Study of the Photovoltaic Energy Production And Storage Scenarios in Poland and Portugal

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Abstract

The work concerns study of the photovoltaic energy production from the big-scale photovoltaic farm and study of the incorporation of the battery energy storage into the system. A photovoltaic farm has power of 5MW. It consists of more than 20 000 panels of the power of 240W each, covering around 3 ha of land. The Lithium-Ion battery storage system has capacity of 2MWh. The first aim was to study the power produced in Poland and Portugal from the same installation and creating scenarios when the battery will be charged (the sunniest 2 hours of a day) and discharged (2 hours of the highest electricity price). After comparing them and the circumstances for realizing such project, the further analysis in done for Polish conditions only. For the economic assessment, the Variant 1 was concerning the photovoltaic farm with the battery storage system and Variant 2 was the photovoltaic plant alone. As the result, both of the installations had NPV<0 throughout the 25 years of the lifetime of the project, IRR were below the assumed discount rate of 2%, but the SPB for Variant 2 is almost 21 years. Even though the results were not entirely positive, they led to important conclusions about the state of renewables in Poland (and Portugal). The points were made about what needs to be done for these projects to become feasible.

***Keywords**:* Renewable energy sources; photovoltaic energy; battery energy storage systems; profitability assessment; Li-Ion battery.

1. Introduction

The electrical energy is considered to be challenging when it comes to the daily and seasonal demand changes, which can affect an everyday life. It is widely-known that in order for the grid to stay stable and safe, while increasing the share of renewable energy sources – in this case photovoltaic energy - in the energy mix, the most optimal solution can come from the energy storage systems. Effective storage of especially electrical energy helps in smoothing the transitioning from classical fossil fuels into renewable energy sources energy generation, that under proper management can be very flexible and reliable. [1] [2] The conversation of energy storage system is a highly-raised topic, because in theory it can solve many problems that countries and their grids face. Also, investing in greener solutions, makes the whole continent move step-by-step toward the climate neutral Europe, that is targeted for the year 2050.

The Figure 1 shows the two places of interest for this work – Poland and Portugal and the average variations of the irradiation. What can be concluded here is that as the direct irradiation reaching the Earth's surface is highly seasonal, proportionally the potential electricity produced with photovoltaic panels will be varying during each month, and also accordingly during each day, creating potential challenges in reaching the energy safety goals, creating a great opportunity for the battery energy storage system incorporation.

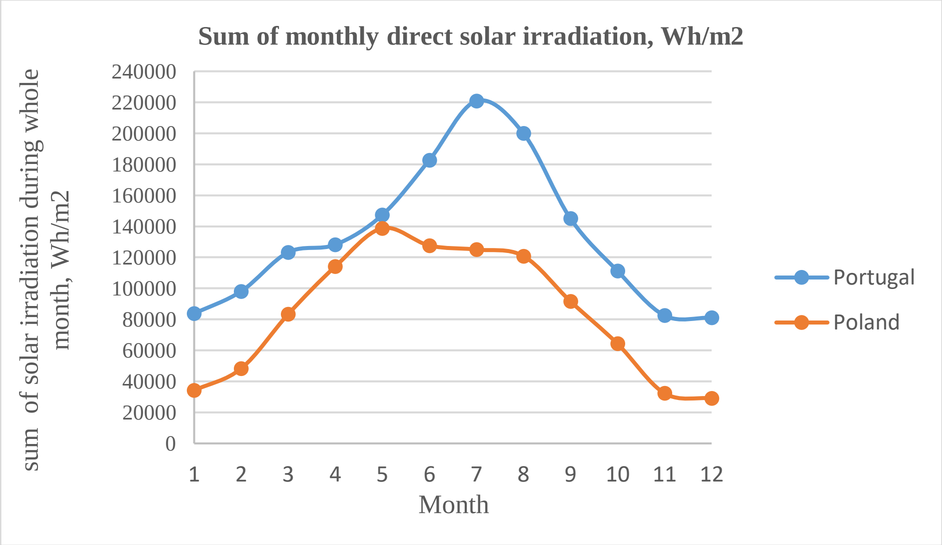

Figure 1 Monthly variations of sums of direct solar irradiation reaching the Earth's surface in Poland and Portugal. Data adapted from: [3], [4]

When it comes to comparing the energy markets of Poland and Portugal, the polish one is very focused on the classical fossil fuels power plants, run mainly by the hard coal, with an around 80% share in the energy mix. When the Portugal is treated as a whole, it has a little lower than 50% dependency on the fossil fuels when it comes to electricity production. The generation of electricity from renewable energy sources, due to the climatic conditions like direct normal irradiation, is much different in both countries, which can be seen in Table 1. Solar PV still does not pay play the most significant role in the energy mixes of both countries, so it makes the model worth checking.

Table 1 Comparison of the renewable sources for electricity generation in Poland Portugal in the year 2019. Data adapted from: [5]

		2019			
Country	Geothermal	Hydro power	Solar PV	Wind Energy	Unit
Poland	-	2664	712	15040	GWh
Portugal	216	10165	1275	13738	

2. Methodology

The system under consideration consists of the big-scale photovoltaic farm supported by the Lithium-Ion battery energy storage system. The total power output of the PV farm is assumed to be 5 MW and the battery storage has a total capacity of 2 MWh with the whole infrastructure needed for the system to properly work, like inverters or control systems. The photovoltaic panels that could be used are, for example, standard Jinko Solar 240W_p panels [6]. When it comes to the Li-Ion battery storage, the famously known Tesla power- and giga-packs [7] or even some other companies like Mitsubishi could be used for a real example. The project is assumed to be realised on the 3,28 ha of land. After calculations of the energy that can be produced by the photovoltaic power plant, to check how well the Li-Ion battery energy storage system could generate the extra profit thanks to storing the energy in their peak production points. The charging of the system lasted for two hours when the electricity production was the highest and the two hours of discharging were when the market electricity prices were the highest to maximize the profit in the chosen circumstances. Knowing these results, it was chosen that thanks to the comparison of the energy markets, auction systems, the stage of development of the renewable technologies in Poland and Portugal, for further analysis it was chosen to go with application of the model in Poland. This is because in Poland the share of renewables in the energy mix is much smaller and promoting such solutions is much anticipated. The calculations consisted of the following stages:

- **Energy production** – calculated as shown below, knowing the Direct Normal Irradiation (DNI) for average hour during every month in Poland and Portugal, the efficiency of the panel (18,27%) and total surface area of all the panels (27363,43m^2):

$$P = S_{total} * \eta * DNI,\ \ Wh \quad \text{Eq. 1}$$

- **Energy storage** – knowing the electricity produced, which is highly seasonal and the market prices, that can vary especially when comparing the morning and evening hours; charging (when it is the most sunny) and discharging (when the market electricity prices are the highest) scenarios in Variant 1 of the system (photovoltaic farm connect to the battery storage system) were developed (see Table 2 and Table 3);

- **Economic assessment –** it is to check whether at least one of two variants of model is profitable. For calculating the cash flow, the income is determined. It consists of three parts: from selling the discharged energy which was stored thanks to the battery system, it is assumed that the stored amount equals to 20% of the daily electricity production, but not more than 2MWh a day, from the won auction bet - it is assumed to be 95% of the remaining energy that was not stored and from 5% of remaining produced electricity that will be sold to the grid with the average market electricity price. The costs are: the initial investment costs (taken into account only in the year 0, consisting of photovoltaic system costs, battery cost and land cost), labour costs (C_{labor}) operational and maintenance costs (C_{om}), bank loan (C_{bank}), an income tax (C_{tax}) and every 7 years battery maintenance works (C_b). For profitability analysis, the NPV, IRR, SPB and DPB are calculated for Variant 1 (photovoltaic farm with battery storage) and Variant 2 (photovoltaic farm by itself) according to the formulas below:

Cash flow:

$$CF_n = I - C_{labor} - C_{om} - C_{bank} - C_{tax} - C_b \quad \text{Eq. 2}$$

Net Present Value:

$$NPV_n = \sum_{n=0}^{N} \frac{CF_n}{(1+a)^n} \quad \text{Eq. 3}$$

Internal Rate of Return:

$$\sum_{n=0}^{N} \frac{CF_n}{(1+IRR)^n} = 0 \quad \text{Eq. 4}$$

Discounted Payback:

$$\sum_{n=0}^{DPB} \frac{CF_n}{(1+a)^n} = 0 \quad \text{Eq. 5}$$

Simple Payback:

$$\sum_{n=0}^{SPB} CF_n = 0 \quad \text{Eq. 6}$$

3. Results

The power production results were represented on Figure 2 and Figure 3. The electricity produced was primarily used for prediction of the time of charging of the storage system, that is presented below. Knowing the hourly averages, the monthly energy productions were determined, to later sum up and calculate the yearly income needed for the cash flow formula.

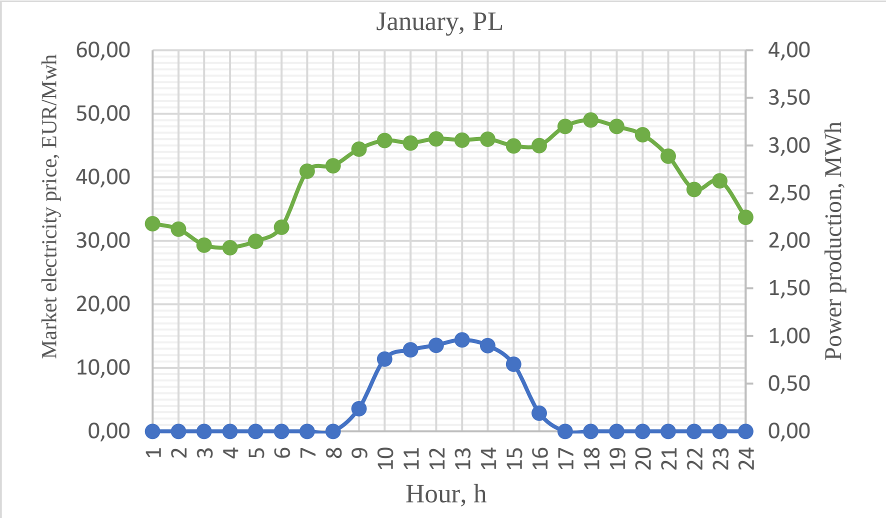

Figure 2 The representation of the average power production and market electricity prices in January in Poland, Prices data from [8]

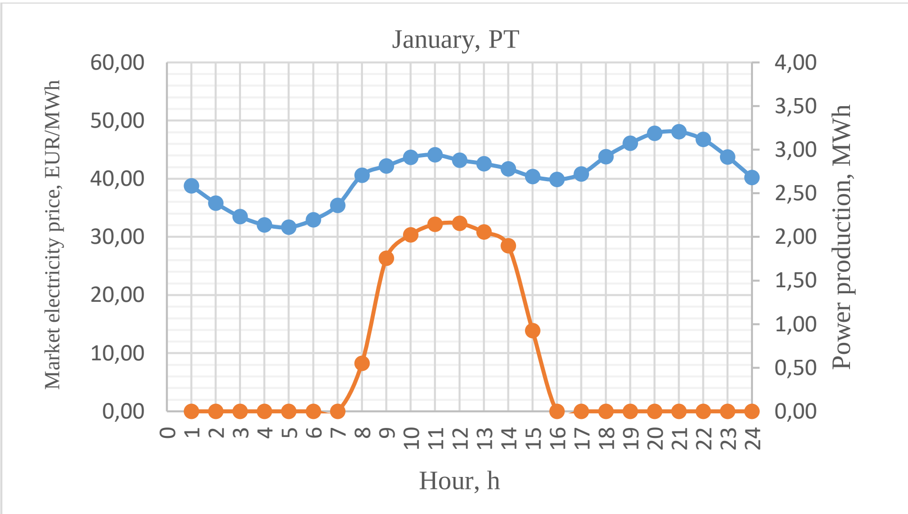

Figure 3 The representation of the average power production and market electricity prices in January in Portugal, Prices data from [9]

Table 2 Hours predicted for charging and discharging the battery storage for Poland

	Charging and discharging scenarios											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Charging	12,13h	13,14h	12,13h	11,12h	10,11h	10,11h	10,11h	10,11h	10,11h	12,13h	12,13h	12,13h
Discharging	17,18h	18,19h	19,20h	20,21h	20,21h	12,13h	19,20h	13,14h	20,21h	19,20h	17,18h	17,18h

Table 3 Hours predicted for charging and discharging the battery storage for Portugal

	Charging and discharging scenarios											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Charging	11,12h	11,12h	11,12h	10,11h	10,11h	11,12h	11,12h	11,12h	10,11h	10,11h	10,11h	11,12h
Discharging	20,21h	20,21h	20,21h	22,23h	22,23h	22,23h	22,23h	22,23h	21,22h	21,22h	19,20h	20,21h

The so-called charging and discharging scenarios are presented in Table 2 and Table 3. The charging and discharging hours differ between the each month's averages, but the general tendency says quite the same. Charging of the battery is always done around midday – not later than after 1 pm. The peaks of the electricity market prices, are almost always in the evening, so naturally this when the discharging daily session takes place, typically after 8 pm. Knowing this, the two variants for economic analysis were chosen – Variant 1 (photovoltaic farm and battery storage in Poland) and Variant 2 (photovoltaic farm alone in Poland). The results of the economic analysis are presented below.

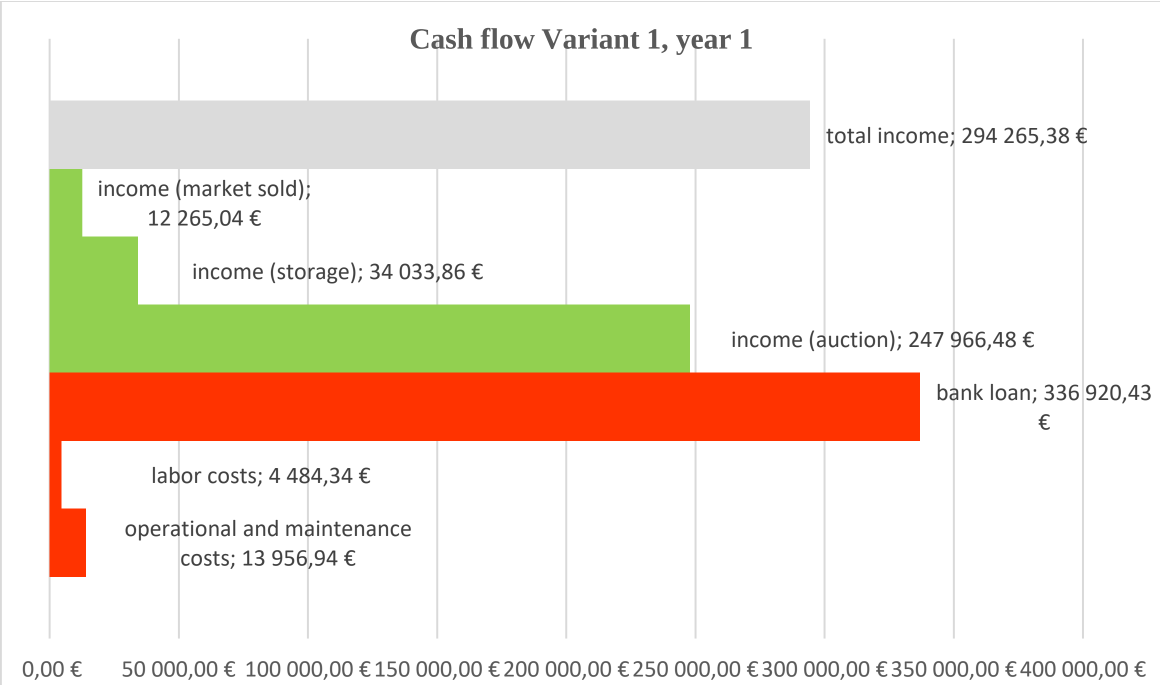

Figure 4 Cash flow representation for Poland in the year 1 of the investment for Variant 1

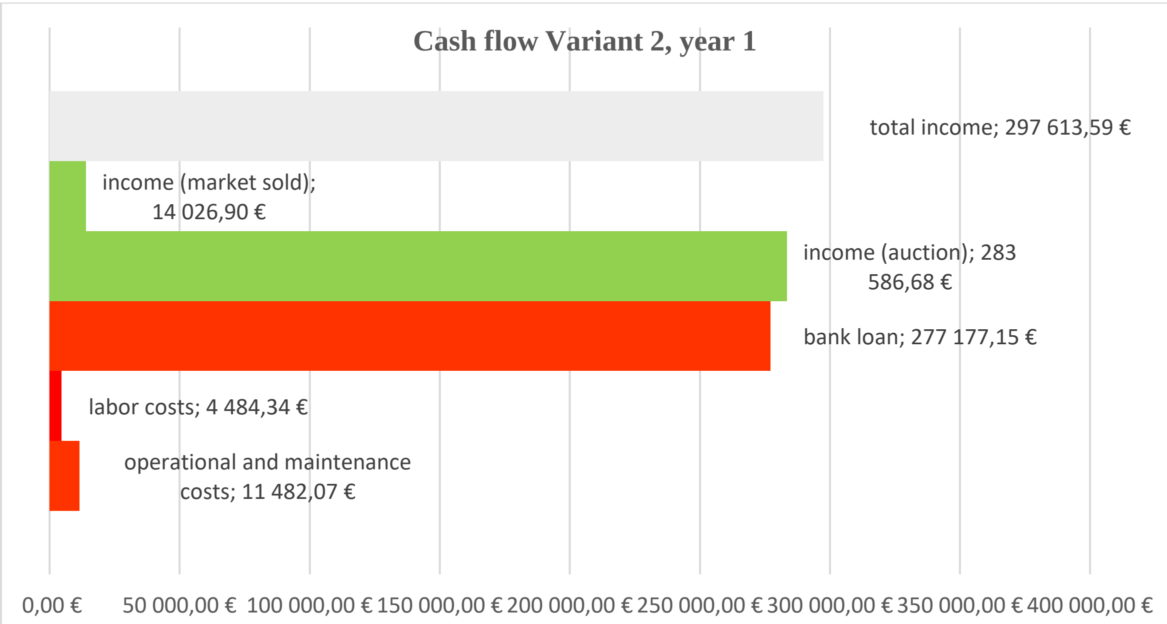

Figure 5 Cash flow representation for Poland in the year 1 of the investment for Variant 2

The graphs above represent the average relations between all kinds of the incomes and the costs of the installations, showing all the flows in a year. It visualises well which kinds of notions contributes on which scale to the final results (the visualization is done in the first year of operation, where there is not profit generated, so the tax is not present). It also shows how big of a cost is the bank loan compared to the rest of them. The cash flow in the variant with the battery storage stays negative for the longer period of time, while in the standard option of photovoltaic farm without the BESS, the cash flow is after the first year of operations positive. In the final year, the values of the cash flow are somewhat similar with a difference of around 10 000 EUR in favour of the Variant 2.

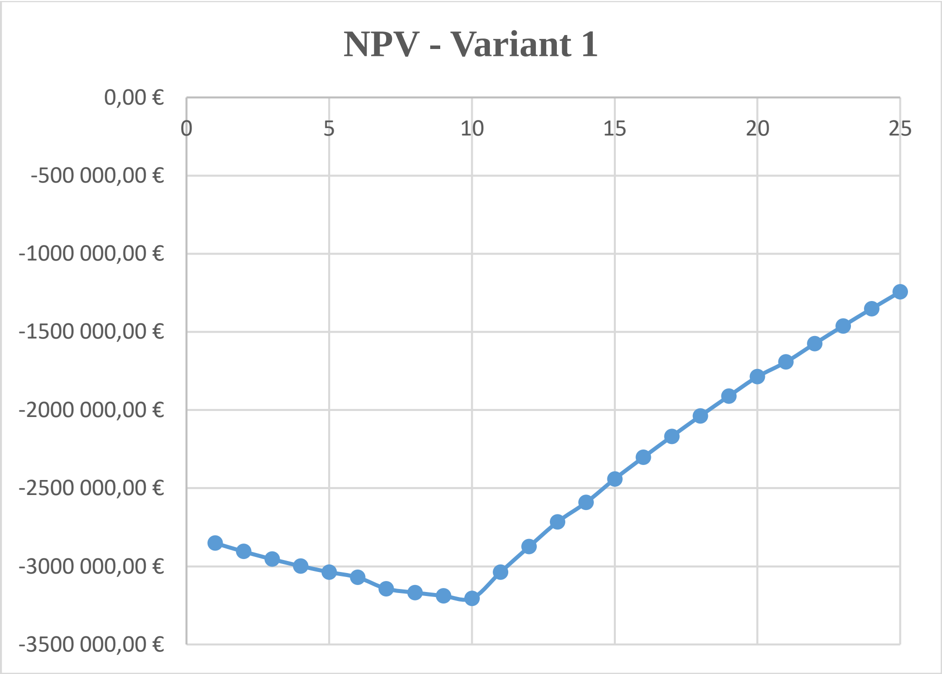

Figure 6 Year-by-year Net Present Value representation for Variant 1

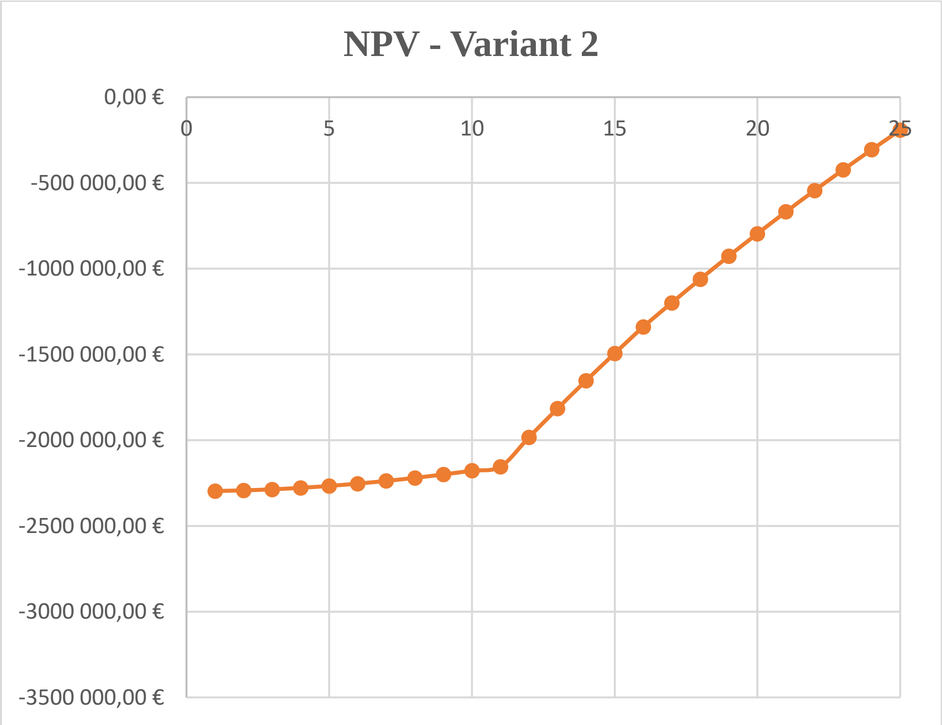

Figure 7 Year-by-year Net Present Value representation for Variant 2

Figure 6 and Figure 7 show the change of the Net Present Value parameter through the years of the project realisation. As can be seen on the figures, the feasibility criteria is not met (NPV<0) in both cases of the photovoltaic farm solutions. This is due to extremely high initial cost with mediocre incomes both in Variant and Variant 2. This again raises the question of how much the government or big investors could help, for the projects realised in conditions like those in Poland. For the shape of the first 10 years of the graph, there are responsible the huge bank loan yearly payments. After giving back all the borrowed money, the installation's feasibility (in the form of NPV indicator) rises rapidly. The NPV for the installation of only a photovoltaic farm (where the initial investment cost is obviously lower), at the end of the assumed lifetime, is on the edge of becoming feasible, which again raises the questions for the future funds for such projects. Also the tax of 19% plays a he role in the NPV not being able to reach the 0 value. In conclusion, the Variant 2 - without the battery system – even though it cannot be described as "profitable" is surely closer to the making profit, with a possibility of reaching it under a few adjustments. The Variant 1 does not have a chance for NPV>0 unless the funding for the projects comes from the outside.

Table 4 The profitability indicators' values for Variant 1

Indicator	Unit	Value
IRR	%	-0,90%
DPB	year	0,00
SPB	year	0,00

Table 5 The profitability indicators' values for Variant 2

Indicator	Unit	Value
IRR	%	1,78%
DPB	year	0,00
SPB	year	20,65

As for the Table 4 and Table 5, in the Variant 1, the IRR<a (a=2%), which confirms the unfeasibility of the project, so that is why the payback values are 0. This means that the Variant 1 of the project is not economically justified. In the Variant 2 of the investment, the IRR<a slightly, but that unfortunately is also meaning that the project is unfeasible. What is interesting in the Variant 2, is that the Simple Payback has a value of a bit less than 21 years, meaning that the break-even point is reached and the initial investment is returned.

4. Conclusions

The Renewable Energy Sources Market is very fast-developing which on one hand can mean many amazing opportunities, that solve many serious global problems. On the other hand however, such direction for development creates many new challenges that need our constant, iterative adjustments. The advantages of course are much bigger than the disadvantages so any green initiatives that could potentially help our planet to fight the generations of pollution and climate changes should be, by all means, supported. In the realm of Energy Engineering, the continuous support invented for helping the humanity should be always applauded. The solutions that were tackled in this paper, generally play a huge role in the energy policies in most parts of the European Union and other developed counties. This is particularly why the big-scale installations like photovoltaic farms and battery energy storage systems that support the national grids and increase the energy safety are so interesting to check for profitability and possible kinds of solutions.

The results of the analysis show a perspective on the energy production in two different countries – Poland and Portugal and also the economic aspects of actually constructing such photovoltaic farm with and without the battery energy storage system for the chosen location. A 5MW PV farm can change a lot the local communities' energy mix structure. With more and more of such solutions connected to the adequately modernised grids, the whole energetic system could become more reliable and up-to-date.

The actual analysis and results presented show that the challenges of building and running such an investment are multi-dimensional and often difficult. For example, in the 2021 polish economy, the 5MW

PV farm with brand new Li-Ion battery storage system installed has no change of feasibility on its own. Even the 5MW PV farm alone during its lifetime of operation is on the verge of becoming slightly feasible, but this happens much past the 20 years of operation, which was explained in the previous chapter. This of course does not mean that these solutions are not appropriate, it just brings us to the very important conclusion: environmentally-friendly renewable energy solution should receive a constant support from the government and other organisations to continue the energy transition in countries where it is much needed. Poland is one of the countries where the meteorological conditions may not be optimal for either the wind or solar energy, but that should never stop the transition that has to be made for the pollution decrease of the soil, air and water.

In the nearest future, European Union countries need to aim at the targets set by the EU Parliament. The recommendation for the country in situations like this described in Poland should support development of the big-scale photovoltaic farms like the one developed in this work. When it comes to the battery energy storage systems, in the very near future they will become necessary when increasing the share of renewables in the traditionally built national grids. They will help in stabilising the grid and protecting the end-customers from the renewable energy sources threats connected with disturbing the constant supply of electricity.

In conclusion, although the results may not seem as optimistic as one could have hoped, the upcoming perspectives for development of photovoltaic energy and battery energy storage units have a huge potential. It should never be wasted. It is a relatively simple and known path leading directly to the better and cleaner world for ourselves and the next generations.

5. References

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