Passive House Premium: a viable energetic integration in Portugal?

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ABSTRACT

Buildings are responsible for 30% of primary energy consumption in Portugal, which translates the importance of measures to be applied in buildings, that contributes for the decarbonization, through energy efficiency, implementation of renewables and mitigation of fossil fuels.

The integration of renewables regarding micro generation, is an important contribution to the growth of a more sustainable energy sector. The renewable energy systems are infrastructures and technologies efficient, flexible and sustainable.

In this dissertation, there is an evaluation of the implementation of renewable energy, through photovoltaic system and wind turbines, in buildings, according the requirements of Passive House Premium certification, considering the minimum imposed of primary renewable energy.

The potential of renewable energy, considering the photovoltaic system and wind turbine, is evaluated in several locations in Portugal, which indicates the influence of the geographical location and the conditions associated on site, in choosing the preferable renewable solutions and their specifications in the buildings in question. The economic evaluation demonstrates that in most of the cases, the use of wind turbines, of lower power, in question, still are costly, which jeopardizes the economic feasibility of the projects, according to the renewable solutions in analysis.

Keywords

Buildings; renewables; renewable energy; photovoltaic system; wind turbine; Passive House Premium

1. INTRODUCTION

1.1. Context

The energy sector, in addition to playing a key role in economic growth, also has a major influence on the environmental problems that the planet has been facing. The analysis on the energy sector, through the years, demonstrates the evolution of energy production and consumption, influenced by the availability and accessibility of raw materials, associated with technological advances and even historical events. Energy intensity is a parameter linked to economic growth, which indicates the energy efficiency of a country's

economy. A high value represents a high cost in converting energy into gross domestic product. A lower value, in contrast, indicates a low cost in converting energy into gross domestic product. The ratio of the consumption of final energy to gross domestic product (GDP) describes the energy intensity of an economy, where its analsysis, along with other parameters relevant to energy supply and consumption, over a number of years, provides results of great interest for certain periods, marked by historical, technological, economic, political or social disruptions, (Jarmo, Kaivo-oja, & Luukkanen, 2018). It is important to note that economic growth encompasses several variants besides the energy mentioned in this chapter, namely the influence of the concept of exergy, investment or productivity. As already mentioned, the temporal analysis makes it possible to identify relevant periods, which have somehow impacted a nation's economy, namely industrial revolutions, and given the destructive scenario on the planet, originated from the excessive use of fossil fuels, it is expected a revolution towards the replacement of non-renewable resources, characterized by a new energy transition. The negative consequences of the excessive use of fossil fuels are more and more visible and studied, which translates into the deterioration of the health and quality of life of many populations. These alarming events have changed priorities in the sector, where the goal is to shift the predominant resource from fossil fuel consumption to renewable energy. The studies and analysis of fossil fuel consumption in various European countries are important for assessing the present and the future expectations, outlining a strategy appropriate to each case, according to resource availability and energy needs. Depending on the renewable energy generated and the fossil fuel consumption for each country, energy dependence becomes a prominent parameter in the energy sector, since the lower is the value, the better it is for the country, resulting in a lower dependence on fossil fuels and the increase of renewable energies, referring to the final energy consumption, (Martins, Felgueiras, & Smitkova, 2018). Energy transition has been a priority to countries that recognize the consequences of the continued use of fossil fuels for several years. The energy transition and the decarbonization of the economy are goals that have become more evident in the political sphere, and have been evaluated as opportunities for economic growth, and are essential to fulfill the commitments made by Portugal in 2016 to achieve carbon neutrality by 2050. The paradigm shift could involve a synergy between energy efficiency and renewable energy proliferation, with much potential in global energy demand, economic growth, and job creation, to achieve the objectives outlined by the Paris Agreement, (Gielen, et al., 2019). Renewable energy, as already mentioned, is part of the solution. Their sources are the sun, wind, water or other renewable provided by the planet, which contribute to the reduction of greenhouse gas (GHG) emissions and other harmful pollutant to health. The introduction of solar panels for sanitytary water heating and photovoltaic solar panels for electricity production has contributed to a greater understanding and awareness of the importance of obtaining energy from natural and renewable sources, resulting directly in energy savings without compromising building efficiency. Energy efficiency has also become a priority in buildings, and energy certification has become a key tool for evaluating buildings. Today the public policy challenge for 2020 requires new buildings to be energy efficient with an almost zero energy balance. The implementation of measures that make a building with almost zero energy needs will become mandatory, where these small needs should be met by renewables, according to the addition of Decree Law No. 118/2013 to the publication of the Energy Performance Directive of Buildings, (UE, 2010). The assessment of buildings can be done through the international standard Passive House. Passive House is a constructive concept based on a high energy performance standard, which contemplates comfort, sustainability and economic viability. Energy performance is based on reduced heating and cooling needs through measures during building design and construction, meeting the requirements for certification, (Passive House requirements, 2019). Passive houses are classified according to the amount of renewable energy generated and the primary renewable energy they require. The energy potential of passive houses is dependent on their location, so when renewable energies are analyzed the energy mix selected is very important to achieve the desired results

1.2. Objective

Verification regarding the implementation of renewable energy in buildings, with the purpose of obtaining a positive energy balance, considering the requirements of a Passive House Premium and the inherent constraints of each building under study, which determine the performance of the energy mix in Portugal. In addition to technological analysis, the economic feasibility is another aim of this dissertation, being an important analysis that determines the acceptance and development of any project.

1.3. Hypothesis

The hypothesis of the dissertation is the investigation of the feasibility of a building, according to the Passive House Premium requirements, which consist in the possibility of achieving a primary renewable energy (PER) production in the building of 120 kWh/m2a. The integration of Passive House Premium in Portugal is studied which special emphasis on the renewable component, in order to analyze the conditions associated with the generation of renewable energy, as the energetic mix for each case is extremely important to obtain the positive values of energy production that is intended. Financial feasibility will also be investigated and indispensable for project validation when it come to the investor and/or consumer level.

1.4. Methodology

First, the heating and cooling requirements that validate a Passive House Premium are confirmed. As the emphasis of this dissertation involved the generation of energy from renewable sources, a calculation model is developed that analyzes the energy solutions to be implemented for the various cases under study. The calculation model of the photovoltaic system and the wind turbine is applied to various locations and then the performance of the energy mix is evaluated. The analysis of the results is carried out and the main conclusions are given, taking into account the energy potential and the economic analysis for the energy mix in question.

2. PASSIVE HOUSE PREMIUM

The Passive House Premium category stands out from the other categories for generating significant additional energy based on primary energy renewable (PER) compared to the building's energy needs. The certification limit is 120 kWh/m2, where the reference area consists of the projected building footprint, i.e., the vertical projection of the floor relative thermal envelope, (Passive House Institute, 2018, p. 56). Renewable power generation systems can be installed on the roof or around the building if there is space available, but can also be implemented elsewhere, if conditions favor and enhance the energy generation, always according the certification requirements, (Passive House Institute, 2018, pp. 56-57). The Passive House Premium category is the most recent category, so there are still relatively few that are certified and reported cases. The examples found confirm the feasibility of buikdings with the characteristics required for Premium certification. Renewable energy is mostly generated through photovoltaic systems installed on the roof or in the available space around the building.

3. RENEWABLES PRODUCTION MODELLING

The calculation model developed for the determination of renewable energy incorporates photovoltaic solar energy and wind energy. The data required for the calculations are obtained from online platforms, with certain geographic information, associated with the location under analysis. Most of the cases analyzed in Portugal used the typical meteorological year, obtained from the European Commission (PVGIS, 2019). In the absence of data provided by PVGIS for the islands of Madeira and Azores, the data used is from the soda-pro online application (Soda pro, 2019). For the islands, only data from 2004, 2005 e 2006 are available, so the typical meteorological year cannot be obtained. Given this situation, the model is applied each year and then the respective calculations are averaged over the period under review.

3.1. Photovoltaic solar energy

The energy calculation model of photovoltaic panels involves several steps. The first step involved preliminary calculations, which involve the day of the year, the location and horizontal position, (Duffie. & Beckam, 2013, pp. 8-29). Inclined irradiance is calculated using horizontal irradiance and its components using the HDKR model (Duffie. & Beckam, 2013, pp. 91-92).The second step results in the determination of the effective irradiance that is effectively used for power generation, due to the losses associated with the photovoltaic panel. The last step translates the conversion of solar radiation to electrical energy through photovoltaic cells.

The selected model is 1 diode and 3 parameters. The study of the photovoltaic cell is performed with the aid of a representation of an equivalent circuit. The current $(\boldsymbol{I})$ is given by subtracting the current generated by the presence of the light beam $(\boldsymbol{I_L})$ by the internal current that travels the diode $(\boldsymbol{I_D})$, resulting in the fundamental equation (1).

$$I = I_L - I_D = I_L - I_0\left(e^{\frac{V}{mV_T}} - 1\right) \qquad (1)$$

The calculated parameters depend on the following characteristic photovoltaic panel data:

- The short circuit current, $\boldsymbol{I_{sc}^{ref}}$, characterized by zero voltage;
- The open circuit voltage, $\boldsymbol{V_{oc}^{ref}}$, maximum voltage of the cell, where the electric current is zero;
- The current $(\boldsymbol{I_{mp}^{ref}})$ and voltage $(\boldsymbol{V_{mp}^{ref}})$ that corresponds to the maximum power point;
- The cell number of the module $\boldsymbol{N_c}$.

The thermal potential given in (2) depends on the Boltzman constant, k, which is $\mathbf{1{,}38 * 10^{-23}}\,\frac{\boldsymbol{J}}{\boldsymbol{K}}$, the electron charge, q, which is $\mathbf{1{,}6 * 10^{-19}}\,\boldsymbol{C}$ and the reference cell temperature $(\boldsymbol{T_{ref}})$.

The inverse saturation current $(\boldsymbol{I_0^{ref}})$ is given by equation (3), while the ideality factor $(\boldsymbol{m'})$ is given in (4). The three parameters of the model are the short circuit current $(\boldsymbol{I_{sc}^{ref}})$, inverse saturation current $(\boldsymbol{I_0^{ref}})$ and ideality factor $(\boldsymbol{m'})$.

$$V_{T,ref} = \frac{k\,T_{ref}}{q} \qquad (2)$$

$$I_0^{ref} = \frac{I_{sc}^{ref}}{e^{\frac{V_{oc}^{ref}}{m'\,V_T^{ref}}} - 1} \qquad (3)$$

$$m' = \frac{V_{mp}^{ref} - V_{oc}^{ref}}{V_T^{ref}\,\ln\left(\frac{I_{mp}^{ref}}{I_{sc}^{ref}}\right)} \qquad (4)$$

The reference values are related to normal operating conditions from the technical data sheet provided by the manufacturer. These normal conditions do not correspond to actual operating conditions, and must, therefore, be corrected for the influenced parameters.

Effect of irradiance and temperature

Irradiance has a particular effect on the short circuit current, so a correction is required, implicit in a linear relation given by (5), which involved the reference irradiance $(\boldsymbol{G_{ref}})$ and the irradiance at each given moment $(\boldsymbol{G})$, (Messenger & Ventre, 2005).

$$I_{sc} = I_{sc}^{ref}\,\frac{G}{G_{ref}} \qquad (5)$$

Ambient temperature $(\boldsymbol{T_{amb}})$ and irradiance $(\boldsymbol{G})$ are two factors that simultaneously influence the determination of cell temperature $(\boldsymbol{T_{cell}})$, as well as the Normal Operating Cell Temperature $(\boldsymbol{NOCT})$, characteristic of the panel, given by the manufacturer. After calculating the cell temperature, equation (6), it is assumed that the value is the same for the module temperature, being the module the sum of the specific cell number for each panel , (Masters G. M., Renewable and Efficient Electric Power Systems, 2004, pp. 475-477).

$$T_{cell} = T_{amb} + \frac{NOCT - 20}{800} G \qquad (6)$$

The thermal potential, $\boldsymbol{V_T}$, is calculated according to the previously corrected cell temperature, equation (7).

$$V_T = \frac{q\, T_{cell}}{k} \qquad (7)$$

The short circuit current ($\boldsymbol{I_{sc}}$) is also modified with the temperature, given by (8), involving the temperature coefficient of the short circuit current , $\boldsymbol{\alpha(I_{sc})}$, given in the datasheet, as the reference temperature ($\boldsymbol{T_{ref}}$) of 25º C, the corresponding short circuit current ($\boldsymbol{I_{sc}^{ref}}$) and the temperature of the cell ($\boldsymbol{T_{cell}}$).

$$I_{sc} = I_{sc}^{ref} \left(1 + \alpha\left(T_{cell} - T_{ref}\right)\right) \qquad (8)$$

The gap energy is influenced by temperature and is corrected by equation (9), taking into account the gap energy under reference conditions for silicon, temperature 25º C with $\boldsymbol{E_{g,ref} = 1,121\ eV}$.

$$E_g = [\, 1 - 0{,}0002677 \left(T_{cell} - T_{ref}\right) E_{g,ref} \,] \qquad (9)$$

The corrected saturation inverse current is given by equation (10).

$$I_0 = I_{0,ref} \left(\frac{T_{cell}}{T_{ref}}\right)^3 \exp\left[\frac{q\, N_c}{m'}\left(\frac{E_{g,ref}}{k\, T_{ref}} - \frac{E_g}{k\, T_{cell}}\right)\right] \qquad (10)$$

The determination of the maximum power begins with the maximum voltage ($\boldsymbol{V_{mp}}$), through an iterative process involving short circuit current ($\boldsymbol{I_{sc}}$), saturation current ($\boldsymbol{I_0}$), thermal potencial ($\boldsymbol{V_T}$), and ideality factor ($\boldsymbol{m'}$), (Kalogirou, 2014).

$$e^{\frac{V_{mp}}{m' V_T}} = \frac{\frac{I_{sc}}{I_0} + 1}{1 + \frac{V_{mp}}{m' V_T}} \qquad (11)$$

After having the maximum voltage, then the current, corresponding to the maximum power point is obtained by solving equation (12).

$$I_{mp} = I_{sc} - I_0 \left(e^{\frac{V_{mp}}{m' V_T}} - 1\right) \qquad (12)$$

The maximum power is simply the multiplication of the maximum current ($\boldsymbol{I_{mp}}$) by the maximum voltage ($\boldsymbol{V_{mp}}$). The energy of each photovoltaic panel is obtained by the introduction of several derate factors, which account for the various losses associated with the panel, for each hour of the year, according equation (13).

$$E_{painel} = derate\ (total)\ P_{mp}\ h \qquad (13)$$

The energy of the photovoltaic systems is calculated by multiplying the number of panels to the energy of each photovoltaic panel. The losses associated with the photovoltaic system are accounted by derate factores.

3.2. Wind energy

The available wind energy of a turbine depends very much on its speed ($\boldsymbol{U}$), as can be seen from the analysis of equation (14) which calculates its power.

$$P = \frac{1}{2} A\, \rho\, U^3 \qquad (14)$$

The power curve is unique for each wind turbine, however the power curve supplied by the manufacturer is associated with a certain density, so that parameter must be corrected, according to the density on location, that depends on the ambient temperature and air pressure, given by the database. Similary, the wind speed should also be corrected for different turbine heights ($\boldsymbol{h}$), depending on the reference heigh ($\boldsymbol{h_{ref}}$) and its speed ($\boldsymbol{U_{ref}}$), given also by the database, according equation (15). The roughness values ($\boldsymbol{\alpha}$) can be calculated by equation (16) which relates the roughness length ($\boldsymbol{z_0}$) and the heigh ($\boldsymbol{h}$). The roughness used was influence by the values displayed on the Global Wind website (Windatlas, 2019).

$$U = U_{ref} \left(\frac{h}{h_{ref}}\right)^{\alpha} \qquad (15)$$

$$\alpha = \frac{1}{\ln\left(\frac{h}{z_0}\right)} \qquad (16)$$

The calculation of the energy generated by the wind tubine requires the characterization of the wind speed, so due to the variation presented in a year, the approach adopted is through a probability distribution, Weibull, given by equation (17). $\boldsymbol{F(U)}$ represents the fraction of time that the average velocity per hour exceeds the velocity $\boldsymbol{U}$, that depends on the scale ($\boldsymbol{c}$) and shape ($\boldsymbol{k}$) parameter

$$F(U) = \exp\left(-\left(\frac{U}{c}\right)^k\right) \qquad (17)$$

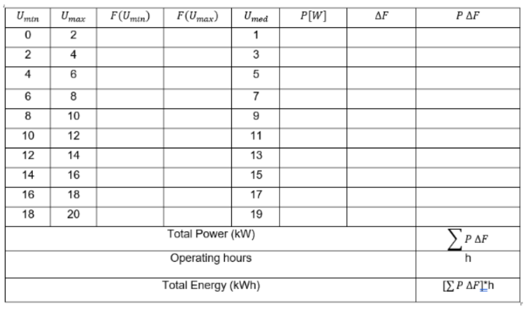
The shape parameter, $\boldsymbol{k}$, is calculated by equation (18), obtained by adapting the moment of methods, which checks the linear relation, which relates the monthly mean velocity ($\boldsymbol{U}$) and its standard deviation (σ), (Tiryakioğlu, 2008). The scale parameter, $\boldsymbol{c}$, is calculated using the gamma function ($\boldsymbol{\Gamma}$), which also depends on the mean wind speed $\boldsymbol{U}$ and the shape parameter, $\boldsymbol{k}$, according to equation (19), (Burton, Sharpe, Jenkins, & Bossanyi, Wind Energy Handbook, 2001, pp. 14-16).

$$k = 1{,}2785\left(\frac{U}{\sigma}\right) - 0{,}504 \qquad (18)$$

$$c = \frac{U}{\Gamma\left(1+\frac{1}{k}\right)} \qquad (19)$$

The shape and scale parameter are calculated for each month of the year, The method used for the calculation of energy, for each month of the year, is to multiply the distribution function between the maximum and minimum speed of a range ($\Delta \boldsymbol{F}$) by the respective power at which the wind turbine operates ($\boldsymbol{P}$). These calculations results in various levels of speed and power at which the turbine operates, where monthly energy is obtained by multiplying the total power by the number of operating hours, as shown in Table 1.

Table 1 - Model that exemplifies the method used for energy calculation of wind turbine.



U_{min}	U_{max}	$F(U_{min})$	$F(U_{max})$	U_{med}	$P[W]$	ΔF	$P\,\Delta F$
0	2			1			
2	4			3			
4	6			5			
6	8			7			
8	10			9			
10	12			11			
12	14			13			
14	16			15			
16	18			17			
18	20			19			
Total Power (kW)							$\sum P\,\Delta F$
Operating hours							h
Total Energy (kWh)							$[\sum P\,\Delta F]$*h

4. ECONOMIC FEASIBILITY

The analysis of investment, from the economic and financial point of view, is crucial in the acceptance and development of any project.

Investment Appraisal Indicators

Net Present Value (NPV)

NPV relates net cash flow (CF_L), obtained by subtracting revenues from operating and maintenance costs, with the discount rate (t), which is considered constant over the project duration. Cash flow is updated and then subtracted from the initial investment (I_i), resulting in the NPV given by equation (20), (Soares, Moreira, Pinho, & Couto, Decisões de Investimento: Análise Financeira de Projetos, 2015, pp. 35-38).

$$NPV = \sum_{i=1}^{n} \frac{CF_L}{(1+t)^i} - I_i \qquad (20)$$

$$n \equiv time\ under\ analysis\ (years)$$

Internal Rate of Return (IRR)

The IRR reflects the rate required to equalize the value of an investment, given by equation (21). The feasibility of the project requires that the value obtained from the IRR be greater than the discount rate (t), relative to the NPV, (Soares, Moreira, Pinho, & Couto, Decisões de Investimento: Análise Financeira de Projetos, 2015, pp. 194-201).

$$\sum_{i=1}^{n} \frac{CF_L}{(1+IRR)^i} - I_i = 0 \qquad (21)$$

Investment Recovery Period or Payback

The investments recovery period sets the period over which all initial investment is recovered, i.e., it is obtained when the sum of cash flow in a year equals the cash flow of the initial investment, given by equation (22), (Soares, Moreira, Pinho, & Couto, Decisões de Investimento: Análise Financeira de Projetos, 2015, pp. 203-205) .

$$Payback = \frac{I_i}{\frac{1}{n}\sum_{i=1}^{n} \frac{CF_L}{(1+t)^i}} \qquad (22)$$

Table 2 indicates the conditions necessary for the economic feasibility of the projects.

Table 2 - Conditions that require project feasibility.

$\sum_{i=1}^{n} \frac{CF_L}{(1+t)^i} > I_i$	$t < IRR$	$NPV > 0$	Feasible
$\sum_{i=1}^{n} \frac{CF_L}{(1+t)^i} < I_i$	$t > IRR$	$NPV < 0$	Non-Feasible
$\sum_{i=1}^{n} \frac{CF_L}{(1+t)^i} = I_i$	$t = IRR$	$NPV = 0$	Indifferent

Renewables Cost

Annual revenue from electricity is obtained through savings on the use of technologies that generate electricity, given by the multiplication of the price of electricity by the annual production of electricity, from renewable sources. The price of electricity considered is 0,2246 €/kWh, value referring to the year 2018, for domestic users, according to various entities, consulted on the website PORDATA, (PORDATA, 2019).Table 3 shows the costs considered for the photovoltaic system and wind turbine, to be used in all analyses, according to the study of reports with information on the subject, (International Renewable Energy Agency , 2019).

Table 3 - Costs regarding investment (CAPEX) and operating and maintenance (OPEX) for the photovoltaic system and wind turbine.

	CAPEX (€/kW)	OPEX (% CAPEX)
Photovoltaic System	2400	1
Wind Turbine	3400	5

5. ENERGY PRODUCTION

The evaluation of the energy potential, in relation to the considered set of solutions (photovoltaic system and wind turbine), in Portugal was carried out for several locations, that contemplate different climatic regions. In each district or city, 6 locations were evaluated. Figure 1 illustrates the results for the system composed by 30 photovoltaic panels of 255 W (7,65 kW), without inclination (horizontal irradiance). Figure 2 represents the results of energy generation of a 5 kW wind turbine at a height of 30 meters.

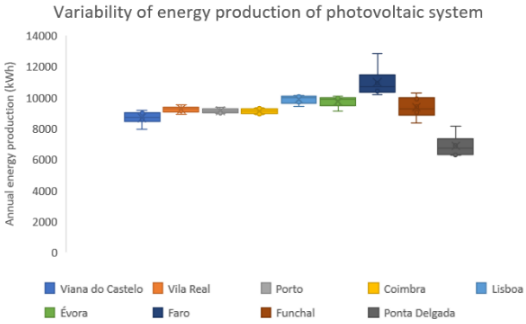


Figure 1 - Variability of energy generated by photovoltaic system (7,65kW), for each district and city.

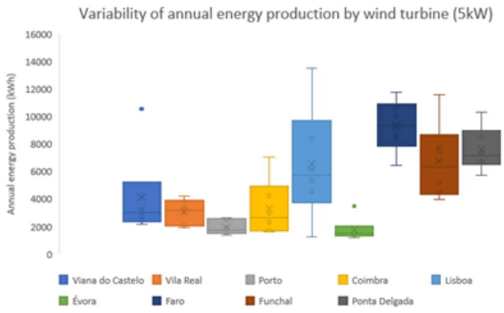


Figure 2 – Variability of energy generated by wind turbine (5kW), for each district and city.

The analysis of the Figures 1 and 2 allows us to state that the annual energy generation by the wind turbine is associated with a higher variability when compared to the photovoltaic system.

Photovoltaic system tilt

In order to verify the slope that enhances the power generation by the photovoltaic systems, a location of each district and city was selected, and the calculation model for various inclinations was applied, The results, in Figure 3, show that the optimal inclination is between 30 and 40 degrees. According to this finding, all evaluations involving the photovoltaic system, in this study, the model to be applied will have a 35 degree inclination.

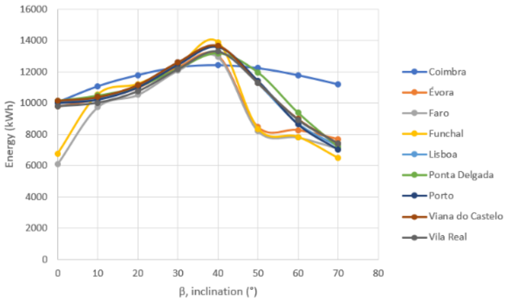


Figure 3 - Energy production by photovoltaic system for several inclinations.

Turbine Height

Figure 4 illustrates the different energy values obtained from using the same turbine (5kW) for different heights at different locations. The increase of the height of the turbine corresponds to the increase in renewable energy generation.

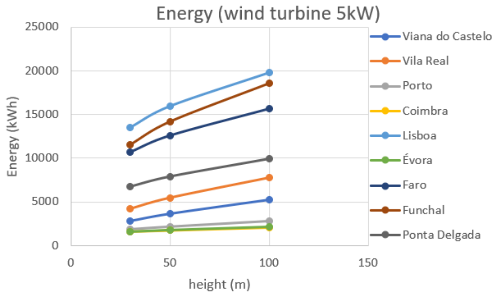


Figure 4 – Energy production by wind turbine (5kW) for several heights, for each district and city.

Energetic Mix

The goal of reaching the Premium certification threshold for renewable energy generation of 120 kWh/m^{2}a is assessed for all locations for a reference area of 100 m^2. Tables 4 and 5 show the minimum and maximum area, for each district and city, of the photovoltaic system required to, together with the respective wind turbine, achieve the minimum of 120 kWh/m^{2}a regarding renewable energy.

Table 4 - Minimum and maximum area for the energetic mix of photovoltaic system and wind turbine (5kW).

Photovoltaic System and Wind Turbine 5kW									
	Viana do Castelo	Vila Real	Porto	Coimbra	Lisboa	Évora	Faro	Funchal	Ponta Delgada
Minimum area (m^2)	1,63	32,54	34,16	19,52	0,00	34,16	0,00	1,63	13,02
Maximum area (m^2)	47,18	40,67	43,93	42,30	37,42	61,82	17,90	32,54	37,42

Table 5 - Minimum and maximum area for energetic mix of photovoltaic system and wind turbine (7,5kW).

Photovoltaic System and Wind Turbine 7,5kW									
	Viana do Castelo	Vila Real	Porto	Coimbra	Lisboa	Évora	Faro	Funchal	Ponta Delgada
Minimum area (m^2)	0,00	21,15	29,28	9,76	0,00	27,66	0,00	0,00	0,00
Maximum area (m^2)	40,67	37,42	42,30	39,05	35,79	56,94	3,25	27,66	22,78

Monthly availability

The analysis of the availability of renewable energy, generated throughout the year, is relevant due to the intermittences and variability of energy sources, namely solar irradiation and wind. It is intended that one system complements the other, when necessary, ensuring the generation of energy, as needed. Figure 5 illustrates a good example of complementarity between systems, while Figure 6 shows a less interesting one, as the monthly power generation by PV system is higher, in most of the months, than the 5kW wind turbine.

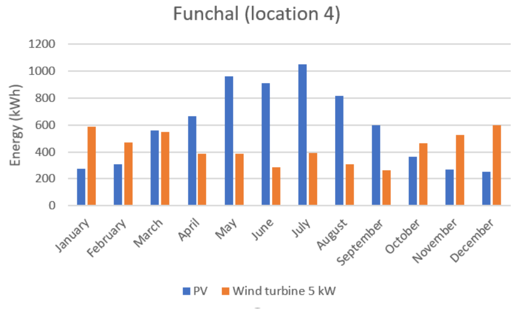


Figure 5 - Energy production by photovoltaic system (PV) and wind turbine (5kW) through the year, in location 4, Funchal.

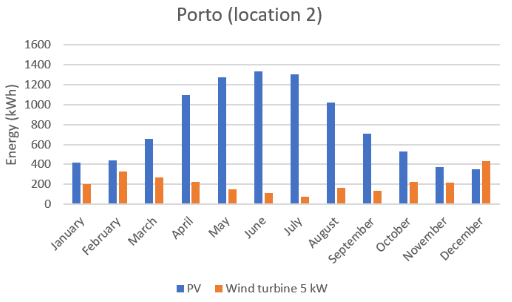


Figure 6 - Energy production by photovoltaic system (FV) and wind turbine (5kW) through the year, in location 2, Porto.

This analysis was performed for all locations for the solution package involving the 5 kW and the 7,5 kW wind turbine and their respective photovoltaic system. From the results, one can state that the selection set must be individual to the location, according to the associated conditions. Energy generation from the photovoltaic system tends to increase in the summer months (June, July, August) and decrease in the month preceding and proceeding. The energy evolution for all wind turbines, under study, varies greatly in location and it is not possible to associate an equal evolution trend in all cases.

Economic and financial analysis

The economic and financial assessment is carried out for a period of 20 years, according to the costs considered, mentioned in chapter 4. The introduction of the wind turbine into the energetic mix increases the investment required, resulting in the non-economic feasibility of all 54 locations. Economic feasibility is only achieved when the energy generated originates solely from the photovoltaic system, although not for all cases. Table 6 shows the results for the different solutions sets. For the 100% photovoltaic system mix, the results for the largest and smallest investment of all locations are presented. Regarding the mix that involves the junction of wind turbines, the results refer to the case with the lower value of investment.

Table 7 - Summary of economic results for different options in analysis.

100% Photovoltaic System (PV)				
	t (%)	NPV (€)	IRR (%)	Payback (years)
Lisboa - location 2	6	12338,48	14	9
	7	10087,64		10
	8	8093,88		10
	9	6321,80		11
	10	4741,47		12
Ponta Delgada - location 5	6	-2361,61	5	-
	7	-4471,32		-
	8	-6340,07		-
	9	-8001,04		-
	10	-9482,28		-
MIX: Wind turbine 5 kW & Photovoltaic System				
Faro - location 2	6	-3206,37	4	-
	7	-4773,82		-
	8	-6162,25		-
	9	-7396,31		-
	10	-8496,83		-
MIX: Wind turbine 7,5 kW & Photovoltaic System				
Faro - location 2	6	-10445,36	1	-
	7	-11688,49		-
	8	-12789,63		-
	9	-13768,35		-
	10	-14641,16		-

6. CASE STUDY EVALUATION - LISBON GREEN VALLEY

The case study considered is one building of Lisbon Green Valley, with 4 store and total of 16 apartments in Belas. The apartments have energy certification A and sustainability certification A+. The model was applied to the photovoltaic system, considering the same photovoltaic panel (255 W), a 35 degree inclination. The wind turbines considered were one of rated power 7,5 kW and 20 kW, with all their technic specifications. In addition, for the location in question, a turbine height of 30 meters and roughness 0,138 were applied. The chosen reference area is 700 m^2, after analysing the floor plants of the building's apartments. The available area on the roof for the implementations of systems is 240m^2.

Table 7 - Results for different options for photovoltaic system and wind turbine (7,5kW).

Nº of turbines	Energy - Turbine 7,5 kW (kWh)	Energy - Photovoltaic System (kWh)	Total Renewable Energy (kWh)	Certification (kWh/m²)	Area of photovoltaic system (m²)
1	7825,57	76231,82	84057,38	120,08	294,47
2	15651,13	68650,75	84301,89	120,43	265,18
3	23476,70	60648,52	84125,22	120,18	234,27

Table 8 - Results for different options for photovoltaic system and wind turbine (20kW).

Nº of turbines	Energy - Wind turbine 20 kW (kWh)	Energy - Photovoltaic System (kWh)	Total Renewable Energy (kWh)	Certification (kWh/m²a)	Area od photovoltaic system (m²)
1	14348,12	69914,26	84262,39	120,37	270,06
2	28696,25	55594,47	84290,72	120,42	214,75
3	43044,37	41274,69	84319,06	120,46	159,43

Tables 7 and 8 show the results of the various renewable system options, including the required energy generation according to Premium certification as well as the area of the photovoltaic system. The monthly energy availability of the systems was studied for all options. In terms of complementarity, between the two types of renewable energy generation systems, the most interesting options refers to the one that has three 20 kW wind turbines and its photovoltaic system, as can be seen by analysing Figure 7.

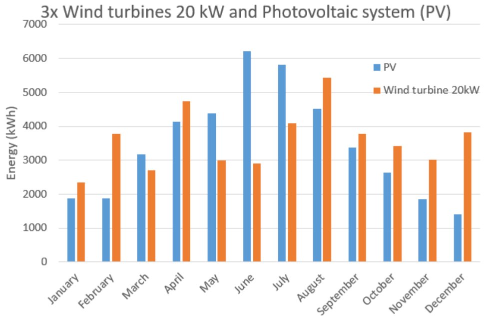


Figure 7 - Energy production by 3 wind turbines (20kW) and photovoltaic system.

Economic and financial analysis

The economic and financial analysis carried out for all possibilities of renewable solutions sets out that, for the conditions considered, the best option in terms of complementarity between photovoltaic system and the wind turbines does not correspond to the best option in economic terms. The results show that the most interesting energy options is not associated with economic viability.

Table 9 - Results of economic evaluation of all solutions involving photovoltaic system (FV) and wind turbine, for all options considered in Lisbon Green Valley building.

MIX	t (%)	NPV (€)	IRR (%)	Payback (years)	MIX	t (%)	NPV (€)	IRR (%)	Payback (years)
Turbine 7,5 kW and PV	6	53190,75	10	12	Turbine 20 kW and FV	6	-2942,36	6	-
	7	38722,32		13		7	-15668,7		-
	8	25906,37		15		8	-26941,4		-
	9	14515,38		16		9	-36960,9		-
	10	4356,967		19		10	-45896,1		-
2x Turbine 7,5 kW and PV	6	40575,44	9	14	2x Turbine 20 kW and PV	6	-47721,4	3	-
	7	25964,31		15		7	-60631,9		-
	8	13021,96		17		8	-72067,9		-
	9	1518,614		20		9	-82232,4		-
	10	-8739,99		-		10	-91297		-
3x Turbine 7,5 kW and PV	6	27555,97	8	16	3x Turbine 20 kW and PV	6	-92500,4	1	-
	7	12879,73		18		7	-105595		-
	8	-120,285		-		8	-117194		-
	9	-11674,9		-		9	-127504		-
	10	-21979,2		-		10	-136698		-

7. DISCUSSION OF RESULTS

The energy results obtained by the calculation model is dependent on the database used, according to the data used for its application. At the same time, the choice of technologies and their technical specifications will also influence the energy calculated by the model, as well the considerations that had to be adopted, such as roughness or turbine height. The analysis of the energy generated by the photovoltaic system is strongly related to solar irradiation, and throughout the year there is a tendency to increase in the warmer summer months and decrease in the rest, in all locations. The resulting wind turbine energy has a high variability, even for different locations in the same district or city. This variability also manifests itself throughout the year, and it is not possible to identify a trend, unlike the energy of the photovoltaic system.

Each renewable system has the ability to generate energy required for certification and is easier in certain locations according to the renewable sources and space available for installation. The combination of different renewable energy generation systems gives greater robustness to the total system, due to the different availability and intermittences of each system, with the goal of achieving a complementarity relationship, meeting the energy needs.

The photovoltaic system requires a much larger installation area compared to that of the wind turbine, so the available space in or around the building may limit its implementation.

The inclination of the photovoltaic system influences the area of the photovoltaic system, as the system installed at different inclinations generates different energy values. Meaning, according to the results, the 35º inclined photovoltaic system needs less area compared to the 10º inclination for the same amount of energy to be generated.

Energy through the wind turbine may be increased if the installation height of the turbine is increased as the available wind speed increases with height.

The economic and financial analysis is dependent on the conditions considered, whether the price of electricity constant over the 20 years of the project considered, the absence of inflation, the discount rate considered, the initial investment costs, and the operation and maintenance costs, or even not accounting for any system failures, which entail more costs. The results show that economic viability is compromised in cases involving the introduction of the 5kW or 7.5kW wind turbine with the photovoltaic system, which leads to the conclusion that the turbines used in the study are still considered an expensive technology. Similarly, when analysing the case study of the building in Lisbon Green Valley, the most energetic hypothesis does not correspond to the economic viability and may compromise the development of the systems with these specifications. Economic viability is mostly associated with cases where renewable energy comes from the photovoltaic system only.

8. CONCLUSION

This study confirms the possibility of renewable energy generation, according to the limit imposed by Passive House Premium certification (120 kWh/m^{2}a). The renewable systems under consideration were the photovoltaic system and the wind turbine, however, there are other options that can be included in the mix or replaced.

The larger limitation will be the area required for the installation of the systems, namely the photovoltaic system. The area available in or around the building may not be sufficient.

In urban areas, the existence of obstacles, shadows, or other constraints, restrains the performance of renewable energy generation systems. These difficulties encountered in urban areas, near buildings, raise the issue, and the possibility of installing systems far away from buildings, where conditions affecting power generation are enhanced, although in these situations additional energy losses will have to be considered, due to the connections between the building and the systems.

According the results obtained, considering the reference area of 100 m^2, for the energy mix involving the 5kW wind turbine and its photovoltaic system, the area required for the installation of photovoltaic system reaches a maximum value of 61.82 m^2. Regarding the energy mix composed by the 7.5kW wind turbine and its photovoltaic system, the maximum area that will have to be available for the installation is 56.94 m^2. Both maximum areas mentioned are in Évora. When renewable energy is generated solely by the photovoltaic system the maximum area is 79.17 m^2, in Ponta Delgada, while the minimum is 39.04 m^2 in Porto. Despite the minimum area being in Porto, most of the locations in the south are related to the lowest areas of photovoltaic system needed.

Regarding the case study (Lisbon Green Valley), the monthly availability analysis shows that the best energy option, regarding the complementarity of the systems, needs the smallest area of the photovoltaic system, of 159.43 m^2, which is lower that the area considered available (240m^2). However, this option is not economically feasible. Of the various options analysed, the maximum area required for the installation is 294.47m^2, higher than the available, associated with the mix of one wind turbine 7.5kW and its photovoltaic system.

The economic analysis reveals that the introduction of the wind turbine in the energy mix influences negatively the economic feasibility. When analysing the results of the photovoltaic system, they are more satisfactory. Therefore, the lower power wind turbines, under study, still have high costs, so there is a need to study and develop new business models or incentives that promote this type of project, at least in the first phase of the developments.

The assessment of several locations in Portugal allows us to conclude that the energy mix selected must be individual at each location, considering all physical and meteorological conditions, and the intermittences associated with each power generation system, according to the energy needs of the building.

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