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CAIO GIUDICE BENTIVEGNA

Economic feasibility of photovoltaic micro-generation:

a comparison study between Brazil and Italy

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a comparison study between Brazil and Italy

Trabalho de Formatura apresentado à Escola Politécnica da Universidade de São Paulo para obtenção do Diploma de Engenheiro de Produção

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FICHA CATALOGRÁFICA

To my family

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I want to say thanks for everybody who, in any way, helped me during all these years.

First, to my family, for always inspiring me, encouraging me and supporting me in all my dreams. I cannot thank you enough. And, to Letícia do Rosário Amado Pacheco, for being at my side in all moments, giving me strength to move on. Thank you for being my life mate.

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“Learn the rules like a pro,

so you can break then like an artist”

(Pablo Picasso)

ABSTRACT

The environmental issues are the principal challenges of our generation, being important drivers for innovation. The electricity market, in special, has a huge potential for intervention and the photovoltaic electricity generation is a possible alternative that is getting importance. Driven by these forces, this study aims the assessment of the economic feasibility of the photovoltaic micro-generation in Brazil and in Italy, drawing a comparison between them. The followed methodology consists in three major steps: a preliminary analysis, where the impact of three PV technologies (monocrystalline, polycrystalline and thin film – CdTe) were tested in different systems sizes (1kW, 5kW and 25kW); at the end the best investment (25kW polycrystalline system) was selected. The second and the third steps consists in a cash flow analysis of the investment in Italy and Brazil respectively, and in a simulation analysis made on both investments, as sensitivity analysis. At the total, the cash flow was built for fourteen cities (seven Italian and seven Brazilian) and the simple payback time, the discounted payback time, the NPV and the IRR were calculated for each one. As a result, this study found that the payback time in Brazil is longer than in Italy, being economic attractive for investor in Italy and not in Brazil. Also, the capex was identified as the principal driver for increase in profitability in Brazil. As conclusion, Italy has a consolidated PV market, while the Brazilian PV market is still in development; new policies should arise to address the tax reduction, what would decrease the capex and turn the investment more economic attractive, boosting the market growth.

Key words: i) photovoltaic electricity; ii) payback-time; iii) micro-generation

RESUMO

As questões ambientais são os principais desafios da nossa geração, sendo importantes impulsionadores da inovação. O mercado de eletricidade, em especial, tem um enorme potencial de intervenção e a geração de eletricidade fotovoltaica é uma possível alternativa que vem ganhando importância. Impulsionado por essas forças, este estudo objetiva a avaliação da viabilidade econômica da micro geração fotovoltaica no Brasil e na Itália, fazendo uma comparação entre eles. A metodologia seguida consiste em três etapas principais: uma análise preliminar, na qual o impacto de três tecnologias fotovoltaicas (monocristalino, policristalino e CdTe) foi testado em diferentes tamanhos de sistemas (1kW, 5kW e 25kW); no final, o melhor investimento (um sistema policristalino de 25kW) foi selecionado. A segunda e terceira etapas consistem em uma análise do fluxo de caixa do investimento na Itália e no Brasil, respectivamente, além de uma simulação feita em ambos os investimentos, como análise de sensibilidade. No total, o fluxo de caixa foi construído para catorze cidades (sete italianas e sete brasileiras) e o tempo de retorno simples, o tempo de retorno descontado, o VPL e a TIR foram calculados para cada um. Como resultado, este estudo descobriu que o tempo de retorno no Brasil é mais longo do que na Itália, sendo economicamente atraente para investidores italianos e não para investidores brasileiros. Além disso, o capex foi identificado como o principal fator de aumento de rentabilidade no Brasil. Como conclusão, a Itália tem um mercado PV consolidado, enquanto o mercado fotovoltaico brasileiro ainda está em desenvolvimento; novas políticas devem surgir para abordar a redução de impostos, o que diminuirá o capex e tornará o investimento mais economicamente atrativo, impulsionando o crescimento do mercado.

Palavras-chave: i) eletricidade fotovoltaica; ii) tempo de retorno; iii) micro geração

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LIST OF ABBREVIATIONS AND ACRONYMS

AC	alternating current
ANEEL	Agência Nacional de Energia Elétrica
BOS	balance of system
CdTe	cadmium tellurium
CO2	carbon dioxide
DC	direct current
EPPEI	Expected Production per Euro Invested
FIT	feed-in tariff
GHG	greenhouse gas
GSE	Gestore Servici Energetici
IRR	Internal Rate of Return
LCOE	levelized cost of electricity
NPV	Net Present Value
O&M	Operation and maintenance
PUN	Prezzo Unico Nazionale – Single National Price
PV	Photovoltaic
RES	renewable energy sources

LIST OF SYMBOLS

eV	electron volt
kW	kilowatt
kWh	kilowatt-hour
Mtoe	million tons of oil equivalen
MW	megawatt
TWh	terawatt-hour
W	watt

CONTENTS

1 INTRODUCTION

1.1 Motivation

This thesis`s appeared from the desire to exchange some knowledge acquired during my stay in Italy, country where I lived and studied for the last two years. I see this thesis as the conclusion of my exchange program, the last step of a cycle, in which I could incorporate a good aspect from there and bring it to my home country, making this experience fruitful, valuable and enriching.

The environmental concern is a thought presents in daily actions, a reality that I was only able to fell in such a deep way there. Being able to bring with me at least a small piece of it was my motivation to develop this study.

During my stay in Italy, I had the opportunity to engage myself in an internship on a PV company that manages and controls some PV systems in Italy and Romania. This experience gave me the technical basis and inserted me on the photovoltaic market, complementing my academic education. Surely, this experience opened my mind, allowing me to see that it is possible to combine financial motivation with other motivations. To use the "money logic" in pro of a bigger cause, changing the world in a positive direction and improving our society.

1.2 Context

During all the human evolution, the ability to manage and control the energy sources was a primordial survival skill. From the fire control to the industrial revolutions, the human species tried to master this ability, always reaching astonishing results. In each step, new dilemmas and challenges arise, forcing the search for new solutions, technologies and strategies to overcome these issues. Now-a-days, your society faces a tremendous environmental challenge: how to reduce emission and lower environmental impacts, attending to the increasing demand for electricity.

Low air quality, global warming and resource depletion were never a reality as they are today and each time more world leaders are meeting themselves (e.g. COP21), becoming committed with strategies and plans (e.g. Europe 2020, 2030 Agenda) for dealing with these matters. The energy market, in specific the electricity market, is one of the principal front of actions as it has a huge potential for improvements and interventions.

The actual electricity market is strongly dependent to fossil fuels. In 2015, only 24% of the worldly electricity produced was from renewable energy source (ENERDATA, 2016), while the others 76% were from fossil fuels. This dependence is harmful, as the fossil fuels not only consume colossal quantities of natural resources, depleting the natural reserves, but also pollute the environment, emitting carbon dioxide (CO2) and greenhouse gas (GHG). 40% of the global energy-related CO2 emission is attributed to the electricity and heat production (ANG; SU, 2016), denoting the high potential for reduction in emission.

On the other hand, the electricity consumption plays also an important role in the countries' growth, being a determinant factor for it (SHAHBAZ et al., 2017; ZHANG et al., 2017); and its social and political importance cannot be neglected.

Many countries started to replace their electricity power plants for renewable ones, discouraging the consumption of fossil fuels and encouraging the generation of clean electricity, providing incentives. Wind power and the photovoltaic electricity are becoming more popular among investors, having a positive trend of growth (LACCHINI; RÜTHER, 2015). The European countries (i.e. Italy, Germany, and Sweden) are leading the race for clean electricity, with well-studied governmental policies, case scenarios and regulations (SPERTINO; LEO; COCINA, 2013; SWEDISH INSTITUTE, 2017).

Brazil has a huge potential for renewable electricity source, however, the lack of incentives, poor regulations and the future uncertainty discourage their implementation (LACCHINI; RÜTHER, 2015; GREENER, 2017).

Facing this challenge that this thesis was designed and developed: to compare the Brazilian and the Italian countries in the perspective of the investment payback for photovoltaic micro-generation.

1.3 Objective and Structure

This thesis has the objective of assessing and valuating the economic feasibility of the photovoltaic micro-generation in Italy and in Brazil, comparing the available policies to spur the photovoltaic micro-generation.

For achieve this goal, this thesis is structured in six chapters, being the first one this introduction chapter. The second chapter consists in the literature review, in which some required concepts are presented. Initially, the electricity importance in society is presented, followed by an overview over some similar studies; after, the photovoltaic technology is detailed, explaining it, it`s stat-of-art of the technology and analysing the PV market evolution. Finally, the principal policies and strategies worldly adopted are introduced, and the actual Italian and Brazilian policies are presented.

Following the literature review, the chapter three contains the methodology followed in this study. The methodology is divided into three major steps: the first, a preliminary analysis, in which different sizes and PV technologies are compared and the best size and PV technology are selected; the second, the investment valuation and assessment for the selected scenario is made for in Italy; thirdly, the valuation and assessment for Brazil.

Chapter four is devoted to expose all the results of the methodology and the chapter five discusses the results, allowing a critical analyse of the actual situation of the PV micro-generation in Italy and Brazil.

Finally, the last chapter summarizes all the findings and concludes this study, answering if the PV micro-generation is economic feasible in Italy and Brazil.

2 LITERATURE REVIEW

The Literature Review is divided into 4 subchapters, in order to lay emphasis on specific concepts and discussions relevant to the development of this study.

In the first subchapter, the big picture of the energy world market is illustrated, defining the different forms of energy and the role and importance that the electricity plays in the actual world. After, in the second subchapter, the renewable energy sources are discussed, highlighting the feasibility of the investment in photovoltaic system and all benefits that the micro-generation can promote. Some similar studies are shown, to enrich the discussion.

The third subchapter is a drill down in the photovoltaic (PV) technology. Initially, a historical analysis of the PV market is made, discussing the main challenges that had to be overcome and its actual stage of development. After, the photovoltaic cells' technical characteristics are discussed, a link between performance and technical features is stablished for the photovoltaic modules and the state of art is shown.

Finally, the fourth subchapter consists in a review of the principal policies implemented by different countries regarding the incentive in the photovoltaic electricity generation. At the end, a comment about the incentives offered by the Italian and Brazilian governments to spur and promote the adoption of photovoltaic electricity generation is made.

2.1 Energy role in society

Energy is a complex concept and it's precisely definition is a bit discussed and debated in literature. For this study, a modern definition that is used in physics and in thermodynamic, is sufficient to aid in the understanding of the different energy classifications (WYLEN; SONNTAG; BORGNAKKE, 2008).

This definition states that energy is the property that must be transferred to an object to perform work, or to heat it. According to the first law of thermodynamic, the energy can be converted in different forms, but cannot be created or destroyed. The principal forms of energy and its application in the energetic field are given on the table 1.

Table 1- Principal forms of energy and their applications in the electricity generation

Energy Form	Description	Electricity Power Source
Kinetic energy	This is the energy present in a moving object	Wind power that converts the energy of the speed of the wind into electricity
Potential energy	This is the energy stored in one object due to its position in a force field (gravity, electricity or magnetic)	Hydroelectric that uses the difference in potential energy of water to generate electricity. Dams are created in order to keep water in a high potential energy level
Chemical energy	This is the energy present in atomic connections	Any fuel source, when burned, releases atomic connection energy that is used to to generate electricity
Nuclear energy	This is the energy present inside the atom, connecting its protons and neutrons	Nuclear energy converts the energy released in the atomic fusion (or fission) into electricity
Radiant energy	This is the energy carried by light	PV utilizes the energy present in the light (photons) to produce electricity
Thermal energy	This is the energy due to an object temperature	Geothermal utilizes the energy stored as heat in the earth's nucleon to generate electricity

Source: adapted from WYLEN; SONNTAG; BORGNAKKE (2008)

The energy sources can be classified in some ways. A first classification of the energy sources consists in differentiating the primary sources from the secondary sources. The primary sources are the ones directly present in nature, while the secondary sources are the ones non-directly present in nature, therefore, derived from the primary sources. Examples of primary sources: oil, natural gas, biomass, nuclear, hydro, wind, geothermic, and solar. The secondary sources are the ones that cannot be considered natural resources, as the electricity and the hydrogenous (CARUSO, 2016)[1].

A second classification of the energy sources is based on their exhaustibility. There are the sources exhaustive (or non-renewable) and the non-exhaustive (or renewable). The non-renewable are majorly composed by the fossil fuels (oil, natural gas, coal) and nuclear (uranium). The renewable, for its time, are all the sources of energy that do not have a finite number in the nature. They can be subdivided into two groups: the classic renewable sources, such as the biomass, hydroelectric and geothermic, that are already exploited from a long time; the non-conventional sources that are more recent and with less utilization (i.e. solar, wind and tidal waves) (CARUSO, 2016)[1].

1 CARUSO, S. Slide presentation for the course: Energetica e fonti rinnovabili. Torino: Politecnico di Torino, 2016. Corso Di Laurea In Ingegneria Energetica – Torino.

From the previous classifications, it is possible to identify that the electricity is a secondary form of energy, which must be produced from other primary sources, which can be either renewable or non-renewable.

In the actual society, the electricity plays an important role for the countries development. As highlighted by Zhang et al. (2017), “the electricity provides the sustainable power for economic and social development”. They developed an overview of the literature aiming to reveal the relationship between electricity consumption and economic growth and they concluded that the electrical power became one of the main drivers to promote the economic and social development, however a special attention must be taken concerning the environmental issues, as the large consumption of energy, resource depletion and environmental pollution are becoming increasingly severe. This concern is highlighted at the end of the study: “It is important to meet the needs of economic growth while reducing carbon dioxide emissions and environmental pollution”.

This relationship between the electricity consumption and countries’ development is well studied in literature. Shahbaz et al. (2017) studied the impact that the oil-price and the electricity consumption have on the economic growth. They used data from 157 countries (from 1960 to 2014) to create a model to analyse the short-term and the long- term relationship; they found that “in spite of the oil prices, developing countries rely heavily on electricity consumption for economic growth”. As a conclusion, the authors comment that more electricity policies should be implemented to attain sustainable long-term economic growth.

Finally, it can be observed that the world energy consumption is yearly increasing, as well as the electricity production. In 2000 the world production of energy from primary sources was 10.027 Mtoe (million tons of oil equivalent (106 toe)) and achieved and 13.887 Mtoe in 2015– and equivalent to an annual growth of 2,2% in the past 15 years. The electricity consumption, for its time, was 13.173 TWh (terawatt-hour; one Mtoe equals to 11,63 TWh) in 2000 and 20.568 TWh in 2015 – equivalent to an annual rate of 3% in the past 15 years (ENERDATA, 2016).

In sum, the electricity is a secondary source of energy, which can be produced by many different primary sources. For the next years, it is expected an increase in its production and consumption, with a positive long-term trend of growth (ENERDATA, 2016). Its importance to the economy is well identified, as it acts as a driver to economic growth; and more electricity policies should be implemented to attain sustainable long-term economic growth (SHAHBAZ et al., 2017). However, the environmental consequences of the electricity production should not be neglected and the environmental impacts should reduce, despite of the economic benefits, as highlighted by Zhang et al. (2017). Therefore, alternatives electricity sources should be used, to attend the electricity demand and reduce environmental impact.

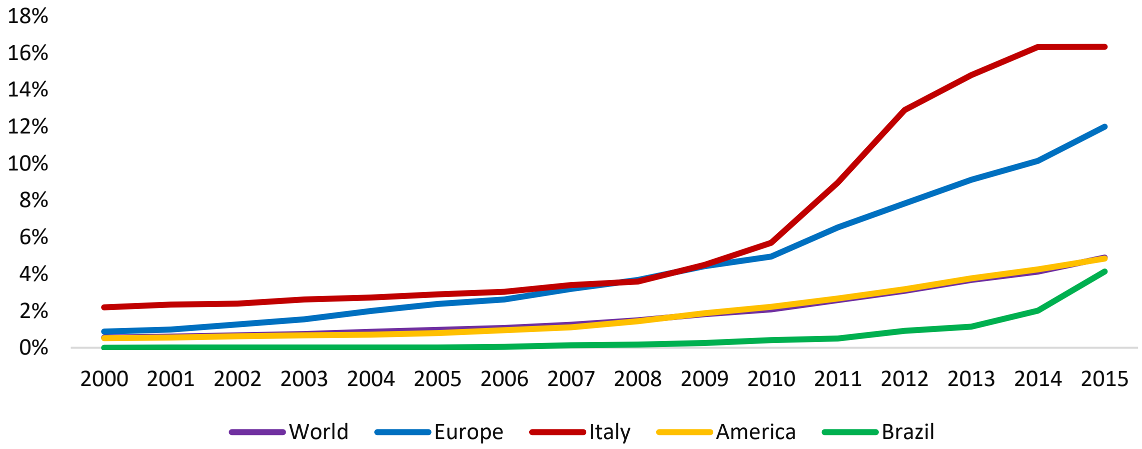
2.2 Renewable energy sources and the micro generation

The renewable energy sources (RES), as commented, are the electricity sources that are not finite in nature, in other words, that cannot be exhausted. It is estimated that in 2015 around 23% of the electricity production was from RES (ENERDATA, 2016), while around two-thirds of the global electricity were generated from fossil fuels, being the coal the primary. This sector is strongly dependent to fossil fuels and more than 40% of the global energy-related carbon dioxide (CO2) emissions are attributed to emissions from electricity and heat production (ANG; SU, 2016).

Ang and Su (2016) in their study identify two major potential areas to act in pro to the global reduction of CO2: improving the thermal efficiency of the “low performers” producers, reducing the emissions to a desired level; switching the electricity source for non-polluting ones. This concern in reducing the global emission of CO2 and the greenhouse gas (GHG) is part of many goals (e.g. Europe 2020 goals) imposed by global leaders as an alternative to reduce harmful effects to the environment and to the society, such as improving the air quality and reducing the greenhouse effect.

New electricity sources (such as the photovoltaic) are winning some investors attention and their participation in the total electricity production are rising. As an example, in 2000 the photovoltaic (PV) and wind world share in the total electricity production was 0,6% and in 2015 it was almost 5%, which denotes an accelerated rate of growing (ENERDATA, 2016). The figure 1 contains the solar and wind share from 2000 to 2015.

Figure 1 - Solar and wind share in electricity consumption



Source: Adapted from ENERDATA (2016)

For understanding the PV investments, it is necessary to first identify the different types of PV systems. According to Lacchini and Rüther (2015), PV systems can be classified in three groups based on their size and relative cost:

a) **Small residential systems:** usually focus on the self-production of electrical energy to satisfy the monthly demand and therefore reduce the electricity bill.
b) **Medium-sized commercial or industrial systems:** envision the reduction of the electricity bill by internally generating the electricity. The electricity generated can be directly used or stored to be used in peak hours.
c) **Utility-scale PV plants:** the goal is to generate and sell electrical energy to the distribution grid through Power Purchase Agreements.

This classification is important to understand that different size of PV systems have different mechanisms for the investment payback: while a small residential system (or household system) aims it payback majorly through the savings in the electricity bills, a utility-scale PV plant aims the investment payback through the income earned with the electricity sales. The investment economic feasibility is a recurrent theme in literature, as different countries have different policies and environmental characteristics, therefore, many studies are made to assess and valuate it. Next, few examples are shown, and during this literature other studies are commented.

Numbi and Malinga (2017) studied the potential of the energy cost saving of 3kW residential grid-interactive solar PV system in the city of Durban, South Africa. A grid-interactive system is a new technology that combined both the advantages of a grid-connected and off-grid system, as it can supply power to the user, it feeds the excess to the grid, boosts grid stability and provides back-up power during failure periods. The authors concluded that there is a potential of 69% of energy cost saving, however with the actual incentive (feed-in tariff (FIT)[2]) the payback time is 19 years. They also simulated scenarios with higher FIT and concluded that the investment becomes more attractive the higher the tariff.

In other study, Tomar and Tiwari (2016) developed a techno-economic evaluation of grid connected photovoltaic rooftop systems, assessing the impact of the feed-in tariff and the net metering[3] governmental policies in New Delhi, India. Their analysis indicates a potential for the spread of decentralized residential application of PV power systems in New Delhi; and that the policies available (the feed-in tariff and the net metering process) present executable solutions for the photovoltaic dissemination. According to the authors: “This present study shows that the perspective of solar energy in growing world cannot be neglected”.

Hartner et al. (2017), for its time, analysed the optimal sizing of grid connected rooftop PV systems for the household perspective (1 to 20 kW systems) in Austria. The goal of their study was to evaluate the Austrian subsidy schemes and the electricity tariffs over the economies of scale point of view. They concluded that a substantial cost inefficiency may occur resultant from incentives to install small PV systems (less than 5kW) in presence of economies of scale, and therefore the existing tariff schemes do not fully reflect the actual costs and benefits associated to the photovoltaic generation for the household investors.

Besides these three studies, all around the world researches are assessing and evaluating the feasibility of the photovoltaic micro-generation of electricity. (EL-SHIMY, 2009; PACHECO; LAMBERTS, 2013; SPERTINO; LEO; COCINA, 2013; TALAVERA et al., 2016).

It is important to comment that the PV micro-generation can provide other benefits than the financial one for the investor. Not only the micro-generation of energy systems can reduce the CO2 emission, it also increases the grid stability and in energy security (as the dependence of a principal source of electricity is weakened) and it can postpone the investment in enlarging

[2] The feed-in tariff is an agreement in which a fixed amount is paid for the electricity produced (or injected into grid) over an agreed period (CURTIN; MCINERNEY; GALLACHÓIR, 2016).
[3] The net metering is an incentive that allows the household producer to sell electricity surplus back to the grid. (COMELLO; REICHELSTEIN, 2017).

the grid capacity and reduces transmission loss. These characteristics enrich the discussion about the dissemination of the distributed generation of electricity (BRANDONI et al., 2014).

2.3 The photovoltaic technology

This subchapter explores the photovoltaic (PV) history, its context and its presence in the world market. The principal PV technologies and the state of art are described, as well as the principal technical issues and the expected results/efficiency.

2.3.1 PV history and world context

The origin of the PV technology remotes to the 1950's when the first commercial cell device was produced by Bell Laboratories. In the following years, the PV had its subsequent development mostly in spatial applications as it could be a viable option for supplying energy to satellites: in adopting PV cells as energy source it was possible to reduce the extra heavy weight added by nuclear electricity (or by other conventional generators and fuels) that penalizes their launchers. Only some years later the PV started to be used in terrestrial application and became a potential large-scale electricity source. It is important to comment that although the PV found its first market as aero spatial application it was only as terrestrial application that the PV succeeded to stablish itself (LACCHINI; RÜTHER, 2015)

In literature, a common explanation can be found for this shift of markets, which was mainly managed by 'two forces': the cost reduction and the environmental concern (NEMET, 2006; BAZILIAN et al., 2013; DUAN; ZHU; FAN, 2014; LACCHINI; RÜTHER, 2015; AMANKWAH-AMOAH; SARPONG, 2016). These 'two forces' will be analysed individually, however the synergic interaction between them cannot be disregarded.

Lacchini and Rüther (2015) affirm that "the PV is the most elegant and cleanest renewable energy technology currently available for the present and future large-scale production of electricity". This statement illustrates the concern on the environmental issues and the seek for alternative ways to generate electricity. Two of most debated environmental issues are the global warming and the world climate change. Meetings like COP21 and resolutions like the Kyoto Protocol, show the world concern in reduction to the emission of greenhouse gasses (GHGs) and carbon dioxide (CO2) that bring hazard to the atmosphere. The growth of the industrialization and the increase in the electricity demand due to the increase in the world population are the principal causes of it, according to Ngan and Tan (2012).

Therefore, many countries decided to adopt policies to reduce their emission of GHGs and started to stimulate alternative sources of energy such as PV, wind, biomass and tidal waves, in replacement of the conventional electricity generation that uses oil, natural gas and coals as fuel and emits CO2 gas during the conversion (NGAN; TAN, 2012). One important fact is that as consequence of the Fukushima accident in Japan (March 2011) many countries as Italy and Sweden decided to the gradual abandonment of their nuclear power plants (DUAN; ZHU; FAN, 2014).

One of the 5 targets for the Europe in 2020 establishes an overall policy to reduce in 20% the GHGs emission comparing with the 1990 values (EUROPEAN COMMISION, 2017), therefore, the EU countries must fulfil 20% or more of their energy needed by RES, being it achieved through individual national targets (EUROPEAN COMMISION, 2017). Specifically, for Italy, the Directive 2009/28/CE establishes an objective for the RES of the energy share of 17% until 2020. This commitment illustrates the global concern with the environmental issues.

The second “force” is the cost reduction. For understanding its influence, it is initially necessary to analyse the PV technology’s historic context and the main challenges that had to be overcome. According to Bazilian et al. (2013), since the beginning, the PV technology was widely associated with a range of technical challenges in its value chain. The first challenge was the lack of scale in manufacturing and the perceived inadequate supply of raw material (the polysilicon is expensive to produce it in the purest form, which is required for better efficiency, therefore the economy of scale was not possible to achieve). The second challenge was the limited performance of the balance of system (BOS) components (e.g., batteries, inverters and mounting structures), and the third was the economic barriers, in particular, the high upfront capital costs.

Nemet (2006) developed a study to verify if the improvements in the PV industry was driven by the learning curve effect or not. Aiming to understand the drivers behind the technical changes in PV, the historic cost reduction was disaggregated into seven observable technical factors (cost; module efficiency; plant size; yield; poly-crystalline share - the increase in the use of poly-crystalline modules in reduction of the mono-crystalline ones - silicon cost; silicon consumption; wafer size). The time period used in this study was from 1975 (the nascent commercialization) to 2001.

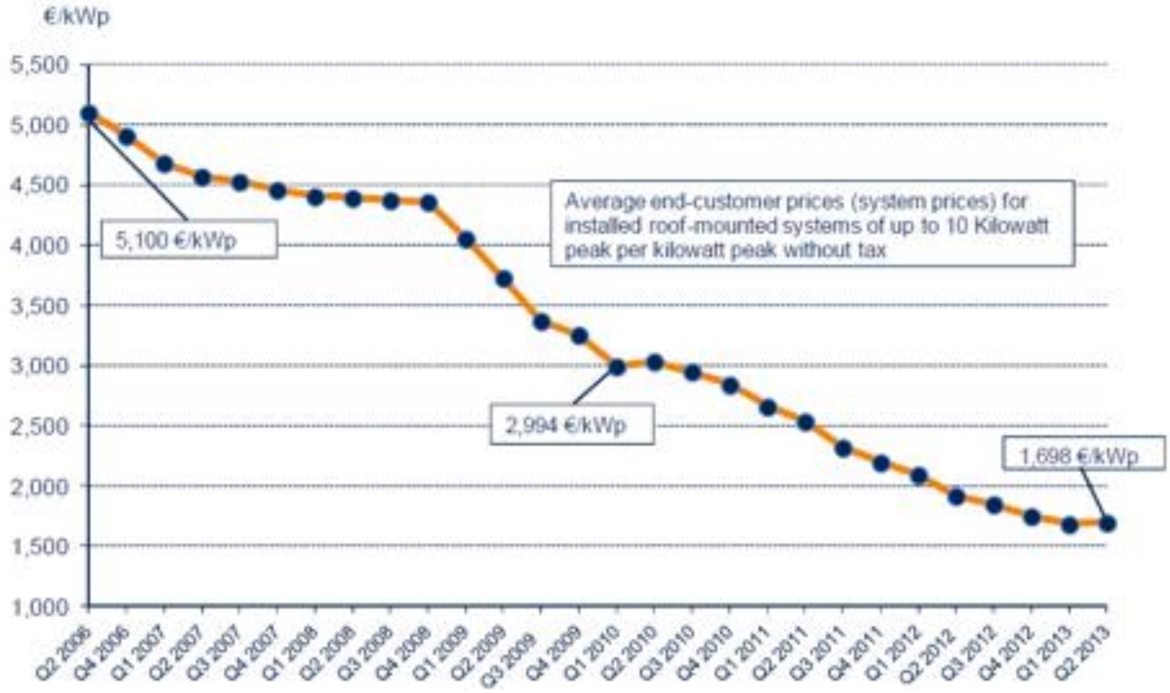
The first finding of this study was that the learning curve model could not explain the cost reduction in this time period, as less than 60% of the cost reduction was explained by the seven factors. A second analysis was made, dividing the time period in two: the first from 1975 to 1979; the second from 1980 to 2001 (in 1980 the terrestrial applications had become dominant over space-based applications). In the first period 41% of the cost reduction was explained by the seven factors, while in the second period 95% was explained, being the module efficiency and the plant size the most important drivers to the PV development. Finally, this study concludes that further models should also include research and development, knowledge spillovers and market dynamics as drivers to promote PV development (NEMET, 2006).

Other finding in the study is that the expected future demand, the ability to manage investment risk and the learning-by-doing effect also played important roles in the PV evolution, therefore, the fourth challenge that the PV industry had to overcome is the reduction of the future uncertainty and of the risk for investment in PV (NEMET, 2006). In summary, it is possible to identify that the value chain of the PV industry was not sufficiently developed in the early stages, and the high upfront capital cost and the future uncertainty will create a scenario in which fewer investors will be willing to invest, struggling this sector development.

At this point of time, in the first years of the new millennium, as a solution for these challenges and driven by the environmental issues, many governments started to develop incentive policies for pushing the PV development. Spain (TALAVERA et al., 2016), Germany and Italy governments (SPERTINO; LEO; COCINA, 2013) focused in incentive policies aiming the reduction in future uncertainty, making the economic barrier relatively less impacting for the investment and turning the investment safer. The Chinese government (WANG; LUO; GUO, 2014), by its time, adopted a series of incentive aiming the industry development, relying in the European demand for PV modules. In this way, a global market has started to stablish.

One of the results observed by Bazilian et al. (2013) in his study of Spanish incentive on PV, is that the PV price from 2004 to Q3 2008 remained approximately constant ($3,50 - $4,00/W) despite the continuous improvements in this technology and in the scale by the manufacturers, once the demand was constantly high. The manufacturers average operating margins were of 14.6% - 16.3% from 2005 to 2008 (data obtained from the 18 largest quoted solar companies followed Bloomberg (BAZILIAN et al., 2013)). Consequently, both the polysilicon companies and the downstream manufacturers had a rapid expansion on those years and in the end of 2008, with the end of the Spanish incentives, the demand for PV cells decreased and the manufacturers started to compete in price, reducing it in 50% ($2,00/W in 2009). The figure 2 shows the historic price for rooftop PV systems up to 100kW in Germany, which is declining over the years.

Figure 2 - Price evolution for rooftop PV systems up to 100kW in Germany

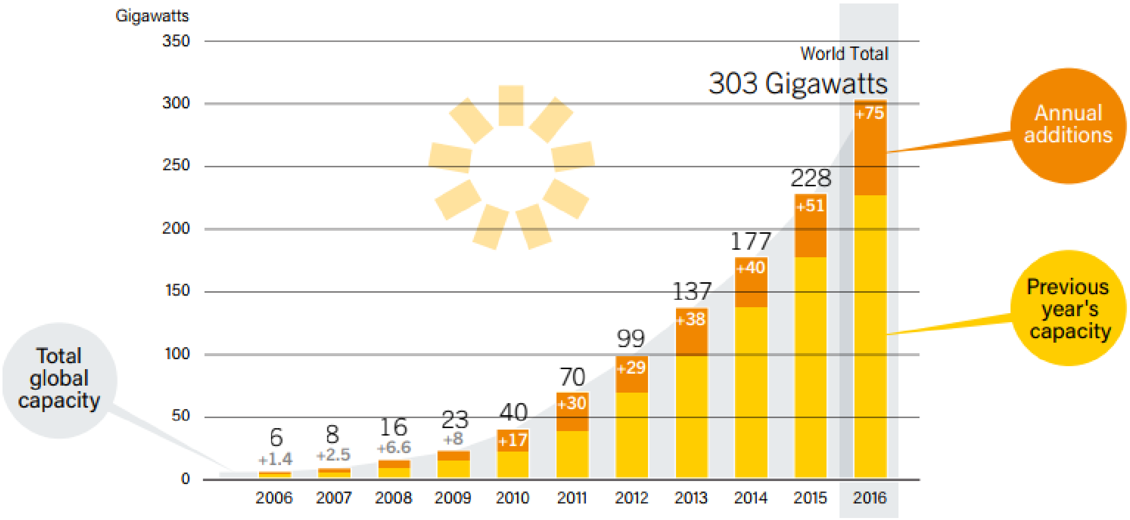


Source: IRENA (2015)

Recently, new technologies are appearing and competing with the traditional silicon PV modules, however, the polycrystalline has still the highest market share (56% - 2014 values) and the monocrystalline has the second position (36% - 2014 values). The cadmium tellurium (CdTe) module is a PV technology that is growing in the market (it has the third higher market share – 5% in 2014) (LEE; EBONG, 2017). The market price per kilowatt of the polycrystalline is 0,70 Euros per watt; for the monocrystalline is 1,00 Euros per watt; and for the CdTe is 0,60 Euros per watt (IMAM, 2017)[4]. The figure 3 shows the evolution of the installed capacity according to Zou et al, 2017.

[4] Information obtained during an internship in IMAM AMBIENTE. Torino, Italy. 2017

Figure 3 - World cumulative PV installed capacity from 2009 to 2013



Source: REN21 (2017)

In synthesis, the PV technology is although known for a long time, a new technology in terms of mass generation of energy. As any new technology, it is facing political and economic barriers and it is threatening well established players (traditional power generation), having to compete with them. The political, economic and environmental forces are still uncertain and each time stronger, directly contributing to the fast PV development. Many studies in this field are being done, in order to identify the PV competitiveness (PACHECO; LAMBERTS, 2013; SPERTINO; LEO; COCINA, 2014; BRUSCO et al., 2016) and other studies to determinate optimal mix strategies (DALTON; LOCKINGTON; BALDOCK, 2009; NGAN; TAN, 2012; YANG et al., 2014; SCHMIDT; CANCELLA; PEREIRA, 2016). For many countries, the future is still uncertain with respect to the PV technology (and other alternatives power sources, such as wind power), in special due to the lack of long-term and uniform programmes and a stable environmental policy (DUAN; ZHU; FAN, 2014).

"In spite of this struggling situation, PV has experienced an exciting evolution since the beginning of its history, and is currently the fastest-growing energy generation technology worldwide" (LACCHINI; RÜTHER, 2015).

2.3.2 Technical characteristics

The Photovoltaic (PV) technology consists in the conversion of the most abundant and widely distributed renewable energy resource, the sunlight, visible or not, directly into electrical energy. Differently from all the other sources of energy, the PV technology does not require any movement conversion (as wind power and tidal waves) or cooling system and has no emission during the conversion (as fossil fuel power plants) (DIO, 2015). The PV efficiency is between 6% and 21% and it depends on many factors, being the module's technology and the operating temperature the two most critical ones (SPERTINO; COCINA, 2016)[5].

In one hand, the advantages of PV modules consist in the long and high reliable life-time (usually the module's life is 25 years and the producers usually offer a 10-years guarantee on production defects and a 25-years guarantee over the linear expected loss of productivity (information available in the product datasheet)), the low maintenance cost (i.e. glass cleaning and replacement of small components), absence of noise and air pollution during operation, versatility as it is possible to produce near the consumers (reduction in the transmission loss and investment) and the possibility to recycle it without wastes (SPERTINO; COCINA, 2016 op.cit.)[5].

On the other hand, the principal disadvantage of the PV modules is the fluctuations in the electricity production (i.e. it can only generate electricity during sun hours) as during the night or in cloudy/raining days the electricity production is zero or almost inexistent. One possible solution is to install batteries to storage the surplus of electricity produced during the day or alternatively to connect the PV system into other electricity network that will supply electricity during non-productive hours (SPERTINO; COCINA, 2016 op.cit [5]. IMAM, 2017 loc. cit. [4]).

Besides the batteries, other components are needed to produce useful electricity. The electricity produced by the modules are in direct current (DC) and must be transformed into alternating current (AC), requiring an inverter. A transformer can also be needed in the case of connection to the high voltage network (required in PV plants). The selection of the inverter and the transformer (if required) depends on the size and capacity of the system (IMAM, 2017 loc. cit.) [4].

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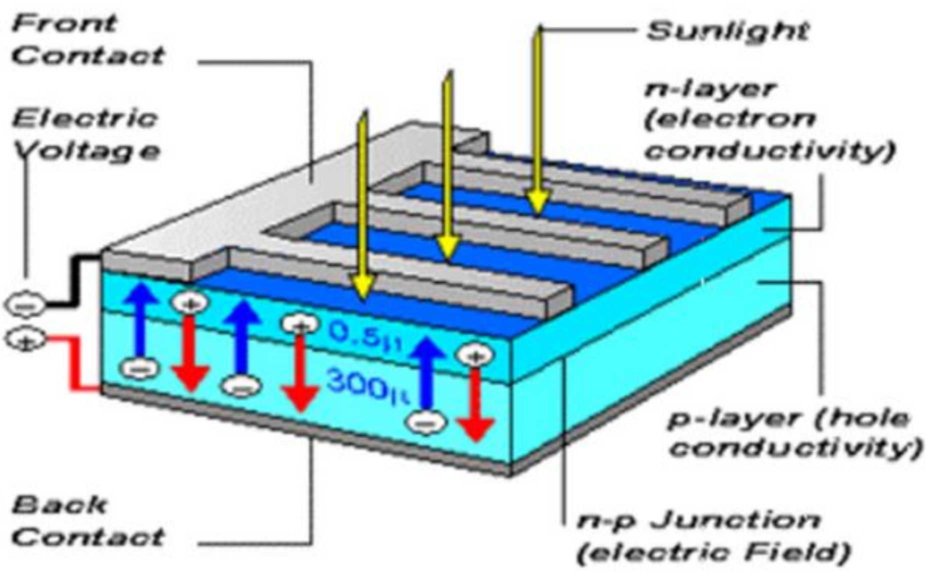
5 SPERTINO, F.; COCINA, V. Slide presentation for the course: Generazione fotovoltaica ed eolica di energia elettrica. Torino: Politecnico di Torino, 2016. Corso Di Laurea In Ingegneria Gestionale – Torino.

The way PV modules are connected is other important characteristic of the system. During sun hours, it is also possible to notice reduction in the electricity production, as consequence of spot shadows in some modules (i.e. clouds in passage). These spot shadows cause a small and focalized reductions in the electricity production of those modules, which will consume the electricity produced by the other illuminate modules, globally reducing the system efficiency (SPERTINO; COCINA, 2016 loc. cit. [5]; IMAM, 2017 loc. cit. [4]).

The main principle of the PV technology is the photovoltaic effect, which consists on the incidence of photons with enough energy to create electron/hole pairs. These pairs, in the presence of an electric field, are separated (the electrons are attracted to the positively charged area, denominated N area; the holes to the negative area, denominated P area) and this charge motion is the source of the photovoltaic current. The figure 1 is a representation of the structure of the solar cell (COOK; BILLMAN; ADCOCK, 1995).

Figure 4 - Photovoltaic cell representation

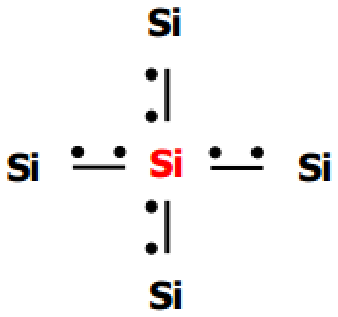


Source: Spertino; Cocina (2016) loc. cit. [5]

The PV cell is the basic component of the PV system and the silicon is one of the most important elements in the cells. It is a tetravalent crystal (i.e. 4 valence electrons) with 14 electrons in total: 4 electrons in the valence band and 10 electrons in the conduction band. The electrons in the valence band are responsible for being excited by the photons and create the electron/hole pairs, while the ones in the conduction band permit the motion in the crystalline lattice. The amount of energy required for one electron to move from the valence band to the conduction band (therefore, creates the electron /hole pair) and is called band gap. The figures

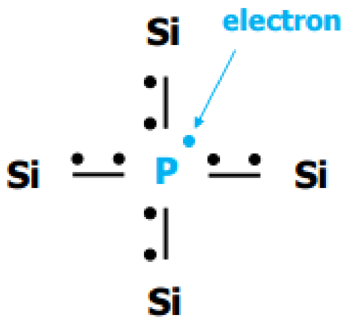
5, 6 and 7 illustrate the creating of the electron /hole pair (COOK; BILLMAN; ADCOCK, 1995; SPERTINO; COCINA, 2016 loc. cit.)[5].

Figure 5 - Atom of Silicon



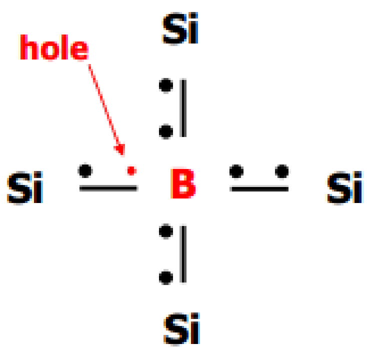
Source: Spertino; Cocina (2016) loc. cit [5].

Figure 6 – n-type doping



Source: Spertino; Cocina (2016) loc. cit. [5]

Figure 7 – p-type doping



Source: Spertino; Cocina (2016) loc. cit.[5]

The sunlight is composed by many different waves with different energies, therefore PV cells made with different materials (e.g. with different band gaps) will have different responses to the light irradiation. The photons with less energy than the band gap are absorbed as heat or pass through the silicon; the photons with more energy are absorbed but the extra energy heats the cell. About 55% of the energy of the sunlight cannot be converted in electricity in most PV cells, as their energy either is below the band gap or carries excess energy (COOK; BILLMAN; ADCOCK, 1995).

Materials with lower band gap can exploit a broader range of the light, producing higher current with low voltage. In comparison, materials with high band gap exploit a smaller range of energy, producing a less intense current, but with higher voltage. As the power (P) is given by the product of the current (I) and the voltage (V) (P = V * I) neither types of cells can be said better when compared with each other. Usually, cells made with materials with band gaps between 1 and 1,8 electron volt (eV – unit used to measure the band gap) develop a better efficiency (COOK; BILLMAN; ADCOCK, 1995).

Therefore, different cells are recommended for different regions and clime. In areas with more indirect reflexion lower band gap cells are the most efficient, while in areas with less indirect reflexion higher band gap cells are the better. Therefore, it is important to carefully design the PV system as the surrounding environmental conditions have a direct impact on the system efficiency (COOK; BILLMAN; ADCOCK, 1995).

Other important variable that can influence the system efficiency is the operation temperature. The higher the temperature of the PV cells the lower will be its efficiency (SPERTINO; COCINA, 2016 loc. cit.)[5]. A contra-intuitive behaviour is that during summer the efficiency is lower than the efficiency during winter, although the production is higher in summer. This can only be explained by the increase in the number of sun hours during summer that compensate the reduction in efficiency, leading to a higher electricity production (IMAM, 2017 loc. cit.)[4].

In sum, the photovoltaic technology is in continuous development, with several fronts of research. New solutions are arising, and the actual state of art of the PV technology is: the research in hetero-junctions (led by Panasonic HIT Heterojunction technology) which consists in improving the classic monocrystalline cell by reducing the losses at the boundaries of the cell (PANASONIC, 2017), with module's efficiency of 19-20% (SPERTINO; COCINA, 2016 loc. cit.)[5]; the multi-junction layer which consists in cells composed of different deposition layers of semiconductor material (different band gap) that can better absorb the different light waves improving the module's efficiency (the highest efficiency achieved is 43% and the theoretical limit is 70%) (SPERTINO; COCINA, 2016 loc. cit.)[5]; the thin film technology, which consists in the deposit of one or more thin layers of PV material on a substrate that can be glass, metal or plastic, is considered a potential solution because of its minimum material usage and rising efficiency and with the research and development in science of materials some new technologies (Perovksite solar cells, Copper zinc thin sulfide solar cells, and quantum dot solar cells) arose (LEE; EBONG, 2017).

2.4 Incentives in renewable energy sources

As commented in the previous chapter, many countries and world leaders started to spur the development of the RES, mainly in consequence of an environmental awareness and the environmental benefits that they could bring in comparison with conventional energy sources, especially when considering the risk of climate change (AVRIL et al., 2012).

This subchapter explains some incentives and subsides offered by governments to stimulate the growth of RES.

2.4.1 Principal incentives

The public polices for the spur of the RES are one of the principal strategies to overcome the barriers (e.g. technical, social, political) that these energy sources have (CAVALCANTI, 2016). For the specific case of the photovoltaic electricity source, the two principal barriers for its development are the elevate capital cost (e.g. the investment capex is high for some small/household investors, which are not willing to commit a significate amount of money in pro of the "environmental benefits") (BALCOMBRE; RIGBY; AZAPAGIC, 2013); and the risk and uncertainty in the investment return, as any new technology would have to face when entering in as established market (e.g. no previous experience to prove that the investment is payable) (LACCHINI; RÜTHER, 2015).

A distinction must be made in this point: barriers are different from motivation. Motivation is the force that makes the individual (or group of people) to adopt the technology, while the barriers are the challenges that limit its adoption, raising doubts and making the investor to rethink about the investment. For the photovoltaic technology, considering the micro-generation systems, the principal motivations for its adoptions are the financial (as there is a potential of saving in electricity bills and increase the value of the building) and the environmental (BALCOMBRE; RIGBY; AZAPAGIC, 2013).

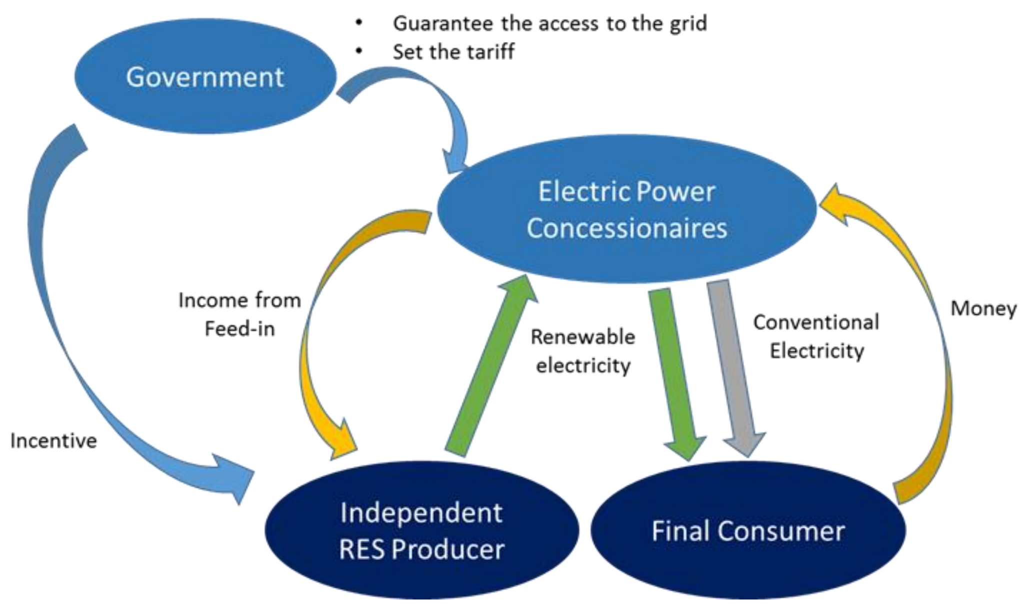
It is possible to identify that the motivations exist, however these barriers (i.e. high capex, uncertainty about the investment economic feasibility) limit and reduce the photovoltaic micro-generation mass adoption. It is in this scenario that the governments can act and offer incentives and subsides to overcome those barriers, promoting and stimulating the PV adoption.

Other possible way to interpret the public policies supporting the renewable energy is: “From a theoretical standpoint, government support can be justified as a way of correcting negative externalities resulting from the use of fossil fuels and of achieving dynamic efficiency by stimulating technical change” (MENANTEAU; FINON; LAMY, 2001).

In literature, it can be found that there are mainly two types of incentives, the price-driven (feed-in tariffs) and capacity-driven (Tradable Green Certificate[6]) strategies. The principal difference between them is that the former consists in setting the price through government subsides while the latter relies on the market mechanism to form the price for a production quantity (through the Tradable Green Certificates, a parallel market arises, where those certificates are traded as any product (IMAM, 2017 loc. cit.)[4]) (AVRIL et al., 2012).

The feed-in tariff is an agreement in which the producer has the certainty that a fixed amount will be paid for the electricity produced (or injected into grid) during a determined period of time. The amount can vary according to the electricity source (CURTIN; MCINERNEY; GALLACHÓIR,2016). The incentive is created and set by the government, however the agreement is made between the electric power concessionaries and the individual producers of RES. The figure 8 illustrates the scheme of the feed-in tariff.

Figure 8 - Feed-in tariff scheme



Source: adapted from CAVALCANTI (2016)

[6] Tradable Green Certificates is an incentive in which for every unit of renewable electricity produced one green certificate is issued. These certificates can be traded (sold and bought) in market as a normal product and they allow an extra revenue for the producer (CURTIN; MCINERNEY; GALLACHÓIR,2016)

It mainly consists in two sources of income for the independent producer: the incentive and the electricity sales. It is the concessionaires' responsibility to buy the renewable electricity produced (the purchase price can vary according with the governmental policy) and resales it to the final consumer. This tariff reduces the investor's risk, as it guarantees a stable and predictable income source, which almost eliminates one of the PV barriers (uncertainty about the investment economic feasibility) (CAVALCANTI, 2016; CURTIN; MCINERNEY; GALLACHÓIR, 2016).

The fee-in tariffs have proven to be the most effective government incentive program when the boosting in the installed capacity is the main goal (AVRIL et al., 2012). The feed-in tariff can also be combined with a premium on the price in the spot market, which can turn the investment even more attractive (MAESTRO; LÓPEZ; AGUSTÍN, 2013).

The net metering is other policy used for some governments to spur the photovoltaic adoption. It allows households and commercial photovoltaic systems (usually this policy focuses in small systems) to sell electricity surplus back to the grid. (COMELLO; REICHELSTEIN, 2017). The injected electricity can be used to offset the electricity bill; therefore, the remuneration is made considering only the net energy injected into the grid. In case the consumption of electricity from the grid is bigger than the introduced electricity, the bill will have a positive value to be paid, otherwise, the owner of the PV system will have a credit (equivalent to the net value) that can be offset from the next bill or can be liquidated (it can vary according to the country and the policy). It is important to comment that the net metering belongs to a type of policy called compensation mechanisms, in which the injected electricity is somehow converter into credit (that can either be in terms of energy – kilowatt-hours – or in financial terms) that is used to offset the bills. How the credits are calculated depends exclusively on the policy and there is no rule to be followed (MAESTRO; LÓPEZ; AGUSTÍN, 2013).

This policy generates benefits not only for the PV system's owner but also for the concessionaries as one of the advantages of the distributed generation of electricity is the reduction in the transmissions losses (the electricity will not have to travel through a long distance to reach the final consumer). Also, in comparison with the feed-in tariff, all the costs are passed on the concessionaries, which will dilute it through all the final consumers, therefore, there is no cost for the government (CAVALCANTI, 2016).

This characteristic of the net metering, of passing on the cost to the concessionaries that pass through the final consumers, although advantageous for the government, can generate indignation and criticism to the final consumers. Comello and Reichlstein (2017) developed a study over the effects of the net metering as a response to the criticism that some ratepayers were having.

Quotas with tradable green certificates are other type of incentive. Differently from the previous two types of incentives, no subsidy or incentive is given to the photovoltaic electricity producer, however, for every unit of renewable electricity produced one green certificate is issued. These certificates can be traded (sold and bought) in market as a normal product and they allow an extra revenue for the producer (CURTIN; MCINERNEY; GALLACHÓIR,2016).

The demand for green certificates arises from an obligation on electricity distributors (or big electricity consumers) to surrender a quantity of certificates proportional to their annual consumption (equal to the quota). The main idea over this obligation is to force that a percentage (quota) of the electricity consumed is from renewable sources; therefore, if the quota is not achieved, these certificates can be bought to compensate it. In sum, this creates a new market where companies can sell and buy certificates, where the price is defined by the market forces (supply and demand) (MAESTRO; LÓPEZ; AGUSTÍN, 2013; CURTIN; MCINERNEY; GALLACHÓIR, 2016).

2.4.2 Italian policies

This topic is a review of the Italian incentives for spuring the RES. All the information in this part is from the GSE ("Gestore Servici Energetici" – Manager of Energy Services) (GSE, 2017) and from the study of Spertino, Leo and Cocina (2013).

The first incentive for the photovoltaic generation was the "Conto Energia", which was an Italian program that stimulated the grid-connected photovoltaic production of electricity. It was originated from the Directive 2001/22/CE, that started to promote the electricity produced from renewable energy source in Italy, and it introduced the incentive tariff ("tariffa incentivante") that was paid for each kilowatt-hour of electricity produced, over a fixed time period (20 years). It was a feed-in tariff paid over the electricity production. In total, there were five Conto Energia, each one with small alteration in the requisite to join the program or in changes in the value of tariff. The table 2 contains the start and end dates in which new PV systems could apply for the program.

Table 2 - Period for apply for the Conto Energia

	Start	End
First Conto Energia	28/07/2005	06/02/2006
Second Conto Energia	19/02/2007	31/12/2010
Third Conto Energia	01/01/2011	31/05/2011
Fourth Conto Energia	01/06/2011	31/12/2012
Fifth Conto Energia	05/07/2012	06/07/2013

Source: adapted from GSE (2017)

Nowadays, new PV system cannot join the "Conto Energia", however, there are two other services offered by the Italian government to spur the photovoltaic adoption, both managed by the GSE:

a) "Ritiro Dedicato" (Simplified Purchase and Resale Arrangements);
b) "Scambio Sul Posto" (Net Metering).

The GSE ("Gestore dei Servizi Energetici" – Manager of Energy Services), was founded in 1999 and it is the state-owned company responsible for promoting and supporting RES in Italy. All the incentives and actions concerning the RES are created, implemented and controlled by the GSE and its main mission is to spur the sustainable development by providing support for RES electricity generation and by taking actions to build awareness of environmentally-efficient energy uses (GSE, 2017).

The PV is not the only RES stimulated by the GSE, which scope of actions are all the types of RES electricity (i.e. PV, wind power, waves, geothermal, hydro). As this study only focuses in the PV electricity production, just the actual incentives and services for the micro-generation of PV electricity are commented.

As commented, one PV producer can decide to join one of the two available services, if in accordance with the specific requisites of each one. The producer cannot join both services at the same time, but the producer can decide not to join any of these services (it is not mandatory to join one service, but if decided to join, it is necessary to choose one). Also, the producer can change the service joined, however, it is necessary to first close the previous service and then to join the new service as any new PV system.

The first service available for PV producers is the "Ritiro Dedicato" or Simplified Purchase and Resale Arrangements, which consists on a simplified arrangement for the producer to sell the electric energy fed to the grid; it is a service offered by the GSE in which the producer stablishes a sales contract with the GSE. In this power purchase agreement, the GSE becomes responsible for buying all kWh of electricity delivered to the network by this producer and it is GSE's responsibility to trade this electricity in the Italian Electricity Market (GSE, 2017).

The price paid for the producer is the average zonal price – "prezzo medio zonale orario" – (i.e. the average monthly price per hourly band which is set on IPEX for the market area to which the system is connected) and small producers (with nominal capacity up to 1 megawatt (MW)) can benefit from a Guaranteed Minimum Price – "Prezzi Minimi Garantiti" for the first 2 million kilowatt-hour (kWh) annually delivered into the grid. The range of price, given in €/kWh, is between 0,028 and 0,076 (values for 2016) (GSE, 2017).

It is important to comment that this service is not considered an incentive, as it is not a subsidy paid to the producer, as the feed-in-tariff was (the incentive tariff of the "Conto Energia", in which for each kWh produced the producer received an extra income, in addition to the income of the sales (IMAM, 2017 loc. cit.)[4]). In fact, it is considered a service in which the GSE buys the electricity injected into the grid and resales it to the Italian Electricity Market.

To access this service the producer must file an application with GSE within 60 days from the date of commissioning of the system. Once the application is accepted, there is an annual cost related to the service (management, control and monitoring) which is charged or in the first month of the year or in the first month in which the service is used. The value of this cost is 0,7 € per each kW installed with a maximum of 10.000 € (PV system with nominal capacity lower than 3kW are exempt from fees). All the communication is made through GSE's website, where all the measure's result, contestation, communication, doubts and payment are made and scheduled (GSE, 2017).

The second service offered by the GSE is the "Scambio sul Posto" or Net Metering, which gives the producer the right of self-consume the surplus of electricity introduced into the grid. In other words, the producer can offset the electricity withdrawn from the grid with the electricity injected on it (the produced electricity that is not immediately consumed), as if it is using the grid as a battery.

PV systems with production capacity within 500kW are eligible for this service and can apply through the GSE's portal with a maximum of 60 days from the commissioning date.

GSE is the responsible for calculating the value of the compensation (the net metering contribution), that will offset the electricity bill; the equation 1 illustrates how it is calculated. The net metering contribution (Compensation in the equation 1) is equal to the minimum of the correspondent in euros of the electricity introduced in the grid ($.Demand) and the equivalent in euros of the electricity taken from the grid ($.Introduced); plus a service fee that is calculated by quantity of electricity exchanged (ES) times the service fee (Cus [€/kWh] – usually this value is around 0,14 and correspond to the transmission cost of the electricity).

$$\boldsymbol{Compensation} = \boldsymbol{min}\{\$.\boldsymbol{Demand}\ ;\ \$.\boldsymbol{Introd}\} + \boldsymbol{ES} * \boldsymbol{Cus} \tag{1}$$

This value is the amount that will be reimbursed in the electricity bill. The producer will pay the bill normally, however this value will be reduced from it. When the amount introduced is higher than the amount demanded, the producer has a credit, valid for 1 year, that can be used in others bill or can be liquidated. If the producer chooses to liquidate, there will be taxation on the value and the amount that can be liquidated is given by the difference between the $.Introduced and the $.Demanded.

Finally, the GSE charges a fee for this service. This fee that is composed by two terms, one fixed and another proportional to the size of the system. PV systems up to 3kW do not pay this fee, systems up to 20kW pay 30€ and system up to 500kW pay 30€ plus one euro per kW installed. This fee is charged in the first bill from each year, or in the month that this service starts to be used.

2.4.3 Brazilian policies

In Brazil, ANEEL ("Agência Nacional de Energia Elétrica") is the governmental entity responsible for the regulation of the electricity generation, electricity transmission and its commercialization. Its mission is to “provide favourable conditions for the electricity market to develop with balance between the agents in pro of benefits for the society”[7] (ANEEL, 2017).

The Brazilian incentives in PV generation are more recent than the incentives in Italy. Only in 2012 was that a Normative Resolution (REN nº482) stablished the conditions for connecting the micro and the mini generation of electricity on the grid. This Normative Resolution also introduced the first incentive for spur the distributed generation, which was designed as a Net Metering system and called Sistema de Compensação de Energia Elétrica (MOURA; REGO; ZUFFO, 2017).

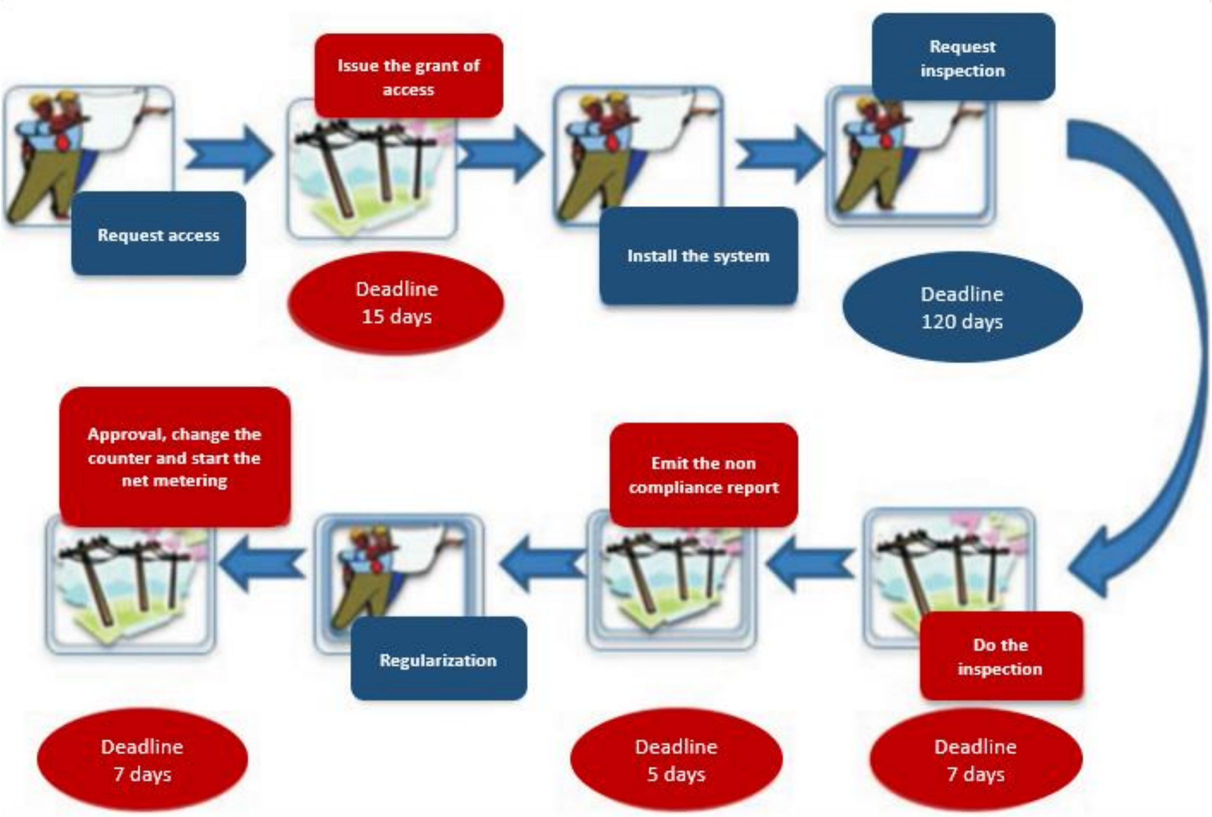
This first Normative Resolution did not have the expected repercussion, being not well accepted by the Brazilian investor, and in 2016, aiming the reduction of cost and time required for connecting the system to the grid, a new Normative Resolution (REN nº687) was published, stablishing the new rules for the Net Metering system and improving some regulatory points. (ANEEL, 2016).

Initially, this Resolution defines the concepts of micro-generation and mini-generation, being systems up to 75kW considered as micro-generation, while systems from 75kW to 3MW are considered mini-generation. Only these systems will be granted with the right of access and takes fifteen days for the micro-generation and thirty days for the mini-generation. The figure 6 contains all the steps required to connect a micro PV system into the grid; in the blue squares are the tasks that the PV system`s owner has to do, while in the red squares are the task of ANEEL responsibility (ANEEL, 2016).

One of the changes in the REN nº687 is that for the micro-generation it is responsibility for the electricity power concessionary to install the electricity meter to measure the amount of electricity injected into the grid and to provide any maintenance or repair work in the electricity. This way the investor will have only the cost of acquiring, installing and maintaining the PV system (ANEEL, 2016).

[7] Original: “Proporcionar condições favoráveis para que o mercado de energia elétrica se desenvolva com equilíbrio entre os agentes e em benefício da sociedade”

Figure 9 - Steps for connecting the micro-PV system into the grid - Brazil



Source: adapted from ANEEL (2016)

As commented, the Sistema de Compensação de Energia Elétrica, the net metering system, was introduced. Differently from the Italian Net Metering, the credit of electricity is equivalent to the electricity injected into the grid (e.g. if a PV system injects 100kWh into the grid, the system`s owner will have a credit of 100kWh to offset from the electricity bills) and can be used to offset the electricity bills. The credits can be used up to sixty months after its concession and it is only emitted when the amount injected is greater than the amount consumed. The REN nº687 also allows the use of the credit for the remote self-consumption, in case the PV system` owner has a second property in the connecting in the same concessionary, or in a share generation, when a group of consumers (inside the same concessionary) installs a shared PV system (ANEEL, 2016).

Although the credit can be used to offset the electricity bills, for the low-tension consumer (i.e. consumer connected in the low-tension grid, usually the household consumers and small/medium offices that do not demand huge amount of electricity) a minimum consumption is charged in the electricity bills. This amount corresponds to the availability cost of the electricity and it is equivalent to 30kWh for the single-phase, 50kWh for the biphasic and 100kWh for the three-phase (ANEEL, 2016).

Finally, according to the Brazilian federal law, there are three taxes charged on the electricity price (R$/kWh). The first one is the ICMS (“Imposto sobre Circulação de Mercadorias e Serviços”), a state tax that has the base for calculation all the electricity taken from the grid. Initially, it was charged over the total electricity consumed from the grid, do not considering the amount of electricity offset with the credits; however, in 2015 the CONFAZ (“Conselho Nacional de Política Fazendária”) authorized the states to use the net of electricity as base for calculation of this tax. Almost all states adopted it and only five states continued using all the electricity consumed from the grid (the states are: Santa Catarina, Paraná, Espírito Santo, Amazonas e Amapá) ANEEL, 2016).

The second and the third taxes are the PIS/COFINS (PIS – “Programa de Integração Social” and COFINS – “Contribuição para o Financiamento da Seguridade Social”). They are federal tax and are charged only based on the positive difference between the electricity consumed and injected (in other words, over the electricity net, when the amount consumed is greater than the amount injected). As they are federal tax, all states them in the same way (ANEEL, 2016).

3 METHODOLOGY

The objective of this study is to assess the economic feasibility of the photovoltaic micro-generation in Brazil and in Italy, drawing a comparison between both countries. For this, a methodology consisting of three main steps was followed considering both the Brazilian and the Italian markets. The principal developed activities of each step were:

a) Preliminary analysis
   - Selection of the PV modules
   - Design of the PV systems
   - Capex calculation
   - Estimated production calculation
   - Italian cities selection
   - Selection of the best investment scenario
b) Investment payback in Italy
   - Investment cash flow calculation
   - Sensitivity Analysis
c) Investment payback in Brazil
   - Brazilian cities selection
   - Investment cash flow calculation
   - Assessment of the investment

This structure follows a logic flow in which firstly a preliminary analysis was made. Its objective was to understand the impact of the different PV technologies available in market in the investment return and to identify the presence of an economy of scale. The output from this preliminary analysis was the system (size and PV technology) that was going to be used in the assessment model.

In the second and in third steps, the assessment of the micro-generation was made, for both countries. For this, a cash flow model and a sensitivity analysis were built for each country to calculate the investment payback.

3.1 Preliminary analysis

This first step consists in designing the investment scenarios based on the principal variables that determine the expected production of a PV system (such as the PV technology and the system size). As seen in the literature review (chapter 2), there are many option of PV modules available in the market, therefore to be able to properly assess the economic feasibility of a micro-generation, it is necessary to identify the best PV technology. Secondly, the system size can influence in the investment capex, being necessary to study its influence in the investment capex (e.g., is the capex per watt installed a constant among different sizes or is there an economy of scale?). Therefore, throughout this preliminary analysis, the principal characteristics of the PV production are analysed and discussed. At the end of this preliminary analysis, the PV technology and the size of system with best cost-benefit was selected to be used in the following steps (Investment payback in Italy and in Brazil).

Finally, this entire preliminary analysis was made considering the Italian market.

3.1.1 Selection of the PV modules

Many factors influence the quantity of electricity produced in a photovoltaic system and among them, the PV technology utilized in the modules. In the subchapter 2.2 of the Literature Review, it was identified that different technologies generate different responses to production; therefore, to consider the intrinsic characteristics of each PV module, this preliminary analysis considers three types of PV modules.

The three PV technologies are: monocrystalline, polycrystalline and thin film (Cadmium Telluride – CdTe); those technologies consist on well-developed technologies available in Brazil and Italian market with competitive products (LEE; EBONG, 2017; IMAM, 2017 loc. cit.) [4]. The table 3 contains the three selected PV modules and the table 4 summarizes the set of the technical information available in the producer's datasheet (full datasheet is in attachment A).

Table 3 - Selected PV modules

	Thin Film - CdTe	Monocrystalline	Polycrystalline
Model	Serie 4V2	VBHN330SA16	TSM-PA05.08
Producer	First Solar	Panasonic	Trina Solar
Price (€/W)	0,60	1,00	0,70

Source: adapted from IMAM (2017) loc. cit. [4].

First Solar is an American photovoltaic manufacturer of rigid thin film solar panels, founded in 1999 with headquarters in Arizona, United States (SOLAR, 2017). Panasonic is a Japanese company that in 1975 started to invest in solar cells and recently acquired SANYO, ex-leader in the monocrystalline solar cells market (PANASONIC, 2017). Lastly, Trina Solar is a Chinese company producer of polycrystalline PV modules, founded in 1997 with headquarters in Changzhou, China. Trina Solar has more than 14.200 employees and more than 1.300 patents filed (TRINA, 2017).

Table 4 - - PV modules technical characteristics

Tech. Characteristics	Unit	Thin Film - CdTe	Monocrystalline	Polycrystalline
W_p	**W**	117,5	330	245
Area	**m²**	0,72	1,67427	1,64142
NOCT	**°C**	40	44	45
γ_{pm}	**% / °C**	-0,0034	-0,0029	-0,0045
γ_{oc}	**V/°C**	-0,0029	-0,174	-0,0035
V_{mpp}	**V**	71,2	58	30,7
V_{oc}	**V**	88,2	69,7	37,3
I_{mpp}	**A**	1,65	5,7	7,89

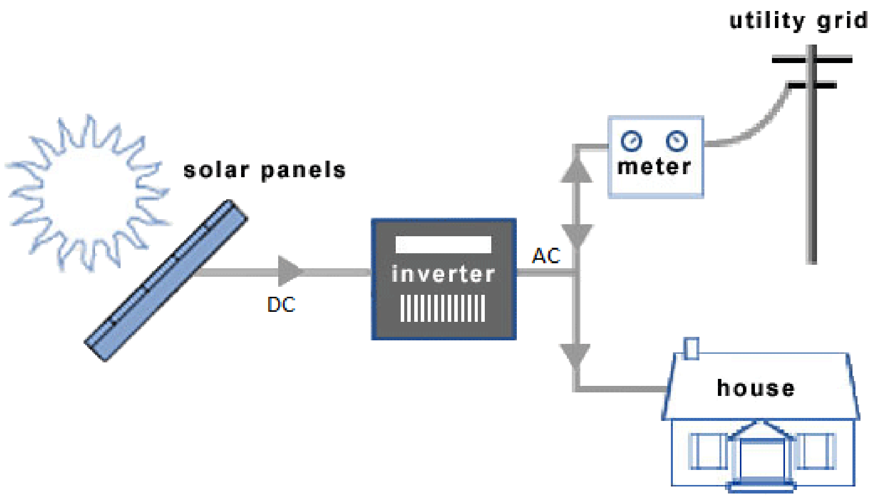
Source: adapted from the module’s datasheet (attachment A)

3.1.2 Design of the PV systems

To design the PV systems, it is important to consider the electricity consumption level, so the systems will not be neither undersized or oversized. Also, as seen in the Literature Review (chapter 2), the electricity produced by the PV modules are direct current and must be converted to alternate current, requiring the installation of an inverter between the PV modules and the load. The figure 10 illustrates how the components should be connected.

It is important to comment that the layout showed in the figure 10 corresponds to a system without battery. Although many systems use a battery to storage the electricity surplus, this study considers only system with no battery connected to it. There are two main reasons: both Brazil and Italy have a net metering incentive for RES, which allows the producer to use the grid as a "battery" (COMELLO; REICHELSTEIN, 2017); there are many layouts that for the use of battery, which would increase the complexity of this study diverting from the objective of this study.

Figure 10 – Grid connected PV system



Source: Adapted from (INFORMATIVE, 2017)

In addition, the way the modules are connect affects the productivity of the system, therefore the dimensioning and sizing of the system is required. Case there are many modules connected in series, the current can exceed the maximum one supported by the inverter and the excess will be dropped, reducing the production. On the other hand, if there are many modules connected in parallel, the minimum voltage required to start the inverter cannot be reached, also reducing the productivity.

Finally, as commented, these preliminary analyses are made Italy, therefore, all parameters are reanalysed for the analyses involving Brazil, which will lead to small difference in some parameters.

CONSUMPTION IDENTIFICATION

This preliminary study considers three different types of investors (Residential, Small Office and Medium Office investors) with different load profiles and annual consumption.

a) Residential (household) Investor – annual consumption 2.700kWh
b) Small Office Investor – annual consumption 8.700kWh;
c) Medium Office Investor – annual consumption 25.000kWh;

The annual consumption for the household investor and for the small office investor are real values obtained from the past electricity bill of a house and an office, respectively. For the household, the annual consumption is 2.700kWh for a 5-persons house with non-electric water and environmental heating (gas heating). For the small office, the annual consumption is around 8.700 kWh considering 10 employees with gas heating. For the medium office, the annual consumption considered is 25.00kWh and it is an estimation for a 30-employee office based in the consumption for the small office.

INVERTERS SELECTION

Table 5 contains the selected inverters. This study only considers centralized production (where all strings are connected to only one inverter), so each PV system has only one inverter. For the Residential Investor the inverter installed is be the Sunny Boy 1,5; for the Small Office Investor the inverter is the PVI5000; and for the Medium Office investor the inverter is the TRIO 20.00TL

Table 5 – Selected inverters

Inverter	Producer	Capacity (kW)	Min DCV (V)	Max DCV (V)	Imax (A)
Sunny Boy 1,5	SMA	1	160	500	10
PVI5000	ABB	5	150	530	36/18
TRIO 20.00 TL	ABB	20	440	800	50/25

Source: from author

Except for the Sunny Boy, most inverters accept the input of electricity in one or two parallel arrays, that explains why the maximum input current (Imax (A) in the table 5) has two values: the first one is for one entry point, while the second one is for two entry points. The Sunny Boy accepts only one input point because its capacity is too small, so there is no need to split the input current. In the other inverters, the maximum input current becomes high, so for safety reason, they accept two entry points.

Finally, all the inverters selected are products available in the Italian market, produced by important players in the market segment, with brand and quality reputation (IMAM, 2017 loc. cit.) [4].

DIMENSIONING/SIZING

The equations 2 and 3 are used to calculate the minimum and the maximum production of a photovoltaic module. The maximum and minimum inverter's voltage divided by these values give the maximum and minimum quantity of PV modules in a string.

The importance of this step consists in the fact that the inverter works in a range of input, so for values outside this range there will be loss of production. In practice, the critical moments are during the mornings when the start voltage must be reach for starting the inverter; and during the pick of irradiance, where the production of electricity reaches its maximum value and the current can exceed the maximum supported one.

$$\boldsymbol{Vmin} = \left(\boldsymbol{Vmpp} + (\boldsymbol{THigh} + \boldsymbol{TRise} - \boldsymbol{TSTC}) \times \boldsymbol{\beta Vmpp} \times \frac{\boldsymbol{Vmpp}}{\boldsymbol{100}}\right) \times \%\boldsymbol{Loss} \qquad (2)$$

$$\boldsymbol{Vmax} = \boldsymbol{Voc} + (\boldsymbol{TLow} - \boldsymbol{TSTC}) \times \frac{\boldsymbol{\beta Voc}}{\boldsymbol{100}} \qquad (3)$$

Vmpp, βVmpp, Voc and βVoc are obtained in the product datasheet for each PV module and consist, respectively, in the peak voltage, the percent loss of Vmpp due to increase in temperature, the open circuit voltage and the percent loss of Voc due to increase in temperature. The other terms correspond to temperature: THigh is the highest temperature, TLow is the lowest temperature, TRise is how much the cell temperature is in comparison with the air temperature and TSTC is the standard test temperature. %Loss, in equation 2, correspond to the expected loss of the system.

Finally, knowing the maximum and minimum number of modules in the stings, it is possible to design the system. There is no defined formula in this step, to return the optimal arrange, therefore, it is defined through trial and error method; however, there are a few empirical rules that must be followed:

a) the system should be as symmetrical as possible (even number of strings when more than one string is required);
b) the same number of modules in each string (case there are different sizes of strings, their voltage will be different, which will create a reverse current and reduce the system efficiency);
c) the number of string should respect the maximum and minimum number of PV modules calculated previously.

3.1.3 Capex calculation

The investment capex is calculated considering six components: i) PV module; ii) inverter; iii) wires; iv) protection and disconnection; v) energy counter and monitoring; vi) installation and commissioning. The values were obtained considering their market price in Italy for the beginning of 2017 and a company that operates in this business helped identifying the market price. The table 6 introduces these six components.

Table 6 - Capex components

Components	Layout Dependent	Direct calculation	Comments
PV modules	No	Yes	Acquisition cost of the PV modules.
Inverter	No	Yes	Acquisition cost of the inverter.
Wire (AC and DC)	Yes	No	Wires to connect the modules, inverter and load.
Protection and Disconnection	Yes	No	To secure and protect the electric system.
Energy Counter and Monitoring	No	Yes	To measure and control the amount produced and injected into the grid.
Installation and Comissioning	No	No	To install the system.

Source: from author

As can be seen in the table 6 some components (procurement, installation and commissioning, protection and disconnection) depend on the physical layout, therefore three layouts were built in AUTOCAD 2013, one for each PV technology selected. These layouts can be seen in the appendix C of this study and correspond to the system for the Medium Office Investor (installed capacity around 25kW).

The PV module acquisition cost, the inverter acquisition cost and the energy counter replacement cost are the easiest to calculate as they depend only on the size of the system: the PV module acquisition cost is calculated multiplying the quantity of modules by its unitary price; the inverter acquisition cost is the unit cost of the inverter selected for the PV system; the energy counter has the same cost for all the systems (the energy counter is responsible for measure the amount of electricity that is introduced into the grid and it is the same for all scenarios in this study). Finally, their contribution to the investment capex is additive.

For the other components, as their contribution to the total capex is not linear (the marginal cost of adding one more unit cannot be easily quantified – e.g., the cost of installing one more module does not necessarily increase the installation cost, as it is measured in days of work), they were calculated being proportional to the installed capacity. For this, initially their capex was calculated for the Medium Office Investor scenarios, based on the layouts produced in AUTOCAD, and their capex per kilowatt installed ([€/kW]) was determined. For the other scenarios (Residential Investor and Small Office Investor), the capex was calculated multiplying the obtained capex per watt by the system's installed capacity.

For the wires (AC and DC) cost, the layout built in AUTOCAD 2013 was used to estimate the length of the wires.

The protection and disconnection cost was calculated according to the number of strings in the system. The tables 7 and 8 show the components of this calculation for the Medium Office Investor. This is very important for the system, as a short-circuit (caused by any external sources) in any component can destroy the module or the inverter, causing the loss of the equipment, interrupting the production and even starting a fire.

Table 7 - Protection and disconnection cost for 6 strings system

Item	Unit Cost (€)	Quantity	Cost (€)
Fuse box	3,50	6	21,00
Fuse	2,50	12	30,00
Overvoltage	50,00	6	300,00
Disconnector	35,00	6	210,00
Box	35,00	6	210,00
Power Breaker	70,00	1	70,00
Monitoring Relays (Low Tension)	180,00	1	180,00
Grounding	458,00	1	458,00
		Total Cost (€)	**1.479,00**

Source: from author

Table 8 - Protection and disconnection cost for 24 strings system

Item	Unit Cost (€)	Quantity	Cost (€)
Fuse box	3,50	48	168,00
Fuse	2,50	48	120,00
Overvoltage	50,00	6	300,00
Disconnector	35,00	6	210,00
Box	40,00	6	240,00
Power Breaker	70,00	1	70,00
Monitoring Relays (Low Tension)	180,00	1	180,00
Grounding	458,00	1	458,00
		Total Cost (€)	**1.746,00**

Source: from author

Finally, the installation and commissioning cost is composed by labour installation cost, the cost of structure material and some contingencies. For labour, it was assumed a value of €25,00 per hour of work and the total number of hours depends on the quantity of PV modules in the system, being 80 hours (10 working days) for the monocrystalline and for the polycrystalline and 120 hours (15 working days) for the CdTe. For the structure cost, each module needs one unit of structure, which individual price is €50,00. Lastly, an additional expenditure of €500,00 is considered to cover the security material and other extra expenditures that may happen.

In all, for the three scenarios for the Medium Office Investor (one for each selected PV technology), the investment capex was detailed calculated. For the other six scenarios (three scenarios for the Residential Investor and three scenarios for the Small Office Investor), some components were directly calculated and others were calculated based on the capex per watt obtained for the Medium Investor.

3.1.4 Expected production

To calculate the expected production, it is first necessary to collect the irradiance data and after estimate the production loss. The model used to calculate the expected production is the model used by Professor Filippo Spertino from Politecnico di Torino, Italy. It consists basically in collecting the irradiance data, calculating the expected production considering the cell temperature and adding the production losses.

IRRADIANCE DATA

The quantity of incident sun light in the earth surface is measured in watts per square meter [W/m²] and it is called irradiance. The irradiance data considered in this model is the one available in the PVGIS photovoltaic software (PVGIS) website. Data collected in 20/02/2017.

PVGIS is a map-based inventory of solar energy resource for photovoltaic electricity generation assessment in Europe, Africa and South-West Asia. The main goal of this initiative is to “contribute to the implementation of renewable energy in the European Union as a sustainable and long-term energy supply” (PVGIS, 2017).

In this study, the PVGIS was utilized only as a data source and not as an assessment tool. Although a production calculation is available in the website, this calculation considers some fixed parameters (e.g. the Nominal Operating Cell Temperature (NOCT) and the temperature coefficients) that varies among the PV cells. As this study considers the PV modules difference, using the assessment provided by PVGIS would lead to a non-accurate estimation.

The tables exported from the PVGIS consist in the month average daily radiation, which provide for each month the average day, calculating the average irradiation and the average surface temperature for each 15 minute interval. The table 9 contains a sample of the data exported from the PVGIS (the data corresponds to the first hours for the April's average day in Torino's city); Time corresponds to the time of the measure [hours:minute]; G is the irradiation in W/m²; Td is the average surface temperature in ºC.

Table 9 - Data sample: first hours of April's average day in Torino

Time	G	T_d
05:37	14	9,1
05:52	29	9,4
06:07	41	9,6
06:22	70	10
06:37	100	10,4
06:52	134	10,8
07:07	171	11,2
07:22	209	11,6
07:37	247	12,1
07:52	287	12,6
08:07	325	13
08:22	363	13,4
08:37	400	13,8
08:52	436	14,2
09:07	470	14,6
09:22	502	14,9
09:37	532	15,1
09:52	560	15,3
10:07	585	15,5
10:22	607	15,7

Source: adapted from (PVGIS, 2017)

The irradiance, as commented, is used to estimate the electricity production for the PV systems, and the temperature is utilized (during the estimation calculation) to introduce the loss due to the temperature. All the tables were obtained considering an inclination of 30º regarding the ground and an azimuth of 0º.

CALCULATION

The expected production is a function of the irradiance; however, it is not a linear relation. As seen in the section 2.2, the cell temperature (Tc) impacts in the efficiency of the generation (i.e. the higher the cell temperature the lower will be the productivity), and it depends not only on the air temperature, but also on the intensity of the irradiation (the cell temperature increases according the irradiation gets higher).

Therefore, the expected production of a PV system (Pm) is a function of the installed peak capacity (Pmpp), the irradiation (G), the temperature coefficient (γpm) and the cell temperature (Tc). The equations 4, 5 and 6 were used to calculate the cell temperature and the expected production (Pm) (SPERTINO; COCINA, 2016)[8].

$$\boldsymbol{Pm = Pmpp \times \frac{G}{1000} \times (1 + \gamma pm \times \Delta Tc)} \tag{4}$$

$$\mathbf{Tc = Td + \frac{(NOCT - 20) \times G}{800}} \tag{5}$$

$$\mathbf{\Delta Tc = Tc - 25} \tag{6}$$

The electricity production is measured in watt-hour (Wh) (or in its multiple: kWh = 1000Wh; MWh = 1000 kWh) and is calculated integrating the production capacity (Pm) for its time interval. Once the irradiation and surface temperature is available in interval of 15 minutes, the expected production is given by the equation 7, bellow:

$$\boldsymbol{Production = \sum Pm\,(t) \times \frac{15}{60} \quad , for\ all\ time\ interval\ (t)} \tag{6}$$

PRODUCTION LOSS

Finally, there are several sources of electricity loss in a PV system. This preliminary study considered the following five principal production losses:

a) **Temperature loss** – it is already considered in the expected production calculation;
b) **Transformation loss** – it is the nominal loss present in the inverter's datasheet provided by the producer;
c) **Transmission losses** (alternated and continue current – AC and DC) – it is the loss during the transmission. To calculate it a layout was designed in AUTOCAD 2013 to estimate the required length of the cables to calculate these losses based on the cables' characteristics;
d) **Reflectance loss** – data from PVGIS photovoltaic software website;

[8] SPERTINO, F.; COCINA, V. Slide presentation for the course: Generazione fotovoltaica ed eolica di energia elettrica. Torino: Politecnico di Torino, 2016. Corso Di Laurea In Ingegneria Gestionale – Torino.

e) **Malfunction/others** – it was considered that, on average, 2 days in a month there will not be production (due to lack of sun, malfunction, repair), therefore a coefficient with the value (1-340/365) is introduced as a loss.

3.1.5 Italian cities selection

The expected production varies according to the irradiance profile of the system's location. The Italian country has a vertically elongated shape that extends for 1.300 kilometres, containing several climatic zones with different irradiance level, therefore, different expected production.

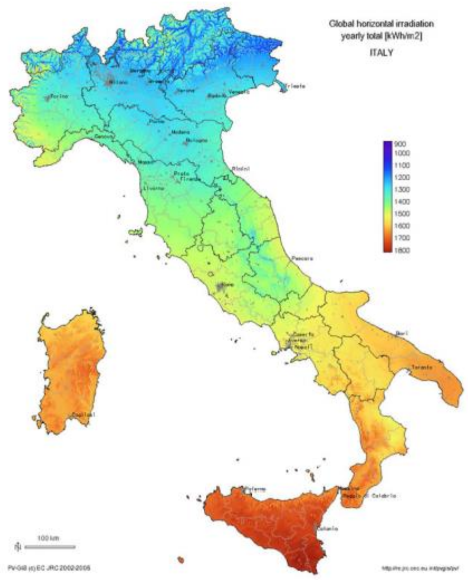
The irradiance varies mainly according to the distance to the equator line. The closer to the equator line (for Italy, the south direction) the hotter is the weather and the higher is the irradiance; the farther to the equator line (the bigger is the distance), the lower is the irradiance and the temperature. It happens because of the earth curvature: in the equator line the sun light arrives almost perpendicular while in the extremes it arrives with an angle.

In addition, the Italian electricity market is divided is six zones, with different electricity price (as commented in the chapter 2, the electricity price is set hourly for each zone). Therefore, the two criteria used to select the cities are the market zone and the irradiance level. The figure 11 contains the Italian electricity market zones and the figure 12 shows the different irradiances in Italy (POI Energia, 2011). Finally, in table 10, there are the seven selected cities.

Figure 11 - Electricity market zones

Source: CANAZZA (2014)

Figure 12 - Global horizontal irradiation



Source: POI Energia (2011)

Table 10 - Coordinates of the Italian cities

City	Lat . (ºN)	Long. (ºE)	Elevation (m)
Torino	45º04'13''	07º41'12''	250
Milano	45º27'55''	09º11'09''	135
Rome	41º54'10''	12º29'46''	65
Lucca	43º50'35''	10º30'9''	27
Bari	41º07'01''	16º52'18''	10
Cagliari	39º13'26''	09º07'19''	33
Palermo	38º06'56''	13º21'40''	30

Source: from author

3.1.6 Selection of the best investment scenario

The main objective of the preliminary analyses is to select the PV technology that provides the higher return for the investor. For this, the Expected Production Per Euro Invested (EPPEI) indicator is defined and calculated. It is calculated dividing one-year expected production (given in kilowatt-hour) by the capex (in euros) and corresponds to how many kWh one euro invested is expected to yearly produce. This indicator was defined by the author and for this analysis, it can be considered a good investment indicator as all the other variables are constant (i.e. O&M costs, efficiency depreciation, expected-life). It is a ceteris paribus analysis in which only the PV technology changes and all the other variables continue with the same value, allowing the selection of the one with best cost-benefit (the one with higher EPPEI).

This analysis is initially made only for the city of Turin and later for seven Italian cities considered in this study. The criteria to select these cities is detailed in the subchapter 3.2 of this thesis.

3.2 Investment payback in Italy

The main goal of this study is the discussion the economic feasibility of the distributed PV micro-generation in Italy and in Brazil. This second step consists in its assessment for Italy, analysing the expected financial return for the PV investment. This study uses the cash flow model as the tool to calculate the financial indicator (payback time, net present value (NPV) and internal rate of return (IRR)) and utilizes some outputs from the preliminary analysis as inputs for the cash flow model.

From the preliminary analysis, it was possible to identify that polycrystalline systems with 23,5kW of installed capacity (Medium Office Investors) are the ones expected to have the best investment payback. The economy of scale explains this result, as it increases the expected production per euro invested (EPPEI – the indicator utilized in the preliminary analysis to select the size and the PV technology); therefore, with the same amount invested, the investor expects a higher production.

In sum, this second step consists in calculating the investment payback for a 23,5kW-polycrystalline system placed in seven different Italian cities (described in the 3.1.5 topic of this methodology).

The cash flow model considers a 25 years' time horizon, that corresponds to life-time of the PV module over which the producer offers warrantee (information in the PV modules datasheet) and two discount rates were used: the first one corresponds to the risk-free rate 4,59% and for the second one the market premium and the country premium were added (9,85%). These rates follow the methodology defined by ANEEL (2014), which is used for the Brazilian analyses.

The positive flows are the savings and the income calculated based on the expected production (already calculated in the preliminary analysis) and on the load profile, which was calculated considering the annual consumption of electricity (in kilowatt-hour - kWh) prorated to the hourly consumption. No residual value is considered.

The savings occur when the produced electricity is higher than the consumed electricity in a certain moment. To calculate it, initially the consumption was prorated and then the self-consumption rate was calculated. The table 11 shows a partial part of an auxiliary table used to prorate the consumption: a Boolean flag was assigned for all the 24 hours' interval with the value 1 ("yes") if there is consumption in that hour, or 0 ("no") if there is not consumption. At the end, the consumption was equally prorated for all intervals with the value 1. It was assumed that the office hours are from 9:00am to 18:00pm without lunch break.

Table 11 - Load profile (partial)

		07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00
Medium Office	Working Days	no	no	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no
	Saturday	no	no	no	no	no	no	no	no	no	no	no	no	no
	Sunday	no	no	no	no	no	no	no	no	no	no	no	no	no

Source: from author

After, with the estimation of the hourly consumption, the self-consumption rate was calculated. The equation 7 shows how this calculation was implemented.

$$\boldsymbol{SelfConsump.} = \frac{\sum \mathbf{min}(\boldsymbol{ElectProduced}; \boldsymbol{ElectConsumed})}{\boldsymbol{TotalElectProduced}}, \boldsymbol{for\ all\ intervals} \tag{7}$$

The income occurs when the total electricity injected into the grid is greater than the total electricity consumed from the grid and depends on the service the system joined. The topic 2.4.2 explains detailed how each service (Ritiro Dedicato or Scambio sul Posto) can generate income for the investor.

The negative flows are the capex and opex. The capex value was calculated in the preliminary analysis and no loan is assumed in this model (all investment is from equit). This study assumes a fixed of opex through all the 25 years, which is equal to 2% of the capex yearly and the life-time of the inverter is ten years, which must be replaced for a new one each ten year (the price for the new inverters are assumed to be the same) (IMAM, 2017 loc. cit.) [4].

The equation 8 illustrates how the flows are brought to present value (n is a generic month; N is the total number of months and d is the discount factor) and all calculations were elaborated in a MS Excel spreadsheet.

$$NPV = \sum_{n=0}^{N} \frac{\left(Income(n) + Savings(n)\right) - (\mathbf{capex} + \mathbf{opex}(n))}{(1+d)^n} \qquad (8)$$

For the electricity price, all price information utilized in this study are from the GSE (2017) or electricity bills. As commented, the Italian electricity market is divided in 6 zones, as shown in figure 6, in which the electricity price is hourly traded for each zone (for each zone, for each hourly band, one electricity price is set). The average daily of this price is the called average zonal price, which is used to calculate the revenue in the first service (Simplified Purchase and Resale Arrangements) and to calculate the $.Introd in the second service (Net Metering). The table 12 shows the average monthly zonal price for each zone.

Table 12 - Average monthly zonal price for 2016

Price 2016

Zone	jan	feb	mar	abr	may	jun	jul	aug	sep	oct	nov	dec
CNOR	49,26	36,76	33,94	30,19	34,44	40,07	48,30	37,75	47,22	51,76	62,30	64,41
CSUD	48,50	36,16	33,69	29,24	33,73	39,76	45,72	34,74	46,14	43,56	54,78	57,58
NORD	58,26	41,72	37,00	31,71	35,61	39,24	48,28	37,74	48,53	64,65	76,10	67,16
SARD	49,06	36,76	34,18	29,56	33,19	39,72	44,86	34,76	46,43	42,85	53,55	56,52
SICI	45,98	39,93	36,17	31,03	35,12	38,40	49,44	50,25	46,61	44,56	52,00	47,00

Source: adapted from GSE (2017)

The PUN (Single National Price – "Prezzo Unico Nazionale") is the purchase price for end customers and it is used to calculate the S.Demand in the second service. It is divided into three times band (F1, F2 and F3) each one with a slight price difference. The table 13 illustrates this division, however, given the load profile for the office, all consumption and production occur in the F1 zone (sun-hours during working days), that was the band price used during the analysis.

Table 13 - PUN for 2016

PUN	jan	feb	mar	abr	may	jun	jul	aug	sep	oct	nov	dec
F1	88,4	41,6	37,4	32,1	36	39,9	48,1	38,5	47,9	60,9	69,9	65,9
F2	75,9	40,8	39,5	37,3	38,9	40,7	45,6	40,3	46,6	58,6	61,7	59,6
F3	59,5	31,1	31,2	28,8	31,6	32,4	37,5	34,2	36,7	44,4	48,1	48,7
Weigh	**72,4**	**37,2**	**35,8**	**32,8**	**35,4**	**37,3**	**43,0**	**37,5**	**43,1**	**53,6**	**58,3**	**56,8**

Source: adapted from GSE (2017)

Lastly, the simple payback time, the discounted payback time, the NPV and the IRR are the output of the model. They were calculated for all the seven cities, considering the five prices evolution. Although the NPV and the IRR are more accurately indicators for assessing investment, this study will rely on the payback time as the main decision variable. This option is based on the fact the capex involved in each project (considered in this study) does not justify the use of a more detailed valuation tools and the micro investors usually consider the payback time as the principal decision tool.

The sensitivity analysis consists in a simulation of the electricity price, consumption, capex, opex, discount rate and PV module efficiency loss, having the simple payback time, discounted payback time, NPV and IRR as target variables. A probability distribution was assigned for each variable and it was used a fifteen-thousand iterations.

3.3 Investment payback in Brazil

The last step of this methodology consists in valuating and assessing the economic feasibility of the PV micro-generation in Brazil.

The cashflow of the PV system selected in the preliminary analysis (a 23,5kW polycrystalline system) was built considering the savings, the capex and the opex associated to the PV system. The Brazilian incentive does not allow any generation of income; therefore, the savings were the only source of positives flows.

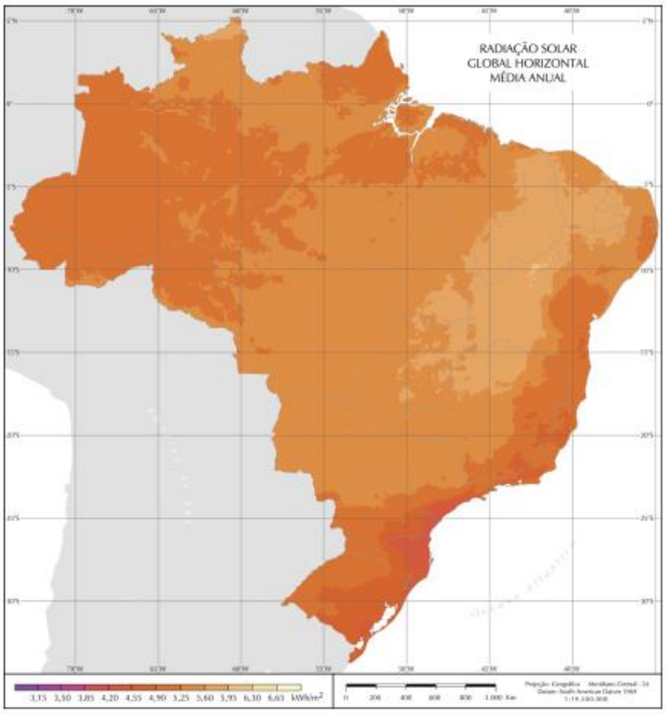
The negatives flows are the capex and the opex. For the capex, benchmark values obtained from GRENNER (2017) were used, and for the opex the same value of 2% per year of the capex was considered (IMAM, 2017 loc. cit.) [4]).

The same time horizon of 25 years was considered, and two discount rates were used, considering the methodology applied by ANEEL (2014) to valuate investment. The first rate considers only the risk-free rate (4,59%) and the second considers the risk-free plus the market premium (given the unlevered beta of the market) and the country premium (10,66%). All rates are nominal and no debt was considered in the study. At the end, this cashflow model allows the calculation of the NPV, IRR and discounted payback time of the investment. As for the Italian analyse, although the NPV and the IRR are more sophisticated investment indicators, the discounted payback time is still the main decision variable as the size of the investment does not justify the use of more detailed valuation and usually household investors considers the payback time as the decision variable.

To calculate the PV system's production, a simulation software, PVSYST V6.38 was used. In this software, all input variables (PV module properties, irradiance data, system layout, inverter) are inputted and it calculates the expected electricity production based on the inputted information. The PV module used is the same selected in the preliminary analysis (TSM-245 PA05.08 from TRINA SOLAR) and the NASA-SSE satellite data 1983-2005 was used. For the inverter, eight Ingecon Sun 6TL M inverters were used, in a decentralized layout (datasheet in the attachment A); the main reason for changing the inverter is that the TRIO 20.00 TL is difficult to find in Brazil, being Ingecon the more used (personal information)[9]. Finally, the PV system dimensions were the same used for the Italian analyse (same number of PV modules and strings), however, they were displayed in a parallel layout. This difference in configuration should not affect the results, as there is no area limitation to lead to an efficiency loss.

A global irradiation map (yearly global horizontal irradiance, showed in the figure 13) was used to select the cities and the table 14 shows some geographic information about them.

Figure 13 Global horizontal irradiation (yearly) - Brazil



Source: ATLAS BRASILEIRO DE ENERGIA SOLAR, 2006

[9] Information provided by Moura, C. during an informal meeting in 23/08/2017 at Polytechnic School of São Paulo University.

Table 14 - Coordinates of the Italian cities

	Lat . (ºS)	Long. (ºW)	Elevation (m)
São Paulo	23,5°	46,6°	760
Brasilia	15,8°	47,9°	1171
Cuiaba	15,6°	56,1°	125
Fortaleza	3,7°	38,5°	16
Rio Branco	10,0°	67,8°	143
Recife	15,6°	56,1°	4
Curitiba	25,4°	49,3°	934

Source: PVSYST database

The consumption level of electricity of the investor considered in this analyse was 35.000kWh and the electricity price used was collected from ANEEL’s website.

Lastly, for the sensitivity analysis, a simulation model was built using the cashflow. A probability distribution was assigned for the electricity price, consumption, capex, opex, discount rate and PV module efficiency loss and the target variables were the payback time, the NPV and the IRR.

4 RESULTS

This chapter presents the results of this study and three subchapters, following the methodology defined in the chapter 3. Each subchapter is one-step of the defined methodology.

In the first subchapter, the results from the preliminary analysis are shown: the systems dimensioned; the capex and its components; the presence of an economy of scale and its implication in the investment.

The second and the third subchapter contain the investment payback for Italy and Brazil respectively and the result from the sensitivity analyses.

4.1 Preliminary analysis

In methodology, three sizes of investors were defined (residential investor – 1kW, small office investor – 5kW and medium office investor – 25kW) and three technologies were selected (monocrystalline, polycrystalline and thin film). A PV system was calculated for each one of the nine combinations of size and technology, using the equations described in methodology. The tables 15, 16 and 17 summarize the dimensioning of them.

Table 15 - Dimensioning for 1kW system

	Residential				
	Qt. Module	Qt. String	Module/Str.	Capacity (kW)	Area (m2)
CdTe	8	2	4	0,94	5,8
Monocrystalline	3	1	3	0,99	5,0
Polycrystalline	4	1	4	0,98	6,6

Source: from author

Table 16 - Dimensioning for 5kW system

Small Office

	Qt. Module	Qt. String	Module/Str.	Capacity (kW)	Area (m2)
CdTe	48	12	4	5,64	34,6
Monocrystalline	16	4	4	5,28	26,8
Polycrystalline	24	4	6	5,88	39,4

Source: from author

Table 17 - Dimensioning for 25kW system

Medium

	Qt. Module	Qt. String	Module/Str.	Capacity (kW)	Area (m2)
CdTe	192	24	8	22,56	138,2
Monocrystalline	72	6	12	23,76	120,5
Polycrystalline	96	6	16	23,52	157,6

Source: from author

In number of units, the thin film technology (CdTe) is the technology that requires more modules (almost the double when comparing with monocrystalline or polycrystalline) while the monocrystalline is the one that requires less. However, in terms of area, the polycrystalline is the one that occupies the biggest area.

In the table 6 of the methodology, the six components of the capex were introduced and the tables 18, 19, 20, 21, 22 and 23 contain the capex contribution of each one of them. The table 24 summarizes the total capex.

Table 18 - PV modules` contribution in the capex

Investor	PV module	Quantity of PV modules	Installed Capacity (kW)	Price (€/W)	PV module expenditure (€)
Residential	CdTe	8	0,94	0,60	564,00
	Monocrystalline	3	0,99	1,00	990,00
	Polycrystalline	4	0,98	0,70	686,00
Small Office	CdTe	48	5,64	0,60	3.384,00
	Monocrystalline	16	5,28	1,00	5.280,00
	Polycrystalline	24	5,88	0,70	4.116,00
Medium Office	CdTe	192	22,56	0,60	13.536,00
	Monocrystalline	72	23,76	1,00	23.760,00
	Polycrystalline	96	23,52	0,70	16.464,00

Source: from author

From the table 18, it can be observed that the monocrystalline is the most expensive technology and the thin film is the cheapest technology. The cost per watt is the same for all sizes, do not observing an economy of scale in the PV modules.

Table 19 - Inverter's contribution in the capex

Investor	PV module	Inverter	Installed Capacity (kW)	Unit Price (€)	Price (€/W)
Residential	CdTe	Sunny Boy	0,94	600,00	0,64
	Monocrystalline	Sunny Boy	0,99	600,00	0,61
	Polycrystalline	Sunny Boy	0,98	600,00	0,61
Small Office	CdTe	PVI5000	5,64	1.880,00	0,33
	Monocrystalline	PVI5000	5,28	1.880,00	0,36
	Polycrystalline	PVI5000	5,88	1.880,00	0,32
Medium Office	CdTe	TRIO 20.00 TL	22,56	4.200,00	0,19
	Monocrystalline	TRIO 20.00 TL	23,76	4.200,00	0,18
	Polycrystalline	TRIO 20.00 TL	23,52	4.200,00	0,18

Source: from author

For the inverters (table 19), it can be observed a strong economy of scale. For the small system, a 1kW inverter (Sunny Boy) costs on average 0,62 euros per installed watt, while for a larger system, a 20kW inverter costs on average 0,18 euros per installed watt.

Table 20 - Wires' contribution in the capex

Investor	PV module	Installed Capacity (kW)	DC Total Cost (€)	AC Total Cost (€)	Total Cost (€)	Total Cost (€/W)
Residential	CdTe	0,94	19,60	21,67	**41,27**	**0,044**
	Monocrystalline	0,99	5,90	21,67	**27,57**	**0,028**
	Polycrystalline	0,98	6,68	21,67	**28,34**	**0,029**
Small Office	CdTe	5,64	117,60	130,00	**247,60**	**0,044**
	Monocrystalline	5,28	31,47	115,56	**147,02**	**0,028**
	Polycrystalline	5,88	40,05	130,00	**170,05**	**0,029**
Medium Office	CdTe	22,56	470,40	520,00	**990,40**	**0,044**
	Monocrystalline	23,76	141,60	520,00	**661,60**	**0,028**
	Polycrystalline	23,52	160,20	520,00	**680,20**	**0,029**

Source: from author

For the wires (table 20), although there is not an economy of scale according to the PV systems size, it can be observed that the layout influences in the cost per watt. The thin film is the technology that requires more modules, and as consequence, the length of wires are bigger.

Table 21 - Protection and Disconnection`s contribution in the capex

Investor	PV module	Installed Capacity (kW)	Total Cost (€)	Total Cost (€/W)
Residential	CdTe	0,94	72,75	0,077
	Monocrystalline	0,99	61,63	0,062
	Polycrystalline	0,98	61,63	0,063
Small Office	CdTe	5,64	436,50	0,077
	Monocrystalline	5,28	328,67	0,062
	Polycrystalline	5,88	369,75	0,063
Medium Office	CdTe	22,56	**1.746,00**	0,077
	Monocrystalline	23,76	**1.479,00**	0,062
	Polycrystalline	23,52	**1.479,00**	0,063

Source: from author

The same behaviour can be seen for the protection and disconnection (table 21): the layout influences in the cost per price. The higher the number of modules the higher is the cost with it.

Table 22- Energy counter and monitoring`s contribution in the capex

Investor	PV module	Installed Capacity (kW)	Total Cost (€)	Total Cost (€/W)
Residential	CdTe	0,94	700	0,74
	Monocrystalline	0,99	700	0,71
	Polycrystalline	0,98	700	0,71
Small Office	CdTe	5,64	1100	0,20
	Monocrystalline	5,28	1100	0,21
	Polycrystalline	5,88	1100	0,19
Medium Office	CdTe	22,56	1100	0,05
	Monocrystalline	23,76	1100	0,05
	Polycrystalline	23,52	1100	0,05

Source: from author

The energy counter and monitoring are fixed costs, therefore, the higher is the installed capacity, the lower is the cost per watt (table 22).

Table 23 – Installation and commissioning`s contribution in the capex

Investor	PV module	Quantity of PV modules	Installed Capacity (kW)	Labour (€)	Structure (€)	Material/Extra (€)	Total Cost (€)	Total Cost (€/W)
Residential	CdTe	8	0,94				545,83	0,58
	Monocrystalline	3	0,99		Non calculated		254,17	0,26
	Polycrystalline	4	0,98				304,17	0,31
Small Office	CdTe	48	5,64				3.275,00	0,58
	Monocrystalline	16	5,28		Non calculated		1.355,56	0,26
	Polycrystalline	24	5,88				1.825,00	0,31
Medium Office	CdTe	192	22,56	3.000,00	9.600,00	500,00	13.100,00	0,58
	Monocrystalline	72	23,76	2.000,00	3.600,00	500,00	6.100,00	0,26
	Polycrystalline	96	23,52	2.000,00	4.800,00	500,00	7.300,00	0,31

Source: from author

The cost of installation (table 23) is proportional to the number of PV modules, therefore although no economy of scale was observed; the different layouts lead to different cost per watt, being the monocrystalline the cheapest one and the thin film the most expensive.

Table 24 - Italy Capex

Investor	PV Technology	Installed Capacity (kW)	PV Module (€/W)	Inverter (€/W)	Wires (€/W)	Protection and Disconnection (€/W)	Energy counter and monitoring (€/W)	Installation and Commisioning (€/W)	Total Capex (€)	Total Capex (€/W)
Residential	CdTe	0,94	564,00	600,00	41,27	72,75	700,00	545,83	**2.523,85**	**2,68**
	Monocrystalline	0,99	990,00	600,00	27,57	61,63	700,00	254,17	**2.633,36**	**2,66**
	Polycrystalline	0,98	686,00	600,00	28,34	61,63	700,00	304,17	**2.380,13**	**2,43**
Small Office	CdTe	5,64	3.384,00	1.880,00	247,60	436,50	1.100,00	3.275,00	**10.323,10**	**1,83**
	Monocrystalline	5,28	5.280,00	1.880,00	147,02	328,67	1.100,00	1.355,56	**10.091,24**	**1,91**
	Polycrystalline	5,88	4.116,00	1.880,00	170,05	369,75	1.100,00	1.825,00	**9.460,80**	**1,61**
Medium Office	CdTe	22,56	13.536,00	4.200,00	990,40	1.746,00	1.100,00	13.100,00	**34.672,40**	**1,54**
	Monocrystalline	23,76	23.760,00	4.200,00	661,60	1.479,00	1.100,00	6.100,00	**37.300,60**	**1,57**
	Polycrystalline	23,52	16.464,00	4.200,00	680,20	1.479,00	1.100,00	7.300,00	**31.223,20**	**1,33**

Source: from author

The table 24 summarizes the cost of all components, showing the capex. A strong economy of scale is observed, as the capex per watt for the medium office investors (around 25kW installed capacity) is lower for the other investors.

The tables 25, 26 and 27 contain the expected production for all the seven Italian cities considered in this study. In northern cities, the production is lower than in southern cities for the same PV system. In addition, the year production is almost the same for the three technologies, being slightly higher for the monocrystalline and slightly lower for the thin film.

Table 25 – Expected Year Production for 1kW system

City	Region	Year Production (kWh)		
		CdTe	Monocrystalline	Polycrystalline
Torino	North	1.319	1.383	1.344
Milano	North	1.247	1.308	1.269
Lucca	North	1.267	1.330	1.288
Rome	Centro	1.417	1.488	1.432
Bari	South	1.443	1.515	1.459
Cagliari	South	1.589	1.666	1.603
Palermo	South	1.508	1.582	1.524

Source: from author

Table 26 – Expected Year Production for 5kW system

City	Region	Year Production (kWh)		
		CdTe	Monocrystalline	Polycrystalline
Torino	North	8.014	7.465	8.165
Milano	North	7.575	7.062	7.708
Lucca	North	7.697	7.180	7.826
Rome	Centro	8.605	8.031	8.696
Bari	South	8.767	8.181	8.860
Cagliari	South	9.648	8.994	9.736
Palermo	South	9.160	8.540	9.257

Source: from author

Table 27 – Expected Year Production for 25kW system

City	Region	Year Production (kWh)		
		CdTe	Monocrystalline	Polycrystalline
Torino	North	32.444	33.999	33.057
Milano	North	30.667	32.163	31.206
Lucca	North	31.164	32.700	31.683
Rome	Centro	34.837	36.577	35.204
Bari	South	35.493	37.262	35.870
Cagliari	South	39.061	40.964	39.414
Palermo	South	37.083	38.895	37.475

Source: from author

The EPPEI (Expected Production per Euro invested) is shown in the tables 28, 29 and 30. There are three main outputs from this analysis: the higher the investment the higher is the EPPEI (which is explained by the economy of scale). Systems in southern cities have higher EPPEI than in northern cities. There is no synergy between the environmental characteristics and the module`s properties, as the polycrystalline (which have the lowest capex per watt) always has the highest EPPEI.

Table 28 - Expected Production per Euro Invested for 1kW system

City	Region	CdTe (kWh/€)	Monocrystalline (kWh/€)	Polycrystalline (kWh/€)
Torino	North	0,523	0,525	**0,565**
Milano	North	0,494	0,497	**0,533**
Lucca	North	0,502	0,505	**0,541**
Rome	Centro	0,561	0,565	**0,602**
Bari	South	0,572	0,575	**0,613**
Cagliari	South	0,629	0,633	**0,673**
Palermo	South	0,598	0,601	**0,640**

Source: from author

Table 29 - Expected Production per Euro Invested for 5kW system

City	Region	CdTe (kWh/€)	Monocrystalline (kWh/€)	Polycrystalline (kWh/€)
Torino	North	0,776	0,740	**0,863**
Milano	North	0,734	0,700	**0,815**
Lucca	North	0,746	0,711	**0,827**
Rome	Centro	0,834	0,796	**0,919**
Bari	South	0,849	0,811	**0,936**
Cagliari	South	0,935	0,891	**1,029**
Palermo	South	0,887	0,846	**0,978**

Source: from author

Table 30 - Expected Production per Euro Invested for 25kW system

City	Region	CdTe (kWh/€)	Monocrystalline (kWh/€)	Polycrystalline (kWh/€)
Torino	North	0,936	0,911	**1,059**
Milano	North	0,884	0,862	**0,999**
Lucca	North	0,899	0,877	**1,015**
Rome	Centro	1,005	0,981	**1,128**
Bari	South	1,024	0,999	**1,149**
Cagliari	South	1,127	1,098	**1,262**
Palermo	South	1,070	1,043	**1,200**

Source: from author

Lastly, an extra analysis comparing this indicator (EPPEI) for the three investors is in the table 31. In the used model, the total production is directly proportional to the installed capacity, therefore all the variation in the EPPEI should be explained by the cost reduction (the economy of scale). The calculation in the table 31 proves it, as the EPPEI is inversely proportional to the capex reduction factor[10] (all the reduction is compared with the value for the residential investor). The Min (kWh/€) and the Max (kWh/€) values correspond to the minimum and maximum, respectively, values of the EPPEI observed in the tables 28, 29, 30[11].

Table 31 - Effect of the economy of scale in the Expected Production per Euro Invested

	Potency (W)	Capex per Watt (€/W)	Min (kWh/€)	Max (kWh/€)	Capex Reduction	(Capex Reduction) $^{-1}$	Min Reduction	Max Reduction
Residential	980	2,43	0,5332	0,6735	-	-	-	-
Small Office	5.880	1,61	0,8147	1,0290	0,66	1,51	1,51	1,51
Medium Office	23.520	1,33	0,9994	1,2623	0,55	1,83	1,83	1,83

Source: from author

4.2 Investment payback in Italy

This subchapter contains the result from the second step of the methodology, showing the investment payback for Italy. Initially, the discounted payback time, the simple payback time (do not considering the opportunity cost of the money), the NPV and the IRR are determined for the seven Italian cities and later a sensitivity analysis is shown. In addition, a detailed analysis is shown for one city in specific.

The table 32 shows the partial cash flow (year 0 to year 10) for a 23,5kW polycrystalline system placed in Palermo city and engaged in the "Scambio sul Posto" service (net metering).

Table 32 - Partial cash flow Italy

Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10
Production Total (kWh)	30.629	30.405	30.183	29.963	29.744	29.527	29.312	29.098	28.885	28.674	28.465
Elec. Self-consumed	17.826	17.696	17.567	17.439	17.311	17.185	17.059	16.935	16.811	16.689	16.567
Elec. Consumed from grid	17.174	17.304	17.433	17.561	17.689	17.815	17.941	18.065	18.189	18.311	18.433
Electricity injected into grid	12.803	12.709	12.617	12.525	12.433	12.342	12.252	12.163	12.074	11.986	11.898
Savings Bill	5.526	5.486	5.446	5.406	5.366	5.327	5.288	5.250	5.211	5.173	5.136
Extra-Savings	2365	2347	2330	2313	2296	2280	2263	2246	2230	2214	2198
Income	0	0	0	0	0	0	0	0	0	0	0
Service Fee	-34	-34	-34	-34	-34	-34	-34	-34	-34	-34	-34
Investment	-31.223	0	0	0	0	0	0	0	0	0	0
O&M	-624	-624	-624	-624	-624	-624	-624	-624	-624	-624	-624

Discounted Payback Time	6
NPV	37.559
IRR	29%
Simple Payback Time	5

Note: Palermo city, 9,85% discount rate; scambio sul posto service; 23,5kW system

Source: from author

10 The capex reduction factor is the economy of scale. It is calculated dividing the capex of the small investor (or medium investor) by the residential investor capex. In example, for the small office case, the capex reduction factor is 0,66, therefore, it is expected the small investor's capex per watt to be 66% of the capex per watt for the residential investor.

11 The Min reduction and the Max reduction are calculated similarly to the capex reduction, with the unique difference that they are the division of the Min and Max instead of the capex.

The table 33 shows the result for all Italian cities. The discount rate considered was 9,85%. From this table it is possible to identify that it is advantageous for the investor to join one of the services, as the payback time is smaller in comparison with the "No service" scenario. Furthermore, the Scambio sul Posto (net metering) is the best service to join as it has the fastest payback.

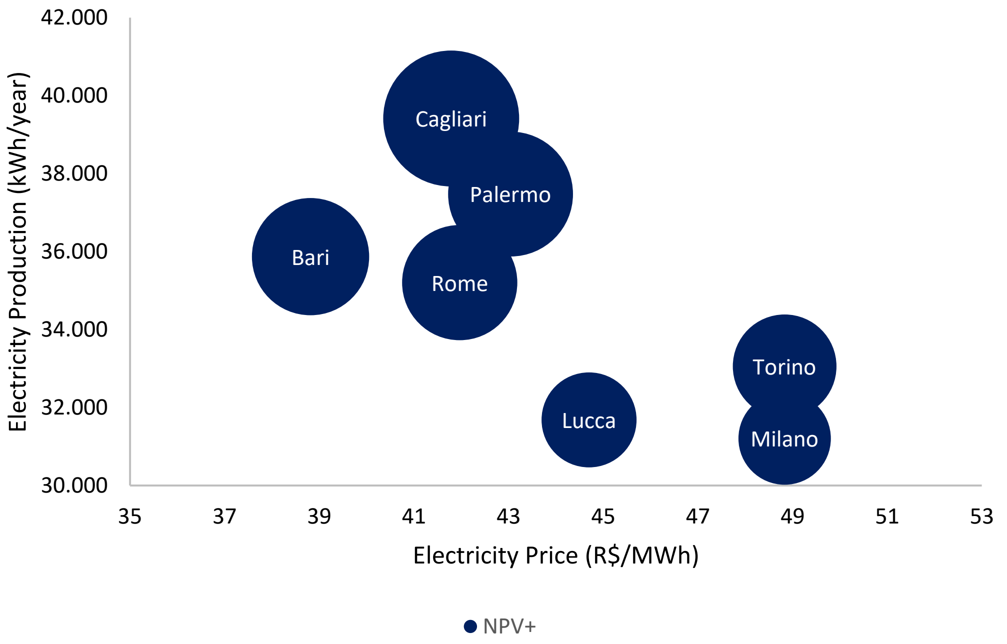
Table 33 - Investment payback for Italy

City	Service	NPV (€)	IRR (%)	Discounted Payback Time (years)	Simple Payback Time (years)
Torino	No Service	17.885	18,2%	8,0	5,8
	Retiro Dedicato	21.429	19,8%	7,3	5,3
	Scambio sul Posto	34.381	25,5%	5,6	4,3
Milano	No Service	14.442	16,6%	9,0	6,0
	Retiro Dedicato	17.780	18,1%	8,0	5,8
	Scambio sul Posto	30.647	23,9%	5,9	4,7
Lucca	No Service	15.294	17,0%	8,8	5,9
	Retiro Dedicato	18.564	18,5%	7,9	5,7
	Scambio sul Posto	31.504	24,3%	5,8	4,6
Rome	No Service	21.827	20,0%	7,2	5,3
	Retiro Dedicato	25.314	21,6%	6,7	4,9
	Scambio sul Posto	38.210	27,4%	5,2	4,1
Bari	No Service	23.095	20,6%	6,9	5,2
	Retiro Dedicato	26.457	22,2%	6,4	4,8
	Scambio sul Posto	38.879	27,6%	5,1	4,0
Cagliari	No Service	28.552	23,2%	6,2	4,7
	Retiro Dedicato	32.539	25,0%	5,7	4,4
	Scambio sul Posto	45.079	30,5%	4,7	3,8
Palermo	No Service	23.918	21,0%	6,8	5,0
	Retiro Dedicato	27.950	22,9%	6,2	4,8
	Scambio sul Posto	41.411	28,8%	4,9	3,9

Source: from author

The figure 14, shows how the electricity price (axis x) and the electricity production (axis y) impacts on the NPV (size of the bubbles). Both of them impacts positively in the NPV, showing the direction of the increase: the higher the production, or the electricity price, the higher would be the NPV.

Figure 14 - Influence of electricity price and production on the NPV - Italy



Source: from author

The table 34 and the figures 15, 16 and 17 detail the investment payback for Palermo city. From the table 3x, joining the net metering service (Scambio sul Posto) is the best option for the investor. The payback can be either between 4 and 7 years, depending on the service joined and if the time value of the money is considered in the valuation (i.e. if the simple payback time is used instead of the discounted payback time).

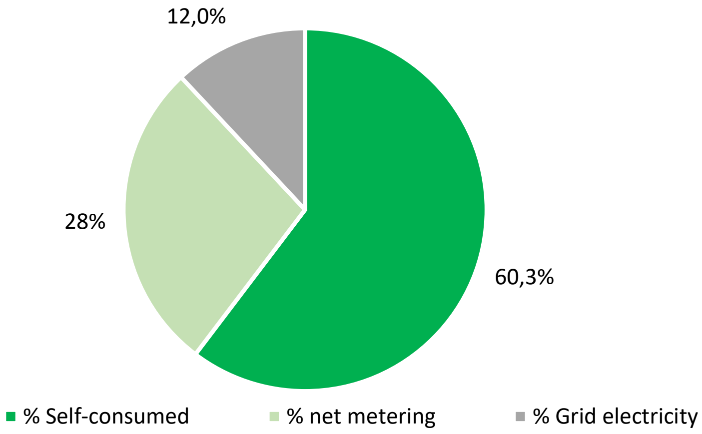
Table 34 - Investment payback for Palermo city

Palermo	No Service	23.918	21,0%	6,8	5,0
	Retiro Dedicato	27.950	22,9%	6,2	4,8
	Scambio sul Posto	41.411	28,8%	4,9	3,9

Note: Palermo city, 9,85% discount rate; scambio sul posto service; 23,5kW system

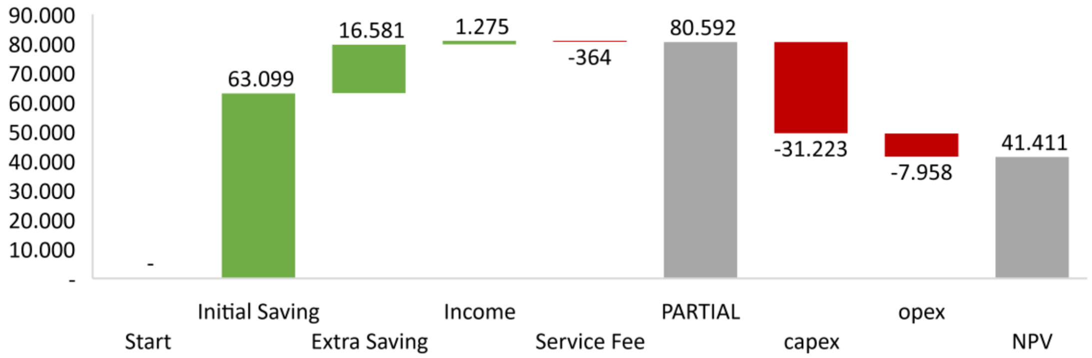
Source: from author

Figure 15 - Sources of the consumed electricity – Palermo



Source: from author

Figure 16 - Detailed cash flow for Scambio sul Posto service

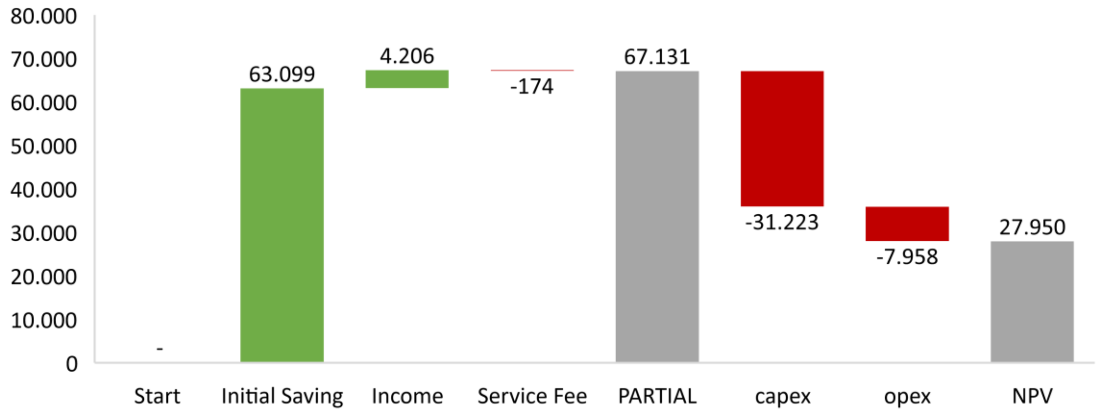


Note: Palermo city, 9,85% discount rate; scambio sul posto service; 23,5kW system

Source: from author

The figure 15 allows understand how the net metering service allows an increase in the consumption of photovoltaic electricity. If no service was engaged, the PV system would be able to provide 60,3% of the total electricity consumed, however, the net metering service allows an increase to 88% the share of photovoltaic electricity consumed. This extra consumption is seen in the figure 16, in the Extra Saving bar, while the initial saving corresponds to the 60,3% from the self-consumption.

Figure 17 - Detailed cash flow for Ritiro Dedicato



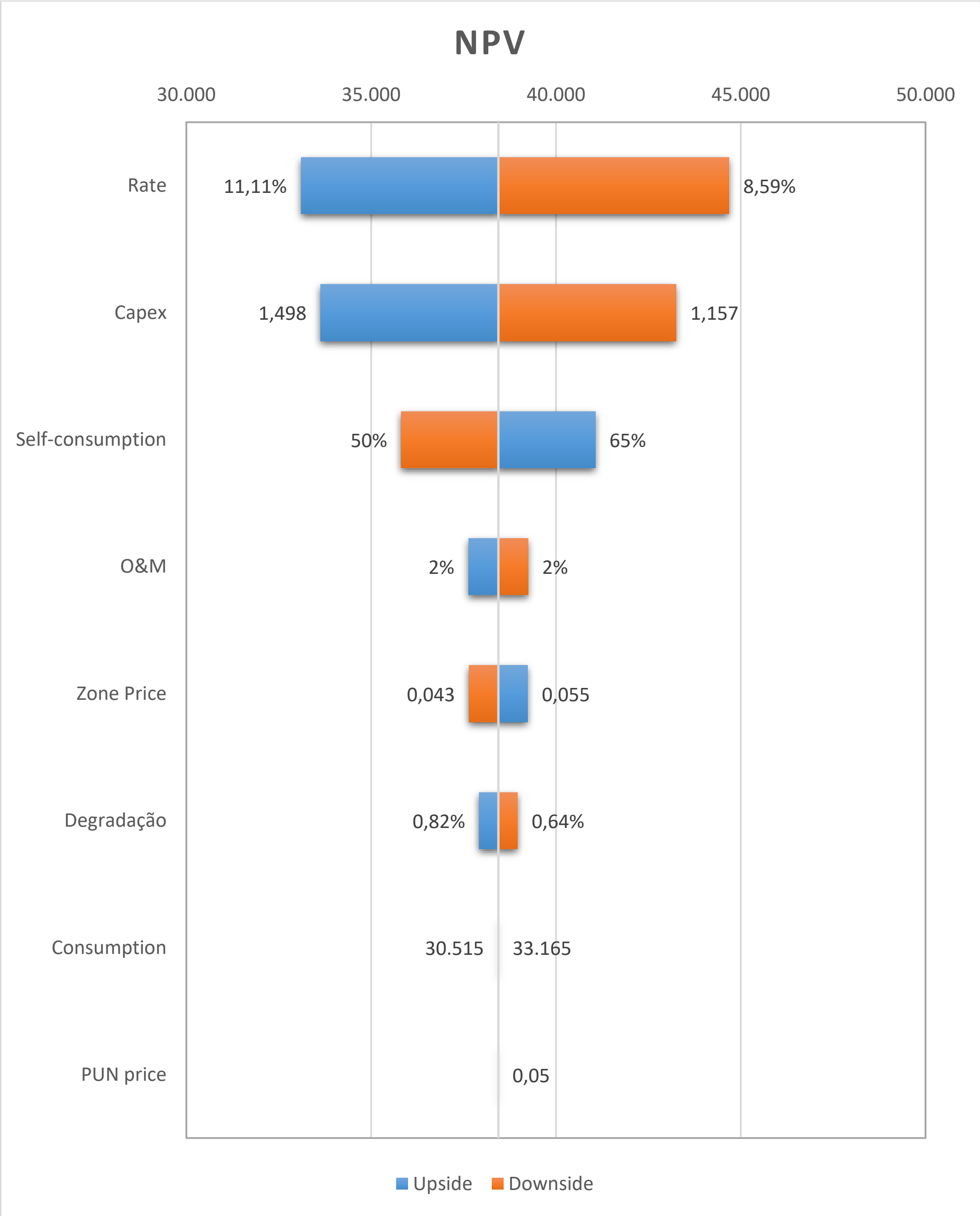
Note: Palermo city, 9,85% discount rate; ritiro dedicato; 23,5kW system

Source: from author

The figure 17 contains a drill down of the NPV for the case where the investor joins the Ritiro Dedicato service. The initial saving is the same in the Scambio sul Posto service (as it is from the self-consumed electricity); however, the income generated is lower than the extra saving that the net metering service allows.

The figure 18 shows how some variables influences the NPV. The discount rate and the capex are the two variables that have a bigger influence on the NPV and any reduction on them can generate a significant increase in the NPV. The self-consumption, on the other hand, has an inverse impact in the NPV: an increase on it generates an increase on the NPV.

Figure 18 - Variables` influence in the investment return - Italy



Note: Torino city, 9,85% discount rate; scambio sul posto service; 23,5kW system

Source: from author

4.3 Investment payback in Brazil

This subchapter contains the result from the third step of the methodology, showing the investment payback for Brazil. Initially, the discounted payback time, the simple payback time (do not considering the opportunity cost of the money), the NPV and the IRR are determined for the seven Brazilian cities and later a sensitivity analysis is shown. In addition, a detailed analysis is shown for one city in specific.

The table 35 contains the partial cash flow for Recife city, considering a 23,5kW polycrystalline system engaged in the net metering service ("Sistema de Compensação de Energia Elétrica"). The positives and negatives flows were calculated based on the production and were bring to their present value dividing them by the discount factor (the rate used is 10,66% according to the methodology defined by ANEEL (2014). This cash flow allows the paybacks, NPV and IRR calculation.

Table 35 - Partial cash flow Brazil

Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8
Production Total (kWh)	34.190	33.940	33.693	33.447	33.203	32.960	32.720	32.481	32.244
Elec. Self-consumed	18.805	18.667	18.531	18.396	18.261	18.128	17.996	17.864	17.734
Elec. Consumed from grid	16.196	16.333	16.469	16.604	16.739	16.872	17.004	17.136	17.266
Elec. Injected	15.386	15.273	15.162	15.051	14.941	14.832	14.724	14.616	14.510
Self-Consumption Saving	13.292	13.195	13.098	13.003	12.908	12.814	12.720	12.627	12.535
Service Saving	10.875	10.796	10.717	10.639	10.561	10.484	10.407	10.331	10.256
Bill expense	0	0	0	0	0	0	0	0	0
Investment	-147.614	0	0	0	0	0	0	0	0
O&M	-2.952	-2.952	-2.952	-2.952	-2.952	-2.952	-2.952	-2.952	-2.952
Net	-126.400	21.038	20.863	20.689	20.516	20.345	20.175	20.006	19.839
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483
PV	-126.400	19.012	17.038	15.268	13.683	12.262	10.988	9.847	8.824
PV ACC	-126.400	-107.388	-90.350	-75.082	-61.399	-49.137	-38.149	-28.302	-19.478

Discounted Payback Time	**11**
NPV	**43.458**
IRR	**15,37%**
Simple Payback Time	**7**

Source: from author

The table 36 summarizes the results obtained for all the seven Brazilian cities. Considering the time value of the money, for all cities the investment is only economic feasible if the investor joins the net metering service ("Sistema de Compensação") and even so, for São Paulo city, the investment is still not profitable.

Although joining the net metering service increases the return of the investment, the payback time is still high, reaching more than ten years if considering the time value of the money, or around eight years if do not considering it.

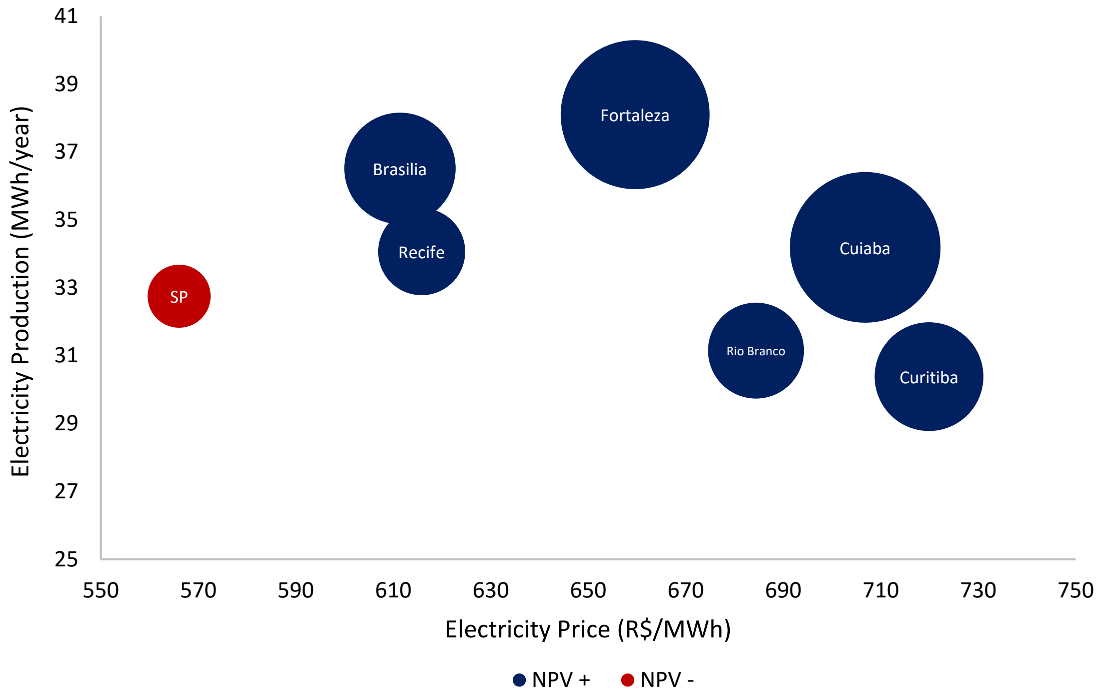
Table 36 - Investment payback for Brazil

City	Service	NPV (R$)	IRR (%)	Discounted Payback Time (year)	Simple Payback Time (year)
Brasilia	No Service	-64.410	3,3%	-	18
	Sistema de Compensação	23.748	13,2%	16	9
Cuiaba	No Service	-55.222	4,4%	-	16
	Sistema de Compensação	43.458	15,4%	12	8
Curitiba	No Service	-66.669	3,0%	-	18
	Sistema de Compensação	22.645	13,1%	16	9
Fortaleza	No Service	-50.406	5,0%	-	15
	Sistema de Compensação	42.471	15,1%	13	8
Recife	No Service	-71.143	2,4%	-	19
	Sistema de Compensação	14.510	12,2%	18	9
Rio Branco	No Service	-69.435	2,6%	-	19
	Sistema de Compensação	17.615	12,6%	17	9
São Paulo	No Service	-83.306	0,7%	-	23
	Sistema de Compensação	-7.605	9,8%	-	10

Source: from author

The figure 19 shows the influence of the electricity price (axis x) and the electricity production (axis y) on the NPV (size of the bubbles). It can be observed that both the electricity price and the amount of electricity produced increase the profitability of the investment. The irradiance level is the variable that determines the production (as the same system was placed in different cities, the environmental characteristics – majorly irradiation and temperature – determine the production level), therefore, not necessarily cities with more irradiation have higher profitability; the mix of irradiation and electricity price that are going to determine the investment payback.

Figure 19 - Partial cash flow Brazil



Source: from author

The table 37 and the figures 20 and 21 detail the investment payback for Fortaleza city. From the table 37, joining the net metering service is the best option for the city, having a payback time of twelve years if considering the time value of the money, or seven years if not. The figure 20 shows the sources of the consumed during the all investment (25 years) and the figure 21 details the NPV of the investment, showing the present value of each flow and how they compound the net value.

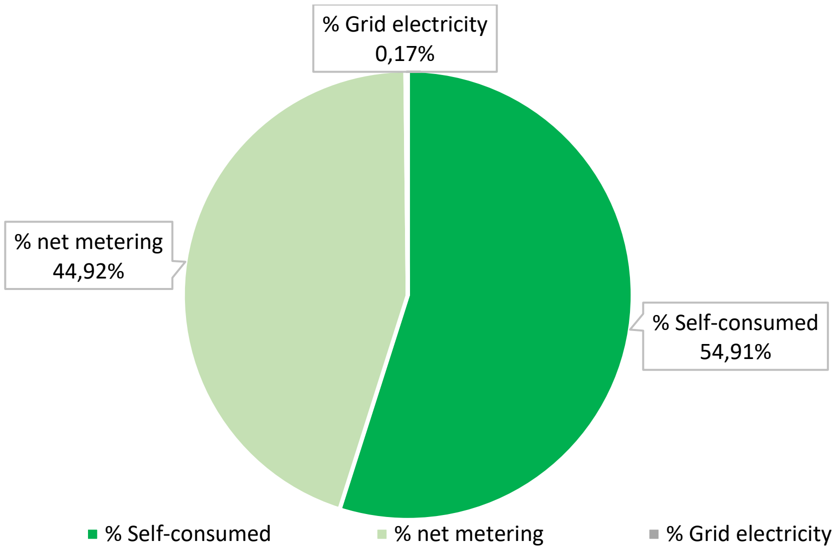
Table 37 - Investment payback for Fortaleza city

Fortaleza	No Service	-50.406	5,0%	-	15
	Sistema de Compensação	42.471	15,1%	13	8

Source: from author

Together (figures 20 and 21) they allow understanding the influence that the net metering service has on the investment payback: the net metering service allows an increase in the quantity of electricity consumed from the PV system, increasing the saving. In other words, the immediately self-consumption corresponds only to 54,91% of the total electricity consumed; if there was not this service, the consumer would be billed for the other 45,09% taken from the grid. However, with this service, the consumer can offset the amount inject (the electricity that is not consumed immediately, the production surplus) from the electricity bill, which correspond to 44,92% of the total consumption (generating an extra saving with present value of R$93.359,00), reducing the bill for just 0,17% of the total consumption.

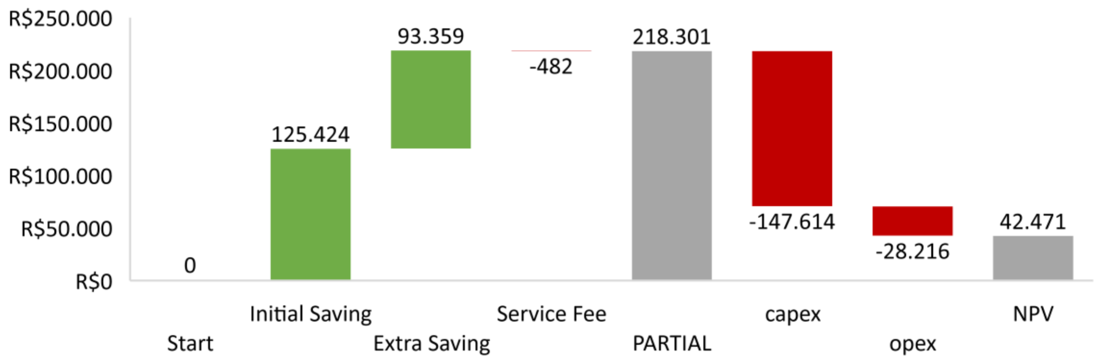
Figure 20 - Sources of the consumed electricity - Fortaleza



Note: Fortaleza city, 10,6% discount rate; net metering service; 23,5kW system

Source: from author

Figure 21 - Detailed cash flow for Sisteme de Compensação



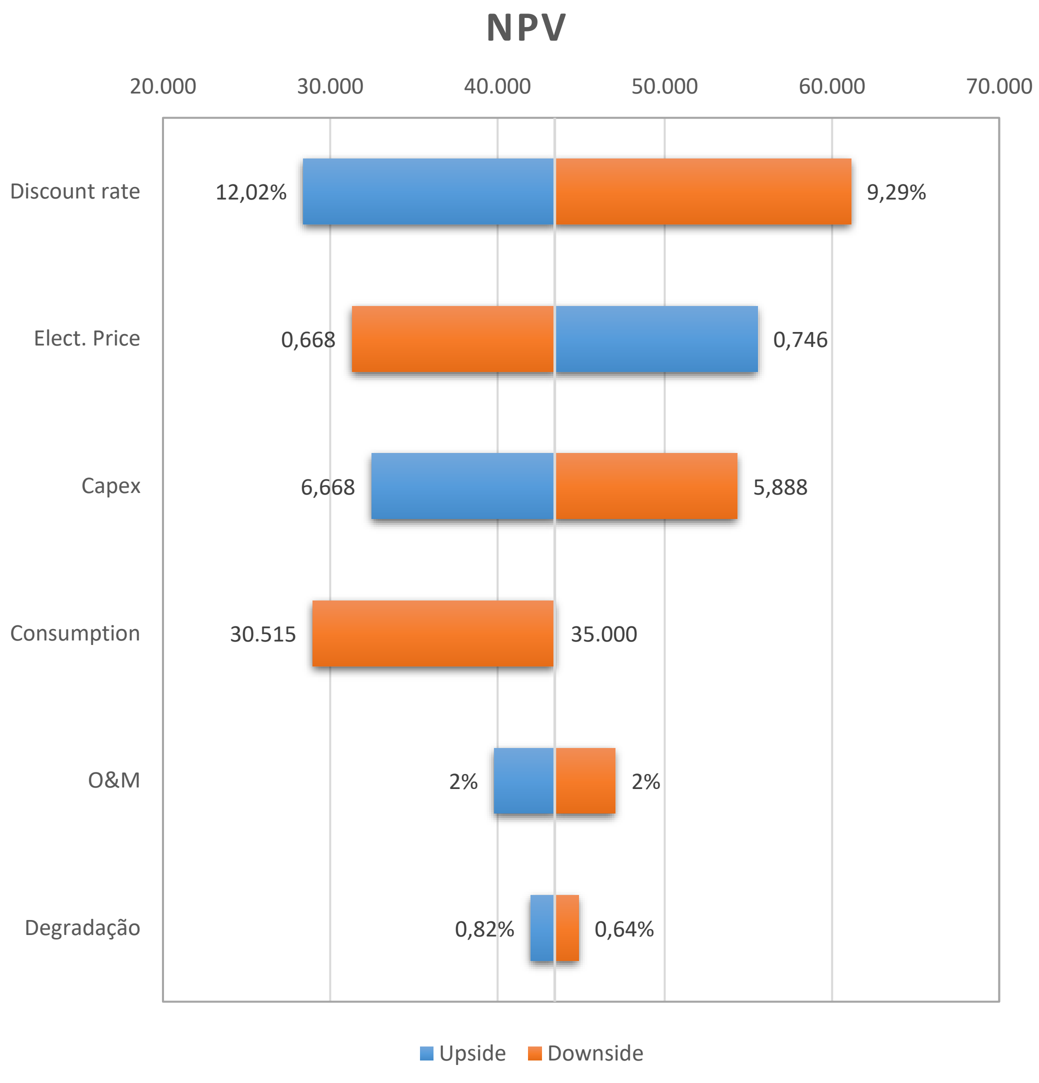
Note: Fortaleza city, 10,6% discount rate; net metering service; 23,5kW system

Source: from author

Lastly, the figure 22, illustrates the result obtained from the simulation of the Brazilian investment. The blue bar indicates an increase in the variable, while the orange bar indicates a decrease. The discount rate, the electricity price, the capex and the electricity consumption are the variables that most explain the variability of the investment.

An increase in the electricity price makes the investment more attractive, an increase in the discount rate or in the capex make the investment less attractive. The consumption, for its time, has an interesting behaviour: although a decrease on it decrease the NPV of the investment, an increase does not make the NPV bigger. This behaviour is explained by the fact that the consumption of the photovoltaic electricity is limited by the production, therefore, even consuming more there is a cap of consumption given by the PV system production.

Figure 22 - Variables` influence in the investment return - Brazil



Note: Curitiba city, 10,6% discount rate; net metering service; 23,5kW system

Source: from author

5 DISCUSSION

This chapter discusses the results obtained and showed in the chapter four of this study; the discussion follows the order of figures and tables presented in result chapter, initially commenting the finds of the preliminary analysis; after, the diagnostic for Italy and Brazil PV micro-generation and finally a comparison between both countries.

The area constraint is an important variable to consider when dimensioning a PV system. Although this study does not consider any area limitation, from the tables 15, 16 and 17, it is possible to observe how different technologies require different areas: the monocrystalline is the option that demands the smallest area, while the polycrystalline demands the biggest area. The module efficiency is the technical characteristic that correlates area and production: the more efficient is the energy conversion, the bigger is the electricity produced, given the same area.

The efficiency is calculated dividing the module`s peak potency by the module`s area and by a thousand (the reference irradiance used to calculate the peak potency). Using the information present in table 4, efficiencies of 16,3%, 14,9% and 19,7% are obtained for the thin film, polycrystalline and monocrystalline respectively.

In situations where there is no area limitation (i.e. there is enough space to place the desired PV system without any shadows), the PV module`s efficiency do not affect the production, as more modules can be installed. However, if area is a constraint, the PV module`s efficiency can be a good proxy for selecting the PV technology, once more efficient modules can lead to a bigger production.

Usually, the micro-generation investors are persons motivated either by environmental (e.g. reduction in emission), financial (e.g. savings) and social (e.g. status) aspect of the investment, do not targeting income generation (BALCOMBRE; RIGBY; AZAPAGIC, 2013). Therefore, the systems are placed in the investor’s properties (not in designated area as for the larger system) and in some case, there will be any kind of area constraint, especially in big cities where the number of high building is elevated.

As this study focuses on the economic aspect of the investment, it assumes no area limitation and uses the EPPEI (year production divided by capex) as proxy to select the PV technology.

For Italy, this study considered six components to compose the capex (as shown in tables 18 to 23 and summarized in figure 24). Isolated analysing the components, three behaviours are observed:

a) Fixed cost per watt among all investment scenarios – observed for PV module cost, which has the selling price constant for the three investors;
b) Decreasing cost per watt according installed capacity (economy of scale) – observed for inverter and energy counter and monitoring. The energy counter and monitoring are fixed costs that are prorated. The inverter presents strong economy of scale (1 kW costs 600 euros, while 5 kW costs 1.880 euros and a 20 kW costs 4.200 euros);
c) Different cost per watt according the technology – observed for the wires, installation and commissioning and disconnection and protection. The layout (number of modules, strings and positions) influences it, explaining the difference.

An important take away from these analyses is that not necessarily the cheapest PV module results in the lowest capex. The PV modules are responsible for the majority of the investment, however, this study identified the thin film module as the lowest market price (0,60 euros per watt), but the polycrystalline (0,70 euros per watt) was the one with lowest capex per watt.

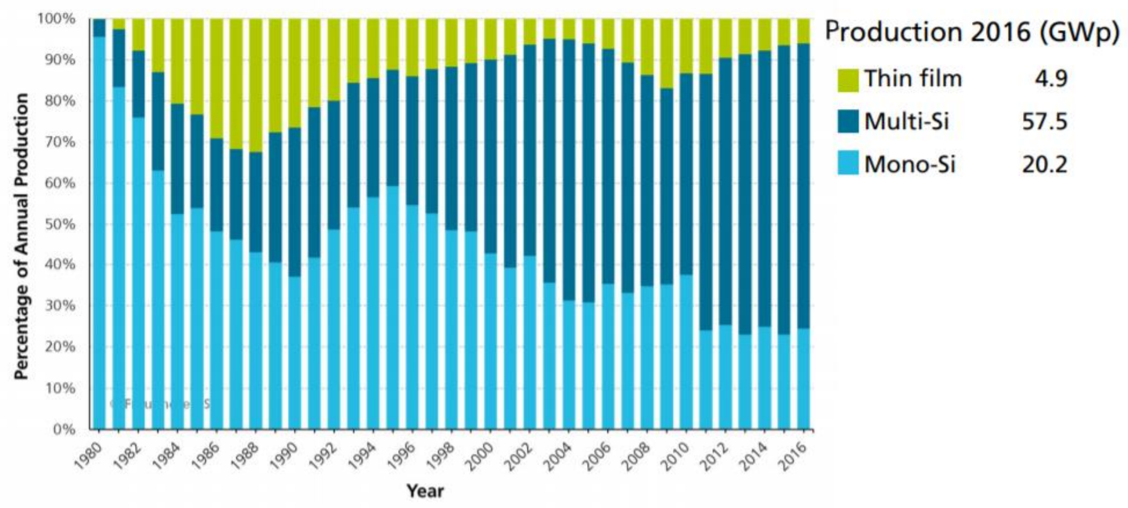
Different PV technologies generate electricity at diverse voltage and amperage. The voltage determines the minimum and maximum quantity of PV modules per string (the higher the voltage, less modules are connected in series, resulting in less modules per string), while the amperage determines the quantity of parallel strings that can be connected in the inverter.

The monocrystalline module and the polycrystalline module have similar output current (58v and 5,7A; 30,7v; and 7,89A; respectively), however the thin film module produces a current in higher voltage with lower amperage (71,2 volts and 1,65 amperes). Therefore, the string size for the thin film is shorter than for the monocrystalline and polycrystalline. Although this characteristic isolated could not be a problem, it is aggravated when coupled with the required number of modules in the system.

The peak capacity of the thin film is 117,5 watts, while the monocrystalline is 330 watts and the polycrystalline is 245 watts. Given the same installed capacity, more modules are required for the thin film (tables 15, 16r and 17); therefore, not only the thin film can support less modules per string, but also much more modules are required, which significantly increase the costs with structure, labour, protection and disconnection, resulting in higher capex.

The figure 23 shows the share evolution of each “big group” of PV technology. Mono-Si contains the monocrystalline technology, while the polycrystalline is contained in the Multi-Si and the Thin Film contains the CdTe (which has the biggest share in this group (FRAUNHOFER, 2017)).

Figure 23 PV production by technology



Source: Fraunhofer (2017)

The capex result obtained for Italy explains the preference for the Multi-Si modules (polycrystalline), which offers the lowest capex per watt. Furthermore, the high voltage of the CdTe technology, that leads to difficulty in dimensioning and designing the PV systems, coupled with the elevate capex per watt can explain it small share.

Finally, the Mono-Si has the second biggest share (more than 20%), showing its preference over the thin film modules (5%). The capex obtained for both technologies are similar (1,54 euros per watt and 1,57 euros per watt, for the CdTe and monocrystalline respectively), being not able to justify this preference. Therefore, the modules` efficiency can explain it: in situation with area limitation (i.e. small rooftop for the desired capacity), the investor prefers the monocrystalline to the CdTe modules, as the electricity production is bigger, given the same area (16,3% and 19,7%; efficiency for the CdTe and monocrystalline respectively).

The capex difference between PV technologies is not the unique output observed in during the capex calculation. In table 24, a strong economy of scale was identified: the higher the installed capacity, the lower is the capex per watt. For the 1kW system, a calculated capex per watt was 2,43 €/W and for the 25kW system it was 1,33 €/W (values from the polycrystalline systems), resulting in a difference of approximately 1,10€/W. The energy counter and monitoring (table 22) explains approximately 0,66€/W economy while the inverter (table 19) explains the other 0,47€/W.

The figure 24 shows the average price for installing PV systems in Brazil (data from January 2017). The higher the installed capacity of the PV system, the lower is the capex per watt, showing the same economy of scale.

Figure 24 - Capex reduction in Brazil

Source: adapted from GRENNER (2017)

The economy of scale can also be observed in the EPPEI (EPPEI values present in tables 28, 29 and 30). The table 31 compares the difference in the EPPEI for the three investors. As in the model used, the total production is directly proportional to the installed capacity, the cost reduction (economy of scale) explains all the variation in the EPPEI.

The EPPEI (from author) was the indicator used to assess the cost-benefit between production and capex. The most used indicator is the levelized cost of electricity (LCOE), calculated dividing all costs associate to the production by the electricity production. EPPEI is similar to the LCOE (one is almost the inverse of the other), however, in the former the opex is not included. During all the study, the opex was assume to be 2% of the capex; therefore, one indictor can substitute the other. Larger PV systems benefits from the lower capex per watt and become more attractive to investment.

When comparing different sizes of systems, the EPPEI gets bigger according the increase in installed capacity, denoting that larger systems are expected to be more profitable than smaller ones (tables 28, 29 and 30). In addition, it is possible to observe that the environment influence on the EPPEI. The hotter the city (more irradiance), the bigger is the production and, given the same capex, the bigger is the EPPEI. The three sizes of investment (1kW, 5kW and 25kW) prove this behaviour.

When analysing the investment payback for the Italian cities (table 33), it gets evident that the southern cities have a lower payback time when comparing with the northern cities. A PV system in Palermo or Cagliari are expected to be more profitable than a PV system in Torino or Milano and this difference is majorly due to the difference in irradiance and the different electricity zone price (that will impact in the valuation of the saving).

The figure 14 correlates the investment return (measured as the NPV) with the electricity production and the electricity zonal price. Both variables have a positive influence on the NPV, proving that higher irradiance generates more production, therefore, enlarging the amount of electricity saved; and the higher the electricity cost, higher is the valuation of the saving.

As example, Lucca, Torino and Milano (all cities in north) have a similar production level, however, different electricity zone prices (being Lucca the city with lowest zonal price), which explains the bigger NPV for Torino and Milano. Lastly, Cagliari and Roma are another example of how the production level enlarges the NPV: although they have similar electricity price, the difference in the PNV is cause by the increase in production.

The consumption turned to be a key component of the investment payback. Analysing payback time for the different incentives (table 33), the net metering service ("Scambio sul Posto") is the best option for the micro-investor, as has the lowest payback time.

In Italy, all investment scenarios are economic feasible, achieving a payback time before the lifetime of the PV system. In fact, even if do not joining any service, it is expected a payback time around 9 years for northern cities and 7 years for the southern cities, considering a discount rate of 9,85%, or 6 and 4 if do not considering the time value of the money.

This study did not assessed how the decision process for investing was made: the discount rate that investors use as opportunity cost. Because of it, both the simple payback time (discount rate equals to zero) and the discounted payback time (using a rate equals to the risk-free plus market premium and country risk (ANELL, 2014)) were calculated. These two payback times are used to identify the range for the investment payback time, in order to consider any rate used by the investors during decision make process. Hypothetically, case a household investor decides to use hers interest rate for investment at bank as the discount rate, it is high probably that this rate is lower than the discounted rate used and the payback time for this investor will be inside the calculated range.

Both the Italian governmental services ("Scambio sul Posto" and "Ritiro Dedicato") play an important role for making the PV investment more attractive. The principal benefit from joining a service is to have a destination for the electricity not immediately self-consumed (electricity surplus). The immediately consumed electricity corresponds approximately to 60% of the produced electricity, and the rest injected into the grid.

The "Scambio sul Posto" is a net metering incentive that allows the use of the grid as a battery, "stoking" the electricity surplus on it to offset from the electricity bills. In reality, the amount of electricity injected is valuated and the equivalent in terms of money is given as credit for the producer that can use it to offset the future electricity bills. The figure 15 shows the increment on the electricity consumption that this service allows, and the figure 16 shows its contribution to the investment NPV.

The "Ritiro Dedicato" allows the generation of an income flow for the injected electricity. The figure 17 shows the contribution of each flow in the NPV of the investment. The amount immediately consumed corresponds to the initial saving and the adjacent bar shows the extra income associated to the selling of the electricity surplus to the utility company.

Comparing both services, the saving contribution is more significant than the income of selling the produced electricity. In Italy, one kWh immediately consumed generates a saving of around 0,31 euros (price charged on the electricity bill). One kWh offset from the bill generates through the net metering system generates a saving of around 0,18 euros (approximately, the cost for transmission of the electricity – "Corrispettivo forfettario" 0,14 euros – plus the electricity cost – 0,04 euros) and one kWh sold generates an income around euros 0,04 euros (electricity cost).

The "Scambio sul Posto" is a better option than "Ritiro Dedicato", considering the micro-generation, as it allows complementing the consumption without having to expand the system's capacity. The cost of one kWh is higher if offset than if sold, however, the consumption level creates an upper limit to the use of this incentive.

The "Ritiro Dedicato" is the best option for larger systems, where the system`s production is much bigger than the consumption. Usually, these systems are not inside the micro-generation (measured in MW) and their investors are aiming the income generation.

Lastly, the simulation analysis (figure 18) allows concluding most point discussed so far: the capex reduction as the main driver for increasing profitability, the impact of the discount rate in assessing the investment, the preference for self-consuming the electricity (an increase in the self-consumption rate increases the investment profitability) and the upper limit of the net metering benefit that the consumption level imposes.

Others variables, such as opex, degradation, electricity price and module`s degradation have smaller impact on the system`s profitability, making evident that the electricity price volatility in Italy is not a risk for the investment.

When comparing with Brazil, the scenario is very different. The table 36 summarizes the investment payback. Considering the time value of the money, only if the invertor joins the Brazilian net metering incentive is that the investment is economic feasible. Even so, the payback time is almost two times the Italian payback time and for São Paulo city, the investment is still unfeasible.

Do not considering the cost of opportunity of the capital, the payback time are around 19/20 years and it goes down to 8 years if engaged in the net metering service. It is evident the difference in the Brazilian payback time, which is larger when comparing with the Italian.

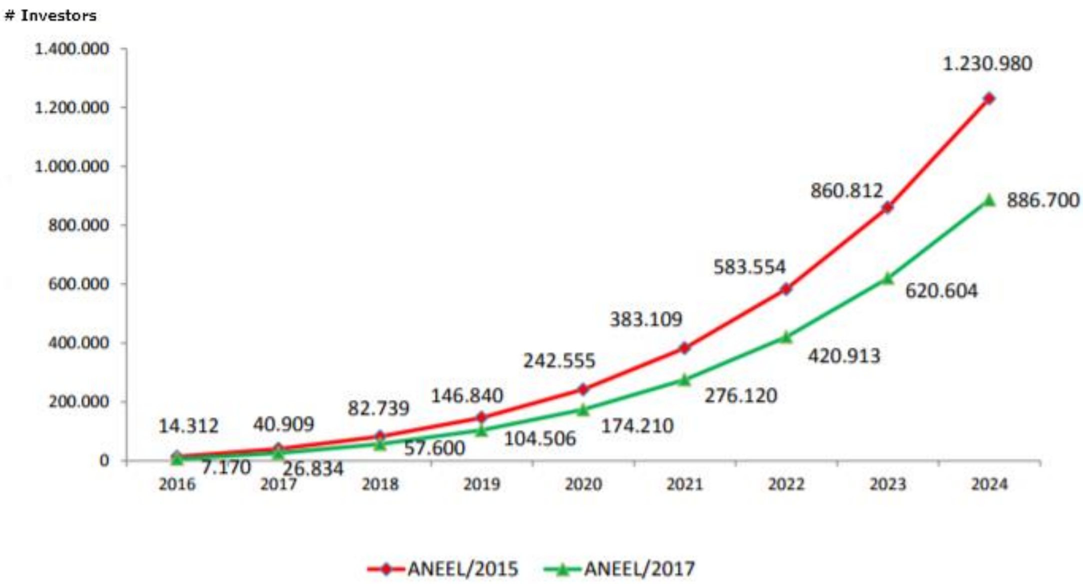
The figure 19 shows the influence that the electricity price and electricity production have on the investment return (NPV). The same behaviour observed for Italy (figure 14) is observed here: the electricity production and the electricity price as determinants to profitability. As example, Cuiaba and Recife have similar electricity production, however, the NPV for Cuiaba is bigger than Refice`s NPV due to the high electricity price in Cuiaba. This price difference makes the valuation of the saving bigger, which directly impacts in the investment return,

In all, it is important to consider the mix between irradiance (that determines the production level) and electricity cost, when considering a region to place a micro-generation PV system.

When analysing the incentive (figures 20 and 21), the Brazilian net metering achieves its objective: it allows an increase in the consumption by letting the injection of the electricity surplus into grid and given a credit to the producer. This credit generates an extra saving, that coupled with the saving from self-consumption, make the investment economic feasible.

Although the net metering incentive works, it does not mean that the Brazilian PV market is stablished and there is not any improvement to occur. The figure 25 shows the comparison between the ANEEL`s projection for micro-generation made in 2015 and 2017. There is a reduction in the projections, demonstrating that less investors are interesting in investing. The elevate payback time (table 36) can be an explanation for this shift.

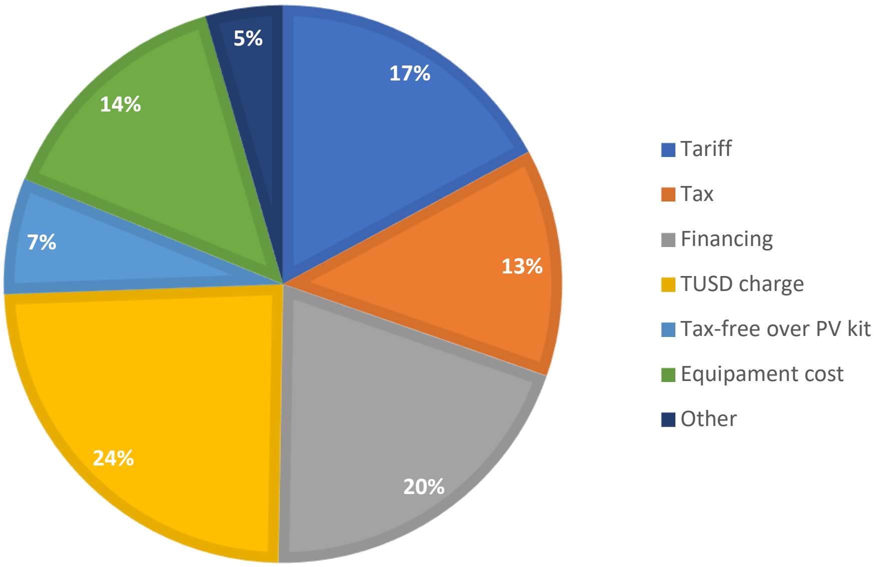
Figure 25 - ANEEL projection for micro-generation



Source: ANEEL (2017)

In addition, the figure 26 contains the result of a survey conducted in April 2017 in among Brazilian investor in PV, showing the main uncertainty about the PV market in Brazil. This survey identified that most investor are unsatisfied with the PV market (59%), fact that explain the reduction in the projection curve. This dissatisfaction is associated to the high risk that the investors have to deal with, majorly associated to the high upfront investment and regulatory uncertainty.

Figure 26 - Principal risk for the Brazilian PV market



Source: GREENER (2017)

Therefore, although the net metering incentive is adequate, the high risks repel investors (as identified in the shift in figure 25), that are not willing to take them. The hypothesis that the micro-generation investors is not an expert in photovoltaic generation, being a regular person, moved by any motivation (environmental, social, financial (BALCOMBRE; RIGBY; AZAPAGIC, 2013)), that desires to install a PV system at her house or office helps in explaining the market growth, besides all uncertainty, risks and high payback time.

The simulation analyse (figure 22) allows identifying the capex as the principal driver for governmental action to reduce the payback time. The high upfront capital is a huge barrier that should addressed by governmental actions.

The table 38 shows how the payback time in Brazil would reduce case the same Italian capex per watt were used in Brazil. Both payback times would be reduce, achieving results closer to the Italian, appointing that a policy focused on taxes reduction could be effective for spurring the PV micro-generation in Brazil.

Table 38 – Impact of a capex reduction in Brazil

		With atual capex		With Italian capex	
City	Service	Simple Payback Time (year)	Discounted Payback Time (year)	Simple Payback Time (year)	Discounted Payback Time (year)
Brasilia	No Service	18	-	13	-
	Sistema de Compensação	9	16	7	10
Cuiaba	No Service	16	-	12	-
	Sistema de Compensação	8	12	6	8
Curitiba	No Service	18	-	14	-
	Sistema de Compensação	9	16	7	10
Fortaleza	No Service	15	-	12	-
	Sistema de Compensação	8	13	6	9
Recife	No Service	19	-	15	-
	Sistema de Compensação	9	18	7	11
Rio Branco	No Service	19	-	14	-
	Sistema de Compensação	9	17	7	10
São Paulo	No Service	23	-	17	-
	Sistema de Compensação	10	-	8	14

Source: from author

Finally, as identified for Italy, the net metering incentive has an upper limit of enjoyment, which is the consumption level. For large PV systems (where the produced electricity is much higher than the electricity consumption), or for systems that aim the income generation, there is no incentive to spur them, being another issue to be addressed by governmental policies.

6 CONCLUSIONS

This study aimed at assessing the economic feasibility of photovoltaic micro-generation in Italy and Brazil, drawing a comparison between both countries. To address this question, several activities were developed, encompassing many engineering areas: dimensioning and design (to select the investment), financial engineering (to assess the investment) and simulation (to understand the uncertainties); requiring the use of some engineering software: AUTOCAD 2013, PVSYST V6.38 and Crystal Ball.

At the end of this study, a diagnostic about the photovoltaic market in Italy and Brazil, (emphasising the micro-generation) was made, allowing a comparison between them and making possible the exchange of the individual experiences.

Italy has a well-developed PV market, with more than fifteen years of public incentives for spurring the photovoltaic electricity generation. During it history, a few incentives were adopted, some being a success (as identified in this study) and others not. Now-a-days, there are two incentives available for new investors: the net-metering, which addresses the demand of the micro-investor; and purchase and resale arrangements, addressed to bigger investors. This study analysed both incentives using the micro-investor perspective and concluded that, in Italy, the net-metering is the best incentive, as it allows lower payback time for the investor.

On the other hand, Brazil has a short history with incentives for photovoltaic; the first incentive in PV generation was five years ago. When analysing it (a net-metering one), the Brazilian payback time is greater than the Italian payback time, being more than the double. This result is aligned with the dissatisfaction mood observed in Brazilian investors and the low growth of the PV market.

Hardly an investor that aims profitability will invest in a risk investment, with high payback time and low level of profit. One hypothesis arose is that some micro-investors are moved by the environmental (or social) motivation, therefore, they tend not to consider the cost of opportunity of the money during the decision-make process. This can explain the reason for having investor deciding to install PV systems, although the high payback time.

The bigger is the cost of opportunity of the capital, the bigger is the discount rate and less attractive is the investment, which has larger payback time. This behaviour is associated to the nature of the flows: high upfront capex and continuous and small savings

Finally, the capex was identified as the main driver to improve profitability, through the sensitivity analysis. Future governmental policies should focus on the capex reduction, addressing tax reduction, or any other mechanism, to achieve capex per watt similar to the Italian.

In sum, the Brazilian net metering by itself is a good policy, however only PV systems that aim the self-consumption of the generated electricity can fully benefit from it. The high capex turns the investment less attractive, when comparing with consolidated markets, and is an issue that must be addressed in future. Also, other policies must arise, to encourage different investors, which aim profit generation and not self-consumption, as observed in Italy.

As limitation of this study, only one capital structure was considered (only equity capital). Future studies should test the impact that it has on the investment payback, determining the optimal capital structure. Also, to the incentives were only discussed on the investors perspective, therefore, future studies should focuses in assessing the governmental policies in the society and government point of views.

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APPENDIX A – CASH FLOW FOR BRAZIL

Cash flow for Brasilia city

Brasilia - Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	36.517	36.250	35.986	35.723	35.462	35.203	34.946	34.691	34.438	34.187	33.937	33.689	33.443	33.199	32.957	32.716	32.478	32.240	32.005	31.771	31.540	31.309	31.081	30.854	30.629
Elec. Self-consumed	20.084	19.938	19.792	19.648	19.504	19.362	19.221	19.080	18.941	18.803	18.665	18.529	18.394	18.260	18.126	17.994	17.863	17.732	17.603	17.474	17.347	17.220	17.094	16.970	16.846
Elec. Consumed from grid	14.916	15.062	15.208	15.352	15.496	15.638	15.779	15.920	16.059	16.197	16.335	16.471	16.606	16.740	16.874	17.006	17.137	17.268	17.397	17.526	17.653	17.780	17.906	18.030	18.154
Elec. Injected	16.433	16.313	16.194	16.075	15.958	15.842	15.726	15.611	15.497	15.384	15.272	15.160	15.050	14.940	14.831	14.722	14.615	14.508	14.402	14.297	14.193	14.089	13.986	13.884	13.783
Self-Consumption Saving	12.279	12.189	12.100	12.012	11.924	11.837	11.751	11.665	11.580	11.496	11.412	11.328	11.246	11.164	11.082	11.001	10.921	10.841	10.762	10.683	10.605	10.528	10.451	10.375	10.299
Service Saving	9.119	9.209	9.298	9.386	9.474	9.561	9.614	9.544	9.475	9.405	9.337	9.269	9.201	9.134	9.067	9.001	8.935	8.870	8.805	8.741	8.677	8.614	8.551	8.488	8.427
Bill expense	-61	-61	-61	-61	-61	-61	-28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-101.506	18.928	18.928	18.928	18.928	18.928	18.928	18.801	18.646	18.492	18.340	18.188	18.038	17.889	17.740	17.593	17.447	17.302	17.158	17.016	16.874	16.733	16.593	16.455	16.317
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	-101.506	17.105	15.458	13.969	12.624	11.408	10.309	9.254	8.293	7.433	6.662	5.970	5.351	4.795	4.298	3.851	3.452	3.093	2.772	2.484	2.226	1.995	1.788	1.602	1.436
PV ACC	-101.506	-84.400	-68.943	-54.974	-42.350	-30.942	-20.633	-11.379	-3.086	4.347	11.009	16.979	22.330	27.125	31.423	35.274	38.726	41.819	44.591	47.076	49.302	51.297	53.085	54.687	56.123

Discounted Payback Time	**10**
NPV	**56.123**
IRR	**18,01%**
Simple Payback Time	**7**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

Cash flow for Cuiaba city

Cuiaba - Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	34.190	33.940	33.693	33.447	33.203	32.960	32.720	32.481	32.244	32.008	31.775	31.543	31.312	31.084	30.857	30.632	30.408	30.186	29.966	29.747	29.530	29.314	29.100	28.888	28.677
Elec. Self-consumed	18.805	18.667	18.531	18.396	18.261	18.128	17.996	17.864	17.734	17.605	17.476	17.348	17.222	17.096	16.971	16.847	16.724	16.602	16.481	16.361	16.241	16.123	16.005	15.888	15.772
Elec. Consumed from grid	16.196	16.333	16.469	16.604	16.739	16.872	17.004	17.136	17.266	17.395	17.524	17.652	17.778	17.904	18.029	18.153	18.276	18.398	18.519	18.639	18.759	18.877	18.995	19.112	19.228
Elec. Injected	15.386	15.273	15.162	15.051	14.941	14.832	14.724	14.616	14.510	14.404	14.299	14.194	14.091	13.988	13.886	13.784	13.684	13.584	13.485	13.386	13.288	13.191	13.095	12.999	12.905
Self-Consumption Saving	13.292	13.195	13.098	13.003	12.908	12.814	12.720	12.627	12.535	12.443	12.353	12.262	12.173	12.084	11.996	11.908	11.821	11.735	11.649	11.564	11.480	11.396	11.313	11.230	11.148
Service Saving	10.875	10.796	10.717	10.639	10.561	10.484	10.407	10.331	10.256	10.181	10.107	10.033	9.960	9.887	9.815	9.743	9.672	9.601	9.531	9.462	9.393	9.324	9.256	9.188	9.121
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-98.676	21.582	21.406	21.233	21.060	20.889	20.719	20.550	20.382	20.216	20.051	19.887	19.724	19.562	19.402	19.243	19.085	18.928	18.772	18.617	18.464	18.312	18.160	18.010	17.861
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	-98.676	19.503	17.482	15.670	14.045	12.589	11.284	10.114	9.066	8.126	7.283	6.528	5.851	5.244	4.700	4.213	3.776	3.384	3.033	2.718	2.436	2.183	1.957	1.754	1.572
PV ACC	-98.676	-79.173	-61.692	-46.022	-31.977	-19.387	-8.103	2.011	11.077	19.203	26.486	33.014	38.865	44.109	48.809	53.021	56.797	60.181	63.214	65.932	68.368	70.551	72.508	74.262	75.833

Discounted Payback Time	**8**
NPV	**75.833**
IRR	**20,87%**
Simple Payback Time	**6**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

Cash flow for Curitiba city

Curitiba - Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	30.382	30.160	29.940	29.721	29.505	29.289	29.075	28.863	28.652	28.443	28.236	28.029	27.825	27.622	27.420	27.220	27.021	26.824	26.628	26.434	26.241	26.049	25.859	25.670	25.483
Elec. Self-consumed	16.710	16.588	16.467	16.347	16.227	16.109	15.991	15.875	15.759	15.644	15.530	15.416	15.304	15.192	15.081	14.971	14.862	14.753	14.645	14.539	14.432	14.327	14.222	14.119	14.016
Elec. Consumed from grid	18.290	18.412	18.533	18.653	18.773	18.891	19.009	19.125	19.241	19.356	19.470	19.584	19.696	19.808	19.919	20.029	20.138	20.247	20.355	20.461	20.568	20.673	20.778	20.881	20.984
Elec. Injected	13.672	13.572	13.473	13.375	13.277	13.180	13.084	12.988	12.894	12.799	12.706	12.613	12.521	12.430	12.339	12.249	12.160	12.071	11.983	11.895	11.808	11.722	11.637	11.552	11.467
Self-Consumption Saving	12.030	11.942	11.855	11.769	11.683	11.597	11.513	11.429	11.345	11.262	11.180	11.099	11.018	10.937	10.857	10.778	10.699	10.621	10.544	10.467	10.390	10.314	10.239	10.164	10.090
Service Saving	9.843	9.771	9.700	9.629	9.559	9.489	9.419	9.351	9.282	9.215	9.147	9.081	9.014	8.949	8.883	8.818	8.754	8.690	8.627	8.564	8.501	8.439	8.378	8.316	8.256
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-100.970	19.305	19.146	18.989	18.832	18.677	18.524	18.371	18.219	18.068	17.919	17.771	17.623	17.477	17.332	17.188	17.045	16.903	16.762	16.622	16.483	16.345	16.208	16.072	15.937
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	-100.970	17.445	15.636	14.014	12.560	11.257	10.089	9.042	8.104	7.263	6.509	5.833	5.228	4.685	4.199	3.763	3.372	3.022	2.708	2.427	2.175	1.949	1.746	1.565	1.402
PV ACC	-100.970	-83.525	-67.889	-53.875	-41.315	-30.059	-19.970	-10.928	-2.825	4.438	10.947	16.780	22.008	26.693	30.891	34.654	38.026	41.048	43.756	46.183	48.357	50.306	52.053	53.618	55.020

Discounted Payback Time	**10**
NPV	**55.020**
IRR	**18,00%**
Simple Payback Time	**7**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

Cash flow for Fortaleza city

Fortaleza - Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Production Total (kWh)	38.099	37.821	37.545	37.271	36.999	36.729	36.460	36.194	35.930	35.668	35.407	35.149	34.892
Elec. Self-consumed	20.954	20.801	20.650	20.499	20.349	20.201	20.053	19.907	19.762	19.617	19.474	19.332	19.191
Elec. Consumed from grid	14.046	14.199	14.350	14.501	14.651	14.799	14.947	15.093	15.238	15.383	15.526	15.668	15.809
Elec. Injected	17.145	17.019	16.895	16.772	16.649	16.528	16.407	16.287	16.169	16.050	15.933	15.817	15.702
Self-Consumption Saving	13.822	13.721	13.621	13.522	13.423	13.325	13.228	13.131	13.035	12.940	12.846	12.752	12.659
Service Saving	9.265	9.366	9.466	9.565	9.664	9.762	9.859	9.956	10.052	10.147	10.241	10.335	10.357
Bill expense	-66	-66	-66	-66	-66	-66	-66	-66	-66	-66	-66	-66	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-99.822	20.613	20.613	20.613	20.613	20.613	20.613	20.613	20.613	20.613	20.613	20.613	20.608
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711
PV	-99.822	18.627	16.833	15.212	13.747	12.423	11.227	10.145	9.168	8.285	7.487	6.766	6.113
PV ACC	-99.822	-81.194	-64.361	-49.149	-35.402	-22.979	-11.752	-1.607	7.561	15.847	23.334	30.100	36.213

Year	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	34.638	34.385	34.134	33.885	33.637	33.392	33.148	32.906	32.666	32.427	32.191	31.956
Elec. Self-consumed	19.051	18.912	18.774	18.637	18.500	18.365	18.231	18.098	17.966	17.835	17.705	17.576
Elec. Consumed from grid	15.949	16.088	16.226	16.363	16.500	16.635	16.769	16.902	17.034	17.165	17.295	17.424
Elec. Injected	15.587	15.473	15.360	15.248	15.137	15.026	14.917	14.808	14.700	14.592	14.486	14.380
Self-Consumption Saving	12.567	12.475	12.384	12.293	12.204	12.114	12.026	11.938	11.851	11.765	11.679	11.593
Service Saving	10.282	10.207	10.132	10.058	9.985	9.912	9.840	9.768	9.696	9.626	9.555	9.486
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0
Investment	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	20.440	20.273	20.107	19.943	19.780	19.618	19.457	19.297	19.139	18.982	18.825	18.670
Disc. Factor	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	5.479	4.911	4.402	3.945	3.536	3.169	2.841	2.546	2.282	2.045	1.833	1.643
PV ACC	41.692	46.603	51.005	54.950	58.487	61.656	64.497	67.043	69.325	71.370	73.203	74.846

Discounted Payback Time	**9**
NPV	**74.846**
IRR	**20,33%**
Simple Payback Time	**6**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

Cash flow for Recife city

Recife - Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	34.062	33.813	33.567	33.321	33.078	32.837	32.597	32.359	32.123	31.888	31.656	31.425	31.195	30.967	30.741	30.517	30.294	30.073	29.853	29.636	29.419	29.204	28.991	28.780	28.570
Elec. Self-consumed	18.734	18.597	18.462	18.327	18.193	18.060	17.928	17.797	17.668	17.539	17.411	17.283	17.157	17.032	16.908	16.784	16.662	16.540	16.419	16.300	16.181	16.062	15.945	15.829	15.713
Elec. Consumed from grid	16.266	16.403	16.538	16.673	16.807	16.940	17.072	17.203	17.332	17.461	17.589	17.717	17.843	17.968	18.092	18.216	18.338	18.460	18.581	18.700	18.819	18.938	19.055	19.171	19.287
Elec. Injected	15.328	15.216	15.105	14.995	14.885	14.777	14.669	14.562	14.455	14.350	14.245	14.141	14.038	13.935	13.834	13.733	13.632	13.533	13.434	13.336	13.239	13.142	13.046	12.951	12.856
Self-Consumption Saving	11.537	11.453	11.369	11.286	11.204	11.122	11.041	10.960	10.880	10.801	10.722	10.644	10.566	10.489	10.412	10.336	10.261	10.186	10.112	10.038	9.964	9.892	9.820	9.748	9.677
Service Saving	9.439	9.370	9.302	9.234	9.167	9.100	9.033	8.967	8.902	8.837	8.773	8.708	8.645	8.582	8.519	8.457	8.395	8.334	8.273	8.213	8.153	8.093	8.034	7.976	7.917
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-101.866	18.415	18.263	18.112	17.962	17.813	17.666	17.519	17.374	17.229	17.086	16.943	16.802	16.662	16.523	16.385	16.247	16.111	15.976	15.842	15.709	15.576	15.445	15.315	15.185
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	-101.866	16.641	14.914	13.366	11.979	10.736	9.621	8.623	7.727	6.925	6.206	5.562	4.984	4.467	4.003	3.587	3.214	2.880	2.581	2.313	2.073	1.857	1.664	1.491	1.336
PV ACC	-101.866	-85.225	-70.311	-56.945	-44.966	-34.230	-24.608	-15.986	-8.258	-1.333	4.873	10.435	15.419	19.886	23.888	27.475	30.689	33.570	36.151	38.464	40.536	42.393	44.058	45.549	46.885

Discounted Payback Time	**11**
NPV	**46.885**
IRR	**16,90%**
Simple Payback Time	**7**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

Cash flow for Rio Branco city

Rio Branco - Sistema de Compensação de Energia Elétrica

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Production Total (kWh)	31.148	30.921	30.695	30.471	30.248	30.028	29.808	29.591	29.375	29.160	28.947	28.736	28.526	28.318	28.111	27.906	27.702	27.500	27.299	27.100	26.902	26.706	26.511	26.318	26.125
Elec. Self-consumed	17.131	17.006	16.882	16.759	16.637	16.515	16.395	16.275	16.156	16.038	15.921	15.805	15.690	15.575	15.461	15.348	15.236	15.125	15.015	14.905	14.796	14.688	14.581	14.475	14.369
Elec. Consumed from grid	17.869	17.994	18.118	18.241	18.363	18.485	18.605	18.725	18.844	18.962	19.079	19.195	19.310	19.425	19.539	19.652	19.764	19.875	19.985	20.095	20.204	20.312	20.419	20.525	20.631
Elec. Injected	14.017	13.914	13.813	13.712	13.612	13.512	13.414	13.316	13.219	13.122	13.026	12.931	12.837	12.743	12.650	12.558	12.466	12.375	12.285	12.195	12.106	12.018	11.930	11.843	11.756
Self-Consumption Saving	11.725	11.640	11.555	11.470	11.387	11.303	11.221	11.139	11.058	10.977	10.897	10.817	10.738	10.660	10.582	10.505	10.428	10.352	10.277	10.202	10.127	10.053	9.980	9.907	9.835
Service Saving	9.593	9.523	9.454	9.385	9.316	9.248	9.181	9.114	9.047	8.981	8.916	8.851	8.786	8.722	8.658	8.595	8.532	8.470	8.408	8.347	8.286	8.225	8.165	8.106	8.046
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-101.524	18.754	18.600	18.446	18.294	18.143	17.993	17.844	17.696	17.550	17.404	17.259	17.116	16.973	16.832	16.691	16.552	16.413	16.276	16.140	16.004	15.870	15.736	15.604	15.472
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	-101.524	16.948	15.190	13.613	12.201	10.935	9.800	8.783	7.871	7.054	6.322	5.665	5.077	4.550	4.077	3.654	3.274	2.934	2.630	2.356	2.112	1.892	1.696	1.519	1.361
PV ACC	-101.524	-84.576	-69.387	-55.773	-43.572	-32.638	-22.838	-14.055	-6.184	870	7.192	12.857	17.934	22.484	26.561	30.215	33.490	36.424	39.054	41.410	43.522	45.414	47.109	48.629	49.990

Discounted Payback Time	**10**
NPV	**49.990**
IRR	**17,32%**
Simple Payback Time	**7**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

Cash flow for São Paulo city

São Paulo - Sistema de Compensação de Energia Elétrica

Year	0	1	2	3	4	5	6	7	8	9	10	11	12
Production Total (kWh)	32.751	32.512	32.275	32.039	31.805	31.573	31.342	31.114	30.887	30.661	30.437	30.215	29.994
Elec. Self-consumed	18.013	17.882	17.751	17.621	17.493	17.365	17.238	17.112	16.988	16.864	16.740	16.618	16.497
Elec. Consumed from grid	16.987	17.118	17.249	17.379	17.507	17.635	17.762	17.888	18.012	18.136	18.260	18.382	18.503
Elec. Injected	14.738	14.630	14.524	14.418	14.312	14.208	14.104	14.001	13.899	13.797	13.697	13.597	13.498
Self-Consumption Saving	10.197	10.122	10.048	9.975	9.902	9.830	9.758	9.687	9.616	9.546	9.476	9.407	9.338
Service Saving	8.343	8.282	8.221	8.161	8.102	8.043	7.984	7.926	7.868	7.810	7.753	7.697	7.640
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-120.434	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	-104.304	15.995	15.861	15.727	15.595	15.464	15.333	15.204	15.075	14.947	14.821	14.695	14.570
Disc. Factor	1,0000	1,1066	1,2245	1,3550	1,4994	1,6592	1,8361	2,0317	2,2483	2,4879	2,7530	3,0464	3,3711
PV	-104.304	14.455	12.953	11.607	10.401	9.320	8.351	7.483	6.705	6.008	5.383	4.824	4.322
PV ACC	-104.304	-89.849	-76.896	-65.289	-54.889	-45.569	-37.218	-29.735	-23.029	-17.021	-11.638	-6.814	-2.492

Year	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	29.775	29.558	29.342	29.128	28.916	28.704	28.495	28.287	28.080	27.875	27.672	27.470
Elec. Self-consumed	16.377	16.257	16.138	16.020	15.904	15.787	15.672	15.558	15.444	15.331	15.220	15.108
Elec. Consumed from grid	18.623	18.743	18.862	18.980	19.096	19.213	19.328	19.442	19.556	19.669	19.780	19.892
Elec. Injected	13.399	13.301	13.204	13.108	13.012	12.917	12.823	12.729	12.636	12.544	12.452	12.361
Self-Consumption Saving	9.270	9.203	9.135	9.069	9.002	8.937	8.871	8.807	8.742	8.679	8.615	8.552
Service Saving	7.585	7.529	7.474	7.420	7.366	7.312	7.258	7.206	7.153	7.101	7.049	6.997
Bill expense	0	0	0	0	0	0	0	0	0	0	0	0
Investment	0	0	0	0	0	0	0	0	0	0	0	0
O&M	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409	-2.409
Net	14.446	14.323	14.201	14.080	13.959	13.840	13.721	13.604	13.487	13.371	13.255	13.141
Disc. Factor	3,7304	4,1280	4,5679	5,0548	5,5935	6,1896	6,8493	7,5792	8,3870	9,2808	10,2700	11,3645
PV	3.873	3.470	3.109	2.785	2.496	2.236	2.003	1.795	1.608	1.441	1.291	1.156
PV ACC	1.380	4.850	7.959	10.745	13.240	15.476	17.480	19.274	20.882	22.323	23.614	24.770

Discounted Payback Time	**14**
NPV	**24.770**
IRR	**13,95%**
Simple Payback Time	**8**

Note: discount rate = 10,66%; Sistema de Compensação de Energia Elétrica (net metering service)
Source: from author

APPENDIX B – CASH FLOW FOR ITALY

Cash flow for Bari city

Bari - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	35.870	35.609	35.350	35.093	34.838	34.585	34.334	34.084	33.836	33.590	33.346	33.103	32.863	32.624	32.387	32.151	31.917	31.685	31.455	31.226	30.999	30.774	30.550	30.328	30.107
Elec. Consumed	22.709	22.544	22.380	22.217	22.056	21.895	21.736	21.578	21.421	21.266	21.111	20.958	20.805	20.654	20.504	20.355	20.207	20.060	19.914	19.769	19.625	19.483	19.341	19.200	19.061
Saving Bolletta	6.813	6.763	6.714	6.665	6.617	6.569	6.521	6.473	6.426	6.380	6.333	6.287	6.242	6.196	6.151	6.106	6.062	6.018	5.974	5.931	5.888	5.845	5.802	5.760	5.718
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.490	1.506	1.522	1.537	1.552	1.567	1.581	1.595	1.608	1.621	1.634	1.647	1.660	1.673	1.686	1.693	1.700	1.706	1.712	1.717	1.723	1.729	1.733	1.735	1.738
Scambio Income	113	108	103	98	93	88	83	78	73	68	64	59	54	49	45	53	50	46	43	40	37	33	33	30	28
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-22.876	7.718	7.680	7.642	7.603	7.565	7.526	7.488	7.449	7.411	3.173	7.335	7.298	7.260	7.223	7.194	7.153	7.112	7.070	7.030	2.789	6.949	6.909	6.867	6.825
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**38.879**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Bari - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	35.870	35.609	35.350	35.093	34.838	34.585	34.334	34.084	33.836	33.590	33.346	33.103	32.863	32.624	32.387	32.151	31.917	31.685	31.455	31.226	30.999	30.774	30.550	30.328	30.107
Elec. Consumed	22.709	22.544	22.380	22.217	22.056	21.895	21.736	21.578	21.421	21.266	21.111	20.958	20.805	20.654	20.504	20.355	20.207	20.060	19.914	19.769	19.625	19.483	19.341	19.200	19.061
Saving Bolletta	6.813	6.763	6.714	6.665	6.617	6.569	6.521	6.473	6.426	6.380	6.333	6.287	6.242	6.196	6.151	6.106	6.062	6.018	5.974	5.931	5.888	5.845	5.802	5.760	5.718
Retiro dedicato - Income	387	385	382	379	376	374	371	368	365	363	360	358	355	352	350	347	345	342	340	337	335	332	330	328	325
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-24.056	6.507	6.455	6.404	6.352	6.301	6.251	6.201	6.151	6.102	1.853	6.004	5.956	5.908	5.860	5.813	5.766	5.719	5.673	5.627	1.382	5.536	5.492	5.447	5.403
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**26.457**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cash flow for Cagliari city

Cagliari - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	39.414	39.127	38.843	38.560	38.280	38.001	37.725	37.451	37.179	36.908	36.640	36.374	36.109	35.847	35.586	35.327	35.070	34.815	34.562	34.311	34.061	33.814	33.568	33.324	33.082
Elec. Consumed	24.687	24.507	24.329	24.152	23.977	23.802	23.629	23.457	23.287	23.117	22.949	22.783	22.617	22.452	22.289	22.127	21.966	21.807	21.648	21.491	21.334	21.179	21.025	20.872	20.721
Saving Bolletta	7.406	7.352	7.299	7.246	7.193	7.141	7.089	7.037	6.986	6.935	6.885	6.835	6.785	6.736	6.687	6.638	6.590	6.542	6.494	6.447	6.400	6.354	6.308	6.262	6.216
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.493	1.511	1.530	1.549	1.567	1.585	1.604	1.622	1.640	1.657	1.675	1.692	1.707	1.721	1.736	1.750	1.764	1.778	1.791	1.805	1.819	1.832	1.846	1.859	1.870
Scambio Income	164	158	151	145	139	133	126	120	114	108	102	96	104	99	94	89	84	80	75	70	65	60	56	51	46
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-22.229	8.363	8.322	8.281	8.240	8.200	8.160	8.121	8.081	8.042	3.803	7.965	7.938	7.898	7.858	7.819	7.780	7.741	7.702	7.664	3.426	7.588	7.550	7.513	7.475
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**45.079**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cagliari - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	39.414	39.127	38.843	38.560	38.280	38.001	37.725	37.451	37.179	36.908	36.640	36.374	36.109	35.847	35.586	35.327	35.070	34.815	34.562	34.311	34.061	33.814	33.568	33.324	33.082
Elec. Consumed	24.687	24.507	24.329	24.152	23.977	23.802	23.629	23.457	23.287	23.117	22.949	22.783	22.617	22.452	22.289	22.127	21.966	21.807	21.648	21.491	21.334	21.179	21.025	20.872	20.721
Saving Bolletta	7.406	7.352	7.299	7.246	7.193	7.141	7.089	7.037	6.986	6.935	6.885	6.835	6.785	6.736	6.687	6.638	6.590	6.542	6.494	6.447	6.400	6.354	6.308	6.262	6.216
Retiro dedicato - Income	455	452	449	445	442	439	436	433	430	426	423	420	417	414	411	408	405	402	399	396	394	391	388	385	382
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-23.394	7.163	7.107	7.050	6.994	6.939	6.884	6.829	6.775	6.721	2.467	6.614	6.561	6.509	6.457	6.406	6.354	6.303	6.253	6.203	1.953	6.104	6.055	6.006	5.958
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**32.539**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cash flow for Lucca city

Lucca - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	31.683	31.453	31.224	30.997	30.772	30.548	30.326	30.106	29.887	29.669	29.454	29.239	29.027	28.816	28.606	28.398	28.192	27.987	27.783	27.581	27.381	27.182	26.984	26.788	26.593
Elec. Consumed	19.877	19.732	19.589	19.446	19.305	19.164	19.025	18.887	18.750	18.613	18.478	18.344	18.210	18.078	17.946	17.816	17.686	17.558	17.430	17.303	17.177	17.053	16.929	16.806	16.683
Saving Bolletta	5.963	5.920	5.877	5.834	5.791	5.749	5.708	5.666	5.625	5.584	5.543	5.503	5.463	5.423	5.384	5.345	5.306	5.267	5.229	5.191	5.153	5.116	5.079	5.042	5.005
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.612	1.623	1.633	1.642	1.649	1.654	1.657	1.661	1.664	1.667	1.670	1.673	1.677	1.680	1.683	1.686	1.689	1.692	1.695	1.698	1.701	1.704	1.707	1.709	1.711
Scambio Income	86	82	77	75	71	68	65	62	59	56	54	51	48	45	42	39	37	34	31	28	26	23	20	18	15
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-23.630	6.965	6.929	6.892	6.853	6.813	6.772	6.730	6.690	6.649	2.409	6.569	6.529	6.490	6.450	6.412	6.373	6.335	6.297	6.259	2.021	6.184	6.147	6.110	6.073
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**31.504**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Lucca - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	31.683	31.453	31.224	30.997	30.772	30.548	30.326	30.106	29.887	29.669	29.454	29.239	29.027	28.816	28.606	28.398	28.192	27.987	27.783	27.581	27.381	27.182	26.984	26.788	26.593
Elec. Consumed	19.877	19.732	19.589	19.446	19.305	19.164	19.025	18.887	18.750	18.613	18.478	18.344	18.210	18.078	17.946	17.816	17.686	17.558	17.430	17.303	17.177	17.053	16.929	16.806	16.683
Saving Bolletta	5.963	5.920	5.877	5.834	5.791	5.749	5.708	5.666	5.625	5.584	5.543	5.503	5.463	5.423	5.384	5.345	5.306	5.267	5.229	5.191	5.153	5.116	5.079	5.042	5.005
Retiro dedicato - Income	377	375	372	369	366	364	361	359	356	353	351	348	346	343	341	338	336	333	331	328	326	324	321	319	317
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-24.915	5.653	5.608	5.562	5.517	5.472	5.428	5.384	5.340	5.297	1.053	5.211	5.168	5.126	5.084	5.042	5.001	4.960	4.919	4.879	639	4.799	4.759	4.720	4.681
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**18.564**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cash flow for Milano city

Milano - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	31.206	30.979	30.754	30.530	30.308	30.088	29.869	29.652	29.436	29.222	29.010	28.799	28.589	28.381	28.175	27.970	27.767	27.565	27.365	27.166	26.968	26.772	26.577	26.384	26.192
Elec. Consumed	19.583	19.440	19.299	19.159	19.019	18.881	18.744	18.607	18.472	18.338	18.205	18.072	17.941	17.810	17.681	17.552	17.425	17.298	17.172	17.047	16.923	16.800	16.678	16.557	16.437
Saving Bolletta	5.875	5.832	5.790	5.748	5.706	5.664	5.623	5.582	5.542	5.501	5.461	5.422	5.382	5.343	5.304	5.266	5.227	5.189	5.152	5.114	5.077	5.040	5.003	4.967	4.931
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.605	1.621	1.633	1.641	1.648	1.655	1.660	1.663	1.666	1.670	1.673	1.676	1.679	1.682	1.685	1.688	1.691	1.694	1.697	1.700	1.703	1.706	1.709	1.712	1.715
Scambio Income	87	82	77	74	70	67	64	61	58	55	52	49	46	44	41	38	35	33	30	27	24	22	19	17	14
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-23.724	6.876	6.842	6.804	6.765	6.727	6.688	6.648	6.608	6.568	2.328	6.488	6.449	6.411	6.372	6.334	6.296	6.258	6.221	6.183	1.946	6.110	6.073	6.037	6.001
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**30.647**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Milano - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	31.206	30.979	30.754	30.530	30.308	30.088	29.869	29.652	29.436	29.222	29.010	28.799	28.589	28.381	28.175	27.970	27.767	27.565	27.365	27.166	26.968	26.772	26.577	26.384	26.192
Elec. Consumed	19.583	19.440	19.299	19.159	19.019	18.881	18.744	18.607	18.472	18.338	18.205	18.072	17.941	17.810	17.681	17.552	17.425	17.298	17.172	17.047	16.923	16.800	16.678	16.557	16.437
Saving Bolletta	5.875	5.832	5.790	5.748	5.706	5.664	5.623	5.582	5.542	5.501	5.461	5.422	5.382	5.343	5.304	5.266	5.227	5.189	5.152	5.114	5.077	5.040	5.003	4.967	4.931
Retiro dedicato - Income	385	382	379	376	374	371	368	366	363	360	358	355	352	350	347	345	342	340	337	335	332	330	328	325	323
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-24.996	5.573	5.528	5.483	5.439	5.394	5.351	5.307	5.264	5.221	978	5.136	5.094	5.052	5.011	4.970	4.929	4.888	4.848	4.808	569	4.729	4.690	4.652	4.613
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**17.780**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cash flow for Palermo city

Palermo - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	37.475	37.202	36.932	36.663	36.397	36.132	35.870	35.609	35.350	35.093	34.838	34.584	34.333	34.083	33.836	33.589	33.345	33.103	32.862	32.623	32.386	32.151	31.917	31.685	31.454
Elec. Consumed	23.013	22.846	22.680	22.515	22.351	22.188	22.027	21.867	21.708	21.550	21.393	21.238	21.083	20.930	20.778	20.627	20.477	20.328	20.180	20.034	19.888	19.743	19.600	19.457	19.316
Saving Bolletta	6.904	6.854	6.804	6.754	6.705	6.657	6.608	6.560	6.512	6.465	6.418	6.371	6.325	6.279	6.233	6.188	6.143	6.098	6.054	6.010	5.966	5.923	5.880	5.837	5.795
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.607	1.623	1.638	1.652	1.667	1.682	1.696	1.711	1.725	1.739	1.753	1.767	1.781	1.795	1.807	1.818	1.827	1.837	1.846	1.854	1.860	1.866	1.871	1.876	1.879
Scambio Income	161	168	163	157	152	146	141	136	130	125	120	115	110	105	100	96	92	88	83	79	77	73	70	66	64
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-22.620	7.986	7.946	7.905	7.866	7.826	7.787	7.748	7.709	7.671	3.433	7.595	7.557	7.520	7.482	7.444	7.404	7.364	7.325	7.285	3.045	7.203	7.162	7.121	7.079
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**41.411**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Palermo - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	37.475	37.202	36.932	36.663	36.397	36.132	35.870	35.609	35.350	35.093	34.838	34.584	34.333	34.083	33.836	33.589	33.345	33.103	32.862	32.623	32.386	32.151	31.917	31.685	31.454
Elec. Consumed	23.013	22.846	22.680	22.515	22.351	22.188	22.027	21.867	21.708	21.550	21.393	21.238	21.083	20.930	20.778	20.627	20.477	20.328	20.180	20.034	19.888	19.743	19.600	19.457	19.316
Saving Bolletta	6.904	6.854	6.804	6.754	6.705	6.657	6.608	6.560	6.512	6.465	6.418	6.371	6.325	6.279	6.233	6.188	6.143	6.098	6.054	6.010	5.966	5.923	5.880	5.837	5.795
Retiro dedicato - Income	460	457	453	450	447	443	440	437	434	431	428	424	421	418	415	412	409	406	403	400	397	395	392	389	386
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-23.892	6.669	6.616	6.564	6.511	6.459	6.408	6.356	6.305	6.255	2.005	6.155	6.106	6.057	6.008	5.960	5.912	5.864	5.817	5.770	1.523	5.677	5.631	5.585	5.540
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**27.950**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cash flow for Roma city

Rome - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	35.204	34.948	34.694	34.442	34.191	33.943	33.696	33.451	33.208	32.966	32.727	32.489	32.253	32.018	31.785	31.554	31.325	31.097	30.871	30.646	30.424	30.202	29.983	29.765	29.548
Elec. Consumed	22.247	22.085	21.924	21.765	21.607	21.450	21.294	21.139	20.985	20.833	20.681	20.531	20.382	20.233	20.086	19.940	19.795	19.651	19.508	19.367	19.226	19.086	18.947	18.809	18.673
Saving Bolletta	6.674	6.626	6.577	6.530	6.482	6.435	6.388	6.342	6.296	6.250	6.204	6.159	6.114	6.070	6.026	5.982	5.939	5.895	5.853	5.810	5.768	5.726	5.684	5.643	5.602
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.565	1.580	1.595	1.609	1.623	1.637	1.650	1.661	1.671	1.682	1.693	1.703	1.712	1.719	1.724	1.730	1.734	1.737	1.740	1.742	1.745	1.747	1.750	1.753	1.755
Scambio Income	113	108	103	98	93	88	86	82	78	73	69	65	61	58	55	52	51	48	45	42	39	37	34	31	28
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-22.939	7.655	7.617	7.578	7.540	7.502	7.465	7.426	7.386	7.347	3.108	7.269	7.229	7.189	7.147	7.105	7.065	7.022	6.979	6.936	2.693	6.851	6.810	6.768	6.727
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**38.210**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Rome - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	35.204	34.948	34.694	34.442	34.191	33.943	33.696	33.451	33.208	32.966	32.727	32.489	32.253	32.018	31.785	31.554	31.325	31.097	30.871	30.646	30.424	30.202	29.983	29.765	29.548
Elec. Consumed	22.247	22.085	21.924	21.765	21.607	21.450	21.294	21.139	20.985	20.833	20.681	20.531	20.382	20.233	20.086	19.940	19.795	19.651	19.508	19.367	19.226	19.086	18.947	18.809	18.673
Saving Bolletta	6.674	6.626	6.577	6.530	6.482	6.435	6.388	6.342	6.296	6.250	6.204	6.159	6.114	6.070	6.026	5.982	5.939	5.895	5.853	5.810	5.768	5.726	5.684	5.643	5.602
Retiro dedicato - Income	401	398	395	392	389	387	384	381	378	375	373	370	367	365	362	359	357	354	352	349	347	344	341	339	337
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-24.181	6.383	6.332	6.281	6.231	6.181	6.131	6.082	6.033	5.985	1.736	5.889	5.841	5.794	5.747	5.701	5.655	5.609	5.563	5.518	1.273	5.429	5.385	5.341	5.298
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**25.314**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

Cash flow for Torino city

Torino - Scambio sul Posto

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	33.057	32.817	32.578	32.342	32.106	31.873	31.641	31.411	31.183	30.956	30.731	30.508	30.286	30.066	29.847	29.630	29.414	29.201	28.988	28.778	28.568	28.361	28.154	27.950	27.746
Elec. Consumed	20.838	20.686	20.536	20.387	20.238	20.091	19.945	19.800	19.656	19.513	19.371	19.230	19.091	18.952	18.814	18.677	18.541	18.407	18.273	18.140	18.008	17.877	17.747	17.618	17.490
Saving Bolletta	6.251	6.206	6.161	6.116	6.071	6.027	5.984	5.940	5.897	5.854	5.811	5.769	5.727	5.686	5.644	5.603	5.562	5.522	5.482	5.442	5.402	5.363	5.324	5.285	5.247
Retiro dedicato - Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Saving	1.597	1.612	1.626	1.638	1.649	1.659	1.670	1.680	1.688	1.694	1.701	1.708	1.714	1.721	1.727	1.733	1.740	1.746	1.752	1.759	1.765	1.771	1.777	1.780	1.783
Scambio Income	104	99	93	89	85	81	77	72	69	66	62	59	55	52	49	45	42	39	35	32	29	26	23	20	18
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-68	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658	-658	-658	-658	-658	-658	-4.858	-658	-658	-658	-658
Net	-23.339	7.258	7.222	7.184	7.147	7.109	7.072	7.034	6.995	6.955	2.716	6.877	6.838	6.800	6.761	6.724	6.686	6.648	6.611	6.574	2.338	6.502	6.465	6.428	6.389
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**34.381**																								

Note: discount rate = 9,85%; Scambio sul Posto (net metering service); NPV* was calculated monthly and summarized yearly in this table
Source: from author

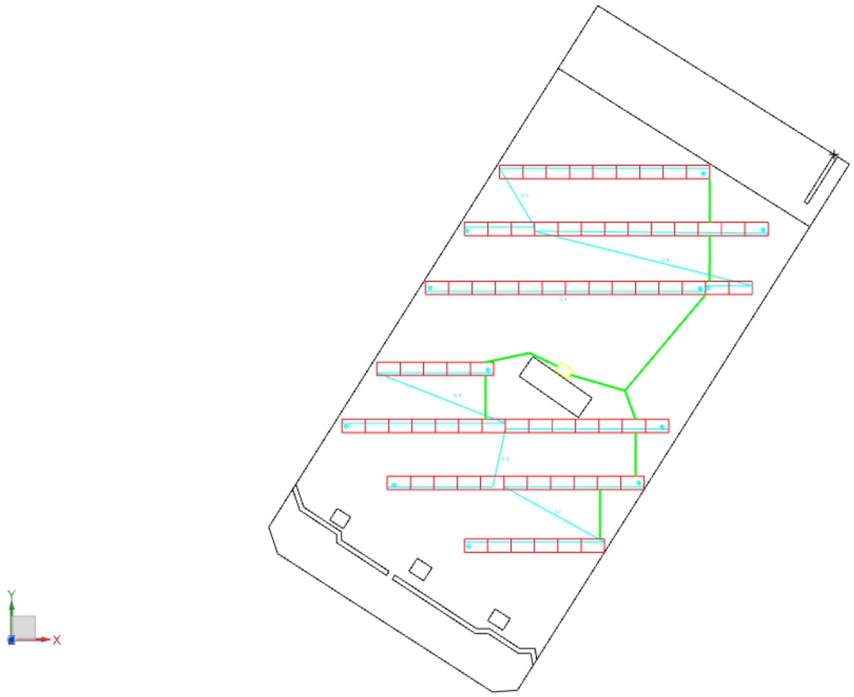
Torino - Retiro Dedicato

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Production Total (kWh)	33.057	32.817	32.578	32.342	32.106	31.873	31.641	31.411	31.183	30.956	30.731	30.508	30.286	30.066	29.847	29.630	29.414	29.201	28.988	28.778	28.568	28.361	28.154	27.950	27.746
Elec. Consumed	20.838	20.686	20.536	20.387	20.238	20.091	19.945	19.800	19.656	19.513	19.371	19.230	19.091	18.952	18.814	18.677	18.541	18.407	18.273	18.140	18.008	17.877	17.747	17.618	17.490
Saving Bolletta	6.251	6.206	6.161	6.116	6.071	6.027	5.984	5.940	5.897	5.854	5.811	5.769	5.727	5.686	5.644	5.603	5.562	5.522	5.482	5.442	5.402	5.363	5.324	5.285	5.247
Retiro dedicato - Income	407	404	401	398	395	392	390	387	384	381	378	376	373	370	368	365	362	360	357	354	352	349	347	344	342
Scambio Saving	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scambio Income	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Investment	-31.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Expenses	-33	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641	-641	-641	-641	-641	-641	-4.841	-641	-641	-641	-641
Net	-24.597	5.969	5.921	5.873	5.826	5.779	5.732	5.686	5.640	5.594	1.349	5.504	5.459	5.415	5.371	5.327	5.284	5.241	5.198	5.156	913	5.072	5.030	4.989	4.948
Disc. Factor	1,099	1,207	1,326	1,456	1,600	1,757	1,930	2,120	2,329	2,559	2,811	3,087	3,392	3,726	4,093	4,496	4,939	5,425	5,959	6,546	7,191	7,900	8,678	9,532	10,471
NPV*	**21.429**																								

Note: discount rate = 9,85%;Ritiro Dedicato (purchase and resale agreement); NPV* was calculated monthly and summarized yearly in this table
Source: from author

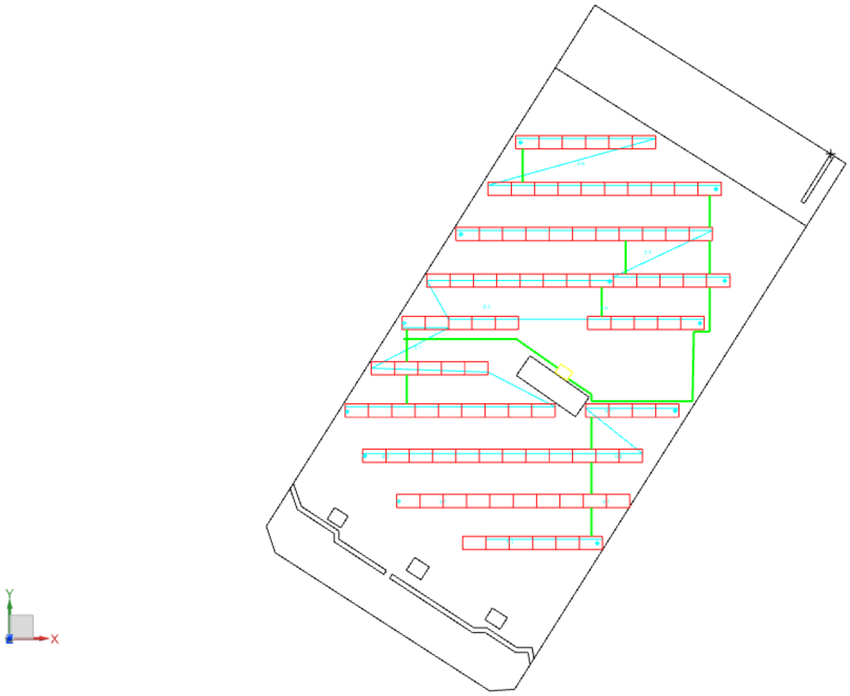
APPENDIX C – SYSTEMS` LAYOUT

LAYOUT FOR THE MONOCRYSTALLINE SYSTEM (MEDIUM INVESTOR)



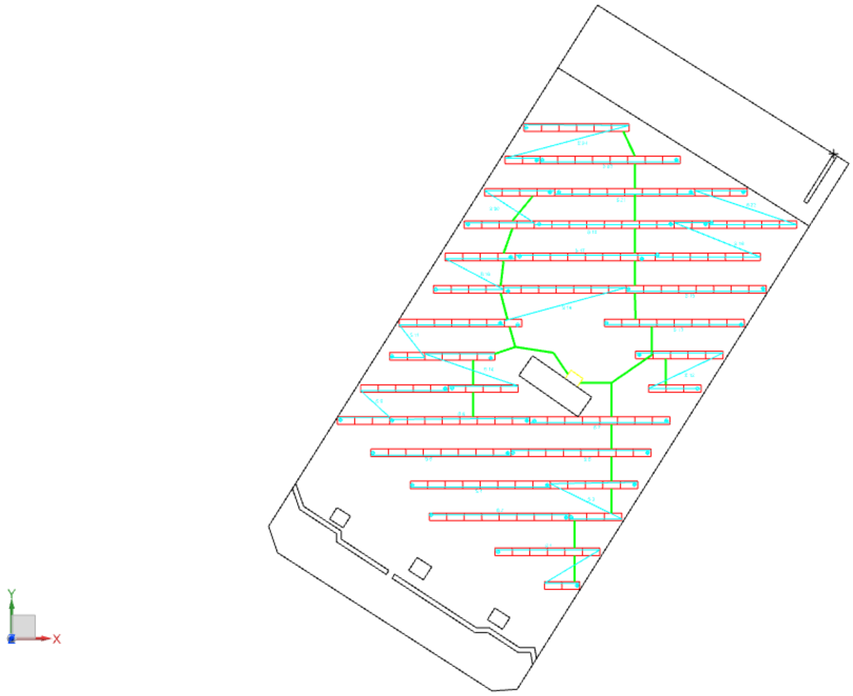
Source: from author

LAYOUT FOR THE POLYCRYSTALLINE SYSTEM (MEDIUM INVESTOR)



Source: from author

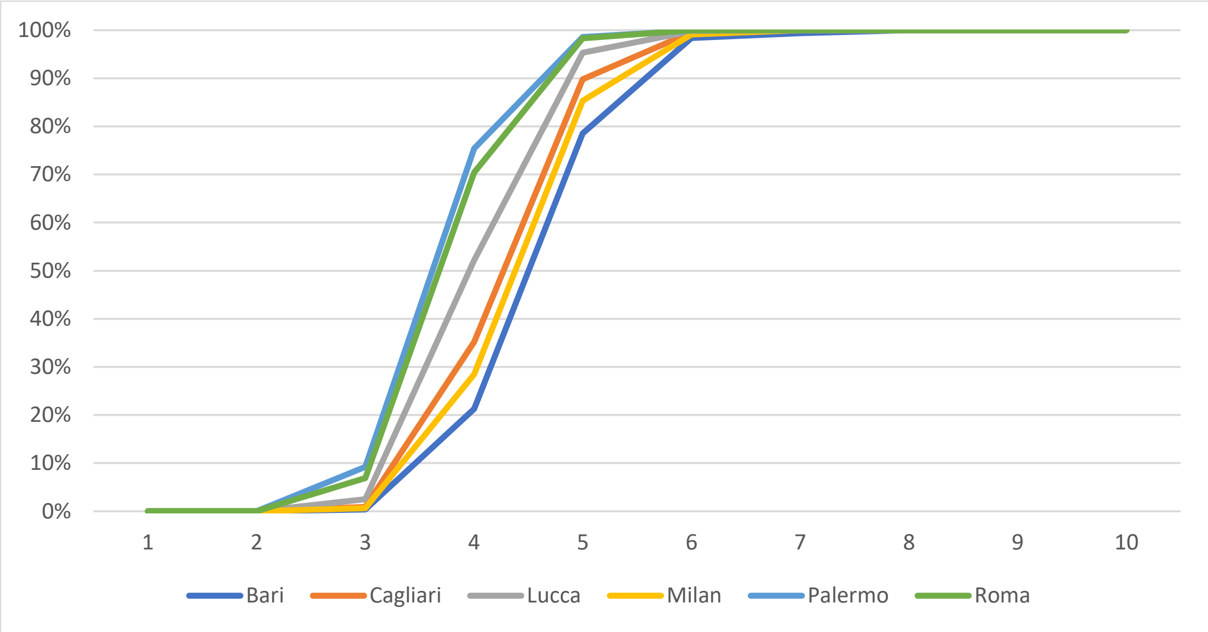
LAYOUT FOR THE CADMIUM TELLURIUM SYSTEM (MEDIUM INVESTOR)



Source: from author

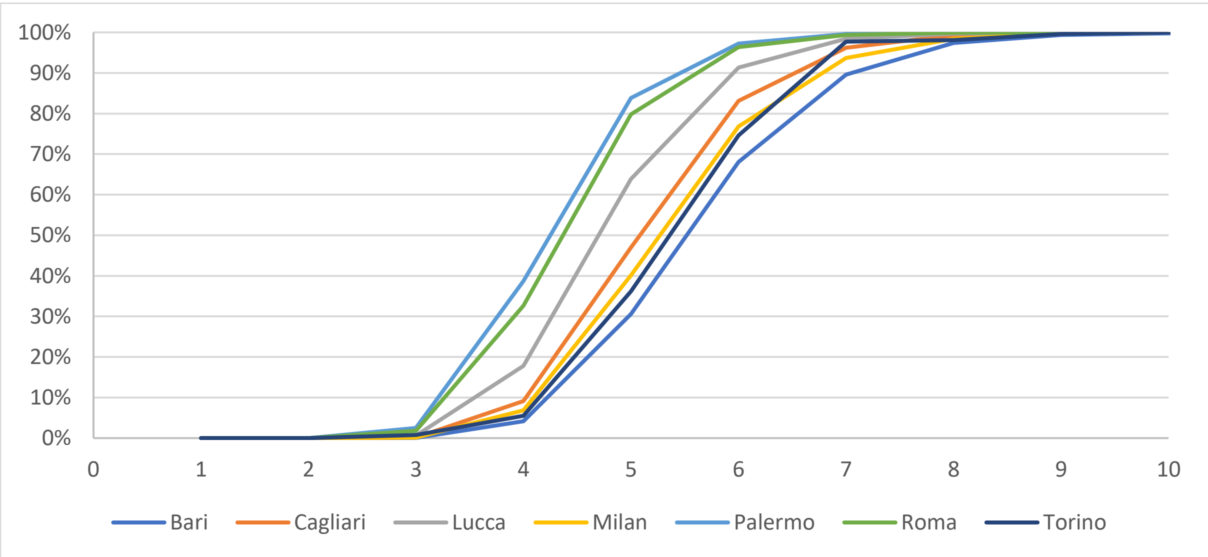
APPENDIX D – SIMULATION PAYBACK TIME

Accumulated probability for simple payback time in Italy



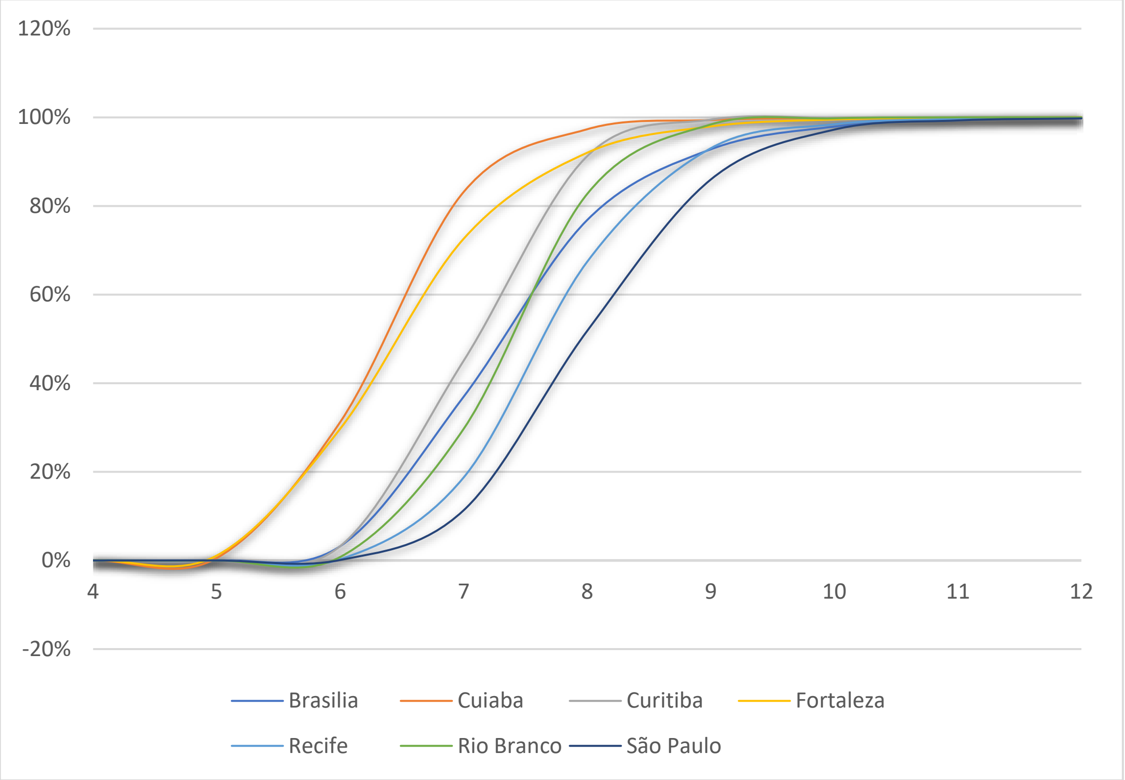
Source: from author

Accumulated probability for discounted payback time in Italy



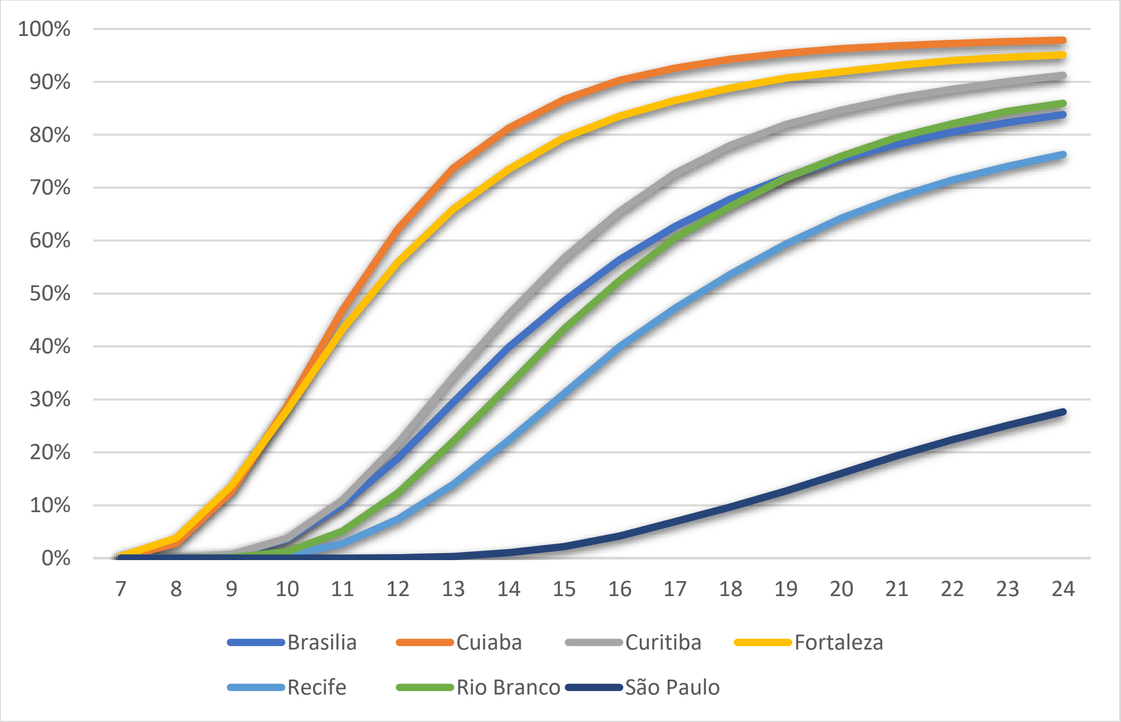
Source: from author

Accumulated probability for simple payback time in Brazil



Source: from author

Accumulated probability for discounted payback time in Brazil



Source: from author

ATTACHMENT A – COMPONENTS` DATASHEET

Sunny Boy 1,5 Datasheet

Dati tecnici	Sunny Boy 1.5	Sunny Boy 2.5
Ingresso (CC)		
Potenza CC max. (con cos φ = 1)	1 600 W	2 650 W
Tensione d'ingresso max	600 V	600 V
Range di tensione MPP	160 V - 500 V	260 V - 500 V
Tensione nominale d'ingresso	360 V	360 V
Tensione d'ingresso min. / tensione d'ingresso d'avviamento	50 V / 80 V	50 V / 80 V
Corrente d'ingresso max	10 A	10 A
Corrente d'ingresso max. per stringa	10 A	10 A
Numero di ingressi MPP indipendenti / stringhe per ingresso MPP	1 / 1	1 / 1
Uscita (CA)		
Potenza nominale (@ 230 V, 50 Hz)	1 500 W	2 500 W
Potenza apparente CA max.	1 500 VA	2 500 VA
Tensione nominale CA	220 V / 230 V / 240 V	220 V / 230 V / 240 V
Range di tensione nominale CA	180 V - 280 V	180 V - 280 V
Frequenza di rete CA / range	50 Hz, 60 Hz / -5 Hz ... +5 Hz	50 Hz, 60 Hz / -5 Hz ... +5 Hz
Frequenza di rete nominale / tensione di rete nominale	50 Hz / 230 V	50 Hz / 230 V
Corrente d'uscita max	7 A	11 A
Fattore di potenza alla potenza nominale	1	1
Fattore di sfasamento regolabile	0,8 sovreccitato ... 0,8 sottoeccitato	
Fasi di immissione / fasi di collegamento	1 / 1	1 / 1
Grado di rendimento		
Grado di rendimento max. / grado di rendimento europeo	97,2% / 96,1%	97,2% / 96,7%
Dispositivi di protezione		
Dispositivo di disinserzione lato CC	●	●
Monitoraggio della dispersione verso terra / monitoraggio della rete	● / ●	● / ●
Protezione contro l'inversione della polarità CC / resistenza ai cortocircuiti CA / separazione galvanica	● / ● / –	● / ● / –
Unità di monitoraggio correnti di guasto	●	●
Classe di isolamento (secondo IEC 62103) / categoria di sovratensione (secondo IEC 60664-1)	I / III	I / III
Protezione da corrente inversa	non necessaria	non necessaria
Dati generali		
Dimensioni (L x A x P)	460 / 357 / 122 mm (18,1 / 14,1 / 4,8 in)	
Peso	9,2 kg (20,3 lbs)	
Range di temperature di funzionamento	-40 °C ... +60 °C (-40 °F ... +140 °F)	
Rumorosità, valore tipico	<25 dB	<25 dB
Autoconsumo (notte)	2,0 W	2,0 W
Topologia	Senza trasformatore	Senza trasformatore
Sistema di raffreddamento	Convezione	Convezione
Grado di protezione (secondo IEC 60529)	IP65	IP65
Classe climatica (secondo IEC 60721-3-4)	4K4H	4K4H
Valore massimo ammissibile per l'umidità relativa (non condensante)	100%	100%
Dotazione		
Collegamento CC / Collegamento CA	SUNCLIX / Connettori a spina	SUNCLIX / Connettori a spina
Display	–	–
Interfaccia: RS485, Bluetooth®, Speedwire/Webconnect, WLAN	– / – / ● / ●	– / – / ● / ●
Web server integrato	●	●
Garanzia: 5 / 10 / 15 / 20 / 25 anni	● / ○ / ○ / ○ / ○	● / ○ / ○ / ○ / ○
Certificati e omologazioni (altri su richiesta) * In Italia certificato per impianti di potenza fino a 6 kW	AS4777.3, C10/11/2012, VDE-AR-N4105, CEI0-21Int*, NEN-EN50438, G83/2, EN50438, VFR2014	

Source: SMA (2017)

PVI5000 Datasheet

Technical data and types

Type code	PVI-5000-TL-OUTD	PVI-6000-TL-OUTD
Input side		
Absolute maximum DC input voltage ($V_{max,abs}$)	600 V	
Start-up DC input voltage (V_{start})	200 V (adj. 120...350 V)	
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	0.7 x V_{start}...580 V (min 90 V)	
Rated DC input voltage (V_{dcr})	360 V	
Rated DC input power (P_{dcr})	5150 W	6200 W
Number of independent MPPT	2	
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	4000 W	
DC input voltage range with parallel configuration of MPPT at P_{acr}	150...530 V	180...530 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null [530 V≤V_{MPPT}≤580 V]	
DC power limitation for each MPPT with independent configuration of MPPT at P_{acr}, max unbalance example	4000 W [220 V≤V_{MPPT}≤530 V] the other channel: P_{dcr}-4000 W [90 V≤V_{MPPT}≤530 V]	4000 W [220 V≤V_{MPPT}≤530 V] the other channel: P_{dcr}-4000 W [120 V≤V_{MPPT}≤530 V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	36.0 A / 18.0 A	
Maximum input short circuit current for each MPPT	22.0 A	
Number of DC inputs pairs for each MPPT	2	
DC connection type	PV quick fit connector [3]	
Input protection		
Reverse polarity protection	Yes, from limited current source	
Input over voltage protection for each MPPT - varistor	Yes	
Photovoltaic array isolation control	According to local standard	
DC switch rating for each MPPT (version with DC switch)	25 A / 600 V	
Output side		
AC grid connection type	Single-phase	
Rated AC power (P_{acr} @cosϕ=1)	5000 W [4]	6000 W
Rated AC power (P_{acr} @cosϕ=±0.9)	5000 W [4]	6000 W
Maximum AC output power (P_{acmax} @cosϕ=1)	5000 W [4]	6000 W
Maximum apparent power (S_{max})	5560 VA	6670 VA
Rated AC grid voltage ($V_{ac,r}$)	230 V	
AC voltage range	180...264 V [5]	
Maximum AC output current ($I_{ac,max}$)	25.0 A	30.0 A
Contributory fault current	32.0 A	40.0 A
Rated output frequency (f_r)	50 Hz / 60 Hz	
Output frequency range ($f_{min}...f_{max}$)	47...53 Hz / 57...63 Hz [2]	
Nominal power factor and adjustable range	> 0.995, adj. 0.8 inductive to 0.8 capacitive	
Total current harmonic distortion	< 3.5%	
AC connection type	Terminal block, cable gland M32	

Source: ABB (2017a)

TRIO 20.00 TL Datasheet

Technical data and types

Type code	TRIO-20.0-TL-OUTD	TRIO-27.6-TL-OUTD
Input side		
Absolute maximum DC input voltage ($V_{max,abs}$)	1000 V	
Start-up DC input voltage (V_{start})	430 V (adj. 250...500 V)	
Operating DC input voltage range ($V_{dcmin}...V_{dcmax}$)	0.7 x V_{start}...950 V (min 200 V)	
Rated DC input voltage (V_{dcr})	620 V	
Rated DC input power (P_{dcr})	20750 W	28600 W
Number of independent MPPT	2	
Maximum DC input power for each MPPT ($P_{MPPTmax}$)	12000 W	16000 W
DC input voltage range with parallel configuration of MPPT at P_{acr}	440...800 V	500...800 V
DC power limitation with parallel configuration of MPPT	Linear derating from max to null [800 V≤V_{MPPT}≤950 V]	
DC power limitation for each MPPT with independent configuration of MPPT at P_{acr}, max unbalance example	12000 W [480 V≤V_{MPPT}≤800 V] the other channel: P_{dcr}-12000 W [350 V≤V_{MPPT}≤800 V]	16000 W [500 V≤V_{MPPT}≤800 V] the other channel: P_{dcr}-16000 W [400 V≤V_{MPPT}≤800 V]
Maximum DC input current (I_{dcmax}) / for each MPPT ($I_{MPPTmax}$)	50.0 A / 25.0 A	64.0 A / 32.0 A
Maximum input short circuit current for each MPPT	30.0 A	40.0 A
Number of DC inputs pairs for each MPPT	1 (4 in -S2X, -S2F, -S1J, -S2J versions)	1 (5 in -S2X and -S2F versions, 4 in -S1J and -S2J)
DC connection type	PV quick fit connector [3] / Screw terminal block on Standard and -S2 versions	
Input protection		
Reverse polarity protection	Yes, from limited current source	
Input over voltage protection for each MPPT - varistor	Yes, 4	
Input over voltage protection for each MPPT - plug In modular surge arrester (-S2X, -S1J and -S2J versions)	-S2X: Type 2; -S1J, -S1J: Type 1+2	
Photovoltaic array isolation control	According to local standard	
DC switch rating for each MPPT (version with DC switch)	40 A / 1000 V	
Fuse rating (versions with fuses)	15 A / 1000 V	
Output side		
AC grid connection type	Three-phase 3W+PE or 4W+PE	
Rated AC power (P_{acr} @cosϕ=1)	20000 W	27600 W
Maximum AC output power (P_{acmax} @cosϕ=1)	22000 W [4]	30000 W [5]
Maximum apparent power (S_{max})	22200 VA	30670 VA
Rated AC grid voltage ($V_{ac,r}$)	400 V	
AC voltage range	320...480 V [1]	
Maximum AC output current ($I_{ac,max}$)	33.0 A	45.0 A
Contributory fault current	35.0 A	46.0 A
Rated output frequency (f_r)	50 Hz / 60 Hz	
Output frequency range ($f_{min}...f_{max}$)	47...53 Hz / 57...63 Hz [2]	
Nominal power factor and adjustable range	> 0.995, adj. ± 0.9 with P_{acr} =20.0 kW, ± 0.8 with max 22.2 kVA	> 0.995, adj. ± 0.9 with P_{acr} =27.6 kW, ± 0.8 with max 30 kVA
Total current harmonic distortion	< 3%	
AC connection type	Screw terminal block, cable gland PG36	
Output protection		
Anti-islanding protection	According to local standard	
Maximum external AC overcurrent protection	50.0 A	63.0 A
Output overvoltage protection - varistor	4	
Output overvoltage protection - plug in modular surge arrester (-S2X version)	4 (Type 2)	
Operating performance		
Maximum efficiency (η_{max})	98.2%	
Weighted efficiency (EURO/CEC)	98.0% / 98.0%	
Feed in power threshold	40 W	
Night consumption	< 0.6 W	

Source: ABB (2017b)

Ingecon Sun 6TL M datasheet

	2.5TL M	3TL M	3.3TL M	3.68TL M	4.6TL M	5TL M	6TL M
Input (DC)							
Recommended PV array power range[1]	2.8 - 3.3 kWp	3.2 - 4 kWp	3.8 - 4.4 kWp	3.9 - 4.8 kWp	5.2 - 6 kWp	5.7 - 6.5 kWp	6.3 - 7 kWp
Voltage range MPP1[2]	125 - 750 V						
Voltage range MPP2[2][3]	90 - 750 V						
Maximum voltage[4]	850 V						
Maximum current (Input 1 / Input 2)	11 / 11 A						
Inputs (Input 1 / Input 2)[5]	1 / 1						
MPPT	2						
Output (AC)							
Rated power	2.5 kW	3 kW	3.3 kW	3.68 kW	4.6 kW	5 kW	6 kW
Max. temperature at rated power[6]	60 °C	55 °C	52 °C	50 °C	58 °C	55 °C	45 °C
Maximum current	16 A	16 A	16 A	16 A	26.2 A	26.2 A	26.2 A
Rated voltage	230 V						
Voltage range	122 - 265 V						
Frequency	50 / 60 Hz						
Power Factor	1						
Power Factor adjustable	Yes. Smax=2.5 kVA	Yes. Smax=3 kVA	Yes. Smax=3.3 kVA	Yes. Smax=3.68 kVA	Yes. Smax=4.6 kVA	Yes. Smax=5 kVA	Yes. Smax=6 kVA
THD	<3%						
Efficiency							
Maximum efficiency	97.6%	97.7%	97.7%	97.8%	97.9%	98%	98%
Euroefficiency	97.3%	97.4%	97.4%	97.5%	97.5%	97.6%	97.6%
General Information							
Refrigeration system	Air convection						
Stand-by consumption[7]	<10 W						
Consumption at night	0 W						
Ambient temperature	-25 °C to +65 °C						
Relative humidity (non-condensing)	0 - 100%						
Protection class	IP65						
Marking	CE						
EMC & Security standards	EN 61000-6-1, EN 61000-6-2, EN 61000-6-3, EN 61000-6-4, EN 61000-3-11, EN 61000-3-12, EN 62109-1, EN 62109-2, IEC62103, EN 50178, FCC Part 15, AS3100						
Grid connection standards	RD1699/2011, DIN V VDE V 0126-1-1, EN 50438, CEI 0-21, VDE-AR-N 4105:2011-08, G59/2, G83/2[8], P.O.12.3, AS4777.2, AS4777.3, IEC 62116, IEC 61727, UNE 206007-1, ABNT NBR 16149, ABNT NBR 16150, South African Grid code, Chilean Grid Code, Romanian Grid Code, Ecuadorian Grid Code, Peruvian Grid code, IEEE 929, Thailand MEA & PEA requirements, DEWA (Dubai) Grid Code, Jordan Grid Code						

Source: INGECON (2017)

VBHN330 SA16 datasheet

Electrical Specifications

Model	VBHN330SA16	VBHN325SA16
Rated Power (Pmax)[1]	330W	325W
Maximum Power Voltage (Vpm)	58.0V	57.6V
Maximum Power Current (Ipm)	5.70A	5.65A
Open Circuit Voltage (Voc)	69.7V	69.6V
Short Circuit Current (Isc)	6.07A	6.03A
Temperature Coefficient (Pmax)	-0. 29%/°C	-0. 29%/°C
Temperature Coefficient (Voc)	-0. 174V/°C	-0. 174V/°C
Temperature Coefficient (Isc)	1.82mA/°C	1.81mA/°C
NOCT	44.0°C	44.0°C
CEC PTC Rating	311.3W	306.5W
Cell Efficiency	22.09%	21.76%
Module Efficiency	19.7%	19.4%
Watts per Ft.²	18.3W	18.0W
Maximum System Voltage	600V	600V
Series Fuse Rating	15A	15A
Warranted Tolerance (-/+)	+10%/-0%*	+10%/-0%*

Mechanical Specifications

Model	VBHN330SA16, VBHN325SA16
Internal Bypass Diodes	4 Bypass Diodes
Module Area	18.02 Ft.² (1.67m²)
Weight	40.81 Lbs. (18.5kg)
Dimensions LxWxH	62.6x41.5x1.4 in. (1590x1053x35 mm)
Cable Length +Male/-Female	40.2/40.2 in. (1020/1020 mm)
Cable Size / Type	No. 12 AWG / PV Cable
Connector Type[2]	Multi-Contact® Type IV (MC4™)
Static Wind / Snow Load	50 PSF (2400 Pa)
Pallet Dimensions LxWxH	63.7x42.2x5.5 in. (1618x1071x140 mm)
Quantity per Pallet / Pallet Weight	40 pcs. /1719 Lbs. (780 kg)
Quantity per 40' Container	560 pcs.
Quantity per 20' Container	240 pcs.

Operating Conditions & Safety Ratings

Model	VBHN330SA16, VBHN325SA16
Operating Temperature	-40°F to 185°F (-40°C to 85°C)
Hail Safety Impact Velocity	1" hailstone (25mm) at 52 mph (23m/s)
Safety & Rating Certifications	UL 1703, cUL, CEC
UL 1703 Fire Classification	Type 2
Limited Warranty	15 Years Workmanship, 25 Years Power Output

Source: PANASONIC (2017)

TSM245-PA 05.08 datasheet

Electrical Data @ STC	TSM-225PA05.08	TSM-230PA05.08	TSM-235PA05.08	TSM-240PA05.08	TSM-245PA05.08
Peak Power Watts-P_{MAX} (WP)	225	230	235	240	245
Power Output Tolerance-P_{MAX} (%)	0/+3	0/+3	0/+3	0/+3	0/+3
Maximum Power Voltage-V_{MAX} (V)	29.4	29.8	30.1	30.4	30.7
Maximum Power Current-I_{MPP} (A)	7.66	7.72	7.81	7.89	7.98
Open Circuit Voltage-V_{OC} (V)	36.9	37.0	37.1	37.2	37.3
Short Circuit Current-I_{SC} (A)	8.20	8.26	8.31	8.37	8.47
Module Efficiency η_m (%)	13.7	14.1	14.4	14.7	15.0

Values at Standard Test Conditions STC (Air Mass AM1.5, Irradiance 1000W/m², Cell Temperature 25°C)

Mechanical Data	
Solar cells	Multicrystalline 6 inches (156 x 156mm)
Cells orientation	60 cells (6x10)
Module dimension	64.95 x 39.05 x 1.57inches (1650 x 992 x 40mm)
Weight	43.0lb (19.5kg)
Glass	High transparency solar glass 0.13inches (3.2mm)
Frame	Anodized aluminium alloy
J-Box	IP 65 rated
Cables/Connector	Photovoltaic Technology cable 0.006inches² (4.0mm²), 39.4inches (1000mm), MC4

Temperature Ratings	
Nominal Operating Cell Temperature (NOCT)	46°C (±2°C)
Temperature Coefficient of P_{MPP}	- 0.45%/°C
Temperature Coefficient of V_{OC}	- 0.35%/°C
Temperature Coefficient of I_{SC}	0.05%/°C

Maximum Ratings	
Operational Temperature	-40~+85°C
Maximum System Voltage	600VDC
Max Series Fuse Rating	15A

Warranty
10 years workmanship warranty
25 years linear performance warranty
(Please refer to Trina Solar product warranty for details)

Packaging Configuration	
Modules per box	25 pcs
Modules per 40' container	650 pcs

TSM_US_2011_RevB

CAUTION: READ SAFETY AND INSTALLATION INSTRUCTIONS BEFORE USING THE PRODUCT.

www.trinasolar.com

Source: TRINA (2017)

Serie 4V2 datasheet

MECHANICAL DESCRIPTION	
Length	1200mm
Width	600mm
Weight	12kg
Thickness	6.8mm
Area	0.72m^2
Leadwire	2.5mm^2, 610mm
Connectors	MC4[9]
Bypass Diode	None
Cell Type	Thin-film CdTe semiconductor, up to 216 cells
Frame Material	None
Front Glass	3.2mm heat strengthened Series 4A™ includes anti-reflective coating
Back Glass	3.2mm tempered
Encapsulation	Laminate material with edge seal
Load Rating	2400Pa[10]

MODULE NUMBERS AND RATINGS AT STC [5,6]							
NOMINAL VALUES		FS-4105-2 FS-4105A-2	FS-4107-2 FS-4107A-2	FS-4110-2 FS-4110A-2	FS-4112-2 FS-4112A-2	FS-4115-2 FS-4115A-2	FS-4117-2 FS-4117A-2
Nominal Power (± 5%)	P_{MPP} (W)	105.0	107.5	110.0	112.5	115.0	117.5
Voltage at P_{MAX}	V_{MPP} (V)	67.8	68.6	69.4	70.2	70.5	71.2
Current at P_{MAX}	I_{MPP} (A)	1.55	1.57	1.59	1.60	1.63	1.65
Open Circuit Voltage	V_{OC} (V)	86.0	86.6	87.2	87.7	87.8	88.2
Short Circuit Current	I_{SC} (A)	1.74	1.75	1.75	1.75	1.78	1.79
Module Efficiency	%	14.6	14.9	15.3	15.6	16.0	16.3
Maximum System Voltage	V_{SYS} (V)	1500 [7]					
Limiting Reverse Current	I_R (A)	4.0					
Maximum Series Fuse	I_{CF} (A)	4.0					
MODULE NUMBERS AND RATINGS AT 800W/m^2, NOCT[8] 45°C, AM 1.5 [6]							
Nominal Power (± 5%)	P_{MPP} (W)	78.3	80.1	82.0	83.9	85.8	87.6
Voltage at P_{MAX}	V_{MPP} (V)	62.6	63.1	64.1	65.0	65.5	65.9
Current at P_{MAX}	I_{MPP} (A)	1.25	1.27	1.28	1.29	1.31	1.33
Open Circuit Voltage	V_{OC} (V)	81.0	81.6	82.1	82.6	82.7	83.1
Short Circuit Current	I_{SC} (A)	1.40	1.41	1.41	1.41	1.44	1.44
TEMPERATURE CHARACTERISTICS							
Module Operating Temperature Range	(°C)	-40 to +85					
Temperature Coefficient of P_{MPP}	T_K (P_{MPP})	-0.34%/°C					
Temperature Coefficient of V_{OC}	T_K (V_{OC})	-0.29%/°C					
Temperature Coefficient of I_{SC}	T_K (I_{SC})	+0.04%/°C					

Source: SOLAR (2017)

ATTACHMENT B – PRODUCTION SIMULATION