MODELING THE CONSUMPTION OF A PHOTOVOLTAIC SYSTEM

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The purpose of this study is to analyze the efficiency of a photovoltaic system. It is done an economic analysis referring to the tariffs, according to the valid legislation in a specific country, Czech Republic in our case and designing a model for calculation methods which has like inputs the characteristics of the photovoltaic station and the legislation applied. Following the general inputs of the model, we will analyze in detail the input consumption and it stands how it is better for a company to have the level of tariff, in order to decide in between the policies applied, to be the most efficient in the specific working conditions.

The study is current, a result of research projects, the aspects mentioned are original.

Keywords: legislation, modeling consumption, mathematical methods, photovoltaic system

1. Introduction

The framework for the studies which lead to this article, among other results, is the legislation valid in Czech Republic related with renewable sources of energy [1]. As it was proved by the latest directions of research, this research area, renewable sources of energy-photovoltaic systems, is one of the most interesting nowadays because of the rapid depletion of conventional energy sources while the demand is rapidly increasing.

In the last years, the new projects which were about renewable sources of energy were more and more sustained by the legislation, many studies were done to avoid any barrier for further development of RES [2]. This is the reason for which the related legislation has been suffering many changes, rapidly in the last years [3]. Our case study will be done for a company located in the Czech Republic. For Czech Republic, a new legislation concerning renewable sources of energy is applied since 1st January 2013 [4]. According to the new legislation,

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the new projects are still sustained but the largest ones already face difficulties, mainly because of network connection.

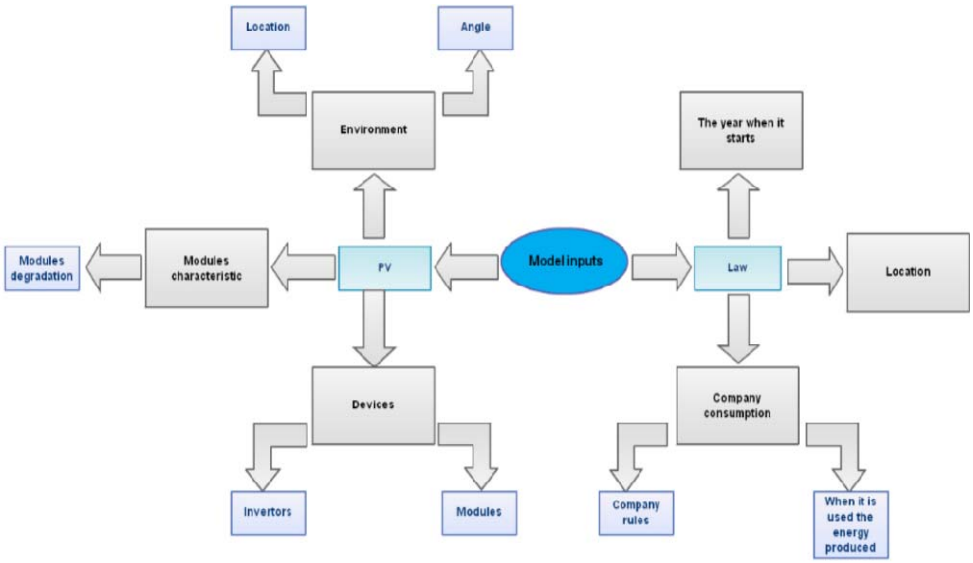

Fig. 1. Block diagram of the inputs of the mathematical model

Once installed, each company or user of an installed system is aiming the highest profit, the fastest recovery of the investment. To reach these targets, it is important for each user to know which policies fit best and, according to the policies applied, the specific tariffs. In order to have a clear image about how the system works, we plan to make the modeling. The area is large but in this article, we aim a part of the model – the consumption.

First of all, it is important to analyze the legislation from the financial and economical point-of-view and the policies applied.

2. Inputs of the model for calculation methods

The purpose of the block diagram of the inputs of the mathematical model is to clear state the influence of each factor which might influence good functioning of an installed system.

As it will be seen, the model for calculation methods has like inputs the characteristics of the photovoltaic station (which is depending on the environment, modules characteristics or the devices used). Another input is referring to the law which is applied for the functional photovoltaic stations and it depends on the location, the year of installation and the consumption of energy which is also depending on the company rules and how it is planned to use the energy produced.

The legislation part and its inputs won't be analyzed in this article but, for more details, can be consulted our paper "Methods for analyzing a photovoltaic system" [5].

It is difficult to determine the input parameters for equivalent models of photovoltaic modules through analytical methods [11].

The charts in the Fig. 1 and Fig. 2 describe the theoretical model taking into consideration the location and the legislation applied to the specific location and the possible modes of operation (policies). The related model with its calculation methods is than applied on a specific case, for a company located in Chotysany in the Czech Republic, where a photovoltaic system is installed.

To present and describe the model on how a station works in relation with inputs and outputs of energy, taxes and payments, the Fig. 2 and an example is provided. See the block diagram for a station of 16 kW which works in one of the possible policies applied in Czech Republic (either in "green bonus" policy or "selling the energy produced").

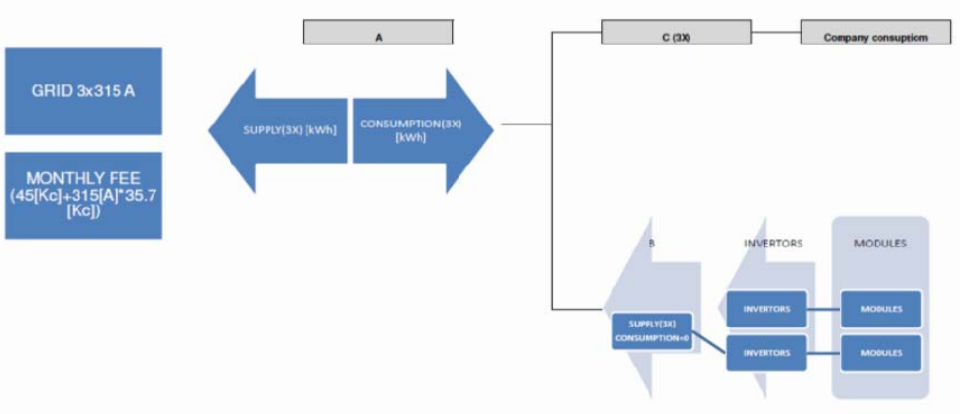

Fig. 2. Block diagram of the model for a functional system

In Table 1 and Table 2 we used the following equations for each term. Besides it exists the monthly fees which are non-mentioned in the table.

$$ASupplied = Selling * ASupplied \quad (1)$$

$$AConsumed = HT + LowT + SS + OZE + TAX \quad (2)$$

$$ConsPV = (SS + OZE + OTE + Tax) * Consumption(\quad 3)$$

$$OTE_{GB},BSupplied = ERU_{GB} * BSupplied \quad (4)$$

$$OTE_{Selling},BSupplied = ERU_{Selling} * BSupplied \quad (5)$$

$$MonthlyFee = (Distrib.point + Month.Distrib) * Month \quad (6)$$

where: *ASupplied*, OTE_{GB},*BSupplied* and $OTE_{Selling}$,*BSupplied* are incomes, while *AConsumed*, *ConsPV* and *MonthlyFee* are payments.

3. Case study on the installed system regarding the consumption

At Chotysany, in Czech Republic, it is installed a 170 kWp photovoltaic station.

From our point of view, it is important to mention that the PV system installed at Chotysany has, through a signed contract, establish an amount of 16–20 hours per day at low tariff (LT as it will be used in the following calculations). The system installed at Chotysany uses the energy produced mainly for heating. Because they use the energy produced for heating, they can have a larger period for "working" at low tariff because, from the economical point of view, they are to be wanted, they are using the heating for longer period than another type of consumers (light, computers and so on).

Table 1

The Green bonus type of support.

PV (kW)	**Device** (kW)	**A-Suppl.** (kWh)	**A-Cons.** (kWh)	**OTE** (kWh)	**Con from PV** (kWh)
–	–	income	payment	payment	income
0	0	–	–	–	–
0	10	0	10	0	0
1	10	0	9	1	1
10	10	0	0	10	10
15	10	5	0	15	10
16	0	16	0	16	0
16	15	6	5	16	5

Table 2

The Selling the energy produced type of support.

PV (kW)	**Device** (kW)	**A-Suppl.** (kWh)	**A-Cons.** (kWh)	**OTE** (kWh)
–	–	income	payment	payment
0	0	–	–	–
0	10	0	10	0
1	10	0	10	1
10	10	0	10	10
15	10	5	15	15
16	0	16	16	16
16	15	6	10	16

We aim in this paper to model the consumption of this company and to decide for the best policy and best working regime. For modeling, we will consider like inputs: all the energy produced by the photovoltaic station is used,

the prices for consuming from the network, prices for using the energy produced, taxes. These data above are since 2009, when the company started producing the energy until 2012. The rest of data base, until the year 2034 are estimated based on calculations and this represents a calculation model for savings estimation of photovoltaic station usage, based on the real data and the current legislation [5].
In the Czech Republic are paid the following, according to current the legislation: a fixed payment (which can be monthly, constant, per connection or monthly, per maximum power input) and a variable payment, per consumed kW (which can be for generated energy in power plant; for distributed energy from the power plant to the consumer; constant charge; regular systematic service; support for "green energy", constant; payment towards OTE, constant (OTE is a company that makes calculations regarding renewable energy, power generation station registration, etc. See more at www.ot-cr.cz).

"Constant" means that it is the same price for the whole Czech Republic (no matter if we are speaking about a large consumer or reduced consumption, household or company). The only difference that occurs between households and companies appears depending on the area in which they are (PRE in Prague, EON in South, CEZ all the rest). But the constant costs are the same for all three companies (PRE, EON or CEZ).

For energy and power consumption are two types of rates: high price, usually during the day and low price, usually in the night (not related with time itself but with the signals from the stations that control the device installed).
All prices are set by the ERU (www.eru.cz) every year and it is forbidden to sell at different prices.

For the system installed at Chotysany we have the data which will be changed for consumption modeling:

- Total production of energy = 151 740 kWh;
- Energy to the network = 97 569 kWh;
- Consumption from PV station during the time when we have two types of tariffs: high tariff = 171 kWh and low tariff = 54 000 kWh;
- Consumption from the network during the time when we have two types of tariffs: high tariff = 972 kWh and low tariff = 111 000 kWh.

But these data will stay unchanged for the comparison in between the policies available in Czech Republic and we will find out the status of the company located in Chotysany, which it is looking for a change.
This modeling takes into consideration the consumption based on time or according to the rules (for example how it is used the energy produced) which than establishes the type of tariff which will be applied for one specific company.

3.1. Comparisation in between possible policies applied. In this subchapter, we follow the legislation, the tariffs according to a specific situation (the company located in Chotysany) and we make a comparison in between the policies applied in Czech Republic.
First we will need to find a general equation for the company's yearly income [5]:

$$CSE = CCnN,HT + CCnN,LT + Stax \tag{7}$$

$$\begin{aligned} CSE &= CE,CEZ,HT * (CnPV\,HT + CnNHT) + \\ &+ CE,CEZ,LT * (CnPV\,LT + CnNLT) + \\ &+ S_{OZE} + Tax \end{aligned} \tag{8}$$

$$\begin{aligned} CSE &= CE,CEZ,HT * (CnPV\,HT + CnNHT) + \\ &+ CE,CEZ,LT * (CnPV\,LT + CnNLT) + \\ &+ (CERU * TP - SOZE * 0.26) \end{aligned} \tag{9}$$

where C_{SE} is cost for selling the energy produced; $C_{CnN,HT}$ and $C_{CnN,LT}$ is cost for consumption from the network, high tariff or low tariff, resp.; S_{tax} is support after paying the taxes; $C_{E,CEZ,HT}$ and $C_{E,CEZ,LT}$ is the electricity cost paid to CEZ at high tariff or low tariff resp.; C_nPV_{HT} and C_nPV_{LT} is cost paid for consumption from PV at high or low tariff, resp.; C_nN_{HT} and C_nN_{HT} is cost paid from consumption from the netwrok at high tariff or low tariff, resp.; S_{OZE} is support from OZE; and *Tax* is the tax paid. If deciding for the policy "green bonus":

$$CGB = CCnN,V\,T + CCnN,NT + Stax + CnPV \tag{10}$$

$$\begin{aligned} CGB &= CE,CEZ,V\,T * CnPV + \\ &+ CE,CEZ,NT * CnPV + SOZE + \\ &+ Tax + CnPV * CPV \end{aligned} \tag{11}$$

where C_{GB} is cost paid when deciding for the policy "green bonus"; and C_{PV} is consumption from PV.

The results, as they can be seen in the Table 3, show that the policy green bonus is more advantageous for the analyzed company.

3.2. Consumption inputs. Modeling the consumption, first modeling. We will continue our analyze, aiming the best condition for the company, an economic analysis concerning the tariff.

The economic analysis corresponds to the part of the model, which refers to the input consumption, see Fig. 3, and it shows how it is better for a company, with a case study in Chotysany, to have the level of tariff.
The taxes are set according to the year of installation 2009 and purpose for which the energy it is used - in Chotysany the energy is mainly used for heating,

and it will be changed according with any change regarding consumption (if energy production from PV is lower than the energy consumption needed; if energy production from PV is equal with the energy consumption needed; if energy production from PV it is higher than the energy consumption needed) according to the company rules regarding the working process; according to the tariff for PV; according to the tariff for network energy according to the purpose for which the energy produced is used.

The results of the comparisation in between the policies showed that green bonus is an advantageous policy considering the inputs mentioned above. But, on the other hand, it is not very usual to have consumption at low tariff higher than the consumption at high tariff. So, the modelling on consumption will treat this aspect. The inputs will be changed as follows: consumption from PV is 54171kW, from which 171 kW in LT (low tariff) and 54000kW in HT (high tariff); consumption from the network is 111972kW from which 972 kW in LT and 111000kW in HT; the energy produced by PV station is less than needed for consumption; the tariffs will be estimative according to the year of installation and taking into consideration that the energy produced will be used for heating. If the energy produced is used for electricity, usually are higher taxes.

Table 3

Comparison in between policies, modeling.

Year ID	Year	Real situation [CZK]	First model [CZK]	Second model [CZK]
0	2009	⁻80014	−142287	121705
1	2010	⁻65035	−150698	121678
2	2011	⁻79511	−168083	127295
3	2012	⁻76431	−155131	134845
4	2013	−110799	−190547	101229
5	2014	⁻66837	−157193	156592
6	2015	⁻58819	−150456	165606
7	2016	⁻50370	−143313	175071
8	2017	⁻41467	−135742	185009
9	2018	⁻32088	−127721	195446
10	2019	⁻22207	−119226	206405
11	2020	⁻11799	−110232	217912
12	2021	⁻836	−100712	229996
13	2022	10708	⁻90638	242684
14	2023	22865	⁻79982	256008
15	2024	35885	⁻68712	269998

16	2025	−259877	−365815	¯24330
17	2026	−261140	−368670	¯24355
18	2027	−262428	−371583	¯24381
19	2028	−263743	−374553	¯24407
20	2029	−265083	−380674	¯24433
21	2030	−266450	−383827	¯24461
22	2031	−267845	−387042	¯24488
23	2032	−269268	0	¯24516
24	2033	−270719	−390322	¯24545
25	2034	−272199	−393668	¯24575

The company working rules takes into consideration the consumption of the output (heating). In our case only one season, winter. As the study is done yearly, it doesn't take it into consideration.

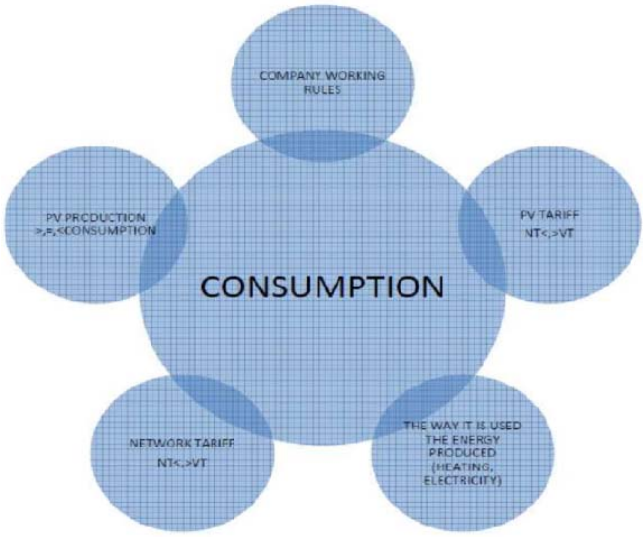

Fig. 3. Inputs for analyzing the consumption

The results shows that green bonus policy became even advantageous and during the whole lifetime of the project. This is a good result for the company which we analyzed because the new legislation becomes more restrictive when speaking about the energy producers' free will (in between those two types of support). If the producers produce less than 100 kWp, he can pick in between those two types of support. If he produces more than 100 kWp he can pick only the option "green bonus". For the results of first modeling, see the second column of Table III.

3.3. Modeling the consumption, second modeling. For more complete analysis we will change the initial conditions as it follows: consumption from PV 54171kW, from which 14000kW in LT and 40171kW in HT; consumption from the network is 111972kW, from which 2972kW in LT and 9000kW in HT; the other conditions stay the same. So, the entire situation change and it became really advantageous if the user decides for the policy "selling the energy produced". But in the year 2025, again, the "green bonus" policy will become more advantageous. So, now, the solution in this case is: the user decides if in the year 2025 will change the policy into "green bonus", or the consumption itself related with tariffs or we change the inputs of model. At this moment, as we were saying above, the legislation doesn't allow to producers which produce more than 100 kWp to pick any policy but "green bonus" policy. See third column of Table 3.

4. Conclusion

The study of current legislation (the latest valid law is the Law 165/ 2012 [4]) leads to the valid policies applied in Czech Republic, the policy concerning selling the energy produced and "green bonus" policy, which will be applied in the case studies made. No matter which policy is applied, there are fixed taxes, which are the same no matter the area where is build the PV station (and the company where they are connected) and variable taxes which are paid depending on the energy created and distributed energy, also the year when the station starts to produce energy and the purpose for which the energy produced is used [6].
The fix taxes mean that it is the same price for the whole Czech Republic (no matter if we are speaking about a large consumer or reduced consumption, household or company). The only difference that occurs between households and companies appears depending on the area in which they are located (PRE in Prague, EON in South, CEZ all the rest). But the constant costs are the same for all three companies (PRE, EON or CEZ) [7].

For energy and power consumption are two types of rates: high price, usually during the day and low price, usually at night (not related to time itself but the signals from stations that control your device installed).
The mathematical comparison shows that, for the company located in Chotysany, only in the year 2022 the model where it is applied the "green bonus" policy becomes more advantages than the policy of selling the energy produced, but only for 3 years.

Modeling the situation, aiming our target we change the consumption according to the tariffs applied and we obtain a model where the "green bonus" policy became advantageous and for the whole time of the project. This result is important because, as the newest law states, the producers which produce more than 100 kWp cannot decide in between the policies applied but only the "green

bonus" policy. The model continues, changing the inputs, we obtain new results but the best result was the one mentioned above.

I think that our paper is bringing new results which are not very often done in the research projects. The available studies are about the mathematical methods for calculation, related with photovoltaic systems. But the studies available refer mostly to technical part, technical modelling, computational method for photovoltaic systems, mathematical modeling of the characteristic $I = f(V)$ [8], [9], [10].

Regarding the technical economical case studies for engineering of photovoltaic systems are not many research projects or articles available besides the companies which have like main activity services for designing a specific system for the consumers' needs. Surely such companies do not offer or make a complete overview. In my opinion our study is interesting for companies which are using or planning to use photovoltaic energy to analyze their own efficiency or to change something for aiming the best, by using one of the policies valid in Czech Republic which are appropriate for their situation.

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