Viability of Renewable Energy Sources in Urban Areas. Potential for Net Zero Energy Buildings.
Civil Engineering Master Thesis

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Abstract

The energy sector is of utmost importance for the world economy, however the current energy mix poses challenges that must be overcome, due to excessive dependence on fossil fuels.

This paper analyses the viability of implementing renewable energy sources in two buildings' models, by taking into account mature technologies such as solar thermal and photovoltaic, as well as small wind power. Other sources, such as biomass and small hydro, were studied, however their characteristics make them more complex to install and maintain, hence were not considered for the energy mix nor in the economic viability model.

It was found that there is an opportunity to save money by implementing renewable energy technologies, with an internal rate of return of 10% for a single-family two-story house and 12% for a six-story building with 5 residential floors, although some challenges emerge related to social acceptance, legal issues and physical constraints. Renewable energy technologies produced 100% of the energy demanded for the house while for the building only 54% of the energy demand was produced locally. To achieve nearly zero energy in buildings, measures should be taken to reduce energy consumption and to promote correct management of the renewable solutions installed. These measures should take into account cultural and human factors that may hinder development of these projects.

Key words: Renewable energy, energy mix, urban areas, zero energy buildings, economic viability

1. Introduction

The turning point for the energy sector occurred during the industrial revolution, between 1780 and 1840 (More, 2000), transforming production processes, creating new forms of transport and opening a new era of opportunities and innovation. The energy sectors' transition is easily observed by analysing energy consumption trends by type of fuel, starting at the end of the 19th century, where biofuels were the main type of consumed energy, and advancing into the 20th century where fossil fuels began to conquer the sector. World energy consumption has more than tripled from 20GJ per capita in 1800 to more than 70GJ today (Roser, 2015).

Fossil fuels make up more than 80% of the global energy mix, with coal and petrol representing 30% of total primary energy production each, while natural gas accounts for 20%. The main drawbacks of this high dependence on fossil fuels are their highly pollutant nature, limited reserves of resources and limited geographical availability, where as the main advantages include their stable and predictable production, high energy density and vast infrastructures already in place.

The energy sector is responsible for 70% of global greenhouse gases (GHG) emissions (IEA, 2014) which are the main cause of human caused global warming. In consequence, countries have agreed to reduce their fossil fuel dependence in order to prevent global temperatures from increasing more than 2ºC from pre-industrial levels, as this would cause aggressive climate change that would impact food production, increase sea levels, reduce water reserves and destroy wildlife and biodiversity (Centre for Climate and Energy Solutions, 2015).

In order to achieve the below 2ºC objective, countries must embrace changes to implement efficiency improvements and renewable energy investments on a national scale and join efforts to encourage international cooperation in order to mitigate climate change costs. Energy efficiency is of utmost importance to reduce energy losses that occur during the transformation of primary energy into final energy, and is many times referred to as the "untapped energy source" (MacKay, 2009) due to the potential of reducing the amount of energy needed to sustain energy consumption.

Urban areas are big consumers of energy, since half of the global population lives in cities, emitting about 70% of global GHG (Becchio *et al.* , 2015). In Europe, 80% of energy consumption is associated to urban activities and buildings are responsible for the main proportion of it (OECD/IEA, 2014). Nearly zero energy buildings (nZEB) will reduce energy dependence by increasing the share of energy produced locally and will contribute to the growth of renewables in the energy mix.

This paper studies the viability of renewable energy in urban areas and the potential for zero energy by analysing the application of solar thermal, solar photovoltaic and small wind power to houses and buildings in an urban environment.

Firstly, the energy mix must be defined by investigating the energy sources available commercially and which are most suitable, taking into account the maturity and cost. Secondly, the economic viability model is presented, using data collected in existing studies to calculate the potential monetary savings of the installation of renewable energy technologies. Finally, results are presented and discussed and recommendations are made.

2. Renewable Energy

The renewable energy sector is fast expanding, having doubled its installed capacity over the past decade, reaching 1 712 GW in 2014 when in 2004 it was only 800 GW. Renewable energy sources represent 19% of global final energy consumption, with traditional biomass representing half of this value, biomass, geothermal and solar heat 21%, hydropower another 21%, while wind, solar, biomass and geothermal power only represent about 7%. Renewable energy sources produce 22.8% of global electricity production, of which 73% comes from hydropower, 14% from wind and 4% from solar. The remainder is generated from bio-power, geothermal and concentrated solar power (CSP) (REN 21, 2015).

Traditional biomass is an important energy source with great historical importance due to its use for cooking and heating. Today, modern biomass may be used for space heating, for domestic hot water heating as well as for electricity generation on a larger scale (Keirstead *et al.*, 2012). The main advantages of biomass are contribution to forest cleaning, fossil fuel dependence reduction and the possibility of using a variety of fuels e.g. wood waste and municipal solid waste, on the other hand, it may contribute to air quality problems in urban areas, transportation of fuels can increase costs considerably and requires operation at least on a weekly basis (Woodland Renaissance, n.d.).

Hydropower is an important source of energy for electricity generation that is mainly produced on a large scale and grid connected. Production is usually centralized and may be used in association with other energy sources for better energy management purposes e.g. wind power may be used to pump water in times of excess wind power generation. Hydropower is a mature energy source that helps control flooding problems as well as water shortages issues. In addition, stored water may be used for agriculture and leisure activities as well as for fire fighting purposes. Drawbacks include flooding of large areas, river flow modification and high costs (IEA, 2010).

Solar power may be used for heating purposes using solar collectors or for electricity generation using photovoltaic cells. The first type of system has been used for decades and is mainly used for domestic hot water heating, using the sun's energy to heat a fluid inside a dark box that is then stored for when it is needed. Technology is mature and commercially available, achieving reasonable paybacks that motivate its installation for domestic purposes. The main problems that arise are related to periods of low solar radiation when there isn't enough solar energy to heat the necessary amount of water. In this case, there would have to be an alternative energy source such as a natural gas boiler, an electric heater or a biomass boiler (Estif, 2015).

Photovoltaic solar energy uses cells and an inverter to convert solar radiation directly to electricity, which may be consumed on site or injected into the grid. A battery may be installed in order to compensate daily fluctuations of supply and demand or fluctuations may be controlled and managed by being connected to the grid. The costs of this type of technology have fallen significantly over the past years, hence increasing investment in photovoltaic cells (IRENA, 2015).

Wind energy is an important energy source that has been around for many centuries yet, it was in the 80's that modern wind power began spreading worldwide (US Department of Energy, 2015). This energy source complements solar power since it is usually available when solar radiation decreases and may be used in pumped storage systems. It is a clean source of energy that represents a significant proportion of electricity in some countries such as Denmark, Portugal and Spain, with minor downsides that are limited to local impacts such as visual impact and noise pollution (EWEA, 2009). Application of this energy source in urban areas is possible by installing small wind turbines (SWT).

The model assumes that domestic hot water is heated by solar thermal, since new constructions are legally obliged to include this technology in certain countries, such as Portugal (Diário da República, 2006), disregarding biomass due to space restrictions, high operation and maintenance needs and air quality issues that may arise in urban areas. For electricity production solar photovoltaic and wind power are the main technologies used, due to their high maturity, while small hydropower is only contemplated in specific cases due to the lack of hydro resources with sufficient quality in urban areas.

3. Case Study

In order to understand how current renewable technologies can be inserted into urban areas, this paper considers two types of buildings: i) a single-family two-story dwelling (figure 3.1(a)) and ii) a six-story building with 5 residential floors (figure 3.1(b)).

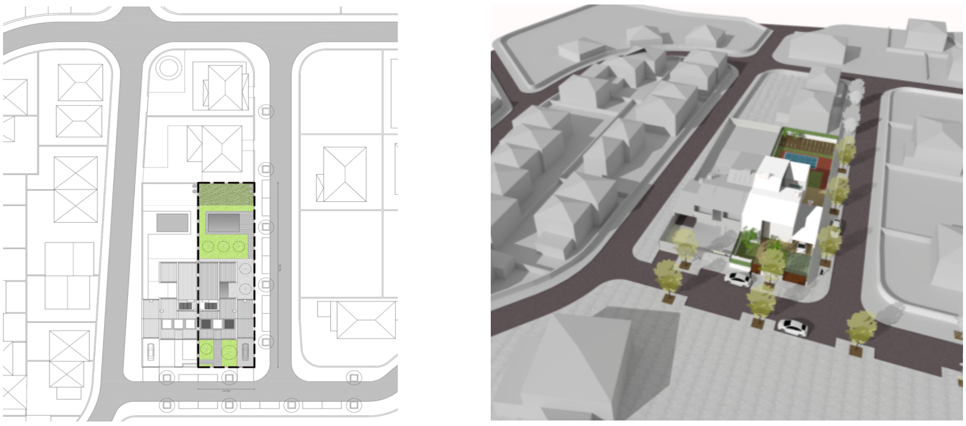

Figure 3.1 (a) – Plant and perspective view of single-family two-story dwelling

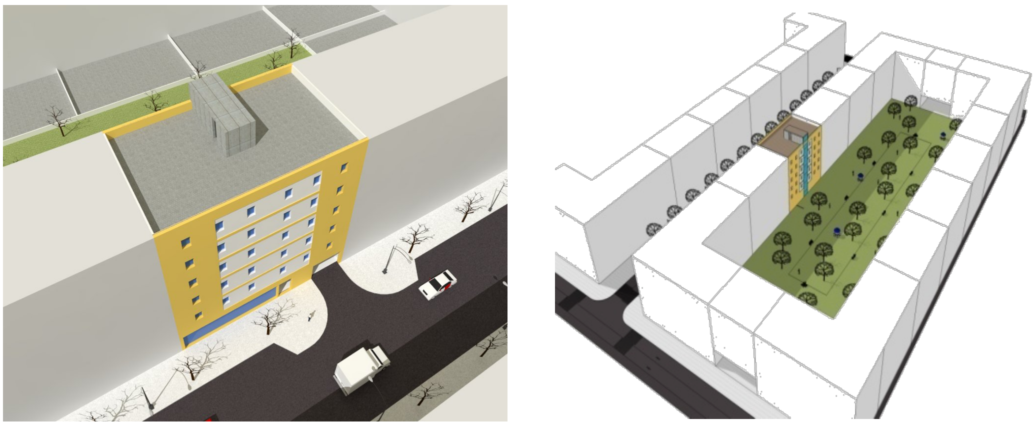

Figure 3.1 (b) – Perspective view of six-story residential building

The installation of renewable energy technologies enables buildings to become less dependent on grid-supplied energy and increases the share of energy produced from renewable sources. Although there are numerous advantages of installing this type of solutions, there are physical limitations and other constraints that restrict the use of certain solutions.

Taking into account the characteristics of the single-family two-story dwelling presented in table 3.1, the application of certain energy sources is evaluated in table 3.2. In the Lisbon area, energy consumption per capita is 5 000 kWh, of which 24% are for DHW heating and the remaining 76% is assumed to be electricity (E-Nova Lisboa, 2005).

Table 3.1 – Characteristics of the single-family two-story dwelling

Nº of Floors	2,0
Inhabitants	6,0
Energy needs	Thermal: 7 200kWh Electric: 22 800kWh
Rooftop area	230,0 m^2

The analysis of the type of technology to be installed takes into consideration space restrictions as well as the convenience of the technology e.g.: the need for maintenance or operation.

Table 3.2 – Evaluation of the applicability of renewable energy technologies for a single-family two-story dwelling

Energy Source	Rooftop	Façade	Ground	Inside
Thermal Energy				
Solar thermal	Yes	No	No	No
Biomass	No	No	Yes	Yes
Electric Energy				
Small Wind	Yes	No	Yes	No
Solar PV	Yes	Yes	No	No
Small Hydro	No	No	Yes	No

*Scale: The darkest colours reflect a stronger Yes or No, whether it is applicable (Green) or not (Red)

Overall, the technologies selected for the single-family two-story dwelling were solar thermal and solar PV both on the rooftop, due to the area available for installation, and small wind turbine on the ground.

Finally for the six-story residential building, characteristics are presented in table 3.3 and the application of certain energy sources is evaluated in table 3.4. Again, Lisbon is the location considered, with energy consumption per capita of 5 000 kWh, of which 24% are for DHW heating and the remaining 76% is assumed to be electricity (E-Nova Lisboa, 2005).

Table 3.3 – Characteristics of the six-story residential building

Nº of Floors	6,0 (5 residential)
Inhabitants	30,0
Energy needs	Thermal: 36 000kWh Electric: 114 000kWh
Rooftop area	400,0 m^2

The analysis of the type of technology to be installed takes into consideration space restrictions as well as the convenience of the technology e.g.: the need for maintenance or operation.

Table 3.4 – Evaluation of the applicability of renewable energy technologies for a six-story residential building

Energy Source	Rooftop	Façade	Ground	Inside
Thermal Energy				
Solar thermal	Yes	No	No	No
Biomass	No	No	No	Yes
Electric Energy				
Small Wind	Yes	No	No	No
Solar PV	Yes	Yes	No	No
Small Hydro	No	No	Yes	No

*Scale: The darkest colours reflect a stronger Yes or No, whether it is applicable (Green) or not (Red)

Overall, the technologies selected for the six-story residential building were solar thermal and solar PV both on the rooftop, and small wind turbine on the rooftop as well, due to the limited amount of ground area available.

4. Energy Mix

To define the energy mix, it is necessary to obtain values of resources availability for the area of study, since this will determine the energy potential for a given place. Average values for Lisbon are presented in table 2.1.

Table 2.1 – Resources availability average for Lisbon *(REN 21, 2015) (Baltazar, 2010)*

Solar (Thermal and PV)	
Load Factor	20%
Solar Irradiation	1 600 kWh/m^2
Wind	
Load Factor	20%
Wind Speed	16 km/h

Each technology has its own efficiency that may vary depending on certain variables. For solar photovoltaic, increases in temperature of modules negatively impacts efficiency, whereas for wind turbines lower wind speeds reduce efficiency. In order to simplify calculations by overcoming difficulties related to the variability of efficiencies depending on manufacturers, average values were taken into account and are shown in table 2.2.

Table 2.2 – Technology efficiency *(REN 21, 2015) (Grieser, Sunak, & Madlener, 2015)*

Technology	**Efficiency**
Solar thermal	50%
Solar photovoltaic	16%
Wind	60%

For a single-family two-story dwelling with six inhabitants and a total roof area of 230m^2, DHW energy needs are 7 200kWh while electricity needs are 22 800kWh. In order to supply the total energy needed, it would be necessary to install 5 solar thermal collectors that occupy 10m^2 (4% of the roof), 25 photovoltaic cells that use up 50m^2 (22% of the roof) and finally 3 wind turbines of 2kW each.

This solution would provide 8 000kWh of solar thermal energy, which is 111% of the DHW heating needs, hence is a solution that is over dimensioned and therefore on the safe side. On the other hand, total electricity generation is 22 800kWh, of which 55% is solar energy and 45% wind energy, exactly the amount of energy needed to meet demand. This solution takes into account the possibility of selling excess energy produced to the grid and buying energy when needed, therefore creating the potential for zero energy in this house.

For a six-story building with 5 residential floors, 30 inhabitants and a 400m^2 roof, DHW energy needs are 36 000kWh while electricity needs are 114 000kWh. To provide the whole of DHW energy needs, it would be necessary to install 23 solar thermal collectors that would generate 36 800kWh of thermal energy and occupy 12% of the roof area.

Assuming that only 50% of the roof is available to install solar photovoltaic modules due to space restrictions caused by chimneys, pipes and other infrastructures, it would be possible to produce 51,200kWh of electricity, which is only 45% of total energy consumption. By additionally installing two 3kW wind turbines on the rooftop, it would be possible to generate 10 512kWh of electricity, which is 9% of total electricity demand. In consequence, 46% of the energy consumed would have to be provided by the grid, hence limiting the potential for zero energy.

5. Economic Viability Model for Urban Areas

The economic advantage that the installation of renewable energy technology brings is the potential to save money by producing energy locally. Therefore it is necessary to evaluate whether savings from generating energy compensates the installation cost and operation and maintenance costs, taking into account average Capex (investment costs) and Opex (O&M) provided by (IEA), (IRENA) and (REN 21, 2015) and energy prices from EDP and GALP (Portuguese energy companies).

Table 4.1 – Average Capex and Opex for different energy sources

Energy Source	Capex (€/kW)	Opex (%)*
Thermal Energy		
Solar thermal	2 100	1%
Electric Energy		
Solar PV	2 500	1%
SWT	3 300	2,5%

**Expressed as a percentage of Capex*

The model uses the discounted cash flows (DCF) method to calculate the internal rate of return (IRR), using various discount rates (D_r) calculating the net present value (NPV), the payback period and the benefit-cost ratio (B/C) for each rate (Portela, 2000).

The discount rate takes into account the time value of money as well as the risk and uncertainty of future cash flows. The analysis is done for a variety of rates from 3% to 10%, in order to evaluate various risk scenarios. The project lifetime is considered to be 25 years since it is considered to be an acceptable timeframe for most technologies.

6. Results and discussion

The installation of renewable energy technologies must take into account not only the economic benefit but also the energy safety of the system installed; hence the selected mix includes both solar and wind technologies.

The energy mix considered for the single-family house, presented before, involves a total Capex of 42 800€ and an annual Opex of 725€ in order to sustain 7 200kWh of thermal energy and 22 800kWh of electricity, which represents a total annual amount of savings of 620€ and 4 583€ from natural gas and electricity respectively.

The project has an IRR of 10% and creates value for all scenarios of D_r, except for the worse case of D_r=10%.

Table 5.1 – Economic analysis results for a single-family house

Discount rate	NPV	Payback period (years)	IRR	IRR/Dr	B/C
3%	36 856,77 €	10	10%	3,41	1,82
6%	16 302,98 €	14		1,71	1,34
8%	7 287,59 €	17		1,28	1,12
10%	678,26 €	24		1,02	0,95

For the six-story building space restrictions inhibited the possibility of the building becoming zero energy, therefore it is necessary to resort to grid electricity to provide 45% of the electric energy required. Nonetheless, installation of renewable energy technologies provides an interesting economic opportunity due to monetary savings derived from the investment. With a total Capex of 118 064€ and an annual Opex of 1 480€, it is possible to produce 36 800kWh of thermal energy and 61 712kWh of electricity, which contributes to a total annual amount of savings of 3 100€ and 12 400€ from natural gas and electricity respectively.

The project has an IRR of 12% and creates value for all scenarios of D_r, with a payback period of 16 years for the worse case scenario of D_r = 10%.

Table 5.2 – Economic analysis results for a six-story building

Discount rate	NPV	Payback period (years)	IRR	IRR/Dr	B/C
3%	131 644 €	8	12%	4,08	2,07
6%	66 784 €	11		2,04	1,52
8%	38 241 €	13		1,53	1,27
10%	17 247 €	16		1,22	1,08

Sensitivity analysis has shown that the project remains interesting for every D_r in case of a 2% reduction of PV production, however in case of a 5% decrease in production, the project only remains profitable for D_r lower than 8%.

In order to take into account the fragile nature of SWT, sensitivity analysis included a one-year breakdown in year 5. Results showed that the project would still be viable, reducing IRR by only 0.16. Other analyses have shown great sensitivity to Capex variations of ±10%, diminishing return significantly when costs are higher. Opex variations of ±20% aren't as punishing, while price variations of ±10% may increase or decrease IRR by ±1.7.

Results have reinforced the importance of a thorough study of resource conditions in the area of the project in order to more accurately evaluate the viability of the project. The process of measuring resources quality is expensive and time consuming, however, it will avoid risks that may hamper profitability.

Additionally, the space available for the installation of the technologies must be evaluated for each project the as well as the orientation of the roofs and their type i.e. whether they are plane or hipped, for this may change production potential dramatically.

Furthermore, for implementation of technologies in existing buildings, an exhaustive study must be done to understand the structural constraints, if existent, since both solar PV panels and SWT have considerable weights and the latter induces vibrations. Again this will increase planning and studies costs but will contribute to a more accurate analysis of the economic benefits derived from such technologies.

It is clear that solutions with higher dependence on solar photovoltaic have higher profitability due to lower prices and payback periods in comparison with SWT. Moreover SWT have greater risks associated with turbine breakdown, efficiency decrease due to changes in wind direction and speed and installation problems on roofs. Changing the energy mix considered above in order to increase solar photovoltaic weight in the total energy production would increase profitability however risks related to the increase of area used by photovoltaic modules would surge. In addition it is important to use different technologies, in order to avoid excessive dependence on just one energy source, although in case of low energy production, demand may be provided by the gird.

7. Conclusions

The energy mix is an important topic when setting up any type of energy project. It is important to implement a varied mix that has redundancy in order to achieve a certain level of resilience and energy security. For grid connected houses and buildings, this topic is less relevant due to the possibility of selling and buying energy in times of excess or weak production, however it is an important topic to ensure a certain level of production when there are space limitations, such as roof area available for solar energy.

Nearly zero energy is promising for houses where 100% of the energy consumed can be produced locally whereas in buildings only 54% was possible, due to the decrease of available roof area in comparison to the number of inhabitants. Atmospheric conditions, correct rooftop orientation and enough space to install the technologies is essential to ensure high levels of energy production while on the consumption side it is necessary to reduce consumption per capita by increasing awareness or by efficiency improvements of buildings and electrical equipment used.

Economic viability is possible, due to great savings potential, achieving IRR (Internal Rate of Return) of 10% in houses and 12% in buildings. The IRR increases for the later due to the greater proportion of energy produced from solar PV since this is a cheaper source of energy, comparing to wind power from SWT. It is fundamental for the implementation of renewable sources in urban areas to analyze the quality of resources and the actual Capex and Opex of the solution to be installed.

In addition, it is necessary to evaluate whether it is physically and technologically viable to implement certain technologies. Structural assessment of the house or building must be undertaken since it will determine the type of technologies that can be installed and in which location i.e. rooftop, walls, green areas, etc.

Another important topic is related to social viability, since the installation of renewables poses a challenge in terms of articulation between tenants, between neighbors and also between various parties within the city. Social viability is inevitably and closely related to legal viability, therefore, it is crucial to setup legislation that helps clarify the conditions upon which renewable energy technologies may be installed on roofs and on buildings facades, especially due to visual pollution and noise restrictions. Although environmental issues are limited, they might arise mainly due to SWT, hence, it is necessary to clarify, alongside with manufactures, the risks they pose in urban areas.

It is possible to replicate the current model to larger scale, such as neighborhoods and cities, and results will be similar to those of buildings. When implementing distributed production on a large scale, it is important to choose the most appropriate energy technology for each building, depending on its orientation and characteristics. In case the model is to be applied to other buildings other than residential, other data must be taken into account and a more detailed description of consumption must be traced.

Centralized production has been important over the past and will continue to be so due to the advantages of centralized management and the possibility to install large capacity power plants.

Although distributed production creates an array of opportunities, it is crucial to continue searching and choosing sites where renewable energy resources are of best quality in order to avoid higher inefficiency and, in consequence, higher energy costs

The evolution of renewable energies will be determinant for their future in urban areas, mainly in terms of costs but also in terms of innovation, mainly for solar photovoltaic energy. Third generation PV cells could revolutionize the market and the energy sector, yet, only time will tell when.

Furthermore, it is necessary to increase energy efficiency in order to take advantage of this "hidden fuel", since it will contribute to reach nearly zero energy in the future, by improving houses and buildings construction or by improving renewable energy technology. Additionally, lower consumption through population awareness campaigns will help reach nearly zero energy targets.

Finally, the importance of realism when it comes to the installation of renewable energies in urban areas must be emphasized, since it is important to evaluate all the risks and costs and weighing them against the benefits.

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