Small Wind Power Plants

Feasibility Study

Viktor Kádek
viktor.kadek@gmail.com

Instituto Superior Técnico - Universidade de Lisboa, Portugal

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Abstract

This thesis studies feasibility of installing small domestic wind turbines for objects of small to medium power consumption, like for instance farms, smaller manufacturers, or neighbourhoods in the scope of the Czech Republic. In the first part, the paper reviews current energy situation of the Czech Republic and compares to the one in Portugal. Thereafter, the climate conditions and legal requirements are studied in more detail, with respect to the wind energy and subsidies policies for domestic wind generation in the Czech Republic.

In the second part, this work focuses on simulation and optimisation of renewable energy instalment for a model dairy farm. For a study period of 30 years, we evaluate four scenarios altogether. Firstly, a grid-connected solution using wind generation and electricity injections from a distribution grid (both with and without subsidies). Additionally, in the grid-connected variant, we will assess the economic feasibility of adding batteries in such an installation, with the constraint of maximum 5 % of allowed unmet load (which will be injected from the grid). The second variant simulates an off-grid instalment with wind generation, photovoltaics, AC generator and batteries (again, with and without subsidies). Finally, we compared all the results with a traditional AC grid connection without using renewables.

The best scenario was the off-grid solution with subsidies. However, traditional AC grid was still a bit more efficient. Furthermore, we reveal that subsidies are still crucial for such instalments and can significantly affect the economic results of the whole project.
Keywords: renewable energy, wind turbine, subsidies, feasibility, simulation

1. Introduction

Currently, the Earth is facing several key challenges, such as growing population levels, rising demands of people, severe environmental pollution and degradation of traditional (fossil) resources. The common denominator of all these issues is energy and its efficient generation and usage. These difficulties, and much more, are bringing us on the edge of the sustainability. Luckily, most of the people already realised the seriousness of the problem and impact of decisions made regarding the environment.

Regarding environmentally and financially friendly solutions, the most used technologies nowadays is wind generation and photovoltaic units. These principles are the most promising and belong to the most developed renewable energy sources (RES) of electrical energy. The main advantages are their non-depleting and non-polluting nature, but the drawback can be their site-dependency and unforeseeable intermittent behaviour. However, these disadvantages can be overcome by using proper energy storage system or integrating two or more resources into a hybrid system. Both forename technologies are currently in a continuous development phase and are becoming a significant game changer in the field.

The framework of this work will focused on the Czech Republic mostly. Unlike in most of the Europe countries, wind generation is not a popular source of clean energy here. The reasons are various: political (mainly), historical and climatic. Doubtful public opinion is not an exception. There are strong political driving forces in favour of conventional energy generation (nuclear, coal) and quite an ignorance towards alternative energy sources. Public opinion of the masses is also strongly affected by this political blindness. There is also a lack of legislative background and support for either domestic or industrial generation of renewable energy, mainly wind energy.

According to the IEA, the renewables industry achieved an important milestone in 2015, when the annual power capacity additions exceeded the conventional fossil and nuclear sources. Moreover, 150 GW of power additions in RES was a new record and was nearly 4-times bigger than a decade before, when these capacity additions were also at an all-time record [5].

As is visible in Figure 1 these outstanding power capacities additions in 2015 were led by WG. New wind power capacities installed (65 GW) in 2015 were roughly 35% higher than the previous year, and by the end of the year, there were around 433 GW of wind power globally. The absolute leader in the sector is China, with half of the wind power additions, followed by the EU (led by Germany) and the USA. These three countries (or political formations) accounted approximately 80% of the global wind power additions. Still, the majority of new wind installations were located in developing countries, and this trend will probably continue. For instance, cumulative wind power installed at the end of 2015 in China (145 GW) was higher than in all EU countries combined (141.6 GW) [3, 5].

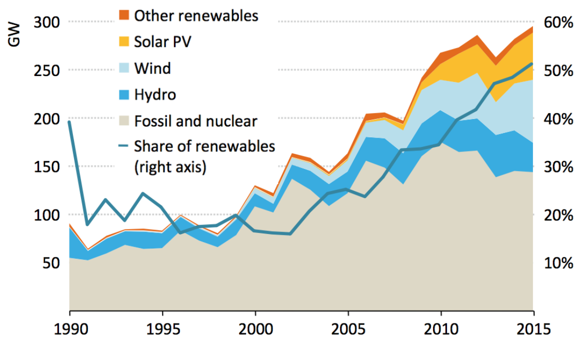

Figure 1: World power capacities additions in renewables sector by types and share [5].

Inside the EU, in 2015 as much as 44.2% of new power installations came from wind power. This reflects a rapidly growing trend of WG. However, even market inside of the EU is not consistent, as almost half of the every new GW installed took place in Germany, which makes this country a leader in WG in the EU (45 GW installed). Germany is followed by Spain (23 GW), the UK (nearly 14 GW), France and Italy (both around 10 GW). Denmark, Poland, Portugal and Sweden each have installed more than 5 GW [3].

1.1. Objectives

The principal objective of this thesis is to provide a complete overview of wind generation in the Czech Republic. Secondly, to deliver a feasibility study of several installations of wind power plants focused on the sustainability and economic efficiency of a smaller wind power plants dedicated to households, communities, farmers and manufacturers. The aim is also to develop a case study and determine its potential in the framework of small wind generation in the Czech Republic. The secondary objective is to promote RES in the Czech Republic and point out the advantages and drawbacks of the policy in the country.

1.2. Outline

The thesis is divided into two main parts: Theoretical and Computational (Case Study) part. In the first part, a brief overview of the energy situation and policy in the Czech Republic will be presented. This chapter will be followed by analysis of climate conditions with regards to wind generation. We will also determine a location for the further computational modelling. Analysis legislation background is also a fundamental part of the work, subsidies policies, feed-in tariffs, permission processes and weaknesses of the policies will be explained in more details. Later we will identify and describe our target group and its energy needs to understand better and design the proper energy system. Also, we will focus on research on the current wind turbine technologies and technical solutions and alternatives for domestic use.

In the second part, a complex techno-economical assessment for an on-grid and off-grid installation will be conducted under the framework of iHOGA software. We will focus on evaluating feasibility of such installations for a model object in a real location in the Czech Republic. The simulation and optimisation will be focused on minimisation of the total costs (and incomes) for a study period of 30 years.

2. Conditions for Wind Power

Wind turbines obtain their energy from the reduction of speed of the surrounding flowing air - the wind. In other words, the kinetic energy of the wind is (partially) converted into kinetic energy of the rotor of the wind turbine, which is subsequently converted into electric energy. As can be seen in Figure 2, the kinetic energy of the flowing mass E through a surface withe area A during the time t is given by equation 1.

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3\,, \qquad (1)$$

where m is the mass of the air, v is the velocity of the wind and ρ is the density of the air.

Then, because energy is the integral of power, the power P of the wind passing through a surface with area A, which is considered as perpendicular to the direction of the air flow, is:

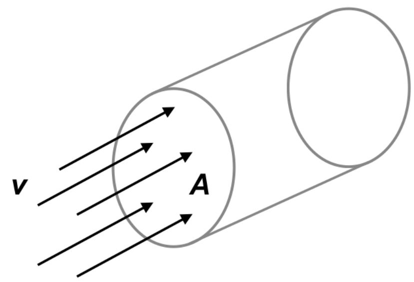

Figure 2: Scheme of the available power from wind.

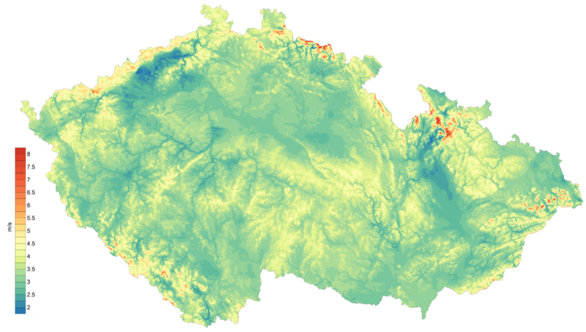

Figure 3: Wind map of the Czech Republic, calculated for the altitude of 10 meters above the ground level [4].

$$P = \frac{dE}{dt} = \frac{1}{2}(\rho A \frac{dx}{dt})v^2 \,. \tag{2}$$

$$P = \frac{1}{2}\rho A v^3 \,. \tag{3}$$

Where x is the thickness of the volume of air.

Now, we introduce the Betz's law (published in 1919 by the German physicist Albert Betz) which shows the maximum power that can be obtained from any Newtonian fluid (including the wind) independently on the design of a particular wind turbine. It was proven, that the theoretical maximum energy which can be captured by a wind turbine is 16/27 or 59.3% of the kinetic energy of the wind [1].

Then, the maximum power of wind turbine is:

$$P_{max} = C_p \frac{1}{2} A \rho v^3 \,, \tag{4}$$

where C_p is the power coefficient with maximum value of 0.593. However, modern large wind turbines can reach maximum value for C_p from 0.45 to 0.50 [1].

Most of the modern wind turbines are able to generate electricity at the minimal speed of the wind 4 m/s. To achieve economic feasibility of a wind turbine project, we need the minimum average wind speed of 4.5 m/s. In Figure 3, this speed is represented by yellow colour. We can see that a reasonably significant part of the surface of the Czech Republic is marked as yellow thus with favourable minimum wind speed [9, 7].

The average annual wind speed is usually determined by the absolute frequency of measured wind speeds during the year. The majority of wind turbines generate maximum power at around 15 m/s (effective wind speed). In areas with the average annual wind speed of 4.5 m/s, the effective wind speed is reached only for few hours a year.

Regarding the climate conditions for wind energy in the Czech Republic, we can conclude, that there are rather favourable wind conditions for implementing either small domestic wind power plant or big industrial one. Although there are countries with far better conditions, there are also countries with comparable or even worse conditions which are implementing wind power at a much more intensive level.

3. Legislation - Subsidies

For the installations of RES with the nominal power above 10 kW, it is obligatory to get a license from the Energy Regulatory Office of the Czech Republic, which involves more administration and bureaucracy. However, with the license, it is possible to become an official energy market participant and reach on one of the two subsidies policies, based on the amount of produced electricity. One has a freedom to choose either *Green Bonuses* or *Feed-in Tariff*.

Green Bonuses

Surpluses are purchased by individual traders on the electricity market, and *the DSO pays for each kW produced* according to the price decision in the given year, which is regularly issued by the ERO and it varies for every renewable energy systems and year of the construction.

The possibility of higher economic efficiency compared to the *feed-in tariffs* is given by the amount of own consumption and the price of electricity. In this solution, all the energy produced is preferably fed into the sub-distribution system of the building, where it is preferably consumed by its own appliances and surpluses are supplied to the distribution system via a 4-quadrant electricity meter.

This method is particularly convenient when the energy can be produced and consumed at least partially at the same time. The advantage is saving in the installation of a new connection - the power plant will be connected to the existing distribution. The disadvantage is purchase price per 1 kWh, compared to the *feed-in tariffs*. This drawback of the lower purchase price is compensated by saving electricity purchased directly from the distribution network.

Feed-in Tariffs

For this case, the buyer of the electricity produced in renewable micro-source is the DSO or TSO and the fixed price for the whole period is guaranteed by law. Similarly, as in the case of *Green bonuses*, the price level strongly depends on the mean of renewable energy production and year of the installation.

In this solution, all generated energy is supplied directly to the distribution system's transfer point. This place is usually an electric pillar equipped with an electricity meter that measures all the electricity produced. All produced electrical energy is sold to the DSO and supplied to the distribution system.

This connection method is suitable for larger installations, especially where the power plant is built only for the purpose of supply to the grid. The advantage of this option is the higher purchase price per kWh delivered compared to the electrical connection. At the same time, however, the owner has to pay the share for connection according to the law - approximately 20EUR/Amp and to set up a new supply point - the necessity of further investment. Also, any energy consumed by the own facility must be bought from the DSO - it is not possible to directly use self-produced energy.

Installations under 10 kW

Unfortunately, installations under 10 kW of the nominal power cannot reach on production amount based subsidies like *Green bonuses* or *Feed-in tariffs*, unless they received a license from the ERO, which is, of course, a more complicated process. The only option of government support for small domestic micro-sources, which did not have the license, is to get a one-time financial support based on the level of installation investments.

This programme is called *New Green for Savings* and is operated by the State Environmental Fund. Through this fund, we can get a maximum subsidy for a micro-source with an accumulation of energy up to 50 % (or approximately 6000 EUR) of the total investments, which is not a negligible amount. Unfortunately, the programme only supports solar thermic and solar photovoltaic micro-sources, so there is no possibility to get a subsidy for a small domestic wind turbine [11].

4. Simulation and optimisation

The following section will be dedicated to a techno-economic simulation, in which two possible scenarios will be assessed: off-grid and on-grid installation. Further more, we will assess economic feasibility of using batteries for the grid-connected solution with regards to the constraints. Both of the variants will be evaluated with and without subsidies, to prove or disprove the economic feasibility of the subsidies policy, as can be seen in Figure 4. The simulation and optimisation process will be run in iHOGA software. It is needed to state, that we set the constraint of maximum 5 % of grid-injected electricity (95 % or electricity must be produced by the domestic RES).

We will simulate and optimise the variants as mentioned earlier in a software tool called iHOGA (Hybrid Optimization by Genetic Algorithm), which was developed at the University of Zaragoza, Spain. This software is primarily used for simulation and optimisation of stand-alone hybrid systems for power generation based on RES. This software models systems with electricity load (both DC and AC) and hydrogen consumption, as well as the use of water from reservoir tank [10].

As was discussed in earlier, this thesis aims to evaluate the techno-economic feasibility of a small wind power plant. For this purpose, the object of the power consumption should be relevant to the size of the power plant - smaller manufacture, farm or neighbourhood. For this simulation, we will choose a model object - small dairy farm with an exact load curve defined monthly and a real feasible location in the Czech Republic.

Thanks to the article of Upton [6] we can define power consumption in a small-size dairy farm very exactly. In this work, Upton focused on defining and demonstrating a model that allows dairy farmers assess the impact of various technical innovation on their electricity consumption and costs. The model took into account the following dairy farm's components and their consumption [6]:

- milk cooling,
- water heating,
- milking machines,
- lighting,
- water pumps,
- wash pumps,
- winter housing,

This model for electricity consumption on dairy farms was validated by empirical data of 1 year with actual commercial, grass-based dairy farms counting 45, 88 and 195 milking cows. For our case, we will calculate with a small farm with 45 cows.

The model predicted a total consumption of electrical energy of nearly 8 500 kWh per year and electricity-related emissions of more than 4 600 kg of CO_2 (0.546 kg of CO_2 per kWh [2]). Because of the limitation of the education version of iHOGA software, which sets maximum average load to 10 kWh per day, we have to set the maximum annual load to 3 650 kWh. This means that all values regarding power consumption of the model farm will be multiplied by a correction factor of 0.429. The adjustment will set the total annual power load to 3 645 kWh (9,99 kWh per day - allowable limit).

After describing power demand patterns and power load curve of the model farm, we set a possible location of the object. Taking into regards all

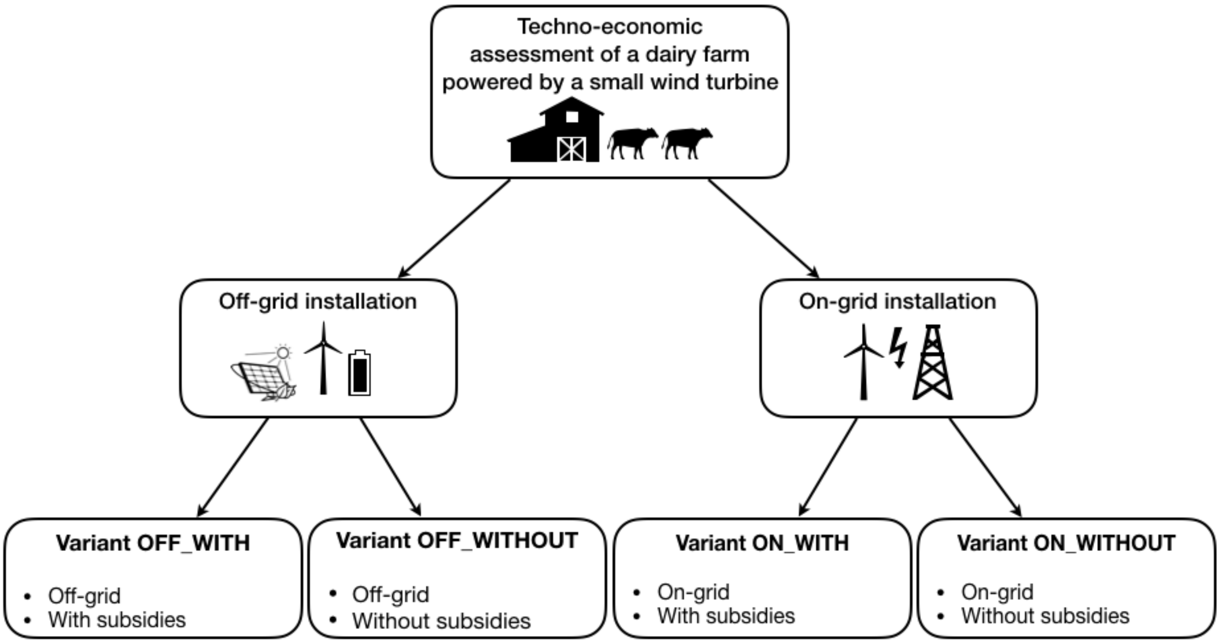

Figure 4: Scheme of the simulation variants.

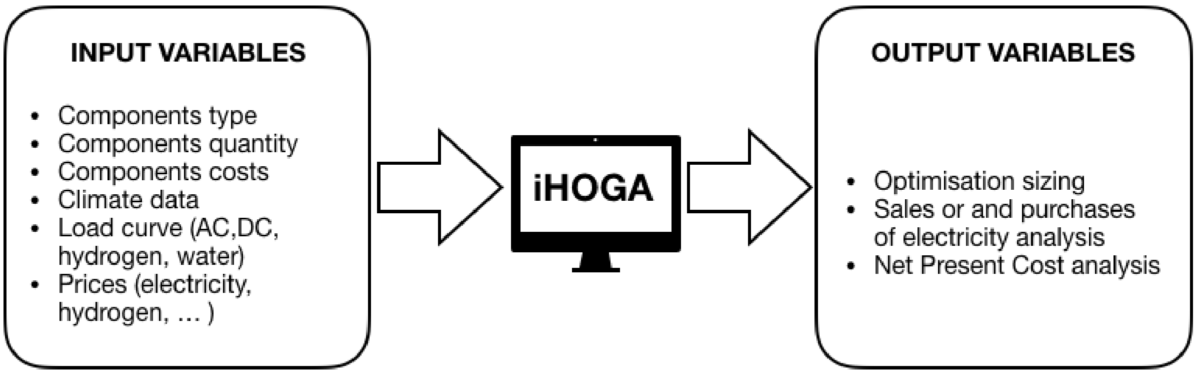

Figure 5: Schematic representation of the iHOGA software.

climate, biological, geographical and other important conditions, the most feasible location for a farm which is supposed to use all climate conditions for the wind energy, yet be sufficient enough for a high production yield, is the region of Vysočina (literally translated as *Highlands Region*).

The location's climate data relevant for our simulation were downloaded from *NASA Surface meteorology and Solar Energy* database and are listed in Table 1 [8].

Table 1: Main characteristic of the model object [6, 8].

Characteristics of the Model Farm	Unit	Value
Latitude	°N	49.677
Longitude	°E	15.592
Elevation	m	427
Annual wind speed average (at 10 m)	m/s	7.4
Annual air temperature average	°C	7.8
Annual horizontal daily solar radiation average	kWh/m^2/d	2.99

Additionaly, we can see a monthly average wind speed in Figure 6. We can say that the average wind speed in this location is favourable enough for installing a wind turbine [8].

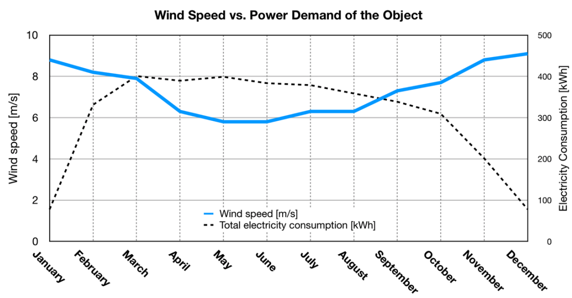

Figure 6: Monthly average wind speed and power demand of the model location [6, 8].

We can also see the probability distribution of the wind speed (Figure 7). The probability distribution is showing us, that wind with speed from 3 to 6 m/s are the most probable to occur.

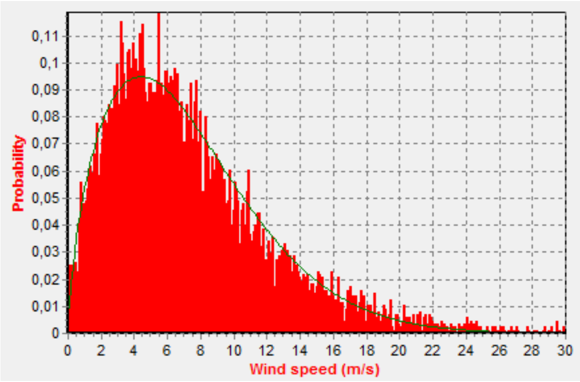

Figure 7: Probability distribution of the wind speed on the model farm as modelled and obtained from iHOGA.

4.1. Grid-connected Solution

Firstly, we will simulate, optimise and evaluate a grid-connected solution, consisting of the following components:

- wind turbines,
- batteries (optional),
- DC/AC inverter,
- grid connection.

Note, that batteries are only optional because their economical feasibility will be assessed during the simulation. Scheme of the grid connection is illustrated in Figure 8.

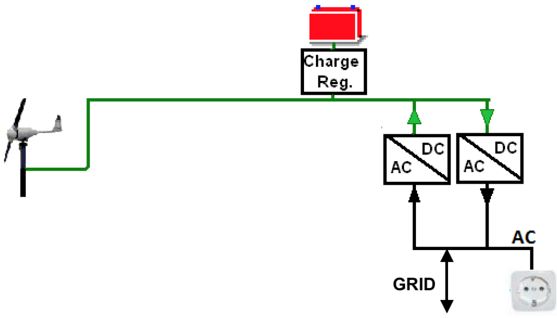

Figure 8: Scheme of the grid-connected solution for the model farm.

4.2. Off-grid Solution

Second option to be evaluated is an off-grid installation containing:

- wind turbines,
- PV panels,
- AC generator,
- batteries,
- DC/AC inverter.

Scheme of the off-grid installation is depicted in Figure 9.

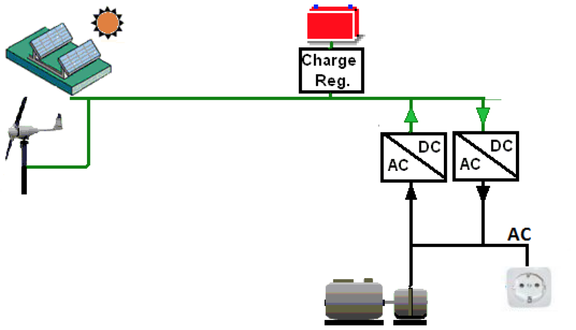

Figure 9: Scheme of the off-grid solution for the model farm.

For every simulation, there is a database of components that were hand-picked according to the available renewable technology market in the Czech Republic (or Central Europe, if it was available in Czech market).

4.3. Wind Turbines

Regarding wind power, we selected nine wind turbines from three different manufacurers: Southwest (USA), Bornay (Spain) and Hummer (China). The maximum power output varies from 0.4 kW (Southwest Air-X) to 27 kW (Hummer HWP-20). The price range is between 1 040 to 24 200 EUR. Since wind turbines are the subject of intensive research, development and both public and scientific attention, a continuous decrease in wind turbine costs is expected. Therefore, we introduce a negative annual inflation rate for wind turbine costs of -1 % with maximum reduction of wind generation technologies costs of -25 %. This limit would be reached in nearly 29 years.

4.4. PV Panels

In order to ensure stable power output for the off-grid variant of our model system, solar PV panels are an integral part of such an installation. Solar irradiation compensates lower wind speeds during summer months when there is higher power load. Therefore such a hybrid wind-solar installation seems like an ideal solution for off-grid schemes. We selected nine PV panels with nominal power ranging from 100 to 300 Wp and price level from 123 to 437 EUR (VAT excluded). Additionally, we introduced a virtual Zero PV panel, which represents the possibility of excluding PV panels from the simulation. Similarly as in the case of wind turbines, according to the situation in PV market and R&D, we expect a cost reduction in solar PV technologies. Therefore, we set the annual inflation rate for PV panels costs to -1.5 % and the maximum reduction in current PV costs to -40 %. This limit would be reached in nearly 34 years.

4.5. Batteries

Batteries are also an essential element of stand-alone renewable energy systems. In case of assessment the grid-connected variant, we will assess if there is economic feasibility to install a battery into the system. In the off-grid case, we assume that battery is a necessary part of the installation and we will evaluate which type of the battery is the most efficient for our model farm. For the simulation, we selected 21 lead-acid battery plus one virtual zero battery for evaluating the case without any form of energy storage (especially for the grid-connected case). The nominal capacities of the batteries vary from 5.1 to 686 Ah, and the price range is between 40 and 256 EUR. Among this selection, there are two types of batteries: OPzV and OPZS. They are both tubular lead acid batteries.

4.6. AC Generators

Regarding the off-grid variant of our case study, an AC generator is a crucial element in order to ensure stability and backup option. Although we will design the energy storage to last for at least six days, an object like a farm must have a backup source as it can directly affect lives of the animals. We introduced four possible AC generators: two diesel and two gasoline powered. Their rated power output range from 0.5 kVA to 3 kVA and price changes from 250 to 1050 EUR. We also assumed the annual inflation rate of the fuel costs at the level of 2 %.

4.7. Other Components

As our installation will contain elements, which produce DC output as well as we will charge and discharge batteries, we need additional essential auxiliary devices, such as:

- inverter
- battery charger (rectifier)
- PV battery controller

Thanks to the development in RES area, many manufacturers started to produce hybrid all-in-one devices that join the functionalities of all devices mentioned above. Since the offer of these devices is extensive and they are not the objects of the primary interest, we introduced a generic all-in-one inverter which satisfy all the system's needs.

5. Other Input Data and Assumptions

To simulate the real conditions most accurately, we have to introduce additional input data and assumptions before running the optimisation.

For the grid-connected solution, we will allow purchasing unmet load from AC grid at a fixed price including tax, DSO fees, and contracted current fees. Therefore we also set annual inflation for electricity prices. Additionally, in the subsidies-free variants, we will not allow selling excess electricity to the AC grid. Selling excess energy will be allowed only in the grid-connected variant with subsidies. In the Czech Republic, neither net metering nor smart meters are available readily on the market, and the grid is also not ready for purchasing excess electricity. Therefore, surpluses injected to the grid are not paid. Furthermore, they can be even a matter of additional fees to the DSO if they excess certain level.

The situation will be different if we take subsidies into account. As was mentioned earlier, one can choose between Feed-in tariffs and Green bonuses. The Green bonuses are paid out for every kWh of produced electricity, while Feed-in tariffs for every kWh injected to the distribution grid. Therefore, for installations where we expect that significant part of the generated electricity will be consumed on the same site, the Green bonuses are the preferred option. For this purposes, we will assume that our model power plant will be deployed in 2017. We will also assume a one-time investment into connection to the AC grid at the level of 1 500 EUR. This investments cover all the expenditures regarding constructing a new supply point on a field without previous connection.

In case of the off-grid variant, we can use neither Feed-in tariffs nor Green bonuses. The only possibility to reach on subsidies is to get a one-time financial aid as high as 6 000 EUR for the PV part of the installation (note that maximum financial aid is 50% of the overall PV installation costs).

We consider residual costs of the installation after the study period (based on the remaining lifetime). Additionally, we will assume a constant quota loan for 80% of the initial cost of investment, duration of 15 years and interest rate 7 %. All other input data are shown in Table 2

Table 2: Additional input data

Additional input data		
Fixed buy price of the electricity (total)	EUR/kWh	0.2056
Green bonuses	EUR/kWh	0.0548
Feed-in tariffs	EUR/kWh	0.0739
Maximum load purchased from AC grid	%	5
Annual inflation rate	%	2
Days of energy autonomy	day	6
Time step for the simulation	min	60
Study period	yr	30
Nominal interest rate (price of money)	%	6
Annual real discount rate	%	3.92
Installation cost (fixed)	EUR	300
Installation cost (variable)	% of initial cost	2
Amount of loan	% of initial cost	80
Loan interest rate	%	7
Duration of loan	yr	15

6. Results

We ran simulation and optimisation for four possible scenarios:

- Variant ON WITHOUT: grid-connected solution without subsidies,
- Variant ON WITH: grid-connected solution with subsides,
- Variant OFF WITHOUT: off-grid solution without subsidies,
- Variant OFF WITH: off-grid solution with subsidies.

The simulation and optimisation in iHOGA software was mono-objective, the object was NPC costs over a 30 years study period.

We ran four simulations in iHOGA software, considering power load of a model farm, composition of various renewable components and their prices on current market and availability of resources in the location. The outcome of the simulation and optimisation was the optimal composition of technology, optimised in regards to the lowest Net Present Cost for a studied period of 30 years.

In Table 3 and Figure 10 we can see comparison of all earlier mentioned cases.

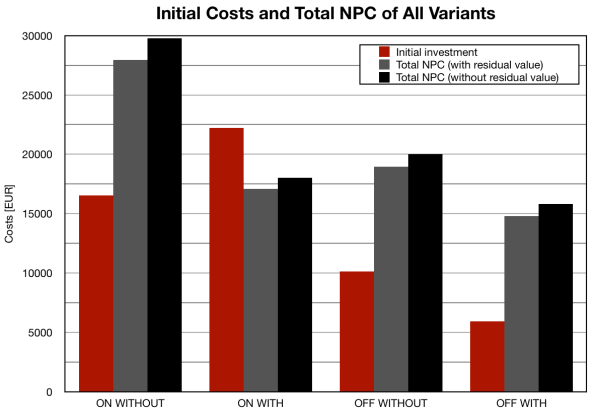

Figure 10: Comparison of initial costs and NPCs of all scenarios.

As one can observe, the economically worst option is a grid-connected scenario without subsidies. With this scenario, the LCOE is 0.27 EUR, which is almost twice that much as in case of the best option: off-grid with subsidies (0.14 EUR).

On the other hand, the best option (regarding NPC) is the off-grid installation with subsidies, where the initial costs are only as low as 5 948 EUR which is far lesser than all other options. The NPC, in this case, reach only 14 795 EUR.

We can make two conclusions: options with subsidies are more efficient, which was expected. Secondly, off-grid installations are more profitable than grid-connected. This is a valuable observation, as off-grid installations, besides the NPC, have more advantages such as independence on AC grid, political decisions, or natural disasters. Therefore, investing in an off-grid project can pay off faster.

Finally, we compared all the scenarios to a standard AC grid scheme, where we supply all the power from a DSO network. In this case, we assumed that the costs regarding connecting to the distribution network are as high as 1 500 EUR and the annual bill for the electricity costs is 750 EUR. The NPC of such a configuration was 14 601 EUR (LCOE 0.13 EUR). This is the most efficient option, but we must take into account, that the difference between the standard AC connection and an off-grid installation is only 194 EUR in 30 years (see Table 3). Taking into account other, non-economical advantages of the off-grid scheme mentioned above, we do recommend installing an off-grid system (assuming the possibility of the subsidies).

We also proved, that the actual renewable market and political situation in the Czech Republic does not to compute renewables with conventional resources. Without the subsidies, the RES would not be economically efficient at all.

7. Conclusion

In first (theoretical) part of this work, we researched the economic background of the power field in the Czech Republic, comparing to Portugal. After introducing all common and all different element in country's economy, we found out the attitude towards has many differences. While population, area, or GDP is almost identical between those two countries, approach toward power engineering is an entirely different story. While 49 % share of the power mix in Portugal belongs to renewables, it is only 12 % in the Czech Republic. In Portugal, the majority of the public is in favour of wind energy (or renewables at all). The opposite situation occurs in the Czech Republic, where the majority of people are in favour of maximising the use of available and known coal resources or searching for a new one. Additionally, almost two-thirds of Czechs would not agree with building a new wind power plant near their municipalities. In Portugal, 86% of the people would agree with such an installation. Therefore, in order to improve the national power mix towards renewables, we found out it is crucial to educate people about the advantages of these new technologies. Additionally, power field in the Czech Republic relies on Nuclear Power even more than in RES and the nuclear creates one-third of the overall power generation in the Czech Republic.

Regarding legislation conditions for wind power in the Czech Republic, the laws are still not clear and universal. Most of the wind power (or RES in general) legislation is in hands municipalities and

Table 3: Comparison of initial costs and NPCs of all scenarios

Variant	Initial costs	NPC with residual values	NPC without residual values	LCOE
	[EUR]	[EUR]	[EUR]	[EUR/kWh]
ON WITHOUT	16 536.9	27 927.7	29 759.5	0.27
ON WITH	22 201.4	17 094.9	18 041	0.16
OFF WITHOUT	10 113.9	18 960.7	19 999.8	0.18
OFF WITH	5 947.9	14 794.7	15 883.8	0.14
AC Grid	1 500	N/A	14 601	0.13

not unified. Therefore, when searching a new location for a wind power plant (even small domestic one), it is crucial to make legislation research of the location as the initial step of the project. On the other hand, subsidies for RES are quite developed in the Czech Republic, even if the whole renewable sector is still in the beginning. The government offers two types of subsidies (Feed-in tariffs and Green bonuses) based on the amount of generated electricity and also a one-time financial aid 50 % of the initial costs (up to 6 000 EUR), but only for domestic PV panels.

7.1. Case Study

The second part of the work dealt with a case study focused on simulation and optimisation of a RES instalment for a small model farm. For this purpose, we used the iHOGA Software, which is capable of evaluating numerous variants of renewable instalments taking into account all climate data and economic conditions. The aim was to evaluate four possible scenarios: grid-connected variant (with and without subsidies), which was based on wind generation and injecting unmet power from the distribution network. It is needed to stay, that we constrained maximum unmet power to 5% of the total annual consumption. We also evaluated the economic feasibility of the batteries for this case - batteries were feasible even for grid-connected cases. The other two scenarios were off-grid installations with and without subsidies. For the off-grid variant, we used wind generation complemented with PV panels, batteries and a backup AC generator.

Firstly, we described the object of the power load: we chose a small dairy farm, which's electricity consumption was described into much details in a previous study [6]. When we had the power load for every month in the year, we determined the location of the model object. To obtain optimal results from the wind turbines, we chose of the windiest regions in the Czech Republic - the Vysočina region. With the iHOGA software, we downloaded real measured data about wind speed and solar irradiance directly for this location which we used for the simulation of energy potential in the area.

After determining the data about the object of the power consumption - small dairy farm, we researched the Czech and Central European Market to pick possible components such as wind turbines, solar panels and batteries. We only used a generic inverter as it was not an object of primary focus. Then we run several simulations to find the optimal results. The optimisation was mono-objective, focused on minimising the Net Present Costs over the studied 30 years period. We did take into account residual costs of the components after this period, as well as inflation rate for specific technologies (in case of renewable technologies, the inflation rate was negative as we expect that these prices will be dropping down continuously).

Against our expectations, the results were more in favour of the off-grid solutions (see Table 3). Additionally, besides the lower NPC, this independence on the national grid brings also non-financial advantages like resistance against electricity prices fluctuations or legislative regulations or partial resistance against natural or human disasters (e.g. war). Also, initial costs in both off-grid cases were much lower than in grid-connected scenarios.

When we took into account the subsidies, they had a significant effect on lowering the NPC, and therefore we can state that government incentive has still sense in boosting the RES in the Czech Republic.

It is also needed to stay, that in the most efficient case - an off-grid scenario with subsidies, the amount of energy generated by wind was approximately 11 times lower than the PV generation. Giving it in numbers, while PV panels generated 42 kWh/EUR (amount of investments in PV panels), wind-generated only 7 kWh/EUR. Therefore, we assume that solar energy has more potential and is more visible than wind energy solely. However, combined solar and wind system can optimally complement each other.

Finally, we compared all the scenarios mentioned above with a traditional connection to the

AC Grid. With LCOE of 0.13 EUR/kWh, it was still better than the most optimal off-grid scenario (0.14 EUR/kWh). However, the difference in total NPC over the 30 years period was less than 200 EUR, which is only 1.4 %. Taking into account the independence, and other non-financial advantages, we would recommend the off-grid scenario.

7.2. Future Proposals

Since we found out, that there probably higher potential in solar generation than in wind power, we would recommend working on similar optimisation using primarily solar power, to prove if our hypothesis is right.

Additionally, all the examined scenarios could not compete with a conventional AC grid without subsidies. The only thing how to overcome this is to improve the technology, make it more efficient and minimise the investment costs.

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