Profitability Assessment of Building Integrated Photovoltaic Systems through Comparative Analysis of Energy Policies using Real Data Sets

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***Abstract*—The consumers with building integrated photovoltaic (PV) systems have become prosumers, and their profit depends on network regulations, especially in the treatment of surplus electricity. Net-metering and feed-in tariff are the most common remuneration mechanisms for prosumers. Increasing the number of prosumers can cause various technical problems in the grid, therefore the distribution system operator sometimes imposes legal/regulatory and technical restrictions that are reflected in zero energy export. Integration of the energy storage systems can help with problems arising from these restrictions, but will make the initial investment significantly more expensive. This may negatively affect the profitability of investment. The main aim of this paper is analysis of different regulatory policies and their impact on building integrated PV system profitability. Two profitability metric factors were calculated for the purpose of better policy comparison. For the presented analysis, real data sets of a load demand and PV energy production were used. As an example, the integrated PV system installed at the Faculty of EE University of Sarajevo is analyzed.**

***Index Terms*—energy storage system, net-metering, photovoltaic system, profitability, zero energy export**

I. Introduction

This generation is a witness to a power system shift towards decentralization, sustainability and renewable energy sources (RES). The goal of achieving net-zero emissions can be done by introducing as many RES as possible. The switch to greener energy system involves energy producers, as well as energy consumers, who can adjust their consumption to better accommodate RES production. Alongside to decentralization process, there is another important paradigm change in the power system: from the traditional categorization of power producer/power consumer to the modern idea of prosumers, the consumers which produce power for their own use, therefore being producers at the same time. There are four types of prosumers mentioned in literature: residential, community/co-op, commercial and public [1]. Depending on the distribution system operator (DSO) policy, prosumers can export the produced power, or a part of it to the grid. The prosumer idea also has the additional benefits of enhancing the local electricity self-sufficiency ratio and lowering net load fluctuations [2].

PV systems are becoming the leading elements in distributed, cleaner and more efficient power generation, and can be used as the means of reducing maximum demand charge as well as energy losses. They are cost-effective source of electricity, accessible to an individual investor but also interesting to utility companies and large power system investors. The technological advancement related to power converters and solar power conversion, environmental awareness and favorable policy incentives are all factors driving the popularity of PV systems, thus making them a significant component in global energy mix.

Depending on the power system regulations and policies, there are several remuneration mechanisms often used for compensating PV owning prosumers for their energy contributions to the grid. The most used policies are feed-in-tariff (FIT), net-billing (NB) and net-metering (NM) for power systems which allow export of excess energy to the grid, differing in the remuneration for the prosumer. Another possibility which will be explored is the zero energy export (ZEE) policy, which is the regulatory restriction of not allowing export of energy in any amount, often for small PV systems. Use of ES can also be favorable for PV systems efficiency and profitability, therefore it will be examined in that context.

The authors acknowledge the support provided by the Ministry of Science, Higher Education and Youth of Canton Sarajevo, B&H, for funding this work. Authors are thankful to Luxor Solar GmbH and SMA Solar Technology AG for donating equipment.

One or more of the profitability indices can be used to explore whether an investment to a PV system installation is profitable or not. Profitability index is a rule based decision making metric, that helps the investor decide whether to support the proposed project or not. Two of the most used profitability indices are the net present value (NPV) and internal rate of return (IRR). NPV is a potential change in wealth resulting from the project, and IRR is a discount rate that makes the net present value of all cash flows regarding the project equal to zero thus giving the investor information whether the future cash flows would equal to zero or exceed, thus bringing profit.

Researchers are exploring the profitability of PV installations depending on different factors, and in various legislative frameworks. In [3] authors explored profitability of installing PV panels and heat pump for household sized prosumer, where payback time was used as profitability factor. Similar conditions were explored in [4] where household PV profitability was calculated based on NPV, IRR and modified IRR indices while accounting for availability of public financial support. Adding battery ES to a PV system was assessed in [5] where battery operation strategies were studied depending on several economic factors, and in [6] where different sizes of PV systems were explored based on IRR in a FIT policy system. The Croatia energy legislation was considered in [7] for assessing PV size based on economic factors like NPV, levelized cost of electricity and return of investment. Some new social models of PV prosumers like collective self-consumption framework were explored in [8] where profitability was considered depending on several policies regarding distributing the profit among members of the collective. Most of the literature refers to the analysis in the NM policy environment. None of the reviewed literature explores the option of ZEE regulatory policy which will be included in this paper.

One can conclude that the economic performance of PV systems is more interesting to the potential investors than the technical aspects of the system, namely control and monitoring. The regulatory changes happening all over the world regarding energy tariffs related to RES make new research on profitability of different options desirable. This paper will explore options of financial viability of PV investment in the framework of several different regulatory policies. The aim of the paper is to provide the possible investor with useful information on profitability of PV investment in different regulatory environments. By examining the explored economic perspectives, policymakers or investors can make informed decisions regarding the deployment, financing, and regulation of renewable energy systems, thereby accelerating the power system transition to a more sustainable and resilient energy future.

This paper is organized as follows. The most popular energy policies are presented in Section II. Section III provides an energy management flowchart for different energy policies. In Section IV, a case study for considered PV power plant installed at the Faculty of EE University of Sarajevo is presented, followed by Section V giving its results and discussion. Finally, Section VI summarizes the main conclusions and offers some future steps.

II. Energy Surplus Policies

Due to the changing power demand as well as significant intermittency in RES power generation due to weather conditions, it is inevitable to have energy surpluses at least during some time intervals. The energy surplus can be handled in a different manner, which is determined by the legal policies imposed by the DSO. The most popular policies are: FIT, NB, NM and ZEE. Each of these mechanisms has its advantages and disadvantages, and the choice depends mostly on regulatory policies in the considered power system.

A. *Feed-in-tariff*

This mechanism is recently becoming outdated, as it was used in the early stages of RES use, with goal of supporting RES growth. It is an government set incentive to increase the RES deployment in which there is a guaranteed price, typically higher than the standard retail price, paid to RES owner for each unit of power they generate. The prosumer would, in this case pay for their full consumed power, but would receive separate payment for the generated power.

B. *Net-billing*

The NB policy is a remuneration mechanism, where the prosumer uses the generated power on site and any excess energy is transferred back to the grid at a predefined price [9]. The compensation for the exported power is typically lower than the retail price, thus encouraging the prosumer to use as much generated power on site as possible. In this way this mechanism protects the power system from the intermittency of RES generation.

C. *Net-metering*

The NM policy is usually more in favor for the prosumers than NB. The prosumer still uses the generated power on site as much as possible, and all the power exported to the grid is paid at market retail price. In NM policy, the idea is to encourage the prosumer to match their generation to their total consumption as closely as possible thus lowering the electricity bill for the prosumer.

D. *Zero Energy Export*

ZEE policy is a regulatory approach aimed at eliminating the export of surplus energy generated by the RES to the power grid. The goal is to address technical or economic challenges related to the problems in the power grid management arising from the intermittency of RES. To comply with ZEE policy the prosumers often use ES, demand response techniques or smart appliances to help them with their energy use control. The combination of all these techniques is naturally the best possibility.

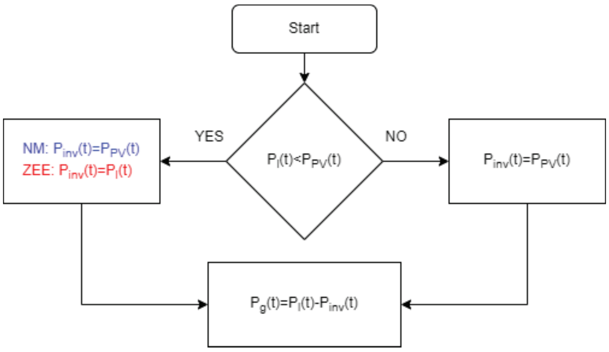


Fig. 1: Energy management for NM and ZEE without ES

E. Modern Emerging Models

Modern emerging models of energy management strategies are blockchain based incentives. Blockchain is a decentralized and distributed ledger technology, which could be used in energy sector for the purpose of creating better energy policies. Blockchain technology includes using smart contracts, transparency and traceability in transactions, tokenization and of course, decentralization.

For example, utility companies or DSOs can use blockchain based incentives to create tokens of renewable energy certificates which would enable the consumer to buy some amount of RES based energy, to be used as desired. The tokens could also be related to demand response. In this case, the bought token would oblige the consumer to participate in demand response program, where it would be required to reduce electricity consumption during peak hours, for what the consumer would receive some sort of reward.

Peer to peer energy trading mechanism is another blockchain based incentive, which refers to a policy allowing RES based energy producers, to sell the excess power directly to other consumers within the same local energy market or similar entity like a microgrid. This form of energy trading is typically based on use of digital platforms to execute the transactions without central intermediary like an utility company.

All of these mechanisms still don't have enough examples of real world use. Implementation of such incentives would require collaboration between DSOs as the policy makers, RES owners, consumers and technology providers to develop framework able to satisfy everyone's needs.

F. Using energy storage under different policies

When considering the addition of ES elements, most often batteries, to a prosumer with PV, one must consider the price of such elements compared to potential benefit they would bring to the customer. The domestic ES, such as batteries to store the surplus energy, could be considered an important element, influencing the profitability of the PV installation, much more in the NB, than in the NM scheme [10], due to their different prices for exported power. In FIT it could be beneficial to use ES as option for storing energy when PV generation is highest, and selling it back to the grid when FIT rates are higher, thus maximizing the profitability. ES can help prosumers under ZEE policy to maximize the PV installation size, with the excess energy during peak PV production being stored in batteries for later use, as opposed to limiting PV installation size or dumping the excess energy. Also, self consumption could be increased, irrelevant on the DSO imposed energy policy, if the prosumer owned some sort of ES, making them less dependent on grid supply and thus increasing their reliability.

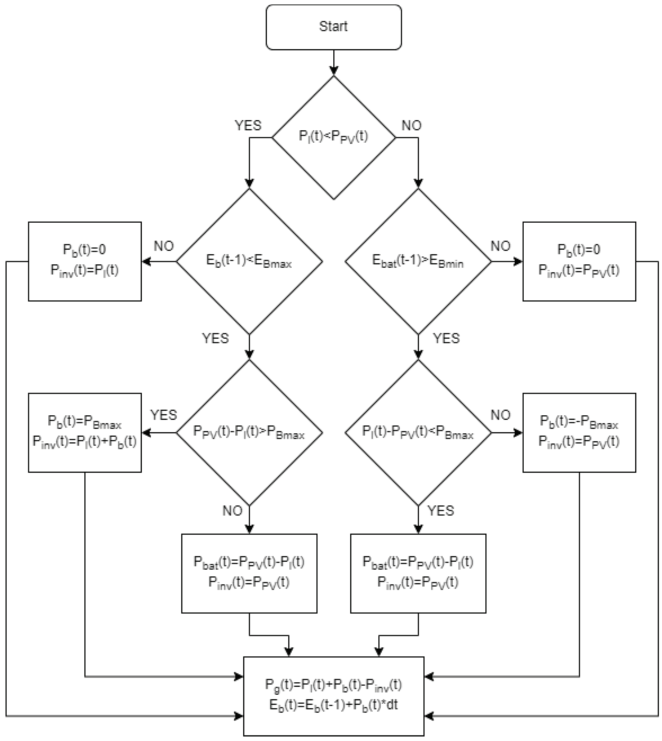
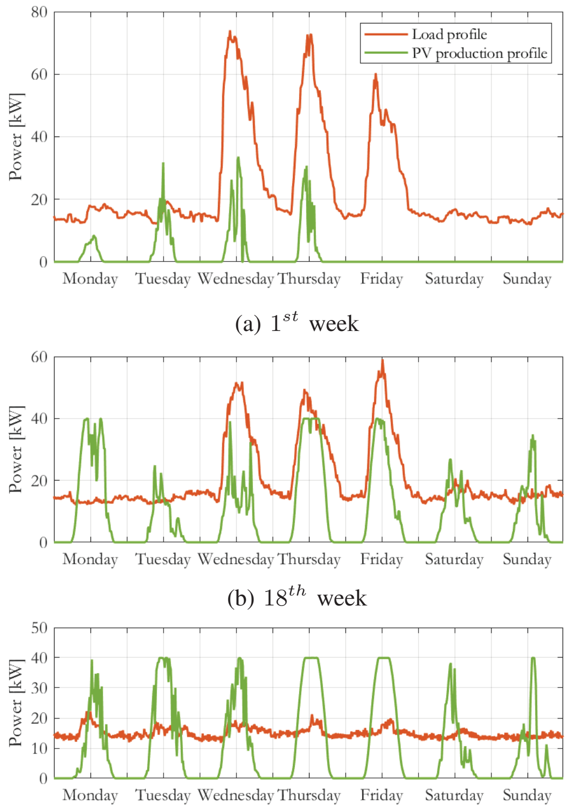


Fig. 2: Energy management for ZEE with ES

III. Energy Management for Different Energy Policies

In this paper NM, ZEE and ZEE with ES are analyzed and compared. FIT and NB policies are not considered due to them being less used recently and obviously less profitable than NM, respectively. In order to compare the profitability of these policies first the energy management algorithms will be presented, since they determine the energy flow in the considered system. The energy management flowchart for NM and ZEE without ES is quite simple and similar, as shown on Fig. 1. The difference is only during surplus of PV generation, where the production for ZEE is limited to the consumption, while the NM mechanism allows full utilization of the generation and export of generation surplus to the grid.

The energy management flowchart becomes more complex for the case of ZEE with ES, as shown on Fig. 2. The basic idea is to charge the batteries during surplus of PV generation, and discharge them when the consumption exceeds the PV generation. The limitations regarding the maximum charging and discharging power are taken into account.



(a) 1^{st} week

(b) 18^{th} week

(c) 33^{rd} week

Fig. 3: Power diagram for different weeks during the year

For both of the given flowcharts, P_g represents power exchange with the grid, P_l is load power, P_{inv} is power generation by the PV power plant, P_b is power of the battery ES, E_{Bmax} is maximum energy of battery ES, E_{Bmin} is minimum energy of battery ES, t is number of calculation step, while dt is time step of calculation, in our case 15 minutes. If the PV production exceeds the load consumption, the battery ES is charging and therefore $P_b > 0$. Otherwise, P_b is negative, meaning that the battery ES is discharging.

IV. Case Study

In order to compare the energy policies discussed in Section II, it is most convenient to do it on an example system. The real PV power plant installed at the Faculty of EE University of Sarajevo was analyzed. The PV system is composed of 90 PV modules Luxor Eco Line Half Cell M120 330 W and 2 SMA STP 10.0-3AV-40 inverters. This results in a total amount of 29.7 kWp of installed PV modules, while the PV generation is limited to 20 kW due the inverter power limit [11].

Since the real installed PV system has relatively small rated power in comparison to the building consumption due to financial reasons, for further analysis the actual PV production obtained by real-time measurement and inverter power will be doubled. Under such assumption, the PV generation reaches 70 MWh while the building annual energy consumption is 198.67 MWh. Financial parameters used in simulation for this case study are given in Table I.

TABLE I: Financial parameters used in the simulation

Parameter	Value
Project life (years)	25.00
HTR price (€/kWh)	0.15
LTR price (€/kWh)	0.10
Discount rate (%)	2.00
PV modules price (€/W)	0.25
PV inverter price (€/W)	0.15
Battery price (€/Wh)	0.35
Battery inverter price (€/W)	0.50
Mounting structure price (€/W)	0.035
Installation price (€/W)	0.10

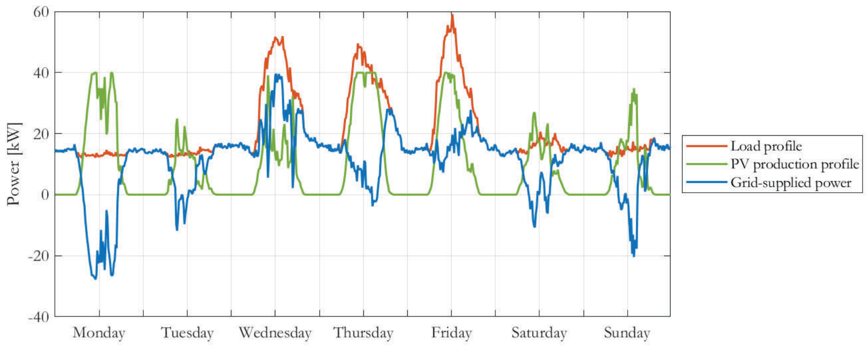
Typical weekly diagrams showing PV production (doubled actual values) and consumption of the analyzed faculty building for three weeks distributed during the year are shown in Fig. 3. The annual PV production profile was measured in 15 minute intervals. In the same way, the annual energy consumption of the faculty building was obtained by measuring the average consumption over 15 minute intervals, resulting in 96 values per day. The diagrams in Fig. 3 show quite different consumption and PV production profiles over the year. Weeks 1 and 18 both have two non-working days because of holidays, and the rest are normal working days, while week 33 has low consumption due to collective vacation. The PV production profiles show saturation in PV generation due to inverter limitation for weeks 18 and 33 during sunny days, while the PV generation for week 1 never reaches the inverter limitation.

The presented diagrams also show different behavior during the week. During working days the PV production covers a significant part of the consumption, but during the weekend and non-working days the PV production surpasses the consumption. In this case the surplus of generation is either exported to the grid or dumped, depending on the energy policy. These results are further used for profitability analysis of building integrated PV system under different energy policies. Furthermore, the analysis for ZEE with ES will be done with an assumed capacity of the ES equal to 80 kWh.

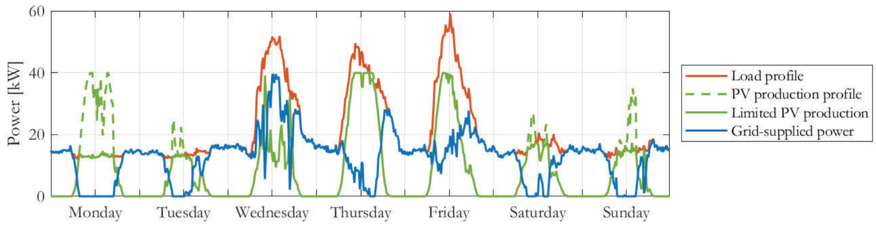
V. Results and Discussion

Based on the power profiles of production and consumption, the power and energy profiles for NM, ZEE without ES and ZEE with ES are calculated for the considered case study. Fig. 4 shows power profiles for consumption, PV generation and power imported/exported from/to the grid, charging/discharging power and energy for week 18.

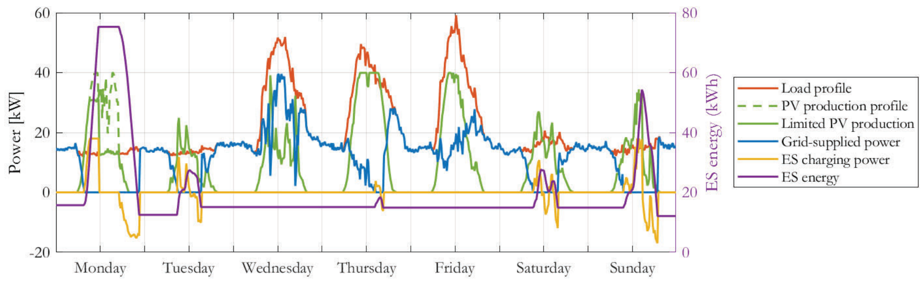
Fig. 4a shows the NM case, where during non-working days the excess of PV production is exported to the grid (negative grid-supplied power), resulting in financial benefits. On the other hand, Fig. 4b shows the same week for ZEE without ES. A significant amount of the generated power is dumped by the inverter in order to prevent energy export to the grid, so this limited PV production profile corresponds to the actual load profile.



(a) NM



(b) ZEE without ES



(c) ZEE with ES

Fig. 4: Power and energy profiles for week 18 for different energy policies

The last case, ZEE with ES, is presented on Fig. 4c. During non-working days, the surplus of PV production is used to charge the ES (positive ES charging power). When the ES is fully charged, the charging is stopped and the remaining surplus energy is dumped, like for the ZEE case. When the consumption exceeds the PV generation, the ES begins to discharge (negative ES charging power). In this way, the ES is used to reduce the amount of energy taken from the grid, therefore reducing the electricity bill.

The economic profitability is determined by calculating the NPV and IRR, which are one of the most common metrics. NPV is the value of all future cash flows over the entire project lifetime discounted to the present, as:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} - C_0 \tag{1}$$

where C_0 is the total initial investment cost, r is discount rate, C_t is net cash inflow during year t, and T is number of years.

The IRR is defined as the interest rate r at which the NPV is equal to zero [12]. Therefore, it can be calculated from:

$$0 = \sum_{t=0}^{T} \frac{C_t}{(1+IRR)^t} - C_0 \tag{2}$$

The profitability indices calculated for building integrated PV system under energy management presented in section III, for a period of one year, considering the presented case study data, financial parameters given in Table I and all analyzed energy policies are presented in Table II. From the presented results, it is clear that the NM case is the most profitable one. When ZEE policy is imposed, better utilization of the generated energy is achieved if ES is installed because in this case the amount of PV generated energy that need to be dumped is smaller. As a consequence, if ES is installed, the amount of grid supplied energy is also smaller. However, this comes with higher initial costs due to investment in the ES.

The net cash flow profitability index comparison, obtained for predicted project life span of 25 years, for all analyzed energy policy cases is shown on Fig. 5. For the given input

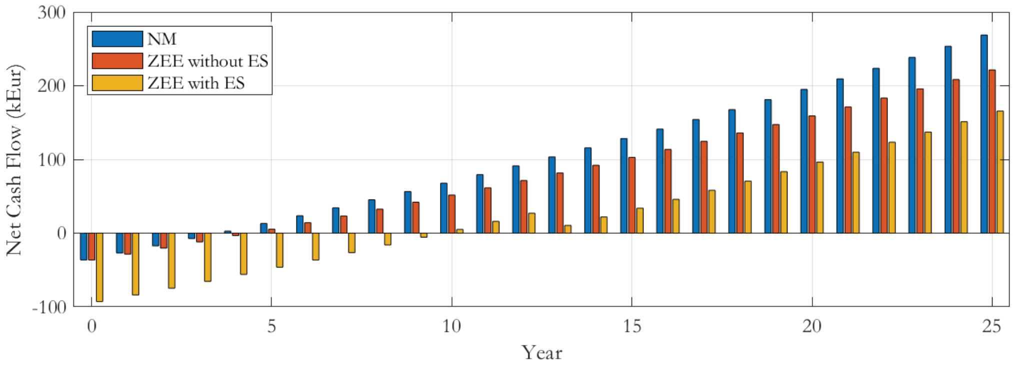


Fig. 5: NPV for different energy policies

TABLE II: Simulation results for a period of one year

Parameter	NM	ZEE	ZEE+ES
Grid-supplied energy (MWh)	128.64	141.04	134.38
PV-supplied energy (MWh)	70.03	57.63	64.28
Dumped energy (MWh)	0.00	12.40	5.74
Self-sufficiency (%)	35.25	29.00	32.36
Internal rate of return (%)	36.33	31.07	12.88

data, the NM policy is the best. If the ZEE restriction is imposed then the simulation shows more favorable results for the ZEE without ES in comparison to ZEE with ES case, since the initial higher investment is not justified. Also, it is assumed that the battery ES needs to be replaced in the mid of lifetime. This is reflected in the diagram of the NPV and also results in a significantly lower value of IRR.

VI. Conclusion

The profitability of building integrated PV systems significantly depends on regulatory policies governing surplus electricity treatment. This paper offers the comparative analysis of such systems, considering the energy management of the system under various regulatory policies and implications of those on system profitability. A valuable case study, using real data sets that include load profile and PV production profile, is the numerical base for the comparative analysis. The profitability indices NPV and IRR were calculated for the purpose of economical analysis for the case of NM, ZEE and ZEE with ES options. The profitability analysis results in conclusion that the NM mechanism has no competition as the most favorable policy for the customer. If DSO imposes ZEE policy due to technical constraints, then the ZEE without ES case gives more favorable results compared to the ZEE with the ES. Presented results are highly dependent on the ES investment cost, as well as the electricity price. Having in mind that there is a decreasing trend in ES prices, while the electricity prices increase, as well as the ES lifespan it is reasonable to assume that in the future the ZEE with ES case will become more profitable. The given profitability analysis could be expanded in the future by including some of the emerging energy policies or examining the role of government incentives and subsidies. Investigating the potential impact of technological advancements in ES technologies on the profitability of building integrated PV systems, considering factors such as efficiency improvements and lifespan extension could also be an future research idea.

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