment funds to maximize their benefits (Jahn, 2012). Commercial catalogs or brochures can provide a good starting point for the optimal selection of PV panels for specific locations and purposes. These catalogs typically provide basic information on each type of PV panel, such as maximum power, nominal power, operating voltage, current, and operating temperature. However, it is important to note that most of the data for a particular PV panel presented in these catalogs may never be achieved under real operating conditions.

If you are considering investing in renewable energy, it is essential to keep three crucial factors in mind when it comes to PV power plants. These factors can make or break the success of your investment, so it is vital to take them seriously. With the right considerations and foresight, investing in PV power plants can be a smart and profitable decision (Fthenakis, 2012):



a) *b)*

FIG 1. TYPICAL PV PANEL DATA: a) CATALOG DATA, b) TEMPERATURE COEFFICIENTS

- The maximum power output of a photovoltaic (PV) panel is usually declared under Standard Test Conditions (STC) which include specific internationally standardized operating conditions such as the angle of incidence of the incident sunlight AM, the solar radiation intensity I_S, and the ambient temperature T_0. However, these conditions are rarely, if ever, achieved during the actual operation of a PV power plant (Fthenakis, 2012; Jahn, 2012).

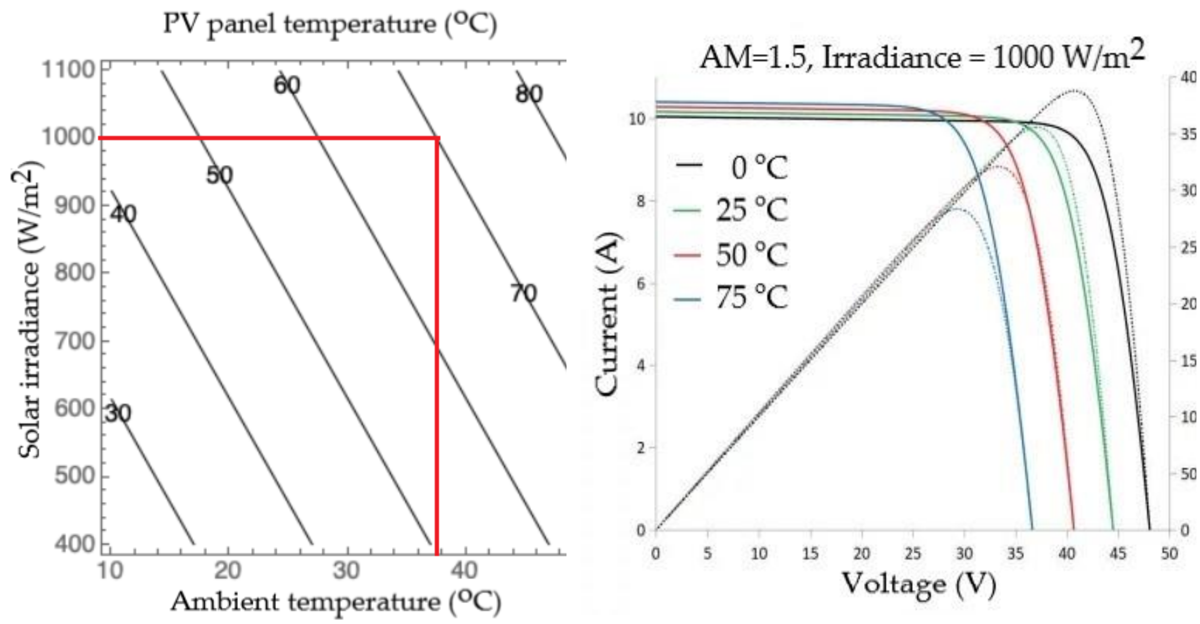
  As a result, the maximum power output declared in catalogs for PV panels can be misleading. For instance, as shown in FIG. 1a, a monocrystalline solar panel with a declared maximum power of 360 W under STC (AM=1.5, I_S=1,000 W/m^2, T_0= 25°C) could generate much less power under real operating conditions. If the solar radiation intensity drops from 1,000 W/m^2 to 600 W/m^2, the maximum output power of the PV cells could drop from the declared 360 W to around 220 W (Fig. 1a). Therefore, it is important to approach the catalog data for the maximum power output of PV panels with caution and more realistic output data reduce it by at least 5-10%.

- The amount of electricity generated by solar PV panels is strongly influenced by the ambient temperature (Paudyal, 2021; QPV Research Group, 2019). This is a lesser-known fact, especially for those not experts in PV panel production and usage. PV plant owners may notice reduced production or unexpected results. For instance, they may observe unexpectedly higher energy efficiency (EE) production per hour on a sunny winter day compared to a warm sunny day during the summer months.

  This is because PV panels have three coefficients that strongly affect EE production. These coefficients are the current temperature coefficient α, voltage temperature coefficient β, and power temperature coefficient γ. Their dependency on the ambient temperature at which the solar panel operates is given in Fig. 1b. The current coefficient α is usually positive but small, resulting in a slight increase in current output. However, the voltage coefficient β is always negative and dominant, decreasing the output voltage of the PV panels. This means that an increase in ambient temperature by 1°C leads to an increase in the output current of the PV panel by the value of the coefficient α but a decrease by the coefficient β, which is almost 10 times larger than α. These two coefficients contribute harmfully to the third one, the power temperature coefficient γ, which is also significantly negative with values of -0.4% to -0.5%. Thus, the output power of the solar panels also decreases by the value of such coefficient γ.

It is unfortunate that the temperature of a PV panel changes rapidly during operation and is highly dependent on the surrounding temperature (QPV Research Group, 2019). FIG 2a provides an estimated correlation between the PV panel temperature, the ambient temperature, and the amount of solar irradiance. For instance, if the solar irradiance is 1,000 W/m^2 and the ambient temperature is 37°C, the estimated PV cell temperature could be as high as 70°C. At this temperature, the PV panel cannot achieve its maximum power production, although the solar irradiation is very high.

Fig. 2b provides a better estimate of the operational characteristics of a single PV panel under different ambient and panel temperatures. If a solar PV panel operates under STC (25°C), the output voltage is 44.5 V, and the maximum power is 360 W. However, if the panel temperature rises to 75°C, then the output voltage drops to 36 V, and the power drops by 22% down to a modest 280 W. The opposite effect is true when the PV panel temperature drops to 0°C. The voltage increases to 48.5 V, and the output power rises by 7% up to 395 W. During summer periods and in locations where PV power plants are installed, the ambient temperature can rise from the nominal 25°C to 40°C, causing the panel temperature to reach 75°C, and the output power of each PV panel decreases by 20%. The opposite is true when the air temperature drops from 25°C to 0°C; the output power increases by 10%. This leads to an apparent energy paradox; PV panels provide hourly more EE during cold but sunny winter days than during hot sunny summer days. However, during the winter period, the daylight is significantly shorter, so there is a lower amount of sunshine, and in general, the daily EE production is lower than the rest of the year. Therefore, it is crucial to provide the best possible cooling conditions for the solar PV panels to reduce their ambient operating temperature.



a) PV panel temperature and solar irradiance influence vs. ambient temperature

b) Output voltage, current, and power vs. solar PV panel temperature

FIG 2. DEPENDENCY OF SOLAR PV PANEL OPERATIONAL CHARACTERISTICS VS. AMBIENT AND PANEL TEMPERATURES

- The third factor that must be considered while preparing a business plan is the reduction in the performance of PV panels over time. This means that with the years of operation, the panels will generate less power from the same amount of sunlight. Various external factors such as weather conditions wear down the panels, reducing their capacity to generate power. Micro cracks that occur in the silicon of the PV panel and the weakening of the electrical connections due to these little fractures result in fewer pathways for the electrons, and therefore less energy reaching the inverter, generating over time less EE power (Svarc, 2023). Moreover, moisture, heat, humidity, ice, and ultraviolet (UV) exposure are the primary factors that cause PV panel degradation, all of which are due to natural causes. The efficiency of a PV panel, which is usually given in the catalog at the time of installation, is between 18% and 24%. However, over the years of operation, its efficiency decreases on average by 0.3% to 1% per year. In other words, the generation of EE under the same operational conditions in 10 or 20 years of operation could be 6% or 20% less than what was expected at the beginning of operation. Table 1 shows the amount of degradation of several LG solar PV panels compared with the other industry average PV panels (Global Solar Report, 2023).

TABLE 1. PERFORMANCE WARRANTY: LG SOLAR PANELS VS. INDUSTRY AVERAGE

Year of operation	LG solar panel type			Industry Average
	NeON$_R$	NeON$_2$	Mono X Plus	
New	98.0 %	98.0 %	97.5 %	97.0 %
After 1 year	97.7 %	97.6 %	97.1 %	97.4 %
After 10 years	95.0 %	94.7 %	93.5 %	91.0 %
After 25 years	90.8 %	90.0 %	87.9 %	82.6 %

Source: Global Solar Report (2023).

Aside from these three main factors already mentioned that contribute to the decline in the performance of PV panels from their original rating, other factors cannot be avoided over time. These include system or component failures, shading of PV panels, frequent inverter problems, long repair times, bad orientation of PV arrays, and more. Often, the actual amount of energy generated by a PV plant does not align with the expected amount as outlined in the business plan. This discrepancy can cause frustration for investors and make it difficult to achieve the expected investment return rates and payback periods. Therefore, conducting a long-term analysis study is essential for obtaining more accurate predictions and business plans before proceeding with the investments and construction of any new solar PV plant.

COMPARISON BETWEEN EXPECTED AND ACHIEVED ENERGY PRODUCTION

Recently, surveys of the PV markets in the USA have been conducted to gather data on the profitability and realization of expectations from investments. Unfortunately, the results are quite concerning. The US company Raptor Maps regularly releases annual solar reports (Global Solar Report, 2023). In their fifth annual report from 2022, they analyzed existing PV power plants with as much as 24.5 GW of installed capacity and discovered that the loss of electricity relative to the assumed amounts led to an estimated loss in annual revenue from targets of $ 82 million. If this analysis is extended to the entire industry excluding households, the revenue losses are likely to reach as much as $ 2.5 billion. The dissatisfaction with the operation and performance of solar PV projects has almost doubled, from 1.61% in 2019 to 3.13% in 2022, with a tendency to continue to grow in the future.

This study shows that the problems of failures in operation and performance expectations depend on the installed capacity of the plant. Smaller sites exhibited the most variability in power loss and the highest average power loss as a percentage of their total generation capacity. This fact has a special negative impact on the small and medium size PV power plant's prosumers. Smaller ranges in power loss as a percentage of total site capacity were observed in larger site sizes. However, the largest sites tend to exhibit higher average power loss. For example, for sites with less than 5 MW installed capacity, the amount of max power loss was above 85%, while the average loss was about 4%. The average power loss for the entire range of installed capacity was 3.4%, varying between 5.1% for the PV plants with installed capacity between 10 and 20 MW, and 2.17% for the PV plants with installed capacity between 50 and 100 MW. These power losses bear a heavy revenue burden: for PV plants with an installed capacity above 200 MW, the average drop in expected production has tripled compared to 2019, from 1.1% to 4%, with a tendency to be as much as 6% in 2025. In conclusion, PV plants larger than 200 MW have an economic loss of about $ 4,329 per installed MW on average, with some plants losing as much as $ 12,900 per installed MW, or between $ 1 and $ 2.5 million annually.

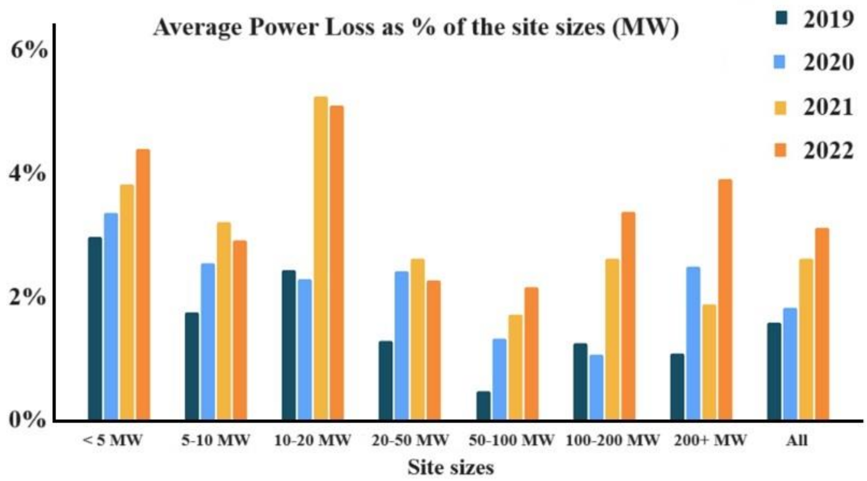


FIG 3. AVERAGE AMOUNT OF POWER LOSS IN % VS. PLANT SIZE COMPARED TO 2019
Source: Global Solar Report (2023).

Data presented in Fig. 3 shows that power loss has significantly increased across all sizes of PV plants since 2019. The average increase in power loss is given in Table 2.

TABLE 2. AVERAGE INCREASE IN POWER LOSS VS. INSTALLED CAPACITY

Installed Capacity (MW)	Average increase in power loss
50 – 100	+ 336 %
100 – 200	+ 168 %
200+	+ 267 %
For all sizes	+ 94 %

Source: Global Solar Report (2023).

Therefore, the analysis concludes that as PV plants become larger and more complex, asset owners and managers should have access to the right tools to manage the health of their sites effectively. Any unexpected deviations from expectations could result in significant financial losses for investors, particularly in the case of private investments. This situation is even worse if the investor is a prosumer who expects to achieve a self-sufficient energy supply and sell excess energy to the local power grid.

Additionally, another recently done study conducted in Spain on the economic performance of various PV installations, such as single-family houses, multi-family houses, and apartment block housing, provides relevant data on investment and expected energy generation for PV plants (Fuster-Palop, 2023).

This study was done for the small housing community of the app. 3,500 houses in the Mediterranean region which makes it exceptionally reliable for our purposes because it deals with a location with significant solar irradiation. The most important conclusion derived from analyzing multiple load profile scenarios revealed that the potential self-sufficiency of the municipality ranges between 21.9% and 42.5%. In other words, the prosumers who are the largest number of investors and who expect that their PV power plant would supply them with enough electricity for their personal needs, and the excess generated power could be sold on the local electricity market, at most could expect to cover only 42% of their electricity needs. Considering the prices for electricity offtake by the power grid, which is usually not very favorable, the investment could not achieve the expected business outcome. In such cases, the expected payback period of the investment could last between 6.75 and 9.07 years and strongly depends on the capacity of the installed PV plant. The shorter payback period correspondence with the 4.68 kW while the longer payback period was obtained for the 9.2 kW installed PV plan capacity (Fuster-Palop, 2023). This data shows that some mitigation actions should be considered or even taken before reaching a final decision for investments by potential prosumers.

POTENTIAL MITIGATION ACTIONS

Considering the differences between expected and achieved goals for the installed PV power plants, we must strongly consider potential mitigation actions that might improve the outcomes regarding the amount of generated EE and expected financial investment benefits. To be realistic, there are some other well-known obstacles in power generation using RES, in general, due to their stochastic nature. Thus, it is not possible on a long-term basis to exactly predict the amount of available energy sources for power generation, e.g. the amount, direction, and duration of wind for wind power generation, or the amount of solar irradiation, sunlight duration, or the amount of shadowing of the panels due to various unfavorable weather conditions, such as clouds, fog, dust, snow or even rain, or due to other solar obstacles such as local vegetation and artificial constructions around PV power plants. In such cases, some mitigation actions must be taken.

To begin with, PV power plants can only operate during daylight, which means they are unusable during the rest of the day. However, the need for EE is constant throughout the day, and therefore an additional energy source is required to ensure a stable, reliable, and secure EE supply. There are several options available to address this issue, including:

1) Connecting the PV power plant to the local power grid if it is economically feasible,
2) Using another more stable energy source such as a diesel unit, hydropower unit, or similar, and
3) Installing an energy storage unit that can store the generated energy that is not used while the PV power plant is in operation.

Each option requires additional investments, whether it be in the local grid connection, procurement of other generation units, or the procurement and installation of energy storage systems. Each option has its pros and cons that must be considered before making a final investment decision.

Although connecting the PV plant to an existing power grid is a reliable option, it may be expensive, especially if there is no nearby suitable power grid. However, this option provides the opportunity to sell excess electricity generated by the PV plant if allowed. On the other hand, investing in stable energy sources like diesel or small hydropower units requires additional investments. Additionally, the installation, operation, and maintenance costs can be a significant burden for the PV plant owner. Nevertheless, owning a generation unit provides energy independence and security, especially if the cost of connecting to the power grid is too high or not feasible. Finally, investing in additional energy storage units such as batteries could be a reasonable solution as they require lower O&M costs than independent power generation units. However, these storage facilities have a limited number of charging and discharging cycles, and their storage capacity decreases over time due to their limited life expectancy, which varies between 5 and 10 years depending on the producer.

Excess energy generated by PV plants can be saved in multiple ways, including chemically in batteries, mechanically using flywheels or compressed air, and thermally in thermal batteries. Depending on the amount of excess energy and the needs of the consumer, thermal batteries can be a favorable option, especially for industrial customers that require heat in their production process or commercial buildings such as hotels that need heating and/or cooling of their facilities. Thermal energy conservation is also a feasible choice for locations with harsh weather conditions, particularly for areas at high sea levels where the number of sunny days in winter is higher than in lower regions due to the lower height of clouds.

After considering all the points mentioned above, it is more suitable for areas like these to move away from installing solar PV power plants and instead focus on installing solar-thermal power plants. This way, instead of generating electricity, thermal heat can be directly generated using solar energy. This solution is also beneficial for small-scale investors such as households, apartment buildings, or farmers. It is important to note that a significant amount of electricity consumed in a typical household or apartment building is used for heating purposes such as generating hot water or heating the living or working space.

Small farmers face a similar situation when it comes to meeting their energy demands. They need to heat their animal farms, produce meat and/or milk products, heat their houses, or power any biogas production facilities. Therefore, before investing in a solar PV plant, each investor/prosumer should have a well-defined business plan and strategy outlining their energy needs. Do they require fuel-free electricity or fuel-free heat energy? By carefully defining their needs and potential for a long-term period, they can make the right investment decision, whether it be in solar PV or solar-thermal power plants. Solar-thermal power plants have lower investment costs and easier and lower O&M costs than PV power plants. Furthermore, they come with heat boilers that can act as energy storage devices, generating hot water and eliminating the need for additional storage. This feature improves the quality of the installation, provides additional independence, and improves the return on investment and overall business.

FINAL REMARKS AND CONCLUSIONS

The use of solar power has become an attractive investment opportunity for many investors, including small household owners and larger-scale investors. However, most of them lack knowledge about renewable energy sources and the characteristics, opportunities, and problems with harnessing solar power. Investors need to conduct a thorough techno-economic analysis before investing in solar PV power sources. Without proper analysis and a sound business plan, the project may not generate the expected amount of energy or commercial benefits.

In this paper, two sets of problems have been identified and discussed. The first set of problems, called objective problems, arises from the nature of the PV technology and its development status, which mostly do not depend on human factors. The second set of problems, called subjective concerns, relates to the needs and expectations of the potential investors, e.g., whether they want to become self-sufficient in their electricity needs, become energy producers, or both. Studies show that neither fully self-sufficient EE generation could be achieved, nor expected investment return rate or payback periods could match what is usually presented in the business plants before making final investment decisions. Thus, careful reevaluation of all relevant data must be done with respectful due diligence.

The paper also proposes some potential mitigation actions that may improve the economic parameters of the available investments, such as additionally connecting to the local electricity grid, installing batteries for energy storage, and considering investments shift from PV power plants for EE generation into solar-thermal power plants that primarily generate heat instead of EE.

In conclusion, investors must conduct a thorough analysis before investing in a PV power plant. They should ask questions about the expected benefits and the quantities of expected energy production. The problems are substantial for the owners and managers of larger PV plants, for which a centralized and standardized system is essential for the PV industry to grow and achieve expected performances reliably.

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