Socioeconomic study of the use of solar photovoltaic technology to optimize the use of electricity in a company

Beatriz Durão
Instituto Superior Técnico
Lisbon, Portugal
beatriz.m.durao@hotmail.com

***Abstract*—In this paper it is going to be designed an autonomous photovoltaic system, in a building, through the application of solar panels in the windows of the building, that is, through the use of the windows as producers of electricity through solar energy. The main objectives of this paper are: (1) to make the building energetically autonomous, using for such an integrated system of solar photovoltaic technology; (2) check the system behaviour and finally comment possible system impacts on the users lifestyle.**

***Index Terms*—component, formatting, style, styling, insert**

I. Introduction

Energy is the foundation of modern economies and the central need for modern life. It is a prerequisite for economic growth, improving living conditions and alleviating poverty. Therefore, access to energy is considered an important development goal [1].

According to a new report produced by the International Energy Agency (IEA), the International Renewable Energy Agency (IRENA), the United Nations Statistics Division (UNSD), the World Bank and the World Health Organization (WHO), 840 million people are without access to electricity globally, out of which majority of people lived in remote and isolated rural areas. To make the scenario more difficult, people are sparsely populated in these places. Out of many other reasons for not being electrified are very low power demand and economic burden to the government to build infrastructure, etc. [2]. Thus, renewable energy technologies offer a unique opportunity to provide affordable and sustainable energy to millions of people. It is believed therefore that modern standard of welfare, education and health cannot be maintained without sufficient energy [3]. This and the awareness of climate change explains why globally investment in renewable energy sources for energy supply has grown continuously during the past decades and it is expected that these will increase considerably in subsequent decades as global demand for energy increases.

The sun serves as a giant nuclear furnace in space, constantly bathing our planet with free energy supply. The average amount of solar energy arriving at the top of the atmosphere is 1330 W/m^2. About half of this energy is absorbed by the atmosphere [4]. Among several solar energy technologies of sustainable energy sources, photovoltaic (PV) appears quite attractive for electricity generation, because it is noiseless, has no carbon dioxide emission during operation, scalable and rather simple operation and maintenance [5]. Also the solar energy is provided as free, needs no fuel, is abundant, achievable in many parts of the world and cheap while the others are limited and expensive. Many scientific developments have allowed PV to be an economically and technically viable solution for many applications, from satellites to remote telecommunication systems and pocket calculators. These are called autonomous systems, since they produce electricity for one specific need, with no other input needed [6].

II. CO_2 sources and availability in Portugal

A significant percentage of global GreenHouse Gas (GHG) emissions are from fossil fuels used in the production of electricity. The latest official portuguese report on GHG emissions (APA, 2017) indicates that net emissions of GHG in Portugal in 2015 are 1.58% lower than 1990 levels. GHG emissions from energy and industrial processes have increased 18% and account for 80% of total emissions in Portugal [7].

Given 2015 GHG sequestration levels, the total GHG emissions in Portugal will need to be reduced until 2050. To meet these goals, Portugal faces the challenge of reducing its GHG emissions by 87% in the next 35 years. The energy sector, and the power sector in particular, will play a major role in this path towards lower GHG emissions [7].

A. Possible Solution

Portugal is strongly dependent on foreign countries in what concerns to fossil fuels but is also a country with plenty of natural resources, allowing the development and the use of renewable energies [8].

Portugal has one of the best yearly solar radiation in the whole Europe. That means a huge advantage for the country, as the electricity produced in Portugal can cost 40% less than in the other european's countries.

III. The Future of Solar Panels

Imagine a world where we could generate electricity using the surface of our windows, smartphones, our cars sun roof or the glass roof of our office building. What sounds like a far-away dream, is on its way to become reality thanks to transparent solar panels. [9].

Sun light is available for free everywhere, but the guarantee of using this light for solar power is restricted to solar farms and rooftop panels. Recently, Transparent Solar Cells (TSC) caught the attention of scientists due to their variety of possible applications in our daily lives. TSC are already in use for these applications in some countries, while others are for the far future, once their efficiency is improved. Building Integrated Photovoltaics (BIPV) is the nearest application for TSC. If all the buildings with 90% glass on their surface used TSC printed on the surface of the glass, the solar cells have the potential to power more than 40% of that building's energy consumption [10].

IV. Wind Turbines

A short introduction to wind turbines will be made as these devices will be considered as an alternative to installing solar panels on the rooftop. Buildings rooftops of can be an excellent location for wind turbines, both because the electric power generation is close to the user and because they allow to take advantages of faster winds while reducing the cost of support towers. The identification of the turbines position must however be preceded by a thorough analysis of available winds, because turbulence or areas of calm, generated by surrounding buildings or different obstacles located on the roofs (air conditioning systems, antennas), could lead to an energy production significantly lower than expected [11].

Wind energy technologies can be classified into two categories:

- Macro wind turbines that are installed for large-scale energy generation such as wind farms and;
- Micro wind turbines used for local electricity production.

Micro wind turbines are suitable for application at the building scale and are called building-integrated wind turbines. The main components of a wind turbine include blades, rotor, gearbox and generator. Small wind turbines were originally designed with a horizontal axis, also known as HAWTs. To reduce the need for a high tower, and for aesthetic reasons, vertical axis wind turbines (VAWTs) become increasingly popular for integrated building applications. Furthermore, VAWTs are also quieter (resulting in less noise nuisance) than HAWTs during operation [12].

Wind turbines can be grid-connected or off-grid. Off-grid systems require battery storage to store surplus electricity, thereby providing a more stable electricity supply. Their application is most suitable for rural and remote areas, such as remote villages and small isolated islands, where grid power is not available. Conventionally, grid-connected systems require power converters to convert the generated DC electricity to AC electricity to be compatible with power grid and AC-electricity-based appliances. As technologies improve, modern wind turbines can also directly generate AC power [12].

Recent developments in building integrated wind turbine technologies involve improving reliability, improving efficiency at low wind speeds and lowering capital cost. Wind turbine blades are now designed with lightweight materials and aerodynamic principles, so that they are sensitive to small air movements. Furthermore, the use of permanent magnet generators, based on rare earth permanent magnets, results in lightweight and compact systems that allow low cut-in wind speeds. In this way, electricity can be generated with wind speeds as low as a few metres per second.

To be more attractive for integrating into buildings, micro wind turbines are also being designed to be more visually attractive, without compromising their performance. Another objective is to reduce or even eliminate noise associated with blade rotation and gearbox/generator noise. This can be achieved by using low-noise blade designs, vibration isolators to reduce sound and sound absorbing materials around the gearbox and generator. Lastly, simplifying wind turbine components also adds to the attractiveness of wind turbine application and reduces maintenance costs. To lower the product costs, advanced blade manufacturing methods, such as injection moulding, compression moulding and reaction injection moulding, are being applied to reduce labour and increase manufacturing quality [12].

V. Design of an autonomous photovoltaic system in a building

As mentioned before this is called autonomous system, since it produces electricity without being connected to the national grid.

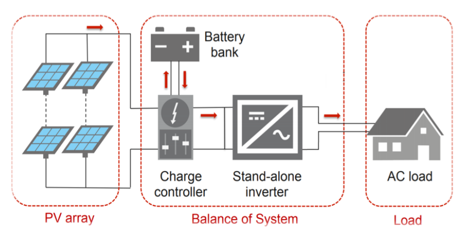

Fig. 1. Basic structure of an autonomous solar energy system

Using the windows as solar panels has the big advantage of enabling the use of as much space as possible to produce more electricity. In this case the North Tower of Instituto Superior Tcnico, in Lisbon, Portugal is the chosen building. The work was completed in 1995 and is marked by a volume on a building that works as a base, and is thus high, presenting the façade on a curtain façade system, adopting the Exterior Glass Casting (EGC) solution type [13]. This block, part of the Campus Alameda, has 4 façades and each façade has approximately a width of 33,11 m and a height of 36,58 m, which makes approximately a total surface area of 5939,8 m^2.

A. Sizing the Project

In order to determine the maximum power produced by the panels, it is necessary to study the irradiance and the temperature. Taking into account the North Tower coordinates, that are: (1) $Latitude = 38.73758208$; (2) $Longitude = -9.13859305$, it was studied the irradiance and the temperature throughout the year through the following site: https://meteoexploration.com/products/SolarCalculator.html. Here, it was checked that August was the month with higher values of average daily temperature and irradiance, and that January was the month with lower values. Despite these being the months with the highest and lowest irradiance values, it turns out that the electrical consumption in the tower is more significant in January and June, because in August the IST is closed.Thus, it was considered that June is the best month to represent the summer and January is the best month to represent the winter. Also, it was taken into account the fact that the facades have non-uniform illumination throughout the day due to their different slope orientation (orientation of the surface, if looking north it will be $0°$, if looking south will be $180°$ and it varies between $0°$ and $360°$) and the slope tilt (inclination of the surface with respect to the horizontal, $0°$ is flat, $90°$ is completely vertical and it varies between $0°$ and $90°$). Thus, the solar radiation values in each facade and in the top of the tower are different.

It is also necessary to analyse the average energy consumption of the tower in these considered months in order to obtain the required number of batteries and photovoltaic panels (PVs).

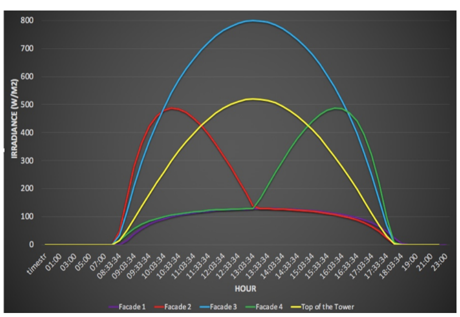

Fig. 2. Daily average irradiance in January

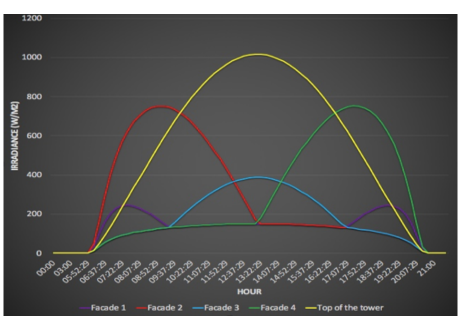

Fig. 3. Daily average irradiance in June

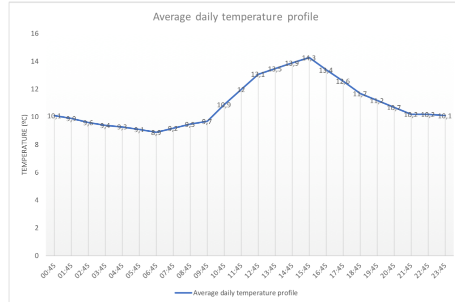

Fig. 4. Daily average temperature in January

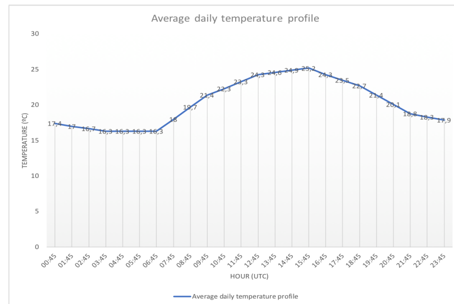

Fig. 5. Daily average temperature in June

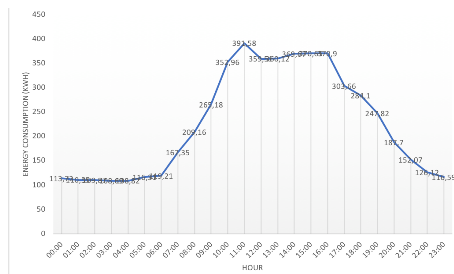

Fig. 6. Daily average energy consumption in January

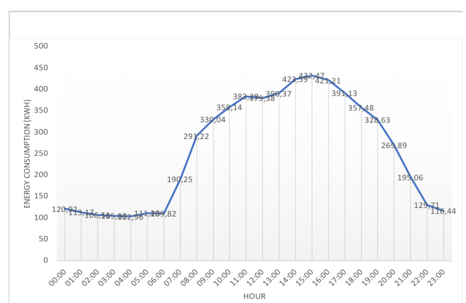

Fig. 7. Daily average energy consumption in June

In the dissertation it is considered some different solutions to install in the tower. The first three solutions are with panels made of amorphous silicon, one cheap, one intermediate and another one more expensive to coat the tower facades. The fourth solution is with panels made of crystalline silicon. For the cheaper one of the solutions of amorphous silicon it was chosen the PS-C transparent panel from Polysolar, for the intermediate one it was chosen the PS-M-NX panel from Polysolar and for the more expensive one it was chosen the panel with the biggest dimensions from Onyx. For the solution of crystalline silicon, it was chosen the PS-PC-SE glass panel with different levels of transparency from Polysolar. In this article, however, only the results of two solutions will be presented: the amorphous silicon panels with an intermediate price and the crystalline silicon panels.

To coat the top of the tower, it will be considered the PS-MC-SE panels also from *Polysolar* and it will be considered a position for this panel, that is, with a slope tilt of 30° and a slope orientation of 180°, that is, the panel will be looking south. It will be sized this solution, because in theory, it is with this position that it is possible to capture more solar light and consequently produce more energy.

The rest of the needed technologies to constitute the system are batteries, a charge controller and an inverter. In the tower it is necessary to install 5 systems of these, one for each facade and one for the top, due to the characteristics of the chosen technologies. The chosen pack of batteries is from Crown, the chosen charge controller is named TriStar MPPT (Maximum Power Point Tracking) and is from MORNINGSTAR, the chosen inverter is a high input voltage industrial DC-AC sine wave inverter and is from ABSOPULSE Electronics Ltd. The cables used to make the connections between each equipment are from Amazon and cost 25,91 dollars per 30 feet, which is equivalent to 23,69 EUR per 9,144 m and thus 2,59EUR/m. These cables can support until 600 VDC.

First, it will be calculated the required number of PVs to coat the top. The number of PVs should be adequate to feed the load during the day and to charge the batteries. Taking into account the specifications and the formulas:

$$T_{pv} = T_{amb} + \frac{G \times (T_{NOCT} - T_{amb_{NOCT}})}{G_{NOCT}} \tag{1}$$

$$P_{max} = P_{max_{pv}} \times \frac{G}{G_{NOCT}} \times (1 - \alpha_T \times (T_{pv} - T_{NOCT})) \tag{2}$$

$\alpha_T \therefore TemperatureCoefficientofP_{max}$

The power produced by one panel PS-MC-SE was obtained. In the formulas, the considered values from NOCT conditions were: $T_{NOCT} = 50°C$; $T_{amb_{NOCT}} = 20°C$; $G_{NOCT} = 800W/m^2$.

Considering the maximum open circuit voltage of the PS-MC-SE panel, that is 47,18 V, the maximum open circuit voltage of the charge controller and the surface area of the top of the tower, it is possible to determine the maximum number of panels in series and in parallel to install on the top. The number of panels in series is determined through the following.

$$47,18V \times n_{pv_{series}} \leq 600V \mapsto n_{pv_{series}} \leq 12panels \tag{3}$$

To calculate the number of panels in parallel it is necessary to be more careful, because if you think about the problem, each panel will have a slope of 30°, so that the area occupied by the panels will be different. Here the following should be taken into account: the fact that each panel has a slope of 30° and that the panels cause the least possible shade to the panels immediately behind it is necessary to have a minimum distance between them. This distance, imagining the Pythagoras theorem, will correspond to the adjacent leg of the angle the panel makes to the horizontal. Thus this distance is given by,

$$cos(30°) = \frac{adjacentleg}{hypotenuse} \tag{4}$$

$$adjacentleg = 0,992 \times cos(30°) \approx 0,859m \tag{5}$$

And, finally, the number of rows in parallel is determined by taking into account the width of the tower and the ”adjacent leg” previously determined.

$$\frac{31,16}{0,859} \approx 36rows \tag{6}$$

$36 \times 12 = 432$ panels in total and a total average energy produced of $3599,84kWh \leq 15632,36kWh$ (this value corresponds to the sum of the energy consumption in each hour considered in a normal day in January) which is less than the average consumption of the tower. Here it is necessary to point out that this energy produced will not only be used to feed the tower but also to charge the batteries. So, imagining that there were no batteries and not taking into account some shadow effect throughout the day, only the panels installed on the top would feed around 23% of the building's energy consumption.

Another important point to note is that the considered slope of the panel and the considered distance between panels may not be the ideal to capture the maximum irradiance and thus producing a greater amount of energy.

Now, considering the characteristics of the amorphous silicon panels with an intermediate price and the previous formulas, the power produced by one PS-M-NX panel is obtained. Once again, it has to be taken into account the maximum open circuit voltage of each PS-M-NX panel in order to not exceed the PV input operating voltage range of the charge controller. Thus, the maximum number of panels in series and the number of rows of panels in parallel are determined through the following.

$$170V \times n_{pv_{series}} \leq 600V \mapsto n_{pv_{series}} \leq 3panels \tag{7}$$

$$\frac{36,58}{1,4} \approx 26rows \tag{8}$$

$26 \times 3 = 78 \times 4facades = 312$ panels in total and a total average energy produced of $636,2kWh \leq 15632,36kWh$ which is much less than the average consumption of the tower. Adding this energy to the energy produced by the panels at the top of the tower makes a total of 4236,04 kWh, which corresponds approximately 27,1% of the building's energy consumption. Considering now the other panels with levels of transparency of 10%, 20%, 30%, 40% and 50%, the result of panels in series and in parallel is always the same because their maximum open circuit voltage does not vary much. Relatively to the energy produced, it is becoming smaller and smaller as transparency increases, as it has already been concluded above.

It is necessary to mention that the panel considered in this next solution is not made with the ideal materials. the ideal would be to use panels made of amorphous silicon, like those that were considered in the previous option. However, this panel made of crystalline silicon is being considered to show that, nowadays, these panels still produce much higher amounts of energy compared to panels made of amorphous silicon.

This solution will be sized with the PS-PC-SE panel with a transparency level of 10%. Doing the same reasoning that was done in the solutions with the panels made of amorphous silicon, one arrives at the following.

$$45,49V \times n_{pv_{series}} \leq 600V \mapsto n_{pv_{series}} \leq 13 panels \quad (9)$$

$$\frac{36,55}{0,992} \approx 36 rows \quad (10)$$

$13 \times 36 = 468 \times 4 facades = 1872$ panels in total and a total average energy produced of approximately 7636,01 kWh which is higher than the average consumption of the tower. Adding this energy to the energy produced by the panels at the top of the tower makes a total of 11235,86 kWh, which corresponds approximately 71,9% of the building's energy consumption. It can be concluded that with this type of solution, the average energy produced per day is more than the double of the energy produced by the panels of the previous solutions.

However, with this solution it is still not possible to produce the energy needed to feed the entire tower.

After this, it is necessary to calculate the required number of batteries to store energy and thus provide the necessary power at night. For that it was obtained the average energy consumption of the tower at night in January, because it is on the winter nights that occurs the highest consumption. Knowing the inverter and the charge controller efficiencies and the capacity of each battery pack, the necessary energy for batteries to store is calculated.

$$E_{batt} = \frac{E_{night_{January}}}{\eta_{inv} \times \eta_{cc}} = \frac{2487,24kWh}{0,85 \times 0,979} \approx 2988,9kWh \quad (11)$$

With this, the total number of battery banks is calculated through the following.

$$n_{batt} = \frac{E_{batt}}{Capacity} = \frac{2988,9kWh}{20,64kWh} \approx 145 packs \quad (12)$$

These battery packs shall be placed in parallel so that the output voltage does not exceed the battery operating voltage range of the charge controller. Based on the load curve in January and on the PV available power of the different solutions previously considered, it is possible to obtain the evolution of the battery power (positive when discharging and negative when charging). Also it is possible to obtain the evolution of the battery state of charge (SOC) considering that it is 100% at 18h. To study these two evolutions it will only be considered the solution with panels made of crystalline silicon.

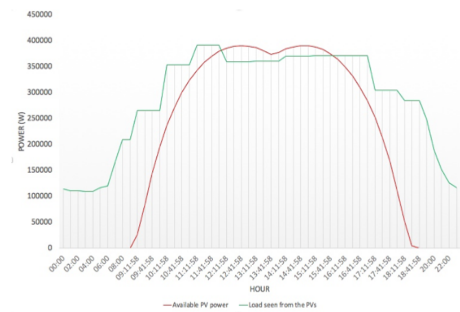

Fig. 8. Daily available PV power and daily energy consumption of the tower

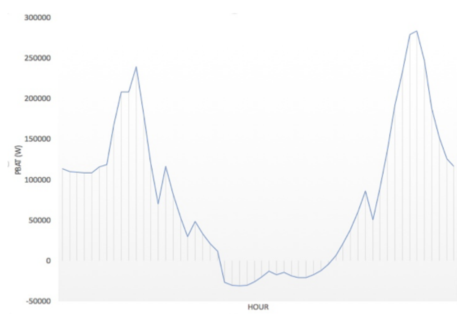

Fig. 9. Evolution of the batteries power throughout the day (positive when discharging and negative when charging)

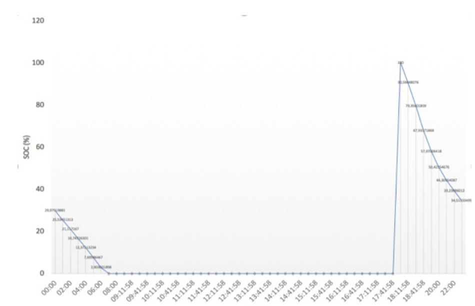

Fig. 10. SOC of the batteries considering that it is 100% at 18h

In 9 it can be observed that even in daylight hours it is used power from the batteries to feed the load because the power produced by the panels is not enough, as shown in 8. Relatively to 10, it can be concluded the following: imagine that as soon as the system is assembled, the power produced by the panels is immediately used to charge the batteries. These are fully charged, that is, with 100% at 6:00 p.m., as was previously assumed. And by the observation of 8, at 6:00 p.m., the power consumption of the tower is already higher than the power produced by the panels, so that the batteries automatically start to feed the tower, whether it is night or not. With this, the batteries discharge over the hours until they get 0% energy, as can be seen in 10. As soon as this happens, it is also verified that it is no longer possible to charge the batteries because the energy produced by the panels is not enough to cover all the energy consumption made during a day in the north tower. Therefore, in 10 it is only considered for the moment when the system is installed in the tower which is when it is possible to get the batteries at 100%. This happens, because, normally stand-alone systems (systems not connected to the utility grid) require batteries to store excess power generated, but as in this case no excess power is generated, the SOC of the batteries is always at 0% and with this it is concluded that with these solutions it is not yet possible to have completely independent systems as they do not produce the energy needed to power the tower. Therefore, it is necessary to connect these systems to the grid so that the grid supplies power when needed.

VI. Economic study of the presented solutions

TABLE I
ELECTRICITY SALE TARIFF IN PORTUGAL. IN THE NORTH TOWER THE TARIFF IS TRI-HOURLY DUE TO THE CONTRACTED POWER.

Fixed Expenditure (EUR/day)	EUR/kWh		
	Peak Hours	Full Hours	Empty Hours
1,8868	0,3010	0,1442	0,0731

Considering the schedule of peak, full and empty hours during the summer and during the winter, it is obtained a total electricity cost per year of approximately 365,5 kEUR. Knowing that the return years is given by $\frac{Totalinvestment}{TotalElectricitycostperyear}$, it is possible to make a study of both solutions previously presented.

TABLE II
ECONOMIC STUDY OF THE FIRST SOLUTION

Equipments	Costs	
	Unitary Cost	*Total Cost*
PS-M-NX panels	285 EUR/m^2	$\approx$ 137 kEUR
PS-MC-SE panels	0,188 EUR/W	$\approx$ 28 kEUR
Batteries	2416 EUR	$\approx$ 1752 kEUR
Charge Controller	1183,7 EUR	5918,5 EUR
Inverter	4820,69 EUR	24103,45 EUR
Cables	$\approx 2,59$ EUR/m	$\approx 3123,7$ EUR
Protections	$\approx$ 2700 EUR	$\approx$ 13500 EUR
Total (EUR)	-	$\approx$ 1964 kEUR
Return (years)	-	$\approx 5,4$

Just to mention that in the second solution only changes the costs of the panels used to cover the facades.

By observing the previous tables and taking into account which solution produces a greater amount of energy, it is immediately apparent that the best solution of all and therefore the most appealing is undoubtedly the solution in which the panels are made of crystalline silicon, because it is the solution that presents the highest values of energy produced and is also

TABLE III
ECONOMIC STUDY OF THE SECOND SOLUTION

Equipments	Costs	
	Unitary Cost	*Total Cost*
PS-PC-SE panels	0,206 EUR/W	$\approx$ 123 kEUR
Cables	$\approx 2,59$ EUR/m	$\approx 7773,2$ EUR
...	...	...
Total (EUR)	-	$\approx$ 1954 kEUR
Return (years)	-	$\approx 5,3$

the one that presents the least number of years of return, that is, a lower investment.

Another thing that has to be mentioned is the fact that the number of years of return is not the expected. Because usually, the number of years of return is around 8 years, so these solutions have a low number of years of return when compared to the usual. This happens because, most likely, some costs, such as the costs of the panels to cover the facades or the costs of the cables and protections are below normal. These costs were considered approximations after some research in Internet sources and in previous works that are similar to this type of study. So it may be due to these approximations made.

Also, this is not at all what one wants to install in the tower. The ideal would be, as is often mentioned in this thesis, to install in the tower, glass windows (windows with panels of amorphous silicon) capable of producing a reasonable amount of energy in order to feed the entire tower. But to do this still many challenges lie ahead.

As seen in the previous theoretical study, the energy produced by the panels during the day is not sufficient to power the tower at night, so in the following section a solution for the production of energy at night through the installation of wind turbines in the top of the tower is going to be presented.

VII. Alternative for overnight energy production

As an alternative for energy production at night it will be considered wind turbines, which as the name implies, are devices that produce energy through the action of wind. And as it is theoretically known, wind speed is higher at night, both in summer and winter.

It is also important to mention here that the turbines in this solution will not only be used at night but also during the day as a complement to the panels installed on the facades. Also because there is wind during the day, so the turbines normally and theoretically run 24 hours a day.

Following the introduction of wind turbines at the beginning of this thesis, it is clear that the most suitable turbines to install in this building under consideration are micro wind turbines.

After some research and based on some references it was chosen the Talon 10 wind turbine from A&C Green Eenergy with the following characteristics.

And also knowing the wind speed over the months of January and June.

It is possible to obtain the power produced by one wind turbine by finding the power curve trend line equation, which

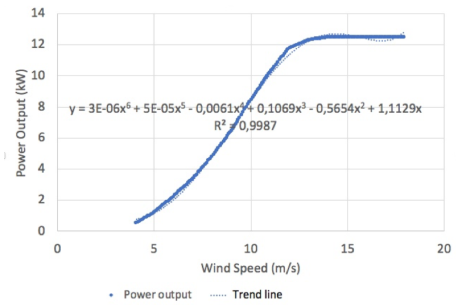

Fig. 11. Power curve of the chosen wind turbine

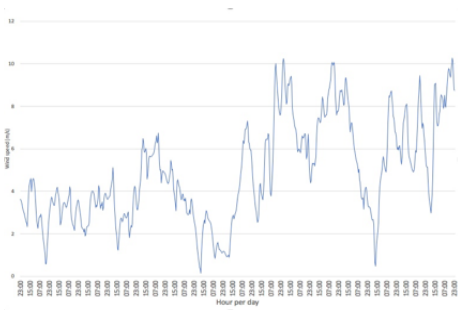

Fig. 12. Wind speed in January in the north tower

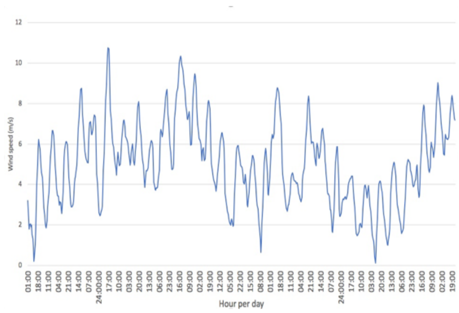

Fig. 13. Wind speed in June in the north tower

in this case is the equation presented in 11 where y corresponds to the power in kW and x corresponds to the wind speed in m/s. To determine the trend line of the power curve, several approximations were verified, such as linear, polynomial, etc. However, it was found that the polynomial approximation is the closest to the ideal value, thus presenting a coefficient of determination, R^2, of 0,9987, that is 99,87%. This means that the trend line equation is a good approximation to use to determine the power output of a wind turbine. With this, the power produced by a wind turbine was determined.

In order to have micro-siting, that is the strategy that places the wind turbines in locations where maximum power production is possible throughout the year, certain minimum distances between the individual wind turbines have to be observed. Obviously, in view of the need for wind power plants to maintain a minimum distance between the generators (at least 4 times the diameter), the possibility of installing more turbines depends on the geometry of the roof and the available power may be less than the one reached by the use of a photovoltaic system installed on the same surface. Then, taking into consideration the dimensions of the top and one turbine, it has been found that it is possible to install 4 turbines in series on the top of the tower. For safety reasons it will be considered only two rows of 4 turbines in series, that is, 8 turbines in total and thus produce the following energy over the months of January and June.

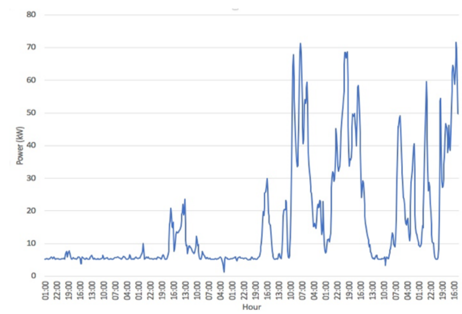

Fig. 14. Power produced by the 8 turbines in January

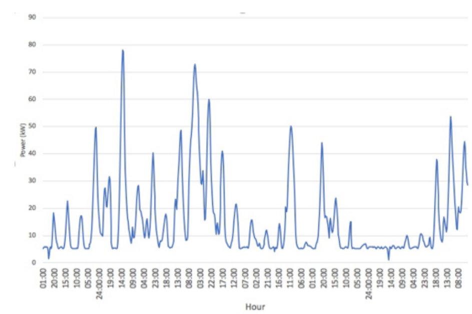

Fig. 15. Power produced by the 8 turbines in June

By observing the graphs it is immediately apparent that the energy produced by the turbines, in these months, is not enough to power the tower, so that a completely independent system cannot be installed, i.e., without having to connect it to the grid. Thus, if the turbine cannot deliver the amount of needed energy, the grid makes up the difference. If, for example, the wind system produces more electricity than the household requires, the excess is sent or sold to the grid. As in this case the system is connected to the grid, the only additional equipment required is a power conditioning unit (inverter) that makes the turbine output electrically compatible with the utility grid, since wind turbines generate direct current (DC) electricity. In these cases, batteries are not usually required.

Relatively to costs, each turbine costs 24514,89EUR, which makes a total cost, only of turbines, of 196,12kEUR. Adding the cost of the panels used to cover the tower facades, considering in this case the panels of the second solution, since they are the amorphous silicon panels with the highest percentage of energy production, plus the cost of the inverters, cables and protections, it gets up a total initial investment of approximately 400kEUR. Here, it should be noted that the investment price is much lower, because the system is not independent or not self sufficient, i.e., it doesn't produce enough energy to feed the entire tower and to charge the batteries, so it has no batteries or charge controller. Therefore, the system needs to be connected to the national grid.

With this type of solution, the price of the annual energy consumption provided by the grid would decrease as only a percentage of it would be used because the remainder would be provided by the system of panels and turbines.

VIII. Socio-Economic Impacts

Based on some research and on what is presented in this paper the first and more obvious impacts are environmental. But the most important and positive effects that PV can bring to a country like Portugal are the social and economic ones. In the positive impacts, the following can be highlighted: reduced transmission lines/grids; energy supply for decentralized, low density off-grid areas; national energy independency from import; lower militar expenses; diversification; deregulation; jobs creation; creation of a new, high added value industrial cluster and improved image. In the negative ones, it can be highlighted: requirement for energy storage for continuous supply; economically detrimental subsidies such as uncontrolled and miscalculated feed-in-tarif mechanisms; intermittent supply issues; health hazards and risks during manufacturing. In short, PV can bring much more benefits than cons. It can benefit the industry, the economy and the environment with long term effects and the security of energy supply in medium term.

Although there has not been made a theoretical study about organic cells and knowing that they do not yet produce the energy needed to suppress today's needs, it is recognized that they will have enormous advantages in the future of our environment. It is necessary to mention that the study was not made due to fact that the sheets found have very few information. Back to the advantages that these type of cells can bring to buildings like the North tower, it can be highlighted that these modules do not show the performance drop usually observed with traditional inorganic PVs in diffuse lightning conditions found in facades. Also, integrating OPV into facades elements reduces both the energy consumption and CO_2 emissions of a building.

Relatively to wind energy, wind power, just like solar power, is a key component of renewable energy utilisation. Implementation of building integrated wind turbines contributes positively to the environment as a climate change mitigation option. In addition to environmental advantages, Building integrated wind turbines offer opportunities for local economic development too, including: Less financial burden to households due to lower electrical costs; Opportunities for households/building owners to sell surplus electricity back to the grid; New skills and job opportunities for the local workforce; Mechanism to grow the local green economy.

IX. Conclusions

A. Achievements

In fact, and despite what was presented in the introduction, amorphous silicon panels have other disadvantages, apart from the fact that the previous scaled systems with such panels are not independent yet. The disadvantages are related to their fabrication which is not environmentally friendly at all, because fabricating the panels requires caustic chemicals which emits greenhouse gases. If not handled and disposed of properly, these materials could pose serious environmental or public health threats. Thus, PV manufacturers must follow US laws to ensure that workers are not harmed by exposure to these chemicals and that manufacturing waste products are disposed of properly. While these chemicals can be considered as hazardous, they arent so while the panels are on your roof. To avoid confusion, it is necessary to understand that the concern for their toxicity comes into play during the manufacturing process, as well as disposal process and at the end of the panels lifetime. And to make the situation worse, right now this suffers from a chicken-or-egg problem: There aren't enough places to recycle old solar panels, and there aren't enough defunct solar panels to make recycling them economically attractive [14]. There are firms that may advertise themselves as "solar panel recyclers" but instead sell panels to a secondary market in nations with less developed waste disposal systems. Perhaps the biggest problem with solar panel waste is that there is so much of it, and that's not going to change any time soon, for a basic physical reason: sunlight is dilute and diffuse and thus require large collectors to capture and convert the sun's rays into electricity [15].

Naturally, the benefits will vary depending on the energy generation and solar irradiance of your location, but overall solar panels provide a positive net impact. So, while solar power isnt a perfect solution, it is much more environmentally friendly than producing electricity from non-renewable sources, especially coal [16].

Another important environmental impact is the visual impact that PV systems may have on buildings and areas. Retrofitting PV systems on roofs and large surfaces of older buildings usually is a viable solution, with the exception of buildings that cannot be visually altered, i.e. those which are of historical or cultural importance. Furthermore, thin film panels could easily replace the mirrors and glass surfaces of large buildings. As thin film panels have a lower solar transmittance than glass, they could also be used as a means to reduce the cooling load of buildings, offering shading or even heat extraction. However, the architect always has to consider the effects of glare as well. The replacement of glass surfaces may very well be the only method applicable to historical buildings and buildings with high cultural value, where visual modifications of the structure itself are impossible [17].

Regarding the efficiency of the panels there are several conclusions that can be drawn. One of the conclusions is that the panel color influences its efficiency. When a panel is covered with a color-filter, it means it is exposed to a light of specified wavelength: shorter for blue, medium for green and longer for red. Red color light generates more electricity than other colors. Contrary to popular belief, longer wavelengths of visible light, the ones with less photon energy, are more efficient with photovoltaic cells than shorter, more energetic wavelengths [18]. Another factor that influences the cell efficiency is its reflectivity. To reduce losses from reflectivity and increase efficiency, solar cell manufacturers usually coat the cells with a non-reflective, light-absorbing material. This is why solar cells are usually black [19]. The cells silicon material responds to a limited range of wavelength, ignoring those that are longer and shorter [20].

A color filter is a material that allows the passage of light through it, a colored filter of a specific color allows its own color to pass through and absorbs the remaining colors. Color filters were used to absorb all wavelengths of light except that of their own color, thus tinting the light that color [20]. For decades, engineers have been waiting for an ultimate solution to customize the color of solar components and a mishmash of photovoltaic technology and glass have given birth to a colorful laminated glass, which are generating electricity. Interestingly, the color of the solar cells can be changed by varying the thickness of the anti-reflection coating. The colored solar panels looks different at the time of solar panel installation, however by altering the thickness of the anti-reflection layer, the overall reflection of solar panels will increase and the efficiency will decrease by 15-30% depending on the color. Simulations showed that the efficiency of colored solar panels could increase up to 20 percent. In reality, the solar panel efficiency basically depends on the designs of the solar system as well as the direction of building faces. But there is the thing that not every color allows you to generate the same amount of electricity. However, there are limitations with certain blends of blue, red and green [21].

In terms of manufacturing matter there is still a long way to go and many challenges lie ahead. The evolution of PV technology and the development of new materials and building components are fundamental pieces in this work. Both, PV sector and construction industry must work together and join their experiences and knowledge in order to develop innovative elements, which in turn comply with all regulations and standards of quality and in accordance with photovoltaic engineering competences. Although an increasing number of BIPV products can be found, looking to the future, collaboration between the photovoltaic and construction industries must be reinforced in order to develop innovative and attractive products, easy to installation, reliable, with low environment impact and cost-effective. In particular, new developments of PV technologies are needed to enable the integration into several materials that make up the skins of buildings today, easy application of PV cells in conventional materials is imperative because that, in a lot of ways, will allow the development of new solutions and thus make the world a better place.

B. Future Work

In the dissertation, the study was based on theoretical formulas, so the results presented are completely dependent on the theory. However, to have a clearer notion of reality it is necessary to perform laboratory tests in the future and thus verify if what has been studied is correctly sized. Apart from the theoretical and practical studies it would also be very interesting and useful to use the already developed optimization algorithm NSGA-II so as, as the name implies, to optimize the installation positions of the panels and turbines in the tower so that they produce the maximum power possible.

Another important point will be to explore and study organic cells, which are part of the third generation of solar photovoltaic technology and made of materials that are much more appealing to our environment. Beyond this, OPV presents other important advantages, especially with respect to BIPV. OPV modules do not show the performance drop usually observed with traditional inorganic photovoltaics in diffuse lightning conditions and under elevated temperatures typical conditions found in facades [22]. One aim of integrating OPV technology into facade elements is to reduce both the energy consumption and CO2 emission of a building [23]. Compared to classic PV technology, OPV can better serve both the functional and aesthetic demands of designers and architects while also enabling the use of building-integrated photovoltaic. OPV modules have been integrated into various glass facades and into structural membrane architectures [23]. However, organic solar cells have very low efficiencies compared to conventional silicon cells. Therefore, a lot of scientific research is currently being done in order to develop these cells because of its various advantages in other branches, as mentioned above.

Finally, it should be mentioned that more inverters and more battery charge controllers could have been used to increase the panel set output voltage, that is, so that more panels could be installed and thus obtained a much higher output power. However, this was not done in this study because it was intended to provide a more cost-effective solution.

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