Renewable Energy Sources Implementation in Urban Area - Case study on electricity generating potential from renewables in Portela civil parish

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The main objective is to quantify the potential for producing energy from renewable sources in urban areas. The Portela civil parish served as a case study, and it was developed a methodology and a group of procedures according to each studied renewable source.

The first step consisted in retrieving important data like geographic and social characteristics of this urban area, and also hourly real measures of electricity consumption during a one-year period. It was created a tridimensional model of Portela's buildings that takes into account shadow effects, so it would be more precise to evaluate the feasibility of implementing solar photovoltaic systems.

The technologies studied in more detail were solar photovoltaics in collaboration with the company WS Energia S.A. and wind energy, achieving important results like, installed power, quantity of electricity generated, associated producing costs, CO_2 avoided emissions and many others.

Finally, it was developed a national energy market model, with special focus on the electricity generation system. A simulation on the future development of supply and demand for electricity was run. Based on some results from Portela case study, the hypothesis of exploring the great potential for producing electricity from renewable sources in urban areas nationwide, was tested on the simulation.

Keywords: Solar photovoltaics, wind energy, renewable energy resources, urban area, electricity generation.

Nomenclature

General

toe	- Tonne of oil equivalent
IEA	- International Energy Agency
OECD	- Organisation for Economic Co-operation and Development
EU	- European Union
INE	- National Institute of Statistics
PV	- Photovoltaics
PVGIS	- Photovoltaic Geographical Information System
LNEG	- Energy and Geology National Laboratory

Equations

l	- PV module height
α	- PV module slope
γ	- surface slope
h_0	- sun's height at winter solstice noon
I_t	- total investment costs
c_{om}	- operation and maintenance costs
E	- electricity produced
a	- discount rate
u	- wind velocity
u_m	- maximum wind velocity
$\bar{u}$	- annual average wind velocity
c	- scale factor
k	- shape factor

I. INTRODUCTION

The current environment circumstances regarding a possible climate change situation, especially the greenhouse effect and the rise of global average temperature, requires the adoption of several sustainability measures like the use of renewable energy sources. The renewable energy arises as one solution for reducing fossil fuels dependence and decrease CO_2 and other pollutants emissions.

A. Worldwide and European energy context and statistics

Worldwide yearly primary energy consumption almost tripled in the period between 1973 and 2007, passing from 6115 Mtoe to 12029 Mtoe, and in the last decade the consumption rate increased, mainly due to emerging economies. Fossil fuels remain the most used source of energy with 81% share in 2007. [1]

Total electricity consumption follows the same trend, rising from 6116 TWh in 1973 to 19771 TWh in 2007. The principal sources for electricity production are fossil fuels, representing 68% of total consumption. In the considered period the use of oil was replaced by natural gas, and an increase

Because of more intensive fossil fuel use, for the same period CO_2 annual emissions increased by 85% to 28962 Mt. All the presented data shows that development paradigm is heavily based on the use of energy, especially fossil fuels.

Europe is a region mainly composed by developed countries, so the growth rate of primary energy consumption is lower than other regions like Africa or Asia. Between 1990 and 2007, the primary energy consumption grew 7,5%, reaching 1759 Mtep in 2007. In this period an average annual growth of 0,44% can be considered small, although the per capita consumption of 3,55 toe is high and very common in developed countries [2]

In the same period electricity consumption increased from 2579 GWh to 3329 GWh. Electricity production from renewable sources was 499,8 TWh in 2007, which represents 15% of total electricity generation in European Union.

Regarding CO_2 emissions, European Union has implemented several measures to reduce emitted quantities and achieved that goal with a decrease of 3,3% between 1990 an 2007.

B. National energy context and statistics

In 2008, Portugal consumed 24462 ktoe of primary energy and imported 24023 ktoe of coal, petroleum products and derivatives, natural gas and electricity. The country exported 3836 ktoe, especially refined products from imported oil.

Domestic production corresponds to 4373 ktoe, mainly comprised of electricity, firewood and forest residues. As a result, in 2008 the country depended on 82% of foreign primary energy and only 18% came from domestic production. [3]

Between 1990 and 2008 the total primary energy consumption raised 38,8%, with an average annual growth of 1,9%, although since 2006 there is a decrease in consumption due to economic slow down.

Electricity production is primarily made by thermal power plants. The national electricity generation system is composed by a group of ten most important thermal power plants, like Sines and Pego coal plants, Ribatejo, Tapada do Outeiro and Lares combined cycle natural gas turbine plants and Setúbal fuel oil plant. These last six plants represent 86% of the total installed thermal capacity which is 6734 MW.

The total installed capacity in large hydroelectric plants is 4578 MW. Regarding other renewable sources, between 2000 and 2008 the installed capacity increased by about 565%. Wind energy was largely responsible for this increase: the installed capacity went from 83 MW to 3030 MW. Other sources like small hydroelectric plants, solar photovoltaics and biomass, reached in 2008 a capacity of 333 MW, 492 MW and 59 MW, respectively. [3]

Between 1995 and 2008, the electricity consumption shows a continuously growing trend, with an annual average increase of 3,8% and reaching 55403 GWh in 2008. In the same year, 55% of the electricity consumed came from fossil fuel powered plants, and the rest from hydro, other renewables and imported.

Until 2000, annual CO_2 emissions due to fossil fuel combustion grew steadily and thereafter stabilized at around 55 Mt. Taking into account all human activities, the value obtained is 63 Mt for 2007.

Table I presents some results and indicators about the facts mentioned before.

Indicators	Absolute	per Capita
Primary energy consumption	24462 ktep	2,30 tep
Electricity consumption	55403 GWh	5,22 MWh
from renewables	13286 GWh	1,25 MWh
CO_2 emissions in 2007	55,2 Mt	5,20 t

Table I: Summary of most important energy indicators for Portugal in 2008. [3]

C. Possible future energy scenario and trends

Based on IEA data, especially its annual World Energy Outlook [1], this section shows one possible scenario for the evolution of global energy system by 2030. The three main drivers for energy use are: population and economic growth and energy prices. World population is expected to grow at an annual average rate of 1%, from an estimated 6,5 thousand million in 2006 to 8,2 thousand million in 2030.

The world GDP growth rate, the most important driver of energy demand in all regions, is assumed to average 3,3% per year over the period 2006-2030. It averaged 3,2% from 1990 to 2006. The increase reflects the rising weight in the world economy of the non-OECD countries, where growth will remain fastest.

The crude oil import price is assumed to average \$100 per barrel in real year-2007 dollars over the period 2008-2015 and then to rise in a broadly linear manner to over \$120 in 2030. In nominal terms, prices double to just over \$200 per barrel in 2030.

Primary energy demand is expected to grow about 45%, from 11730 Mtoe in 2006 to 17014 Mtoe in 2030, resulting in an average annual growth of 1,6%. Demand for primary energy in non-OECD countries exceeded the demand in OECD countries, for the first time in 2005. Due to strong economic growth, China, India and the other non-OECD countries account for 87% of the increase in global demand between 2006 and 2030. As a result, these countries share of world primary energy demand rises from 51% to 62%.

Fossil fuels account for 80% of the world's primary energy mix in 2030, down slightly on today. Oil remains the dominant fuel, though demand for coal rises more than demand for any other fuel in absolute terms. The projected values for world primary energy demand by fuel are shown in table II.

Other renewables, a category that includes wind, solar, geothermal, tidal and wave energy, grow faster than any other energy source, at an average rate of 7,2% per year over the projection period. Most of the increase is in the power sector.

World electricity demand is projected to grow at an annual rate of 3,2% in the period 2006 to 2015, slowing to 2% per year on average in 2015-2030. This reflects a shift in the economies of non-OECD countries away from energy-intensive heavy manufacturing towards lighter industries and services, as well as saturation effects in the OECD and some emerging economies. World demand for electricity grows from 15665 TWh in 2006 to about 20760 TWh in 2015 and to about 28140 TWh in 2030.

Fuel	2006	2015	2030	2006-2030[a]
Coal	3053	4023	4908	2,0%
Oil	4029	4525	5109	1,0%
Gas	2407	2903	3670	1,8%
Nuclear	728	817	901	0,9%
Hydro	261	321	414	1,9%
Biomass and waste	1186	1375	1662	1,4%
Other renewables	66	158	350	7,2%
Total (Mtoe)	11730	14121	17014	1,6%

[a]Average annual rate of growth.

Table II: World primary energy demand by fuel (in Mtoe), between 2006 and 2030. [1]

Most of the projected growth in electricity demand occurs outside the OECD. In the OECD, electricity demand is projected to rise by just 1,1% per year on average, increasing by less than a third between 2006 and 2030. By contrast, demand in non-OECD countries grows by 146%, at an average annual rate of 3,8%.

This scenario is based on a future with established trends and policies, without new initiatives by governments on energy security or climate change. The rising global fossil-fuel use continues to drive up energy-related CO_2 emissions, from 27,9 Gt in 2006 to 40,6 Gt in 2030: an increase of 45%.

Regarding global electricity generation, it rises from 18921 TWh in 2006 to 24975 TWh by 2015 and to 33265 TWh by 2030. Figure 1 shows the world electricity generation by fuel for 2006, 2015 and 2030.

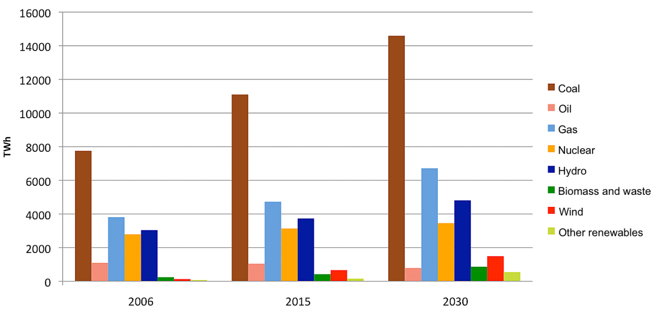

Figure 1: World electricity generation by fuel. Real values for 2006 and forecast for 2015 and 2030. [1]

Coal remains the main fuel for power generation worldwide throughout the period to 2030. On the back of strong growth in non-OECD countries, its share increases from 41% to 44%. The share of natural gas in total generation falls slightly, as a result of higher prices. The share of oil drops to about 2% by 2030, as high oil prices make oil burning extremely expensive. Nuclear power, constrained by the assumption of unchanged government policies, also loses market share, which drops from 15% in 2006 to 10% by 2030, as its capacity does not increase as rapidly as demand for electricity. The share of renewables rises considerably, from 18% in 2006 to 20% in 2015 and 23% in 2030.

Cities are a dynamic and vital part of global culture and are the main engines of social, economic and technological development. According to UN projections, by 2030, cities will house 60% of the world's population: equivalent to the total global population in 1986. The scale and pattern of city energy use has significant implications both for energy security and global greenhouse-gas emissions.

About two-thirds of the world's energy, an estimated 7900 Mtoe in 2006, is consumed in cities, even though only around half of the world's population lives in urban areas. Increases in urbanization through to 2030 are projected to drive up city energy use to almost 12400 Mtoe. By 2030, cities will be responsible for 73% of the world's energy use. Some 81% of the projected increase in energy use in cities between 2006 and 2030 comes from non-OECD countries.

These facts support the great importance of developing climate-change and energy efficiency policies involving a range of activities, such as working in partnership with private sector companies to design, finance, build, own and operate decentralized, low-energy and zero-carbon projects.

D. Renewable energy sources

The use of renewable energy sources has been expanding rapidly in recent years and this trend is set to continue over the next decades. Investment in renewable energy sources for electricity, heating and in biofuels has decreased considerably.

Excluding traditional biomass use, their share of global primary energy demand is projected to climb from 7% in 2006 to 10% by 2030. World renewable electricity generation, mostly hydro and wind power, is projected to increase from 3470 TWh in 2006 to 4970 TWh in 2015 and to 7705 TWh in 2030. Its share of total electricity output will rise from 18% in 2006 to 23% in 2030. In the OECD, the total projected increase in renewable electricity generation is bigger than the combined increase in fossil fuel-based and nuclear power generation. The share of renewables in electricity generation increases by ten percentage points to 26% by 2030.

All this results from lower costs as renewable technologies mature, assumed higher fossil-fuel prices, which make renewables relatively more competitive, and strong policy support. The renewables industry has the opportunity to exploit this development to eliminate its reliance on subsidies and to bring emerging technologies into the mainstream. Table III contains the projected generating costs of renewable energy technologies for 2015 and 2030, and it is evident the continuously decrease in electricity costs.

The European Union has been actively involved in the development of renewable energy sources, creating a se-

Renewable Source	2006	2015	2030
Hydro	2,91 - 6,48	2,88 - 6,48	2,72 - 6,28
Biomass and waste	2,43 - 7,15	2,24 - 5,71	2,05 - 5,03
Wind on-shore	6,38 - 7,44	5,71 - 6,57	5,13 - 5,99
Wind off-shore	7,25 - 8,40	5,99 - 6,86	5,80 - 6,76
Geothermal	4,94 - 5,80	3,88 - 5,42	3,01 - 5,03
Solar thermal	11,00 - 26,79	7,82 - 19,38	5,51 - 14,66
Solar photovoltaics	23,71 - 49,62	12,74 - 26,79	8,62 - 18,61

Table III: Projected generating costs of renewable energy technologies, in € cents per kWh. [1]

ries of support policies and financing energy related research programs. Other important areas like energy efficiency and sustainability are also covered.

One of the most important communication from the European Commission is the COM(2006) 2006, entitled "Renewable Energy Road Map - Renewable energies in the 21st century: building a more sustainable future". Accepted by all countries, this roadmap establishes a set of procedures and objectives in order to deal with issues like climate change, increasing dependence on oil and other fossil fuels, growing imports, and rising energy costs. [4]

This roadmap establishes a set of main objectives, which are: a mandatory (legally binding) target of 20% for renewable energy's share of energy consumption in the EU by 2020, that will reduce greenhouse gas emissions, including CO_2 emissions in a range of 600-900 Mt by 2020, and a biofuels target for 2020 fixed at 10% of overall consumption of petrol and diesel in transport.

E. Sustainability in urban areas

The built environment has considerable operating costs related with energy use, and it is responsible for 40% final energy consumption in Europe. However, more than half of this energy consumption can be reduce by applying energy efficiency measures, and that might represent a 400 million tonnes annual reduction in CO_2 emissions. [5] Being aware of that, the European Parliament created the directive 2002/91/CE on the energy performance of the buildings, that establishes a common framework intended to promote the improvement of the energy performance of the buildings in the European Union (building energy efficiency certification become mandatory).

Energy efficiency passive measures are important but there's also the possibility of active measures like localized renewable energy production. The building integrated photovoltaics and the urban small wind turbines markets have a great developing potential. One good example of combining these two different types of measures is the BedZED housing development in Hackbridge, London, England. Designed to minimize its ecological impact both in construction and operation, this neighborhood achieved some important results like a 45% electricity consumption reduction per household and a 81% heating gas reduction when compared to nearby similar urban areas. [6], [7]

Although newly designed urban areas, like BedZED, can give good results, the great majority of cities are mainly composed by consolidated areas. Initiatives like the SECURE project financed by the EU, [8] or the C40 group of large cities [9] are aimed to develop a set of tools and energy actions plans for cities, in order to reduce CO_2 emissions, improve energy efficiency and sustainability and to use more clean energy like the one provided by renewable sources.

II. CHARACTERISTICS OF PORTELA NEIGHBOURHOOD

Portela is a civil parish with 0,995 km^2 area and located in the southeast edge of Loures municipality. It's mainly a residential neighborhood composed by a great number of tall domestic buildings, but it has also some commercial buildings like a shopping mall and large warehouses.

Based on data from INE the total number of inhabitants is 13742 and the population density is 19316 hab/km^2. There's a total of 302 structures, consisting of 255 residential buildings and 47 non-residential buildings. [10]

One important characteristic of this urban area is that 69% of residential buildings have 10 or more floors, so the majority of these buildings have their rooftops at the same level, which is an advantage for implementing renewable energy sources. In the case of solar photovoltaics there are less shadows on rooftops caused by adjacent buildings and for wind energy there are no obstacles at the same level of wind turbines, so the turbulence will be inferior.

The total gross rooftop area reaches 118976 m^2, with an area of 73295 m^2 for residential buildings. All the relevant physical and social data of Portela is presented in table IV.

Another important issue is the electricity consumption on this urban area. The electricity in Portela is provided by the company EDP Distribution - Energy S.A., through two 10 kV cables, C.1342 and C.1343, that come from Moscavide sub-station. However this company doesn't have the compiled data on electricity consumption for a specific area and there's no information about hourly consumption or end-user type of activity.

The only available data is the half-hourly values of electric current measured at the exit of Moscavide substation, which multiplied by 10 kV gives the load on these two cables. Figure 2 shows the half-hour average load for cable C.1342, on a monthly basis. The load curves have a common shape, showing less consumption during late-night hours, a grater and almost constant load along the day and a peak consumption during evenings. The monthly load curves for cable C.1343 are very similar to those

Physical data		Social data	
Residential buildings	255	Inhabitants	15441
Households	5272	Population density (hab/km^2)	15523
Average per building	18,2	Inhabitants (excluding	
Regular occupied households	4643	Quinta da Vitória neighbourhood)	13742
		Population density (hab/km^2)	19316
Average per building	20,7	Average of people per household	3
Buildings with 10 or more floors	175	Resident families	4730
Gross rooftop area		Average per occupied household	1
of residential buildings (m^2)	73295	Families consisting of:	
Average per building (m^2)	286	1 or 2 people	1849
Gross rooftop area of residential		3 or 4 people	2542
buildings with 5 or more floors (m^2)	68405	5 or more people	339
Average per residential building (m^2)	329	People between 0 to 13 years	1354
Gross area of blank facades (m^2)	9172	People between 14 to 24 years	2543
Non-residential buildings	47	People between 25 to 64 years	8230
Gross rooftop area		People with mote than 65 years	1525
of non-residential buildings (m^2)	45682	Inhabitants with higher education (%)	35,3
Average per building (m^2)	985	Inhabitants with secondary education (%)	25,2

Table IV: Summary of the most important physical and social characteristics of Portela civil parish.

presented in figure 2.

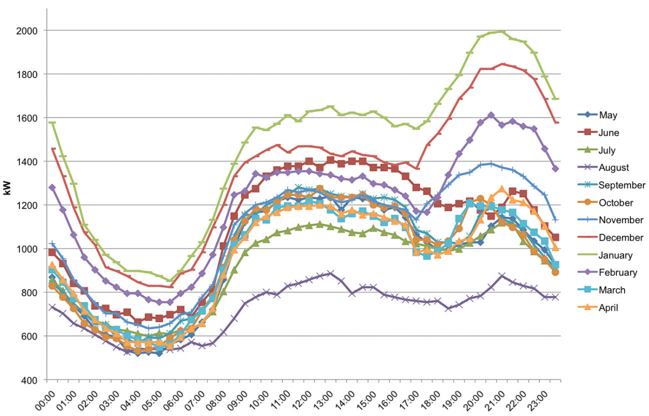

Figure 2: Half-hour average load on cable C.1342 (values in kW). The load curves shapes from cable C.1343 are very similar.

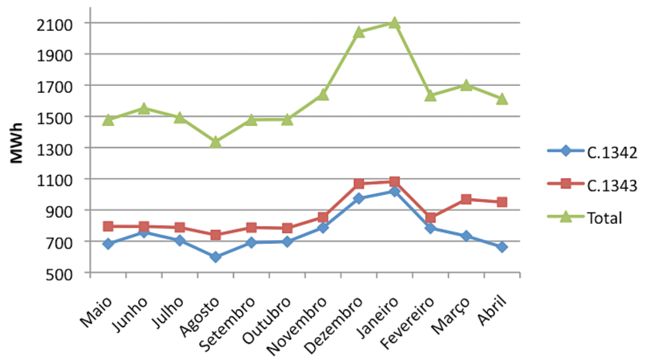

Figure 3: Monthly electricity supply to Portela, by the cables C.1342 e C.1343 (values in MWh).

These half-hourly load values should be multiplied by 0,5 in order to obtain the energy consumption in a 30 minute period, assuming a practically constant load on that time period. Summing all these values for a desired period of time we obtain the respective electricity consumption. Figure 3 shows a graph with the total monthly electricity consumption and the detailed results for each cable.

The total electricity consumption for a one year period, between May 2008 and April 2009, is 19,6 GWh, with higher monthly values during peak winter months. The overall carbon dioxide specific emissions from the electricity generating system was 387,9 g/kWh in 2008, so total emissions for Portela are 7584 t in a one year period. [11], [12]

The obtained total electricity consumption value might be a little higher than the real one for two main reasons: there are a few power transformers installed in small street stations outside the parish limits and the value doesn't account for distribution losses. But regarding the available data, these results can be considered very significant and worth the effort of obtaining them.

In order to get values only for the residential sector, an estimation based on the number of inhabitants must done. According to statistical data, in 2008 the residential electricity consumption per inhabitant from Loures municipality is 1054 kWh. [13] Assuming that value still holds for Portela, the 2008 domestic electricity consumption for this civil parish is 14,5 GWh and then CO_2 emissions are 5620 t. These results corroborate the expected belief that the majority of electricity consumption in Portela is due to the domestic sector, which is responsible for 74% of total consumption.

Electricity consumption in domestic sector	14,5	GWh
per residential gross rooftop area	0,198	MWh/m^2
per inhabitant	1,054	MWh
per regular occupied household	3,121	MWh
CO_2 emissions	5620,2	t
per residential gross rooftop area	76,7	kg/m^2
per inhabitant	409,0	kg
per regular occupied household	1210,5	kg
Electricity consumption in Portela	19,6	GWh
per total gross rooftop area	0,164	MWh/m^2
CO_2 emissions	7583,8	t
per total gross rooftop area	63,7	kg/m^2

Table V: Most important indicators about annual electricity consumption for domestic sector and the whole Portela civil parish.

Table V presents the most important facts about electricity consumption and some significant indicators like the domestic electricity consumption per gross area of residential rooftop or the CO_2 emissions per inhabitant, which are 0,1980 MWh/m^2 and 409 kg, respectively. The annual value of 3,121 MWh for the electricity consumption per regular occupied household, is common and corresponds to a monthly electricity bill of 32,06 € (accounts only for electricity, with a 0,1233 €/kWh tariff).

III. IMPLEMENTATION OF RENEWABLE ENERGY SOURCES

Renewable energy sources implementation and the assessment of their electricity generation potential depends on many factors, like the renewable technology, resource availability, or the local physical characteristics.

This section will expose some possibilities for renewable electricity generation in Portela, especially the cases of solar photovoltaics and wind technology. This two technologies will be treated in detail, describing the successive steps for assessment of electricity generation potential and presenting the most important results.

A. Solar photovoltaic

Photovoltaic modules installation in urban areas is usually done on building rooftops because of more resource availability (less shadows), less visual impact and even for safety reasons.

Knowing the total gross rooftop area, the next essential and required step is to quantify the amount of useful rooftop area, capable of accommodate photovoltaic systems.

1. *Useful rooftop area*

The first objective is to exclude all rooftops that have shadows caused by other building or structures. The second one is to estimate the useful rooftop area for installing photovoltaic systems.

With the help of 2D vectorial cartography at scale 1:1000 and aerial photography in perspective, it was possible to develop a three dimensional model of Portela's built environment, using *Google SketchUp* software. An image of the built environment model with the simulation of shadows is shown in figure 4. Excluding shady rooftops the total gross area is now 72131 m^2 for residential buildings and 38196 m^2 for other building types.

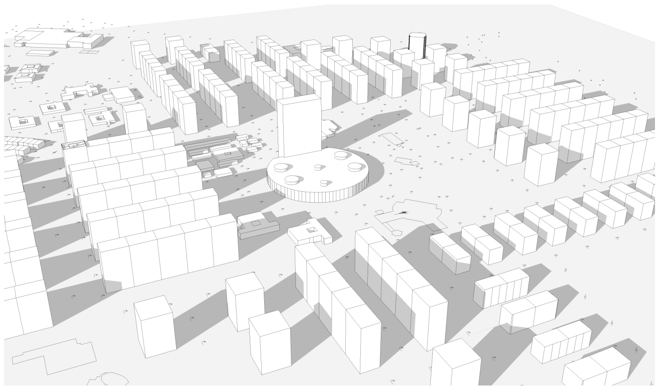

Figure 4: Three dimensional model of Portela's built environment.

The useful rooftop area determination was done by visual estimation of available rooftop area, using aerial photography in perspective. In average the useful rooftop area fraction in residential buildings is 62% and 89% in other buildings. This results in a 174 m^2 average useful rooftop area per residential building and 830 m^2 per other building types.

2. *Photovoltaic installed capacity*

In order to optimize PV electricity production the modules should be placed in a way that maximizes its number per unit of available area and at the same time causing the least shadows on closest modules.

For consecutive PV modules arrays with a slope, the distance between adjacent arrays that balances both maximum electricity production and shadow effects between modules is given by equation 1: [14]

$$d = l\left(\frac{\sin(\alpha-\gamma)}{\tan(h_0+\gamma)} + \cos(\alpha-\gamma)\right) \quad (1)$$

Equation 1 depends on PV module length, so in order to get a value for d it was chosen a typical panel that represents the average characteristics of silicon PV modules in the market. The chosen module was the CS6P 230 model from *Canadian Solar Inc.*, with 230 W of nominal power and a length of 1,638 m for the larger side.

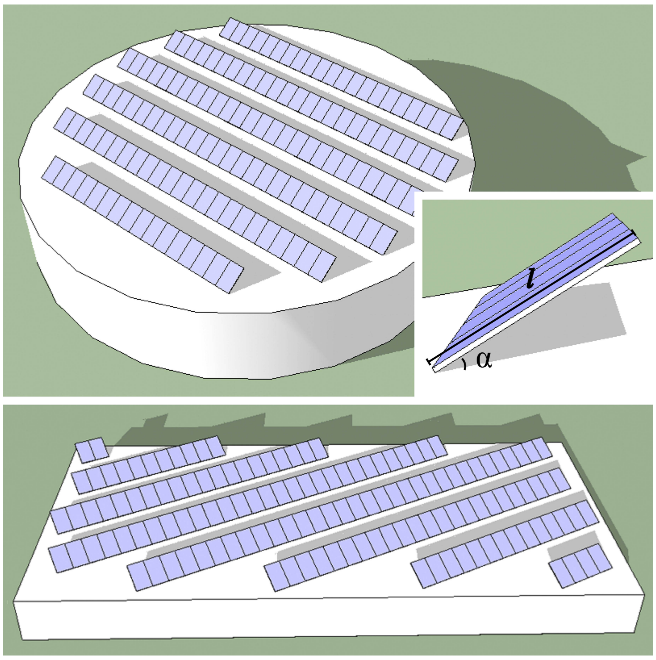

Figure 5: Example of photovoltaic modules installation on two building rooftops.

The optimal slope for the modules was obtained with PVGIS model that will be explained later, and it is $\alpha = 34^o$. The module installation is considered to be done on horizontal surfaces ($\gamma = 0^o$) with the smaller side being adjacent to the installation surface (l = 1,638 m). So the distance between successive arrays of PV modules given equation 1 is 3,10 m. Usually a distance 25% grater is used so the result that will be used is 3,88 m.

Figure 5 shows an example of PV systems facing south, installed on two buildings rooftops according to the previous described conditions. The useful rooftop area of these two buildings are 689 m^2 and 627 m^2. The PV modules area that is possible to install is 225 m^2 and 217 m^2, so the ratio between these two types of areas is 0,327 e de 0,346, respectively.

Similar ratio values are obtained for other cases and the rooftop geometrical shape has little importance on the number of modules that can be installed. The average ratio is 0,33, meaning that for a certain useful rooftop area, only 33% of that area corresponds to PV module area. All these results were obtained using the 3D model developed with *Google SketchUp* software.

Taking 33% of the total useful rooftop area gives the total module area that is possible to install in Portela, which is 25678 m^2. Having this value, the maximum number of PV modules would be 25678 which corresponds to a total installed capacity of 3672 kW or a power per useful rooftop area of 47 W/m^2. Table VI shows the previous results detailed by type of building.

Buildings	Useful rooftop area total (m^2)	Useful rooftop area average (%)	PV modules Area (m^2)	PV modules Number	PV modules Power (kW)
Residential	42296	61,8	13958	8677	1996
Non residential	35700	89,1	11720	7286	1676
Total	77996	-	25678	15964	3672

Table VI: Useful rooftop area and important results for PV systems installation: area, number of units and installed capacity. Results detailed according to residential and non residential buildings.

3. *Electricity produced*

The electricity produced by the PV systems is calculated using an advanced and very complete model named PVGIS. [15] This model calculates the solar resource availability, geographically and time distributed, and determines the electricity produced according to several factors, like PV technology, system losses, module orientation among others. It was developed by Joint Research Center and financed by the European Commission, being widely used for research, demonstration and to support energy policies.

The annual electricity production from PV systems installed only in residential building rooftops is 2770 MWh and corresponds to 19,1% of annual domestic electricity consumption. If only the electricity consumption during PV production is considered, PV systems could cover 41,6% of the domestic consumption. Even in summer months like July and August, where the domestic electricity consumption is lower, PV production will only cover 65% of that. Regarding the other type of buildings, annual PV electricity production can reach up to 2330 MWh.

This means a total PV electricity production of 5090 MWh per year, covering 26,0% of total electricity consumption in Portela civil parish and resulting in a production per useful rooftop area of 65,3 kWh/m^2. During daytime periods, accumulated PV production is less than consumption, even in summer months were it oscillates between 83,6% and 88,9% of consumption.

Buildings	PV electricity production (MWh)	PV/E (%)	
		Total	During PV
Residential	2770	19,1	41,6
Non residential	2330	46,0	100,1
Total	5090	26,0	56,6

Table VII: Summary of annual PV electricity production, its weight on total electricity consumption and during PV production.

Table VII summarizes the most important results previously presented.

4. Cost of electricity

The average present cost of electricity is given by equation 2:

$$c_a = \frac{I_t + c_{om}\sum_{j=0}^{n}\frac{1}{(1+a)^j}}{E\sum_{j=0}^{n}\frac{1}{(1+a)^j}} = \frac{I_t k_a^{-1} + c_{om}}{E} \tag{2}$$

For an installation cost of 3551 €/kW (smaller value than usual because this is a large scale project), total annual operation and maintenance costs of 89920 €, during a period of 20 years with a 4% discount rate, the annual present cost of electricity is 0,2062 €/kWh.

A more precise method for finding electricity cost can be done using an *Excel* sheet to calculate revenues from electricity produced and the costs in order to obtain the net cash flows. Imposing a 0,8% annual decrease in electricity production to simulate modules aging and a 2% increase in O&M costs, the present cost of electricity will be the one that turns the internal rate of return into 0%. Doing that, the present cost of electricity obtained is 0,2234 €/kWh.

5. Advantages

The annual electricity production of 5090 MWh from a renewable source like PV would avoid 1976 t of CO_2 emissions. Using only PV it's possible to have a reduction of 26,1% in CO_2 emissions related with electricity consumption. For a 15 €/t CO_2 price this reduction would result in a "virtual" benefit of 30000 € per year.

A real way to obtain a monetary profit is to turn Portela and its PV systems into a Special Regime Producer, according to the Decree-Law n.º 225/2007, of May 31. Assuming that all legal and required technical specifications are satisfied and an operation license is obtained, the average annual revenue for producing electricity to the transmission grid is 0,42 €/kWh. With this electricity price paid to the producer, the project would have a 9,54% internal rate of return, and a payback time of eight years, making it more economical attractive.

B. Wind energy

Wind energy exploitation in urban areas is not so advanced as PV or solar thermal for hot water. The wind mini turbine technology is currently in a development state and there's no much information about wind resource availability in urban areas. Although these facts, with some assumptions it's possible to estimate in a first approximation, Portela's wind potential for electricity generation.

1. Wind installed capacity

Installation of mini wind turbines should be done in high buildings rooftops, with no obstacles nearby in order to avoid turbulence effects. With these conditions there are 205 residential buildings in Portela. To avoid turbulence caused by other mini turbines it was decided to install only one turbine per rooftop and shadows on PV systems were prevented.

Taking all this into consideration and using the 3D model to better visualize the built environment, a total of 140 mini wind turbines can be installed on residential buildings rooftops.

To get more results it's necessary to choose a wind turbine and the preference fall on the model *T.Urban* developed by LNEG. This is a high efficiency mini turbine, created mainly for urban environment and to be grid-connected. It's an horizontal rotation axis turbine with 2,5 kW of rated power and a 2,3 m diameter rotor.

The installation of 140 *T.Urban* mini turbines constitutes a urban wind farm with a total rated power of 350 kW.

2. Electricity produced

There is no published data on wind resource characteristics in urban areas either experimental data or simulation results considering built environment effects, although an estimation on electricity production can be done.

The wind distribution function for a certain palace can be represented by the Weibull function [16], that gives the probability of the wind speed exceed a specific value u. The modulus of the derivative of Weibull function gives the wind probability density function,

$$f(u) = k\frac{u^{k-1}}{c^k}\exp\left[-\left(\frac{u}{c}\right)^k\right] \tag{3}$$

which yields the proportion of time a specific wind velocity u will occur. The value of c is given by:

$$c = \frac{\bar{u}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{4}$$

Knowing the wind turbine power curve, $P(u)$, the electricity production for a period of time, T, is:

$$E = T \int_0^{u_m} P(u)\, f(u)\, \mathrm{d}u \tag{5}$$

The function $P(u)$ is well known, but to determine $f(u)$ there are two values that need to be estimated: the annual average wind velocity, $\bar{u}$ and the shape factor, k. Based on a Wind Atlas developed by LNEG [17] it's possible to tell that in Lisbon metropolitan area the average wind velocity ranges between 5,5 and 6,5 m/s, and in Portela is 6,0 m/s. For the k value the two closest anemometric stations, S. João das Lampas and Arruda dos Vinhos, have 2,04 and 2,48, respectively. [18]

Considering all this data, the chosen value for $\bar{u}$ is 5,5 m/s, a conservative option reflecting that the atlas is obtained with mesoscale simulations which don't take into account buildings, and $k = 2$ because it's a common value for many places. Figure 6 shows the graph for equation 3 and also the $P(u) \times f(u)$ function graph. Its integral multiplied by the number of hours in one year gives the total expected annual electricity production for one *T.Urban* mini turbine, which is 3344,5 kWh.

So 140 mini wind turbines have an annual production of 468,2 MWh, that corresponds to 3,23% of Portela domestic electricity consumption.

3. *Cost of electricity*

The average present cost of electricity can be again calculated using equation 2. For an installation cost of 2800 €/kW, total annual operation and maintenance costs of 14700 €, during a period of 20 years with a 4% discount rate, the annual present cost of electricity is 0,1854 €/kWh.

4. *Advantages*

An annual electricity production of 468,2 MWh from wind turbines would avoid 181,6 t of CO_2 emissions. For a 15 €/t CO_2 price this reduction would result in a "virtual" benefit of 2724 € per year.

The Special Regime Producer scheme isn't feasible with this type of mini turbines because the revenue will be less than the production cost. The cause is the decree-law that only considers large scale MW wind turbines where the investment costs per electricity produced is much lower than the case of small scale turbines.

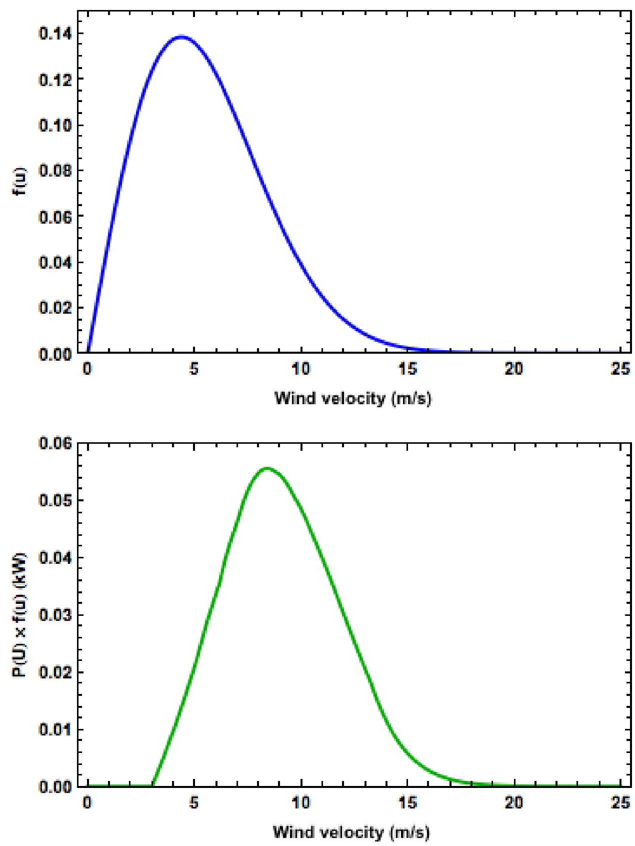

Figure 6: Wind probability density function for Portela (blue graph) and $P(u) \times f(u)$ function for a *T.Urban* turbine (green graph).

An interesting advantage would be the pioneering work in research and development associated with an urban wind farm.

C. Integration of PV and wind technologies and other possible renewable sources

Previous presented results clearly showed Portela's high potential for generating electricity with renewable sources like PV and wind. Together these technologies can produce up to 5558 MWh per year, which corresponds to 28,4% of total electricity consumption in Portela. This amount of produced electricity avoids 2158 t of CO_2 annual emissions.

Table VIII summarizes the most important results obtained in the previous subsections about PV and wind technologies.

Other renewable energy sources could be installed in Portela but require larger structural and building interventions. Examples of that kind of renewable energy sources are mini hydro turbines installed in the water supply system, solar thermal panel for hot water, or combined heat and power plants. Because implementation

Renewable source	Power (kW)	Electricity produced (MWh)	cost (€/kWh)	grid (%)	Avoided CO_2 (t)
PV	**3672**	**5090**	**0,2234**	**26,0%**	**1976**
Residential	1996	2770	-	19,1%	1074
Non Residential	1676	2330	-	46,0%	902
Wind	**350**	**468**	**0,1854**	**2,4%**	**182**
Total	**4022**	**5558**	**0,2202**	**28,4%**	**2158**

Table VIII: Most important results about PV and wind implementation in Portela.

complexity, high cost installation, and lack of available data these sources where not studied.

IV. NATIONAL IMPLEMENTATION OF RENEWABLE ENERGY SOURCES

This section will present a national energy market simulation done with the ENPEP-BALANCE software [19]. A simplified model of the generating and energy distribution systems was built, considering all energy flows from primary energy sources to final consumption. This model accounts for produced electricity quantities regarding the source, average costs, final consumption values, energy exports and imports, among other important quantities.

A. National energy market simulation

Figure 7 shows the electricity consumption by sectors of activity and electricity production by source, both between 2006 and 2008. These are important numbers, but to simulate the evolution of an energy market it's also necessary to know several future policies and trends, or to make forecasts based on present facts.

The National Renewable Energy Action Plan (or PNAER from the portuguese abbreviation) elaborated by the Government in order to comply with the directive 2009/28/EC of the European Parliament and of the Council, has plenty information about future energy scenarios. [21] Forecasts up to 2020 for annual electricity consumption growth and primary energy prices, a detailed roadmap for renewable energy sources with estimated yearly electricity production by source, or future plans for new combined cycle gas turbine and large hydroelectric power plants are explained in this valuable document.

The simulation was based on PNAER values and one significant result is shown in figure 8: the evolution up to 2025 of electricity production by source. Table IX contains the detailed values for the years 2010, 2015 and 2020.

There were some restrictions imposed to a market oriented software like the preference for consuming electricity produced by renewable sources and also a priority for national electricity generation.

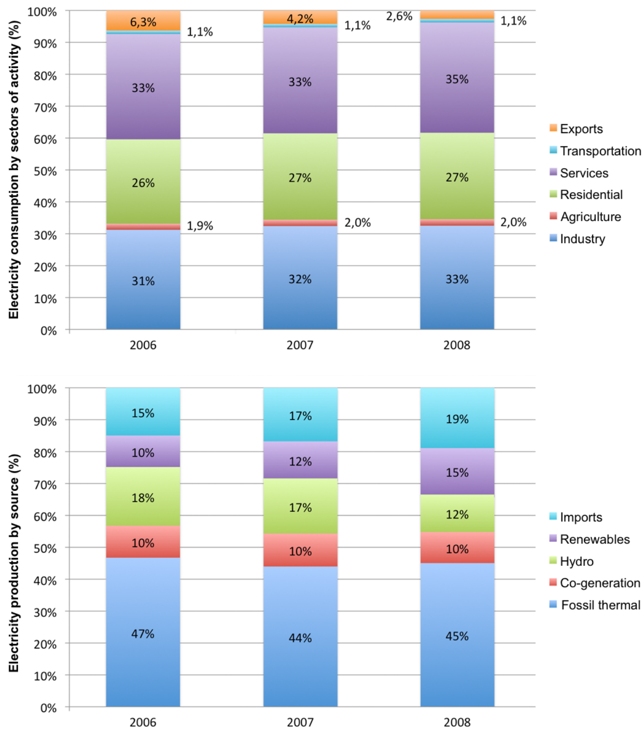

Figure 7: Electricity consumption by activity sectors and electricity production by source, between 2006 and 2008. [3], [20]

Source	2010 (GWh)	2010 (%)	2015 (GWh)	2015 (%)	2020 (GWh)	2020 (%)
Thermal	25512	43,9	27491	42,0	26514	36,1
Gas	13691	23,6	17037	26,0	15455	21,1
Coal	10820	18,6	9798	15,0	10478	14,3
Others	1001	1,7	656	1,0	582	0,8
Cogeneration	6002	10,3	7303	11,1	8885	12,1
Large Hydro	9752	16,8	12397	18,9	17264	23,5
Renewables	13342	23,0	18201	27,8	20698	28,2
Imports	3489	6,0	116	0,2	0	0,0
Total	58097	100,0	65507	100,0	73361	100,0

Table IX: Electricity production values by source, for 2010, 2015 and 2020.

Simulation results confirms a great increase of renewable sources in electricity production, rising from a 39,3% share in 2010 to 51,7% in 2020. The simulated scenario also accounts for an installed capacity increase because of new thermal power plants (combined cycle gas turbine), and although it supports the growing of intermittent renewable sources like wind or hydro, the simulation showed that there will be a great amount of reserve capacity from thermal power plants.

In average terms, between 2010 and 2020, the reserve

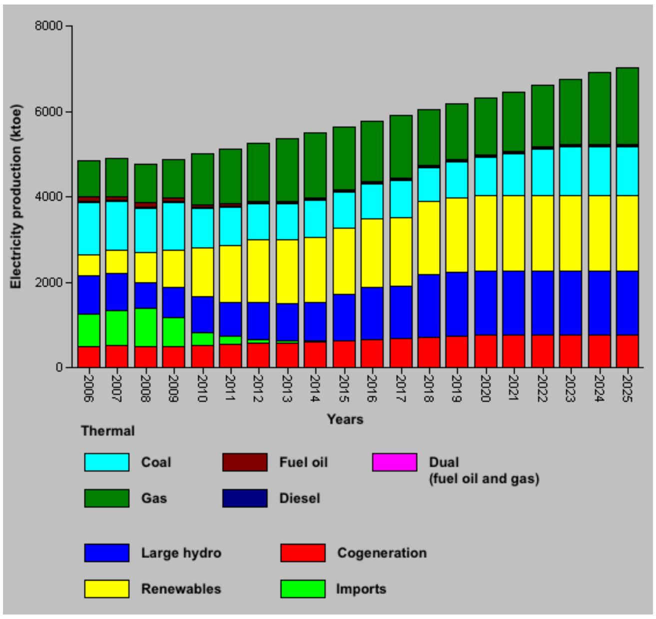

Figure 8: Simulation results of annual electricity production up to 2025, detailed by source.

thermal capacity could cover up to an annual decrease of 28,9% in the forecasted production from renewable electricity. This reserve thermal power opens two new possibilities: lower foreign electricity dependence and electricity export when production capacity surpasses demand although portuguese government is aware of some technical constraints in transmission lines between Iberian Peninsula and France [21].

The simulation confirms that, for a scenario with an increase of 2,3% in annual average electricity consumption, the main objectives can be accomplished. It only depends whether or not the planned projects are implemented.

B. Impact of renewable electricity production in urban areas

Finally, it will be presented an introductory study on the impact of producing electricity from renewable sources installed in urban areas. The results obtained in Portela will be extrapolated, but only for PV systems installed on building rooftops. Then the simulation model developed in subsection IV A is used to get some significant results.

The procedure to evaluate the electricity generating potential from PV systems installed in residential building rooftops at national level, is the following:

1. There are 3247894 residential buildings in 2008. [22]
2. The average gross rooftop area is 200 m^2 [22], so the national total area is 649,6 km^2.
3. With a 62% rooftop useful area ratio obtained in Portela, the total rooftop useful area is 401,2 km^2.
4. The modules area ratio is 33% of useful area, so total module area is 132,4 km^2.
5. The PV modules number would be 82318001, resulting in 18933 MW of total installed capacity.
6. Considering an annual electricity production of 1390 kWh/kW, the total generated electricity would reach 26317 GWh per year.

An annual electricity production of 26317 GWh represents twice the domestic consumption in 2008. It's very important to notice that the obtained result is clearly an overestimated value, because the previous evaluation procedure didn't consider PV modules orientation constraints due to rooftop characteristics or shadows caused by near buildings, like it was done using the 3D model for Portela. Also the installation of 18933 MW during the simulation period is obviously impossible.

For all these reasons it was decided to build a scenario where only 10% of the previous PV capacity is installed. Each year between 2015 and 2025, an additional 172 MW of PV systems are installed in national urban areas, totalizing 1893 MW in 2025.

Figure 9 presents the simulation results: the annual domestic electricity consumption detailed by production source. The only condition imposed to the simulation was the preference for consuming all the PV generated electricity by the local domestic sector.

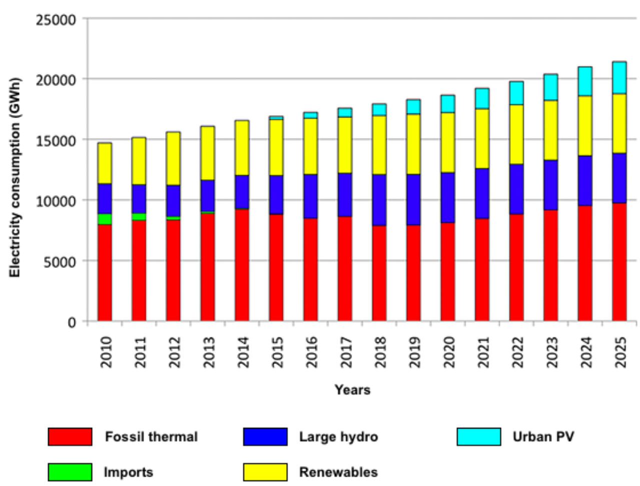

Figure 9: Simulation results of annual domestic electricity consumption between 2010 and 2025. Values detailed by source and including urban PV production.

This scenario simulation shows that is possible to have in 2025, up to 12,3% of consumed electricity from PV systems installed in urban areas. Regarding costs, in the ten year period from 2015 to 2025, the average annual price of electricity is 3,14% higher than in the case where there are no PV systems installation.

Comparing these results with the ones from Portela, they are equivalent of having 516 urban areas with similar characteristics of Portela urban area. Being a first approach to reality, this results might be considered as an overestimate, although only a deeper and complete analysis about various and distinct urban areas could allow a more accurate and solid conclusion.

V. CONCLUSIONS

Portela civil parish, an urban area composed mainly by residential buildings, has a total annual electricity consumption of 19,6 GWh, of which 14,5 GWh is from the domestic sector. So electricity related CO_2 emissions are 7584 t and 5620 t, respectively.

Using a three dimensional model of Portela's built environment, aerial photography in perspective and an adequate methodology, it was demonstrated the great potential for renewable electricity generation, especially for PV and wind energy.

In the PV case, with a 62% average useful rooftop area and a 33% ratio between that one and module area, it's possible to have a maximum installed capacity of 3672 kW which gives an annual electricity production of 5090 MWh. This electricity amount represents 19,1% and 26,0% of domestic and total consumption, respectively. The associated electricity cost is 0,2234 €/kWh.

PV electricity production avoids 1976 t CO_2 emissions per year. In the case of selling electricity to the grid (Special Regime Producer) the price would be 0,4232 €/kWh, with a 9,45% internal rate of return and payback time of eight years.

Wind energy could have an annual production of 468,2 MW, from an urban wind farm with 350 kW installed capacity. This corresponds to 2,39% of total electricity consumption and avoids 181,6 t CO_2 emissions. The electricity cost is 0,1854 €/kWh.

Together these two technologies could produce up to 5558 MWh of electricity per year, which is equivalent to 28,4% of total consumption. The average electricity cost is 0,2202 €/kWh.

Regarding the previous presented results renewable energy sources implementation it's possible but requires a careful planning and the understanding of local characteristics. Alongside with renewable energy sources it's also important to development methods for energy consumption reduction and its more efficient use.

The first simulation results confirms a great increase of renewable sources in electricity production, rising from a 39,3% share in 2010 to 51,7% in 2020. It also showed that in average terms, between 2010 and 2020, the reserve thermal capacity could cover up to an annual decrease of 28,9% in the forecasted production from renewable electricity.

In this way there will be less dependence from foreign electricity in years where renewables production is below average and the reserve thermal capacity will allow the growing of intermittent sources like wind or hydro. The simulation confirms that, for a scenario with an increase of 2,3% in annual average electricity consumption, the main objectives can be accomplished. It only depends whether or not the planned projects are implemented.

An approximated estimation of PV production in residential buildings rooftops at national scale, gives 26317 GWh per year which represents twice the domestic consumption in 2008. It is obviously an overestimated value, because the evaluation method didn't consider PV modules orientation constraints due to rooftop characteristics or shadows caused by near buildings.

So the second simulation consisted in the implementation of a total 1893 MW between 2015 and 2025, or 172 MW of PV systems installed each year. This scenario simulation shows that is possible to have in 2025, up to 12,3% of consumed electricity from PV systems installed in urban areas. Regarding costs, in the ten year period from 2015 to 2025, the average annual price of electricity is 3,14% higher than in the case where there are no PV systems installation.

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