PHOTOVOLTAIC POWER PLANTS IN URBAN AREAS IN PORTUGAL: FEASIBILITY STUDY

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ABSTRACT: This paper presents a study to integrate photovoltaic (PV) production larger than micro-generation in urban areas, using the school roofs as installation sites. This initiative is part of a more comprehensive effort to increase dispersed electricity production as opposition to a conventional policy of centralized electricity production often located far from the consumption sites, resulting important losses in the transmission grid (around 10% in Portugal). This study addresses the following issues: What is the PV capacity potential available in the school's roofs; what is the cost and payback time of those PV systems and what is the resultant reduction of the CO_2 emissions in Portugal as a consequence of this initiative. Each school can account with 60 to 140 kWp of PV installed capacity, depending on the roof area availability. The total PV capacity for 172 schools comprised in this study, with an area of 144000 m^2, is estimated to be approximately 20 MWp. The total electricity production and CO_2 emissions avoided ranges between 20 and 31 GWh/year, and 7 to 11 MtonCO_2/year, depending on the area of the system.

Keywords: photovoltaic, dispersed production, urban integration, emissions

1 MOTIVATION

Most of the electricity consumed in Portugal as well worldwide is produced in large power plants (thermal, hydro) usually located far from the demand, resulting in relevant power losses in the grid (around 10%). The existing energy infrastructure must be improved to meet increased demand with reduced emissions. With high levels of sun radiation, Portugal possesses a great PV potential. Despite such potential, the Portuguese PV market has grown timidly over the past few years, see Figure 1. In this scenario distributed renewable electrical energy production systems are attractive, reducing power losses in the grid and decreasing dependence on fossil fuel. Currently the Portuguese PV scenario is characterized by large-scale solar power plants such as Serpa (11MW) and Moura (43MW), located in remote areas with low energy demand. On the other hand, most of the Portuguese high schools are integrated in populated areas (low transmission losses) and have large roof areas that are free from shading of the surrounding buildings making them a privileged site to install PV solar panels.

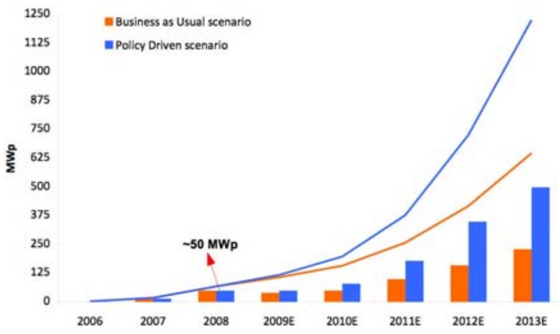

Figure 1: Annual PV market (bars) and cumulative installed capacity (lines) in Portugal. The estimation (E) policy driven scenarios were based on the assumption of the follow-up and introduction of support mechanisms, namely “Feed in Tariff”. The business as usual scenarios is assumed the non-existence of any major enforcement of existing support mechanisms [1].

As a bonus, the integration of renewable energy systems in schools is also important from an educational perspective, as the systems become part of the daily life of the students.

2 METHODOLOGY

The schools comprised in this study are 172 high schools from the different regions of Portugal. These specific schools were chosen since they are part of major governmental initiative of modernizing the country's high schools infrastructures [2-6], making them a preferential target for pilot projects regarding PV generation. The schools are divided in two groups depending on the building /roof type:

1. Pavilion (P): schools built after the 1970's typically composed of five two-story pavilions with flat roofs.
2. Non-Pavilion (NP): four to five story buildings with sloped roofs, built before the 1970´s.

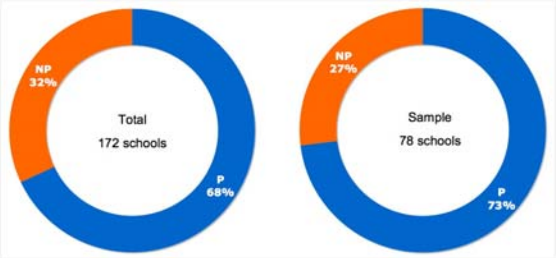

Figure 2: School distribution by type. Total schools involved in the study (left) and sample (right) used to estimate the roof areas.

In order to estimate the PV potential of the school's roofs several phases were needed: Estimation of suitable roof area; estimation of the PV area for those areas; PV production and CO_2 emissions avoided; implementation costs of the PV systems and finally the payback time of the PV system.

The available roof area is the sum of the areas that are suitable to install PV panels. These are the areas where incident solar irradiation is high. In pavilion schools (flat roofs) the available area is equal to the total roof area because the PV panels can be installed with the desired orientation and inclination to favor a better sun collection. For the non-pavilion schools, only the roofs orientated to South, Southeast, Southwest, West and East were considered suitable for PV installation, due to the reduced sun irradiation in the other directions

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3 RESULTS

3.1 PV electricity production

From the PV area and the annual capacity to produce electricity in each district (kWh/m^2) [7], using as reference system the PV setup in Fig 3., the total annual capacity to produce photovoltaic electricity was computed, Fig.4.

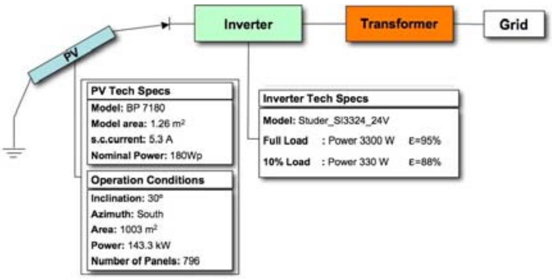


Figure 3: PV system used as reference in the Solterm software [7] to estimate the annual capacity to produce photovoltaic electricity in each district (kWh/m^2).

Not all roof area is usefull for PV, because of the infrastructures required to install the PV panels. Therefore two scenarios of occupation (PV fraction) were considered: 20% and 30% of utile area.

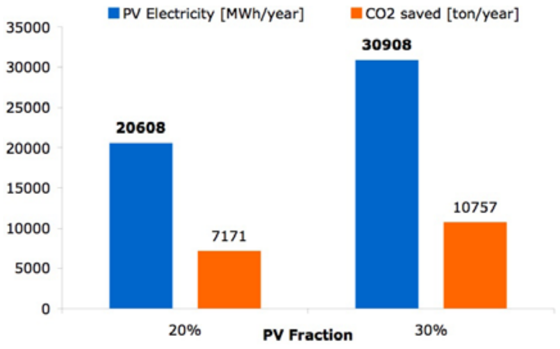


Figure 4: Photovoltaic electricity produced by the 172 schools (blue) with associated avoided CO_2 emissions (orange).

Assuming an average of 1300 Wh/Wp in Portugal, the photovoltaic installed capacity ranges from 16 to 23 MWp, twice the capacity of the solar power plant in Serpa (11MWp).

In the Solar Generation Advanced Scenario assessed by the European Photovoltaic Industry Association (EPIA) and Greenpeace [8], it is expected by 2030 only in Europe 300 million people will be receiving their household electricity supply from grid-connected solar electricity. This figure is based on the assumption that an average household size of 2.5 people and an average annual electricity consumption of 3800 kWh/yr. Using these last two figures from EPIA & Greenpeace for Europe, between 5400 and 8100 households could be supplied by this dispersed urban power plant in Portugal, meaning that between 13500 and 20000 people could take advantage from this dispersed urban solar plant.

If we attend the developing countries reality, these figures get even more dramatic, since their annual electrical consumption per capita is much smaller than in the OECD countries, on average, a 100 Wp system will cover the basic electricity needs of three people per dwelling. This means that up to 230000 people in developing could benefit from a system of this size, probably in most cases stand-alone systems would be used due to the existing weak grid infrastructures.

3.2 CO_2 emissions

The estimation of the avoided CO_2 emissions as result of injecting PV electricity on the grid, see Fig.4, is based on following data: In the Portuguese energy mix 1.2kg of CO_2 is emitted per koe of primary energy consumed [9]. The conversion factor between primary energy and electricity is 0.290 koe of primary energy per kWh of electricity [3]. Therefore, the CO_2 emitted [kg/kWh] is given by:

$$1.2\,[\text{kg/koe}] \times 0.290\,[\text{koe/kWh}] = 0.35 \text{ kg of } CO_2/\text{kWh}$$

In this estimation, the CO_2 emissions due the PV system assembling, manufacturing, and maintenance were neglected. The CO_2 saved does not take in account the CO_2 saved as result of a more efficient transmission grid, i.e., energy production site close to the consumption site.

The CO_2 emission trading market is not very stable yet. Still, in the future it will also be relevant to approach CO_2 as a financial application. For this estimate we used a reference CO_2 value of 24€ per ton of CO_2 emitted. In the present case the total emission certificate value is 170-260 k€/year.

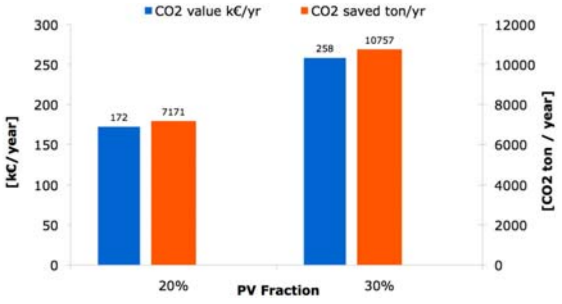


Figure 5: CO_2 emission avoided (in red) and their financial value (in blue)

3.2 Payback of the PV system

The financial analysis combines the impact of different system implementation costs (3€/Wp, 4€/Wp and 5€/Wp) and sale prices of PV electricity to the grid (neglecting the possible profits from the CO_2 emissions reduction, see Fig. 5):

1. 0.11€/kWh: the typical price of electricity in Portugal;

2. 0.20€/kWh: an estimation of the corrected price of electricity, considering the rise of the oil barrel prices in the last years and
3. 0.40€/kWh: the typical price of photovoltaic electricity sale to the grid in Portugal.

If all electricity produced by the PV systems is sold to the grid, their simple paybacks are as shown in Fig. 6.

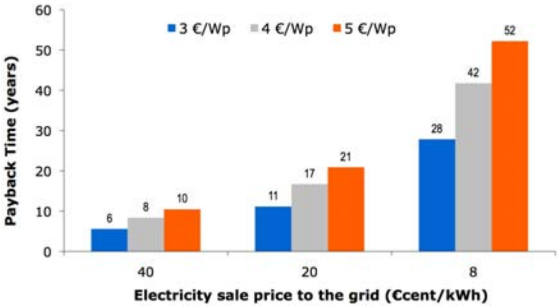


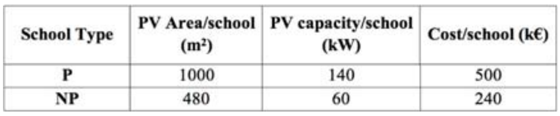
Figure 6: Payback of the PV system if all electricity produced in the schools is sold to the grid.

The 5€/Wp represents the average price of PV in the European market [9]. However if we take in account the huge volume of PV that we are dealing with, it is reasonable to assume that the price of PV decreases. Looking for the European project MUSIC FM [10] and for the Strategic Research Agenda for Photovoltaic Solar Energy Technology [9] the prices 3 and 4 €/Wp appear to be a reasonable assumption.

4 CONCLUSIONS

Regarding the PV systems: the average areas, production and costs per schools are resumed in Table I.

Table I: Costs per school



School Type	PV Area/school (m²)	PV capacity/school (kW)	Cost/school (k€)
P	1000	140	500
NP	480	60	240

The total PV potential of the 172 schools is approximately 144 000 m with a capacity of generation of 25GWh/year. Using data from the International Energy Agency [9] it is possible to see that the total PV production at schools will represent 0.06% of the electricity consumption in Portugal, and the CO_2 avoided will be about 0.02% of the total Portuguese CO_2 emissions. Despite these small figures, we can see this initiative as a trigger device. We cannot forget that in this study we are addressing just a part of the senior high schools in Portugal, disregarding for instance the junior high schools that can be up to 3 times more than the number of the existing senior high schools. Other sites such car parks and public building can be also considered.

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