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SMART GRIDS AS A NEW FRONTIER OF PRODUCTION AND DISTRIBUTION OF ENERGY FROM RENEWABLE SOURCES

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INDEX

EXECUTIVE SUMMARY

Smart grids represent a new frontier for improvement of transmission and distribution of electric energy since they increase the reliability of power grids through a computerized system which allows to detect and prevent potential outages on the same grid and the whole electrical system.
However the introduction of these new technologies requires additional investments in order to provide the traditional network with such sophisticated computer systems.
The purpose of this work is to assess the profitability of this type of investment in case we apply this set of advanced tools in order to connect two photovoltaic plants owned by a residential and a commercial user, allowing them to exchange part of their self-produced power.
In the first chapter we describe technological features of smart grids, a model of regulatory framework necessary to support the development of this technology and the European plan of development of this technology.
In the second chapter we deal with the photovoltaic technology (PV technology) looking at technical features and level of development of global, European and Italian PV market.
We focus on Italian market in order to expose the incentive mechanism currently available for investment in this sector, since a billing mechanism known as ‘net metering’ will be adopted by two owners of PV plant that we will see in chapters 3-4.
In the third chapter we evaluate two investment projects in two PV plants, whose the first provided power to shared facilities of a complex of four condos situated in the Western suburbs of Padua while the second feeds a post office situated close to previous buildings.
In the forth chapter we revaluate previous investment projects under hypothesis that both users invest in smart grids.
We analyze how changes profitability of such investment if both users decide to trade power among themselves.
In the fifth chapter we valuate again previous investments but we collocate them in a future scenario in order to estimate the value of option to wait for investing on the basis of forecast about future cost of PV system, smart grids, ordinary maintenance of PV plant and electrical system.
Finally we estimate the shares of contribution to added value of PV investment provide by each revenue items through adoption of smart grids.

CHAPTER 1

SMART GRIDS AS NEW TECHNOLOGICAL FRONTIER

In this chapter we present the technology of smart grids and we mention the research program that was at basis of development of this smart system.

Then we develop a technical description of power grids equipped with this technology, which includes both technical requirements and the architecture of smart grids, and present a model of regulatory framework that should promote investments in this field.

After that we expose briefly main issues inherent traditional power grid that motivate such innovation of the same grid and we describe as the project of smart grid that has been elaborated in order to modernize power grid of European Union and integrate the Community power market.

Finally we illustrate main hurdles that Governments should face in order to deploy this new technology and policy imperatives that arise after its adoption.

1.1 What is a smart grid?

A smart grid is an amalgam of sophisticated two-way communication systems and sensors which allows electricity providers to interact with power delivery system in order to optimize and regulate demand, supply and price of electrical power.

It represents the next generation of electricity delivery which is becoming more and more capable to identify and cope critical situations involving power grid.

This type of electrical network improves the management of electrical power distribution and transmission with respect to traditional grid because on one hand it provides useful information about demand of electricity to utilities allowing them to regulate electrical power supply accordingly while on the other hand it allows users to adapt their electricity consumption through demand response mechanism.

Since this new type of technologies provide new monitoring capabilities to electrical system, it improves security, resilience and efficiency of electrical power grid.

The grid security is improved through increase of real-time diagnostic capacity which enables electricity providers to prevent potential outages and power disturbances.

The resilience of electrical power grid is the ability of grid to identify and face emergency situations guaranteeing the fulfilment of energy needs of crucial infrastructures (as hospitals,

fire stations, police departments and military infrastructures) and businesses, in order to reduce the socio-economic impact of potential breakdowns in the same grid.
A smart grid makes electrical networks more resilient because it allows a more rational distribution of electricity, re-routing this commodity to areas where it is insufficient compared to local needs.
As we have mentioned before, a smart grid contributes to efficiency of a power delivery system because it is able to adapt electricity provision to consumption in real-time, avoiding both waste of electrical power and potential overloads due to excessive demand with respect to supply of electricity.
Since electrical power is not storable, it needs to balance demand and supply of this commodity: for this purpose it is necessary to create a virtual buffer for electric power grid, as we will see later.
However it is not easy to forecast power demand because it is very volatile not only at seasonal level, with peaks in summer and winter, but even at hourly level: for example consumption of electricity is higher during the day than during the night.
Moreover a smart grid favours the integration of renewable energy sources into electrical power provision that, combined with a more rational coordination of demand and supply of electricity, they are aimed at reduction of consumption and waste of electrical power, and they implement all government policies whose purpose is environmental protection.

However the institution of a smart distribution grid presents the following aspects, which are:
-the integration of new technologies into existing local distribution networks, such as smart meters, which are useful to improve energy efficiency;
-the provision of grid monitoring and control devices, aimed at making energy distribution more resilient;
-the provision of better tools to favour communication among utilities and electrical suppliers;
-the provision of pricing and control systems, necessary for integration of distributed energy sources, such as solar panels, energy storage devices, and electric vehicles.
These aspects will be discussed in more detail in the paragraph which deals with technical requirements necessary to develop a smart grid while topic of next paragraph is the birth of research programs aimed to implement this new technology.

Figure 1. Smart power grid

1.2 The birth of research programs for smart grids

We can trace the birth of research programs about smart grids in the late 80s, when an F-15 aircraft, piloted by an Israeli aviator, collided with his wingman.

In this accident the previous aircraft lost about 90% of the right wing and consequently it lost also its control surfaces and its symmetry: so this airplane would have been flipped over and crashed, but luckily the pilot was able to made an emergency landing.

Then the previous plan underwent particular control tests at McDonnell Douglas (now Boeing) in St. Louis, United States.

This episode inspired a research team at Washington University to deepen their own studies on optimization and control projects, inherent the field of aeronautics, which led to development of a damage-adaptive Intelligent Flight Control Systems (IFCS).

The IFCS was developed in the period 1985-1998 thanks to contribution of Boeing and Nasa. It uses neural network technology to predict the parameters of aircraft, optimizing the control system response.

Actually IFCS is on the basis of the self-healing power system, so it is applied on the power delivery infrastructure.

It has inspired a research program concerning electrical power grids, namely Electrical Power Research Institute (EPRI)/DoD Complex Interactive Networks/System Initiative (CIN/SI).

This research program looks at a smart grid as a power system composed by millions of interconnected sensors which communicate with each other through an advanced communication and data acquisition system which is able to provide real-time analysis in order to prevent potential outages that electric grid may incur.
It has the aim to make the control of the electrical power grid, together with infrastructures connected to itself, robust, adaptive and reconfigurable.
It focuses its researches on complex adaptive systems (CAS), development of measurement techniques aimed to analyze emerging behaviour and management on large-scale and implementation of management and control systems aimed at increase of robustness and operation of power infrastructure.
CAS are considered as a set of smart agents which are able to react to external events but even if their actions are competitive, they act for the good of whole power grid.
These researches are made through development of simulation analyzes and adoption of synthesis tools.
The objectives of researches planned by CIN/SI are the development of:
-methodologies for robust monitoring of interconnected electrical systems which are heterogeneous and dispersed;
-techniques for deployment of interactive network systems;
-tools to protect power grids against potential cascading failures;
-tools/techniques that allows self-stabilization, self-optimization and self-healing of national power grid on large scale;
-strategies to face the trilemma of population, poverty and pollution.

Previous objectives could be achieved through creation of self-regulating systems.
However the creation of such systems should address challenges which concern following areas:
-sensing, measurement and visualization;
-patterns and simulation;
-systems of control;
-operating systems and management.

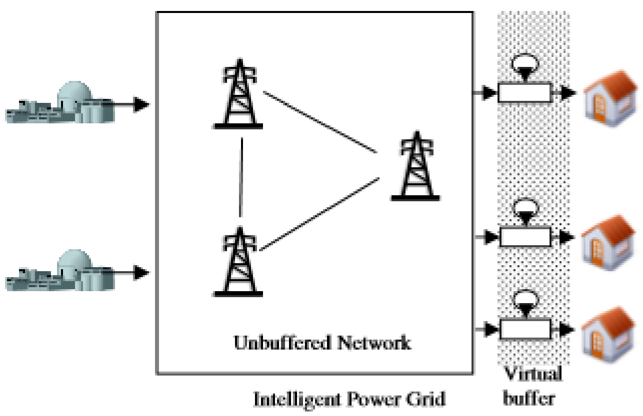
Finally CIN/SI has funded six consortia which involve 28 universities, in order to face challenges described above.
Such consortia have developed further researches that concern the following fields:
-power law and power network;

-grid agents dependent by context;
-reduction of grid outages and efficiency of Complex Interactive Network Systems;
-patterns and monitoring methods for Large-Scale Complex Network;
-smart management of Power Grid;
-technical innovation for protection systems against cascade failures of Complex Interactive Network Systems.

1.3 Technical requirements for a smart grid

In this paragraph we deal with technical requirements necessary for proper functioning of a smart grid.
Such grid is modeled as an Internet-type network, in which power customers are connected among themselves and with electricity providers through sophisticated information and communication systems which allow a real-time transmission of huge amounts of data.
Before describing technical requirements necessary for a smart grid, we present the main operating feature of this type of grid which is the capability to store energy virtually.
This is realized through a virtual buffer between demand and supply of power.
A virtual buffer is based on dynamic scheduling of consumption of electricity by customers in order to balance production and consumption of this commodity allowing an increase of electric bill savings for electrical users: in fact power tariff is determined by both supply-to-demand ratio and capacity of network to transmit energy.
However such dynamic scheduling is made by smart agents which should have anticipatory capability, since virtual buffers are useful to implement stability of an electrical grid.
In the following figure we show how a buffered power network is structured

Figure 2. Structure of a buffered power network



Now we describe the aforementioned technical requirements for a smart network.
The first technical requirement is provision of smart meters with an unique addressable identifier and communication capability.
Smart meters are installed on the customer side and they are fundamental for interaction among customers and electricity providers since hardware support for smart grid bases its operation on exchange of huge amount of information among previous agents in real time.
Such devices are useful to increase efficiency in energy distribution.
The second technical requirement is provision of devices which allow to monitor power grid in order to make forecasts about power demand, implementing resiliency of the same grid.
These devices adopt parametric, non-parametric or hybrid methods in order to make estimates about power consumption.
The third technical requirement is adoption of multi-resolution agents, which are virtual agents that act in order to maximize benefits of their own clients, which could be both power customers, power providers, power grids but not necessarily human beings.
They are rational while people do not always decide rationally.
They could decide to cooperate with other intelligent agents if and only if they could increase gain of their own client with respect to situation of non-cooperation.
The forth technical requirement is application of pricing and control systems which favour integration of renewable sources in the system of provision and distribution of power.
These systems usually adopt short-term price elasticity models that allow to measure how changes of power price affect propensity to electricity consumption of all users.
Finally we remember that predictions produced through previous models should be accurate since these models are useful to develop dynamic negotiations aimed at achievement of a balance among demand and supply of electrical power.

1.4 Architecture of a smart grid

In this paragraph we describe a pattern of architecture of a smart grid that was developed by Electrical Power research Institute (EPRI)/DoD through foundation of Consortium for Intelligent Management of the Electric Power Grid (CIMEG) in 1999.
The starting point of this research program is creation of an anticipatory control paradigm which allows power system to act proactively on the basis of perceptions of potential threats.
The global health of power system is measured through a bottom-up approach.

The security of power grid is maintained through application of another approach, known as Local Area Grid (LAG).

A LAG is demand-based autonomous entity composed by a mixture of various customers and it self-protects by rationalizing power consumption of its members.

This purpose of self-protection is achieved through adoption of intelligent agents.

Such agents monitor all loads inside LAG, estimate demand of electricity and they are able to take anticipatory decisions necessary to avoid potential systemic faults.

Now we describe the scheme of functioning of this model of power grid developed by CIMEG.

First of all a customer, through its smart meter, places its order, containing amount of power that it wants to acquire on the market.

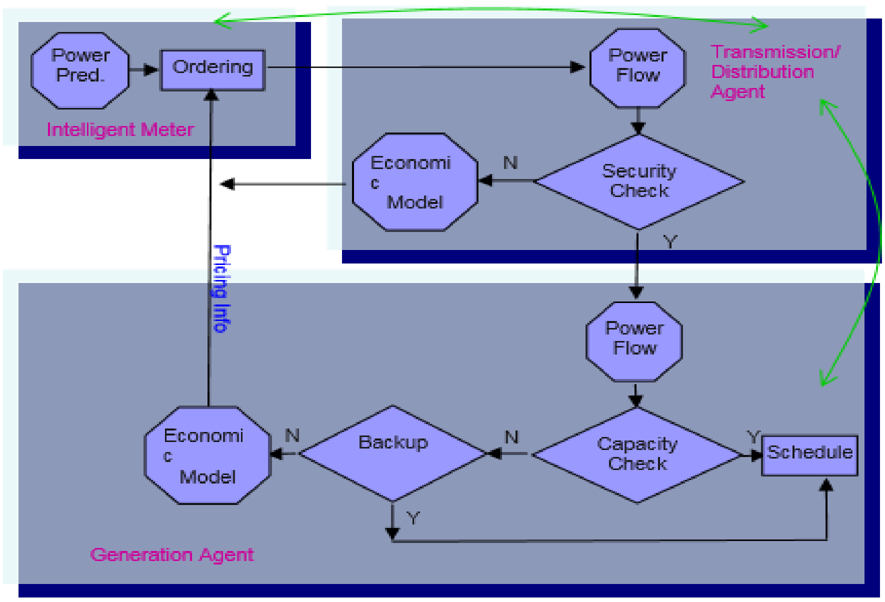
Previous amount is based on estimates of power consumption of such customers and it is affected by market price of electricity.

However market price of this commodity depends by demand and supply and capability of grid to provide required amount of power: so economic models which adopt price elasticity are used.

In this way it is possible to define a virtual buffer between demand and supply of power from interactions among demand and supply.

In the figure below we can see how customers and suppliers interact in CIMEG pattern for a smart grid.

Figure 3. Interactions among customers and suppliers in CIMEG model



1.5 Regulatory framework for smart-grid investments

A necessary but not sufficient condition to rule investments in smart grid is an effective regulation which allows coordination among grid operators and users.

The starting point to establish such regulation is the description of main aspects related to primary factors that affect investments in power networks. These factors are:

-asymmetric information;

-separability of tasks;

-degree of independence of distribution system operators (DSOs) and transmission system operators (TSOs) of smart grid[1];

-role played by externalities.

First of all, asymmetric information involves a cost for acquiring information about expenses inherent smart-grid investments, but such cost depends on possibility of obtaining a reference set of cost observations for operators whose respective structures are comparable.

Secondly current regulation should be based on high separability of tasks among regulated segments since this high level of separability should allow for greater coordination of activities of technical research and development, in order to find effective and interoperable solutions to face problems that occur on electrical grid.

Then we should highlight that high level of independence for DSOs and TSOs is necessary to reduce rent extraction for distribution business of 'old grid' operators.

This last objective could be achieved through disaggregation of accounts for DSOs and disaggregation of ownership for TSOs.

The last factor that influences investments in power grids is represented by externalities on operations of TSOs and DSOs.

Such externalities concern market functioning and environmental impact, but both types of externalities affect TSOs while DSOs are affected only by latter kind of externalities.

Nowadays it is necessary to properly internalize part of these externalities in order to encourage DSOs to invest in such technologies since these last operators are very sensitive to regulatory and business risk of investments.

1. Distribution System Operators (DSOs) and Transmission System Operators (TSOs) are operators which have different tasks: the former is responsible for power system while the latter is focused on local service supply. Moreover in European grid, TSOs are connected to central operator whose voltage is between 220 kV and 300 kV while DSOs distribute power from substations whose voltage is between 110 kV and 132 kV.

After that we have described main aspects involved by regulation of smart-grid investments, we proceed with presentation of primary requirements for this type of regulation, identified by Pollit[2]:

-application of basic principles of liberalized energy market;

-increase focus in regulation without considering end-user tariffs as indicators of regulatory effectiveness;

-focus on economic realization of measures of climate change;

-adoption of advanced risk transfer instruments to manage effectively market and regulatory risk.

The first requirement is based on concept that competition reduces costs and prices by favouring efficient operations, cheap and timely investments while customers react to price signals changing their own power demand.

The second requirement arises since measures of regulation performance should include also environmental impact of a defined regulatory framework together with price paid by end-users.

So it could happen that higher tariffs could be justified by improvement of conditions of surrounding environment.

This last requirement is linked to requirement of developing measures of climate change as a price for CO_2 emissions in order to internalize efficiently externalities brought by emissions of such polluting substances.

However increase of tariff on CO_2 emissions could meet institutional barriers due to reluctance of Governments to invest in low-carbon technologies.

The last requirement of availability of instruments aimed at management of market and regulatory risks is linked to existence of certain risks that should be eliminated or at least their impact should be limited.

So it needs sophisticated tools able to identify which risks are best allocated and where.

To conclude this part about procedure adopted to define a good regulatory framework for smart-grid investments, we illustrate key features that characterize the pattern of regulation described by Pollit[3]together with consequences of these features on configuration of internal organization of power grids. These characteristics are:

2. From paper 'The Future of Electricity (and Gas) Regulation in a Low-carbon Policy World' by Michael Pollit (2008).

3. From paper 'Electricity Network Investment and Regulation for a Low Carbon Future' by Pollit and Bialek.

-delegation of investment choices to negotiated settlements between grid operators and customers;
-promotion of grid expansion and competition among grid operators;
-presence of a regulator which make effective externalities caused by climate change.

As we have said before, such framework presents elements that modify the configuration of internal organization of power grid.
First of all, delegation of investment decisions to negotiations among customers and network operators makes relationship among grid operator and regulator an ex post auditing relationship.
Moreover promotion of grid expansion and competition favours competition for energy services and power generation.
Finally the leading role of regulator in internalization of environmental externalities allows an economic implementation of such externalities.

1.6 Issues about traditional power grid which encourage smart-grid investment by Governments

In this paragraph we illustrate main deficiencies of traditional power grid which require investment aimed at innovation of such grid, namely at making it 'smarter'.
We have identified main deficiencies of traditional electrical network looking at shortcomings of power grid in U.S.A. since European grids present similar deficiencies.
The main functional deficiencies of this type of network are:
-it is not able to meet autonomously power demand of its users, so that it needs to acquire electricity produced by utilities in order to guarantee an energy provision adequate to exigencies of such users;
-it adopts a consumption and revenue-based model which does not encourage users to save power;
-it is based on a 'static design' which does not allow monitoring of data about power consumption and potential failures of power grid;
-it jeopardizes the proper functioning of crucial infrastructures for a Country as hospitals, police stations, military barracks, railways, etc.
-it does not allow users to monitor own power consumptions in real time;

-it involves costs for maintenance of remote connection devices;
-it is not equipped with the communication overlay which would extend its own cyber-security capacities;
-it still exploits an excessive share of power generated by fossil fuels because of lack of incentive to save energy and increase share of renewable sources employed to produce such commodity.

As consequence of each one of previous deficiencies, we have a power grid which is quite vulnerable to cyber attacks and not sufficiently capable of responding to climate change.
We do not forget that not only natural disasters affect negatively energy provision but also global warming has an indirect effect of power provision since it causes melting of glaciers, so that size of water sources which feed power plants is altered by such climate changes.
Moreover such energy network is not able neither to promote exploitation of renewable sources nor to improve quality of energy provided, since an increasing digitalization of economy requires higher and higher quality of energy supply.
So that customers could neither benefit of lower power tariffs nor receive high-quality power as well as environmental policies are not fully implemented.

1.7 An example of project for smart grids on large scale: the European plan for Community smart grid fit for 2020s

1.7.1 Description of four main projects at the base of plan for the European smart grid

We have chosen to describe the European plan for smart grid as a model for development of this technology on large scale since it is one of the biggest project of deployment of large-scale power grids and it presents particular issues about integration of national power markets in an unique continental market of electricity due to different degree of modernization of national networks across Europe and different level of employment of renewable sources for power generation among European Countries.
Now we present the basis of this program, whose aim is creation of a Community electrical infrastructure, which is the 10-years network development plan (TYNDP) [4] which identifies priorities for an European power infrastructure.

4. From paper 'Energy infrastructure-priorities for 2020 and beyond-a blueprint for an integrated European network'.

In order to integrate energy potential of renewable sources of Northern and Southern Europe and the continental power market, the European Commission has indicated the main corridors on which this ambitious project should be developed in the next decade. These corridors are:

1st) offshore grid in the North Sea and connection to Countries of Northern and Central Europe;

2nd) connections in South Western Europe;

3rd) interconnections in South Eastern and Central Eastern Europe;

4th) connections through BEMIP (Baltic Energy Market Interconnection Plan).

The first corridor was chosen to integrate power sources of offshore areas in the North Sea with energy needs of Central Europe.

For this project it needs a coordinated European strategy in order to allow interconnection among national power grids in North-West Europe and all offshore wind farms in the North Sea that will be built within a decade.

The first step that has been done in this direction was the creation of NSCOGI[5]in December 2009 by nine E.U. Member States plus Norway.

NSCOGI is an organism whose purpose is the coordination of development of offshore wind farms and electrical infrastructure of areas surrounding the North Sea.

However this organism could operate optimally if TSOs[6] review plans about development of offshore wind plants in order to find new possibilities of hub interconnections for power trade and regulators authorize new transmission lines that comply with overall development strategies.

Moreover we should highlight that development of offshore power grids implies upgrading of onshore power grids to degree of modernization of offshore ones.

The choice of the second corridor is aimed not only to promote interchange of power among France, Spain and Portugal but also to allow power produced in North Africa through renewable sources to reach users of Central Europe.

The promotion of this project is based on evidence that power lines across Pyrenees are not adequate to guarantee interchange of electricity between Iberian Peninsula and the rest of the continent.

5. NSCOGI is the acronymous of 'North Seas Countries Offshore Grid Initiative' which is an organism funded in December 2009. Source which deals in detail with foundation of such organism is the site 'www.entsoe.eu'

6.TSO is the acronymous of 'Transmission Operators System'

Moreover the renewable energy sector in North African Countries presents great potential for development in the next future, so that it seems a good business to integrate power market of North African Countries to the European one.
Also the project of a submarine power line which connects Italy with Tunisia contributes to favour power interchange among the two shores of Mediterranean Sea.

The third corridor could be seen as a part of strategy of consolidation of regional power grids in Europe through orientation of electricity flows in two directions: North-South and East-West.
The part of program concerning power grid of South Eastern Europe is aimed to overcome the scarce integration of power grid in this geographic area with respect to rest of European continent and exploit hydroelectric potential of Balkan Region.
Another reason for which Countries of this region are so interested in implementation of this project is that they intend to improve own energy production in order to increase amounts of power exchanged with Central Europe and other Countries bordering with European Union as Turkey, Moldova and Ukraine.
The part of program concerning power grid of Central Eastern Europe was elaborated in order to encourage interchange of electricity among Germany and Poland and installation of pumped storage power plants in the Alpine Countries.

The last corridor was indicated in order to allow power markets of Baltic area to be integrated in the European market of electricity through modernization of national electricity infrastructure of Countries as Sweden, Finland and Poland in according to standards of national electrical infrastructures located in Continental Europe.
The main driver of this project was the launch of European Energy Program for Recovery (EEPR) which provides economic incentives for completion of such infrastructure modernization.
Finally also the involvement of stakeholders of Scandinavian region was determinant for such implementation program: in fact both Governments and private investors cooperate with European Commission to achieve goals of this program.

1.7.2 Regulatory context that should be set to implement the European power grid

However implementation of this program, which has continental size, requires setting of a regulatory context suitable for attracting investments aimed at financing such project.
In according to view of European Commission, the starting point for this new regulation is the establishment of the transparency and information platform for smart grids.
This platform should favour the sharing of experiences and good practices inherent the management of this power grid across the Old Continent in order to develop synergies among agents of the same grid and allow a continuous update of previous regulatory framework.
Moreover the European Commission has proposed the introduction of other two tools in order to create such regulation favourable at smart grid development.
These two tools are the dedicated regional platforms and the permitting measures.
The dedicated regional platforms represent an instrument that supports activities as planning, implementation and monitoring of predefined priorities.
Furthermore it raises public awareness on benefits brought by this type of innovation.
The permitting measures improve coordination and transparency toward all stakeholders involved in projects of 'European interest'.
In this way they favour participation of private investors in decision-making they speed up realization of this kind of projects.
Process of decision-making is implemented through:
-institution of a contact authority for projects of 'European size' which mediates between implementers of project and competent authorities responsible at national, regional and/or local level without interfering their competence;
-definition of a time limit for competent authority to take decisions;
-introduction of guidelines that show in a transparent way process of decision-making to all stakeholders involved;
-provision of incentives to favour timely realization of such projects.

Eventually it is necessary to maintain a stable framework for financing.
This last objective could be achieved through a better cost allocation and the catalytic role of funding handed out by the Community bodies.
A better cost allocation consists in application of the so-called 'user pays principle' which states that power tariffs should be regulated in order to allow energy provider to recover the sum invested.

The catalytic role of funding handed out by European Commission is based on the so-called ‘two-front’ approach, which consists in:

-consolidation of partnership between European Commission and International Financial Institution (IFI) and development of smart-grid programs through joint financial and technical initiatives;

-identification of energy priorities through new tools whose base is mix between traditional and innovative financial mechanisms.

1.7.3 Key-actions necessary to face future challenges

After that in previous subparagraph we have seen how a regulatory context should be set in order to promote investments in smart grids, now we conclude the European plan for smart grids presenting all actions that are necessary in order to make smart grids able to face future challenges.

First of all we should continue to maintain a regulatory framework which encourages investments in this field as we have already said in previous subparagraph but this is not sufficient.

Furthermore we should operate in other field as standardisation and interoperability, data protection, R&D and innovation projects and promotion of new skills.

Standardisation and interoperability represent the fundamental premise to create an European power grid.

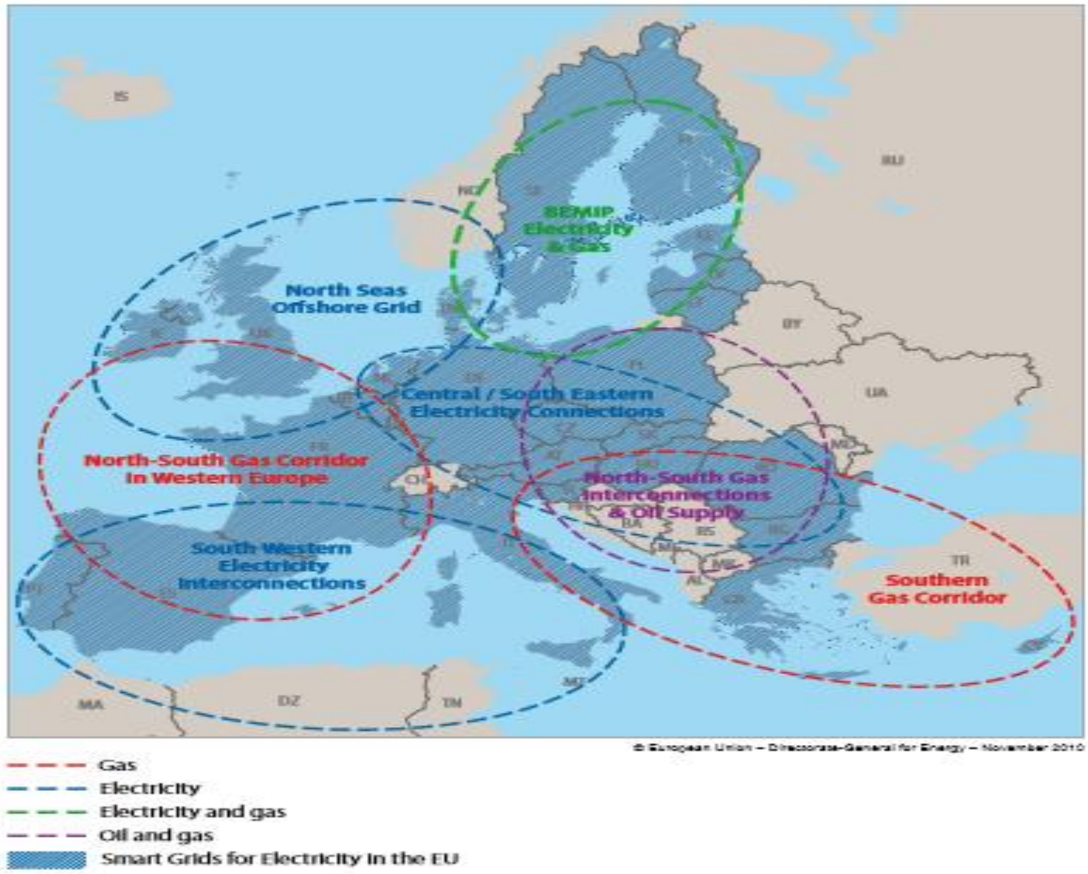
Data protection requires to implement new data protection measures and define roles and responsibilities of agents that operate in the network.

R&D and innovation projects are aimed to make continental power grids smarter and smarter.

Finally promotion of new skills is necessary to eliminate discrepancy between low-skilled and high-skill job through implementation of training activities.

In the figure at the next page we show the geographic location of all planned projects for implementing not only power grid but also oil and gas pipelines that allow energy market of European Union to connect with energy markets of North Africa, Middle East and Russia.

Figure 4. Map of priority corridors for electricity, oil and gas in European Union[7]



1.8 Hurdles to building a smart power grid on large scale

After that we have dealt with European plan for realization of smart power grids, in this paragraph we describe the major hurdles that governments should face to develop smart grids on large scale.[8]

These hurdles could be divided in four macro-areas:

1) Planning;
2) Siting ;
3) Allocation of costs;
4) Ensuring a low-carbon power production.

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7. Source: paper 'Energy infrastructure-priorities for 2020 and beyond-a blueprint for an integrated European network'.

8.'Building a National Clean-Energy Smart Grid' from paper 'Wired for Progress 2.0'

1) Planning

The phase of planning a smart-grid project is necessary to determine the interested parties that are involved in such projects, so that it states clear rules aimed at elimination of potential conflicts among all participating parties.
Moreover planning a smart grid includes also all actions whose purpose is improvement of planning approaches, reduction of environmental impact and overcoming natural constraints.
If we look at American examples of planning smart grids on large scale as Western Renewable Energy Zone processes and Joint Coordinated System Planning, we learn that broad-based planning could be an optimal approach to remove political obstacles to the realization of a smart-grid on wide-scale, which is necessary to overcome the traditional model of power distribution system which was set on regional basis.
This broad-based planning should analyze potential local resources and favour exploitation of on-site renewable resources so that its proposed solution are valid in the long-run.
Moreover it has to contain a valuation of amount of resources necessary to modernize traditional power grid as well.
Finally this broad-based planning works if power users cooperate in realization of advanced procedures of analysis aimed at acquiring essential information for a good planning of such infrastructure.

2) Siting

This last issue concerns the development of a smart power network on large scale starting from realization of transmission projects in several sites served by this infrastructure.
It requires institution of siting authorities in previous sites in order to facilitate the whole realization of these projects on wide-scale.
The task of such siting authorities is identification of deficiencies in power grid at local level as interconnection problems or scarce employment of renewable sources for power generation. Moreover they could act autonomously in order to solve issues of power grid and encourage exploitation of on-site renewable sources.

3) Allocation of costs

Allocation of costs for realization of smart-grid investments on wide scale is an important topic that we should discuss since we are dealing with an infrastructure that provides benefits to a huge numbers of subjects located in wide geographic areas.
So the first principle for cost allocation inherent investments of such magnitude is that all ratepayers should share expenses for building this interconnection-wide system.
Thus such expenses should be distributed on a so-called load-ratio basis.

4) Ensuring a low-carbon power production.

A policy goal linked to plan for smart-grid development is the increase of reliability of low-carbon technologies and minimization of environmental impact due to implantation and maintenance of smart power grids.
This policy goal could be achieved through provision of economic incentives to investments aimed at realization of technologies that allow to generate power without impact on natural environment and climate change.
However this allocation of financial resources to projects aimed at production 'clean energy' requires the identification of sources from which power is generated and injected to the network in order to avoid provision of financing to traditional power sources.

1.9 Policy imperatives for adopting smart-grid technology

In this last part of this chapter we discuss about policy imperatives[9] that come out when a State or an union of States, as European Union, decides to invest in this field.
The main policy imperatives linked to deployment of smart grids on large scale are:
- the security of physical power grid and cybersecurity;
-the possibility to provide new jobs linked to development of this new technology and power production through renewable sources.

9. 'Building a National Clean-Energy Smart Grid' from paper 'Wired for Progress 2.0'

The first policy imperative could be achieved through implementation of monitoring and management activities in order to make physical power grid reliable.
While cybersecurity requires application of sophisticated technologies that are able to manage power flows in according to power demand and react to protect the same grid against manmade disruptions.
The second policy imperative implies that governments should invest in training workforce since this technological sectors requires employment of high-skilled workers.
For example U.S. Government has launched programs in order to increase employment in the so-called 'green jobs', which are job linked to development of renewable energy sources. These programs consist on financing the so called 'green job training, provision of high wages and career opportunities for 'green jobs'.
However both sectors of smart-grids and 'green economy' could represent valid job opportunities if they are supported by private investment, qualification of workforce and accountability to high standards.

1.10 <u>Conclusions</u>

In this chapter we have seen the features of smart grids which represent a new technological frontier, more precisely we have discussed about technical characteristic and architecture of an electrical system equipped with smart grids.
Then we have learnt that development of smart grids mainly depend by legislative framework and private and public financing for this technology.
In fact we denote that both U.S Government and European Commission are more and more involved in supporting this economic sector since they are aware of inadequacy of conventional power grid to actual and future exigencies of good-quality power.
The main driver of increasing demand for high-quality power is the growth of digitalization. Moreover U.S.A. and E.U. have intensified investments in this new technology also because they want to integrate power markets and remove all economic and political barriers that hinder the traditional fragmentation of electrical grid.
Finally such type of investment represents a necessary solution for development of exploitation of renewable energy sources which are more compatible to environment with respect to traditional energy sources and they represent a valid alternative to previous sources in a world in which it is expected the future depletion of fossil fuels as oil, gas and coal.

CHAPTER 2

THE PHOTOVOLTAIC TECHNOLOGY FOR POWER GENERATION

In this chapter we briefly describe the photovoltaic technology applied to convert solar radiation in electricity, which is distributed to residential, commercial and industrial users through power grid.
At first we illustrate technical features of this technology, focusing on three classes of PV systems.
Then we look at degree of development of photovoltaic market on three levels: world, European and Italian level.
Finally we deal with situation of Italian photovoltaic market in more detail through an overview of main changes in Italian regulatory framework and a description of the main support schemes currently available in such market for sale and valorisation of power produced by PV systems.

Figure 1. PV systems with mono-crystalline silicon solar panels

Source: site 'www.logismarket.it'

2.1 Photovoltaic technology: technical features

The principle of operation of this technology is the photovoltaic effect[10], which is chemical and physical phenomenon that consists in conversion of light into electricity at the atomic level.

In nature there are some materials that if they are stricken by photons of light they release electrons, namely they exhibit a property known as photoelectric effect.

This last property was discovered by Edmond Bacquerel in 1839 but the first photovoltaic module was realized in Bell Laboratories in 1954.

A PV module is composed by a certain number of solar cells that are electrically connected to each other and assembled in a frame or support structure.

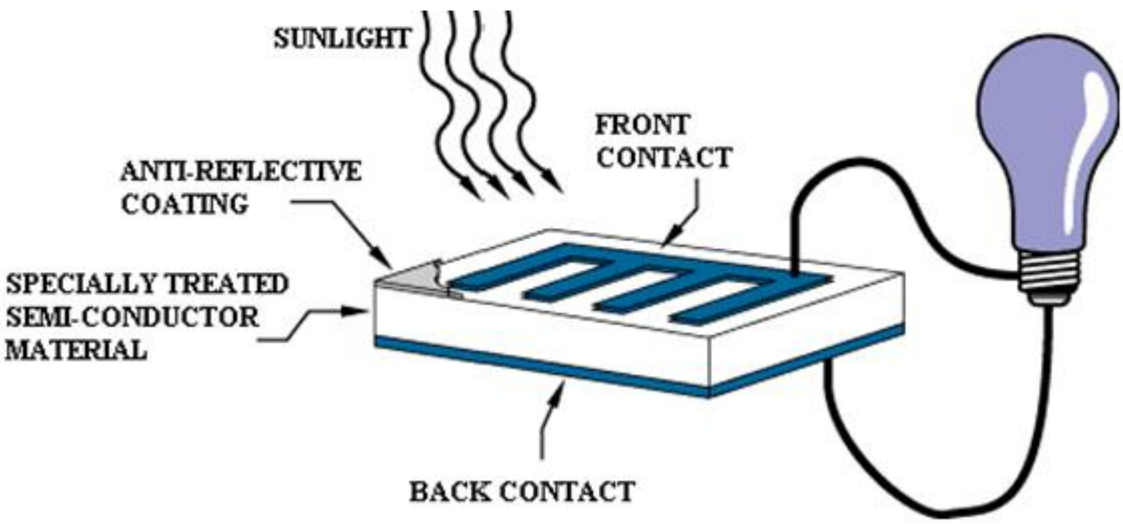
Such cells are made of various semiconductor materials that exploit PV effect.

If such cells are stricken by photons, electrons are loosed from atoms.

Then if electrical conductors are attached to the positive and negative poles of such cells, forming an electrical circuit, these electrons are captured in the form of an electric current.

In the following figure we show how a solar cell works.

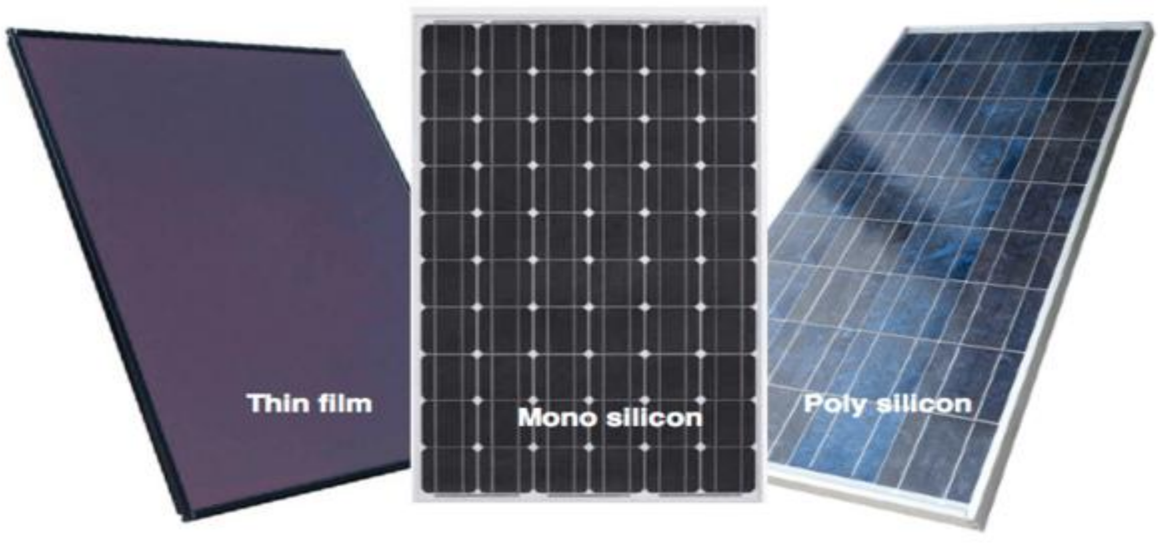
Figure 2. Functioning of a solar cell whose generated power feeds a bulb[11]



10. ‘How does photovoltaic work?’ by Gil Knier
11. ‘How does photovoltaic work?’ by Gil Knier

The most used semi conductor material to build PV modules is the crystalline silicon, but recently new materials for realization of solar cells have been introduced.
We are speaking about new thin-film materials as amorphous silicon, cadmium telluride and cooper-indium-gallium-diselenide.
Today there is a huge range of PV cell technologies that are classified into three generations[12], in according to basic material used to build PV systems and level of commercialization of such systems.
The three generations of PV systems are:
-first-generation PV systems, whose solar modules are composed by wafer-based silicon cells made of mono crystalline or polycrystalline silicon;
-second-generation PV systems, whose solar modules are composed by thin-film cells that could be realized with three alternative materials as amorphous silicon, cadmium telluride and cooper-indium-gallium-diselenide;
-third-generation PV systems includes technologies as concentrating photovoltaic (CPV) cells, dye-sensitized solar cells (DSSC) and organic PV cells that are not available on the market since they are still in course of experimentation.

Figure 3. Types of solar panels currently available on the market[13]



At first PV technology was applied in the space industry, then energy crisis in the 1970s encouraged application of such technology in power generation.

12. 'Solar photovoltaics', IRENA, June 2012
13. From site 'www.cleanenergyreviews.info'

However power produced by solar modules is a direct current while all electrical devices require alternating current to operate, so that PV systems are equipped with inverters which convert direct current generated by solar modules to alternating current.

The two main types of inverters used in solar installations today are[14]:

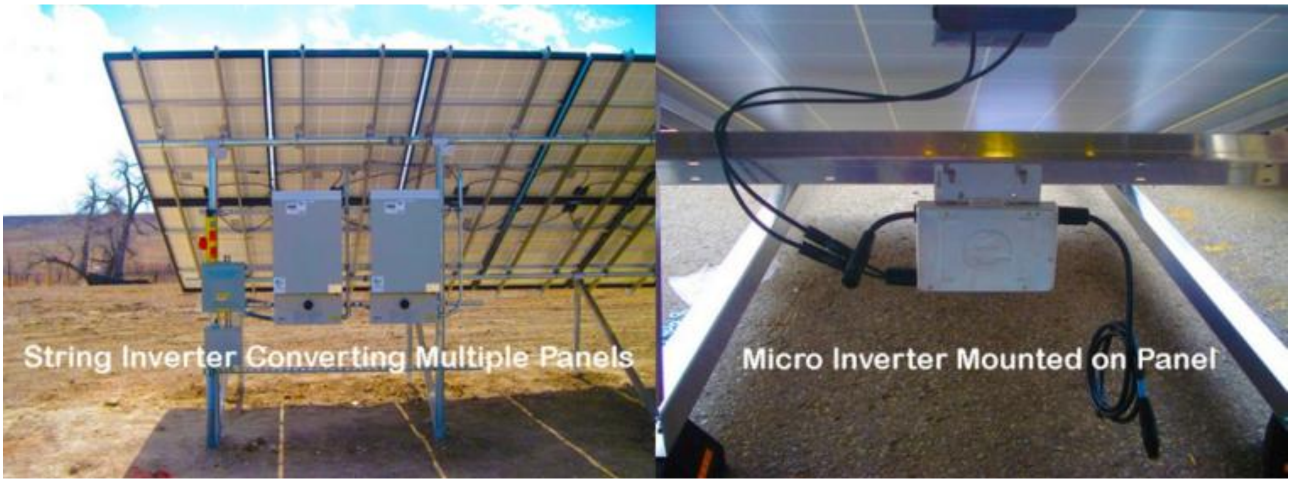
- string inverters;
- micro-inverters.

String inverters convert direct current coming from a string of panels in alternating current. They are cheaper than micro inverters but they are not able to avoid that faults of one panel affect other panels of the same string.

Micro inverters convert direct current that receive from one panel to alternating current. They are more expensive but more reliable than previous ones since faults of one solar panel do not compromise functioning of other panels.

The next picture shows the two aforementioned types of inverters.

Figure 4. String inverters and micro-inverters[15]



Finally we conclude this description of main technical feature of photovoltaic technology dealing with another interesting aspect that concerns photovoltaic technology: the energy efficiency of solar cells. [16]

The level of energy efficiency depends by material used to realize solar cells and solar panels. Lab tests show that energy efficiency of single solar cells is higher than energy efficiency of solar panels.

14. ‘Micro-inverters from string inverters’ from site ‘www.completesolar.com’
15. ‘Micro-inverters from string inverters’ from site ‘www.completesolar.com’
16. ‘Photovoltaics Report’ from site ‘www.ise.fraunhofer.de’

The maximum level of energy efficiency tested in laboratories for each type of solar cells and solar modules is the following:

-it is 25.6 % for mono-crystalline silicon cells and 22.9% mono-crystalline silicon modules;

-it is 20.8% for poly-crystalline cells and 18.5% for poly-crystalline modules;

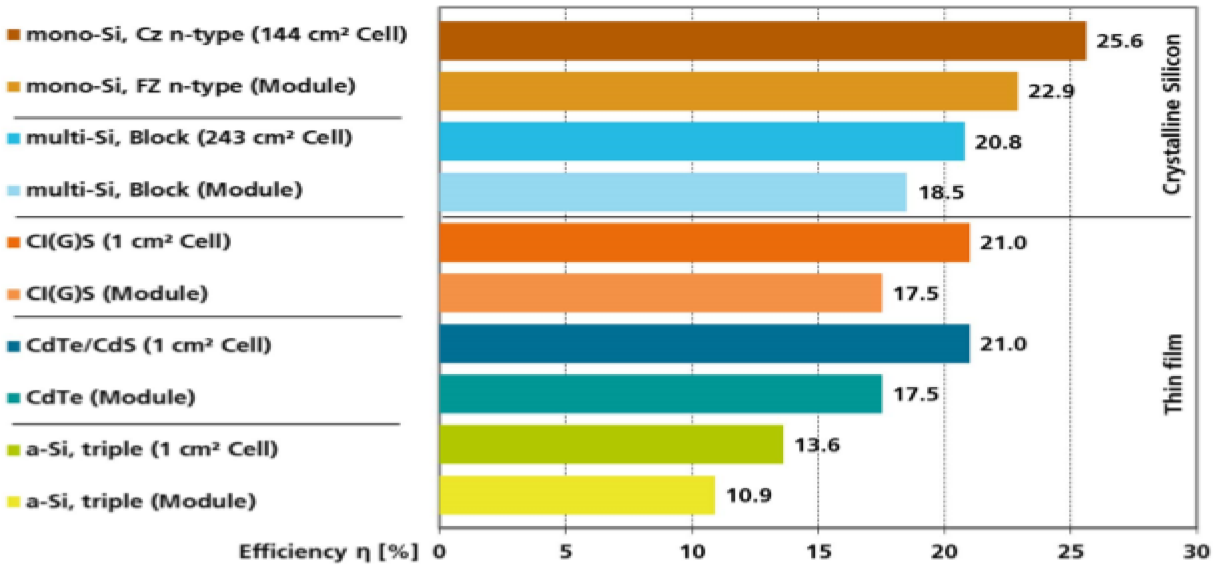
-it is 21 % for thin-film cells made of cooper-indium-gallium-diselenide and 17.5% for modules composed by this type of cells;

- it is 21 % for thin-film cells made of gallium telluride and 17.5% for modules made of this same material;

-it is 13.6% for thin-film cells built with amorphous silicon and 10.9% for modules built with this materials.

In this figure we summarize all these results about levels of energy efficiency of various solar cells and solar modules built with aforementioned materials.

Figure 5. Maximum levels of energy efficiency of solar cells and solar modules[17]



17. ' Progress in PV: Research and Application 2015'

2.2 The global photovoltaic market

In this paragraph we describe the global photovoltaic market.
In the first subparagraph we deal with current level of development of such market looking at cumulative PV installation and market shares held by two main types of solar panel currently available on the market.
In the second subparagraph we present briefly forecasts about future development of global photovoltaic market until 2018.

2.2.1 Current level of development of global photovoltaic market[18]

At the end of 2014 it was estimated that global cumulative capacity of PV installations exceeded the threshold of 180 GW with a growth of more than 40 GW over the previous year. This growth was driven above all by increase of Chinese PV installations, whose cumulative capacity was 60 GW in 2014 versus 40 GW of previous year.
So China is become the second world producer of PV energy behind Germany in 2014.
Its share of global cumulative capacity is 18% versus 20% of Germany.
Other Countries which have high levels of cumulative capacity of PV installations are Japan, USA and Italy whose global shares are respectively 13%, 12% and 10%.
If we compare such data with the ones of 2008, we should denote that cumulative capacity of PV systems all over the world has grown by 6 times in 6 years driven by fall of price of solar modules and increase of energy efficiency of such modules.
In the last 6 years average cost of solar modules has dropped by 43% at global level while average growth of energy efficiency has been 150% for wafer-based silicon modules and 110% for thin-film cadmium telluride modules in the same period of time.
If we look at global market shares of PV technologies adopted[19], we could denote that PV market is dominated by crystalline silicon modules whose market share was 90% at the end of 2014 while thin-film modules had a market share of 10% in the same period.
Thin-film modules recorded a reduction of their market share with respect to six years ago, when it was 18%.
In the following figures we resume all data about global PV installation that we have seen so far.[20]

18. 'Photovoltaics Report' from site 'www.ise.fraunhofer.de'
19. From site 'www.solarcellcentral.com'
20. 'Photovoltaics Report' from site 'www.ise.fraunhofer.de'

Figure 6. Growth of global cumulative PV installation

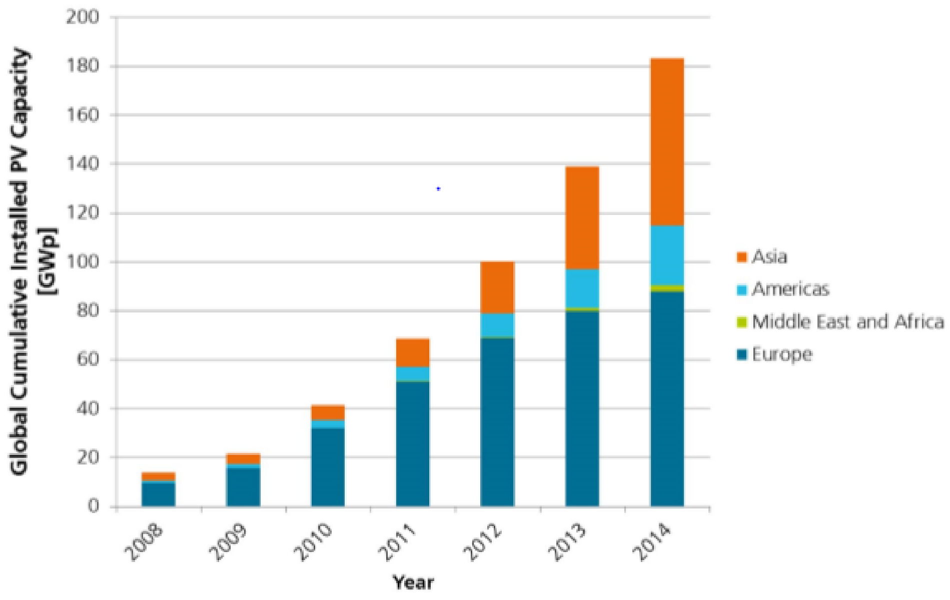


Figure 7. Shares of global cumulative PV installations held by Regions

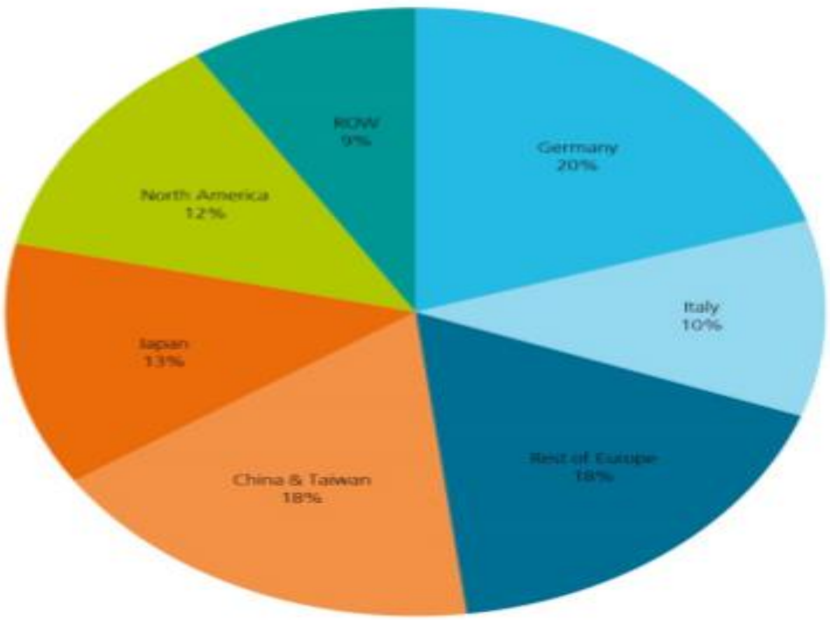
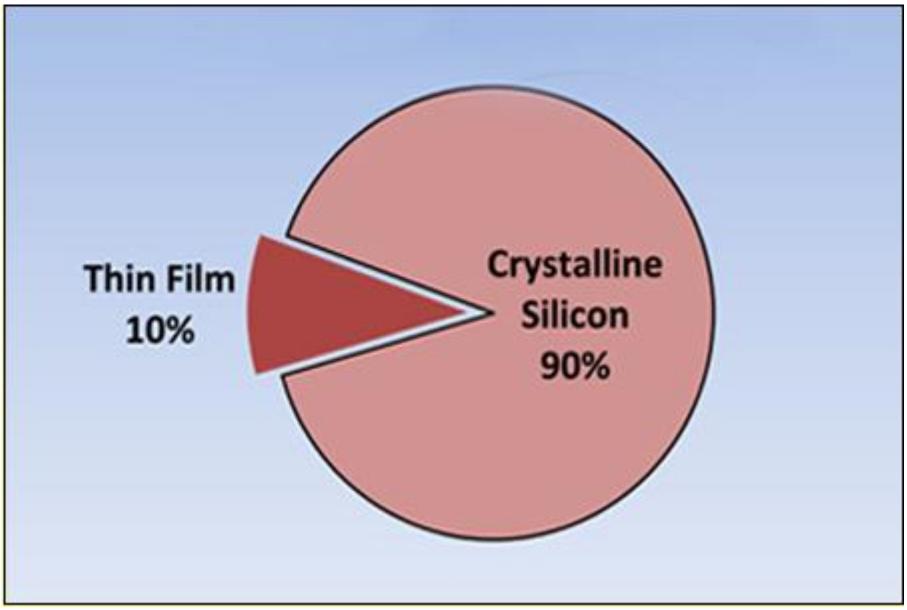


Figure 8. Market shares held by crystalline silicon and thin-film modules in 2014[21]



Development of PV sector is mainly driven by achievement of grid parity, that is the condition in which cost of production of solar power is equal or lower than cost of production of power through traditional sources as fossil fuels and uranium.

Under this condition, PV sector could continue its development without government support.

However development of such sector depends by its competitiveness as well, that is mainly affected by how power tariffs are set.

Investments in PV plants could be considered as low-risk investments since they are characterized by technical reliability and high predictability of output.

Notwithstanding there are two types of perceived risks linked to external factors that influence this kind of investment decisions, increasing cost of capital for investment in PV systems.

Such risks are:

- regulatory risk;

-operational risk.

The regulatory risk is represented by possibility of introducing retroactive measures.

Such risk is linked to political decisions and it not well hedged through financial products.

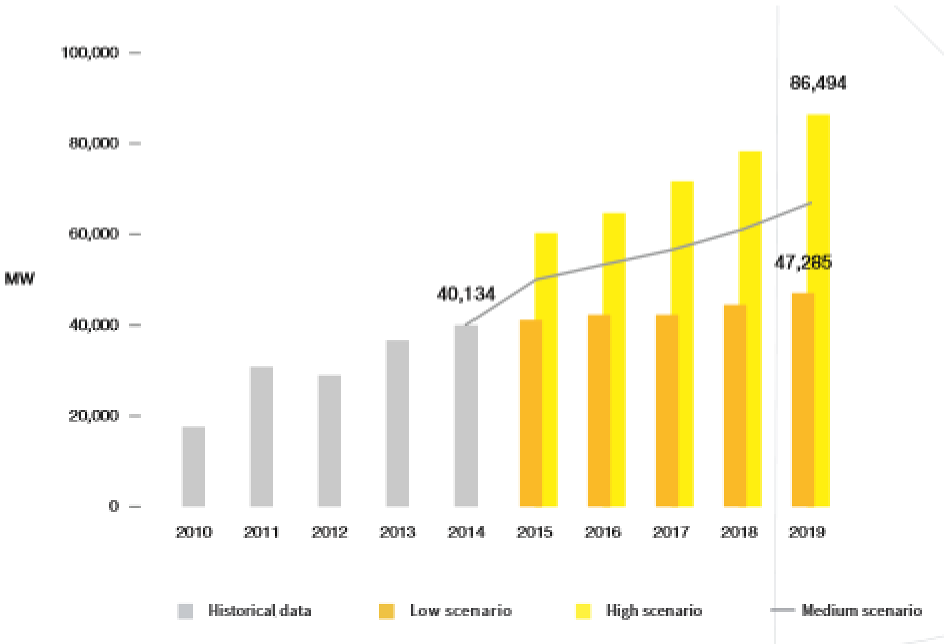
The operational risk is related to possibility that annual performance level of PV system is lower than expected level, but this risk could be minimized through adoption of good-quality PV components.

21. ‘Photovoltaics Report’ from site ‘www.ise.fraunhofer.de’

2.2.2 Forecasts about future level of development of global PV market[22]

Now we present forecasts about future level of development of such market until 2019.
In the Low Scenario the annual growth of global PV installations is estimated between 40 and 47 GW in the next four years.
This last scenario will occur if European PV market will grow slowly and emerging Countries will not be able to stabilize own national PV markets.
It is based on considerations about historical development of PV sector which has been supported by feed-in tariff policies whose it is expected the abolition in the future.
In the High scenario the annual growth of global PV installations ranges between 60 and 86 GW and it is based on expectations of strong political will aimed at support of this sector and a growth of such sector in India.
Finally there is the medium scenario which is represented as the weighted probability that defines the most probable forecast of PV market development.
All forecasts about these three scenarios are shown in the next figure.

Figure 9. Forecast about growth of global PV market until 2019.



22. 'Global market outlook for Solar Power 2015-2018' from site 'www.solarbusinesshub.com'

2.3 The European photovoltaic market[23]

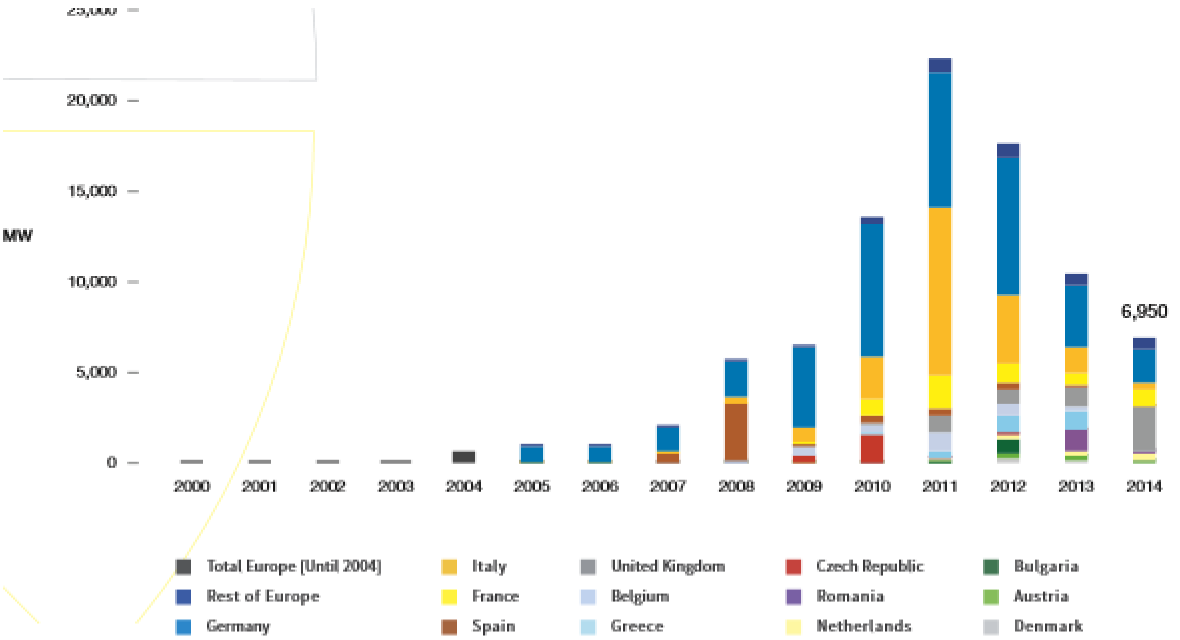
In this paragraph we deal with European PV market.
In the first subparagraph we look at evolution of such market in the last 15 years and describing the current situation of itself.
In the second subparagraph we illustrate briefly outlook about future performance of PV sector in Europe until 2019.

2.3.1 Current status and evolution of European PV market

In 2014 growth of PV installations in Europe dropped to the same level as in 2009.
This is due to transition phase of such market from feed-in tariff support policies toward a more market-based framework.
However development of European PV market is characterized by two opposite forces since on one hand we see a progressive trend to integrate PV sector in electricity markets but on the other hand some European Countries have adopted retroactive measures that increase level of uncertainty associated to investment in PV technologies.
If we look at European data of 2014, we denote that Country with the highest annual growth of PV installations was Great Britain, followed by Germany, France and Italy.
About markets driven by net-metering, PV markets of Belgium and Denmark had a bad performance while Dutch PV market had a good performance.
Evolution of European PV market in the last 15 years is characterized by two important features:
-the adoption of feed-in schemes for the period 2006-2011;
-the gradual abolition of such incentives from 2012.
For the period 2006-2011 we denote a significant growth of continental PV market as effects of introduction of these support policies while for the following period we denote an unstable path of such sectors due to transition to a more market-based model.
The following figure depicts the evolution of European PV market in the last 15 years.

23. 'Global market outlook for Solar Power 2015-2018' from site 'www.solarbusinesshub.com'

Figure 10. Evolution of PV annual installed capacity in Europe for the period 2000-2014



In previous data we could observe the leading role of Spanish PV market in European growth of PV sector in 2008.

Then PV markets of Spain, Bulgaria and Czech Republic were negatively affected by introduction of retroactive measures that discouraged investments in such PV markets.

However the European goal of 90 GW of PV installed capacity planned for 2020 has been achieved in 2014.

Another interesting aspect of European PV market is its segmentation that makes such market heterogeneous.

Segmentation is influenced by support policies and economic context of each Country.

In the last years we denote a progressive change of European regulatory framework due to implementation of policies aimed at integration of renewable energy sources in the continental electricity market.

However the definition of segmentation of European market is ambiguous but it is useful only to compare PV markets in according to cumulative PV installed capacity.

The segments in which PV market of Old Continent has been divided are:

-residential, which includes PV systems whose nominal power is below 10 kWp;

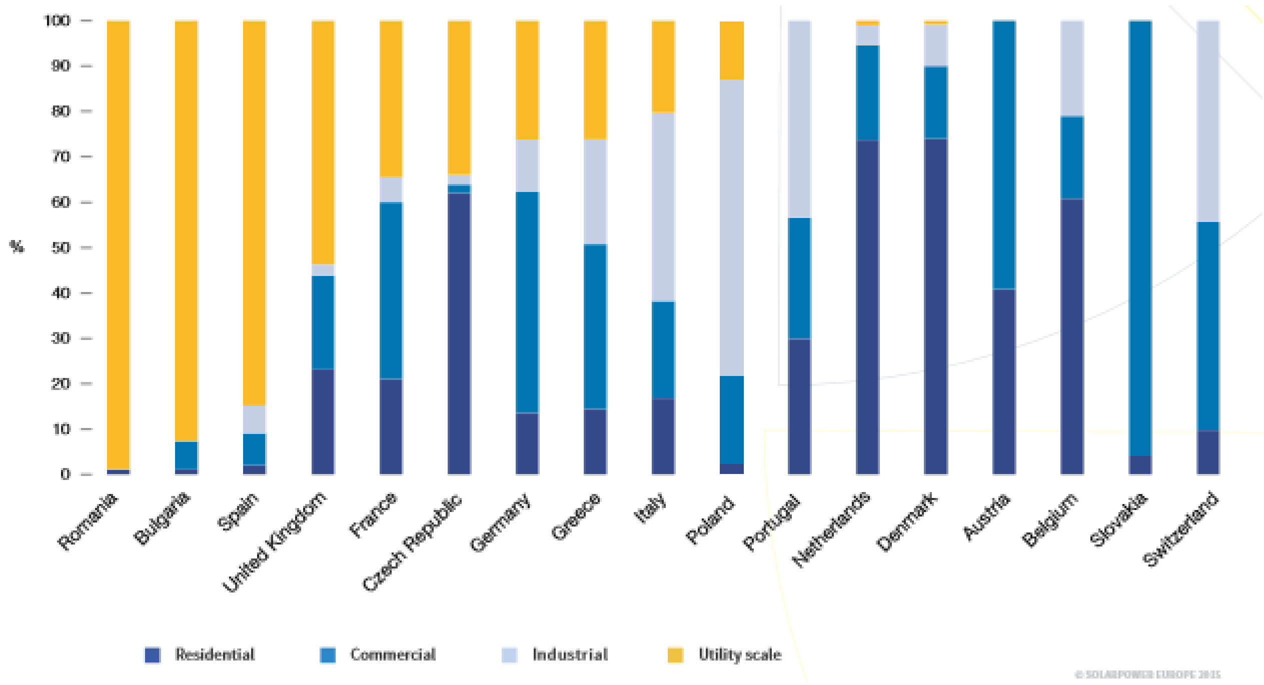
-commercial, which includes PV systems whose nominal power is between 10 and 250 kWp;

-industrial, which includes PV systems whose nominal power is between 250 kWp and 1 MWp;

-utility scale, , which includes PV systems whose nominal power is above 1 MWp.

In the following figure we show the cumulative PV capacity segmentation by Country in Europe in 2014.

Figure 11. European cumulative PV capacity segmentation by Country in 2014.



2.3.2 Forecasts about future performance of European PV market

In this subparagraph we discuss about forecasts inherent future growth of PV market in Europe until 2019.

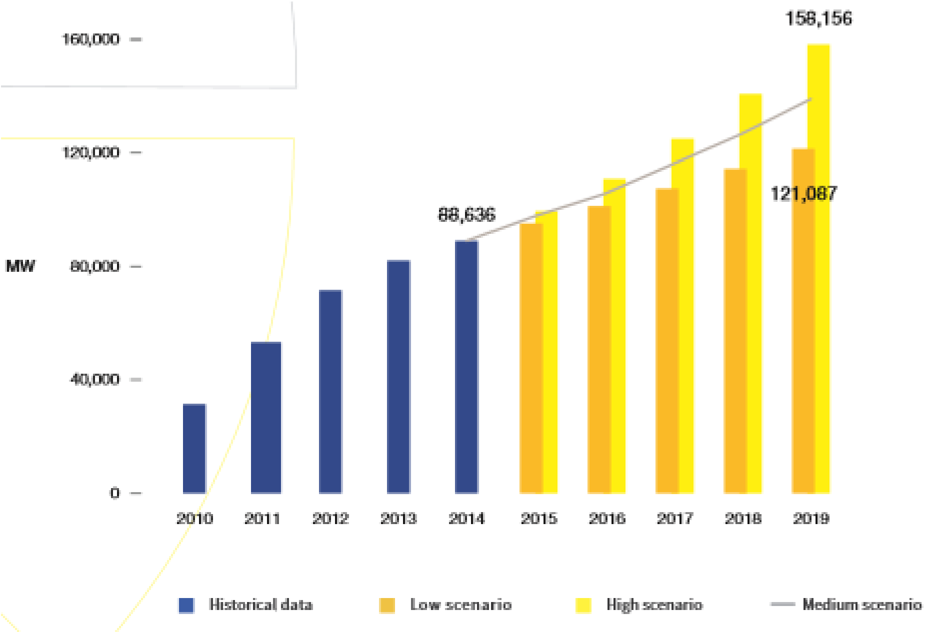
For the next four years the estimated yearly growth of PV installed capacity ranges between 7 and 17 GW, which is a lower growth level with respect to levels of annual growth seen in the last 15 years.

In the high scenario, total PV installed capacity will achieve the threshold of 158 GW in Europe in 2019 with an increase by 80% with respect current level of cumulative PV installed capacity.

While in low scenario, the cumulative PV installed capacity in Europe will be 120 GW in 2019.

The next figure shows expected evolution of European PV installed capacity until 2019 in according with previous scenarios.

Figure 12. Expected evolution of European PV installed capacity until 2019



2.4 The Italian photovoltaic market

In this last paragraph we discuss about Italian PV market.

At first we describe briefly the current level of development of such market and then we focus on two aspects of such market which are the evolution of Italian regulatory framework in the last ten years and the two main support schemes adopted by owners of PV plants of small-medium size in order to sell or valorise power generated by own PV system.

This last aspect about support schemes is important in order to present the billing mechanism that will be considered in the analysis of the two investment projects that we will see in the next two chapters.

2.4.1 Current level of development of Italian PV market[24]

In Italy PV cumulative capacity has reached the threshold of 18.6 GW at the end of 2014 with an increase of 0.44 GW with previous year.

Such yearly growth of PV capacity in Italy was modest compared to annual growth recorded in the last 6 years, considering that it was 431 MW in 2008.

24. 'Rapporto Statistico 2014, solare fotovoltaico' from site 'www.gse.com'

The slowing of this pace of growth of this sector is due to end of feed-in schemes denominated ‘Conto Energia’ but also to other reasons as the reduction of feed-in tariffs, the so-called ‘Spalma Incentivi’, and the inclusion of PV systems in the tax basis of the municipal real estate tax (in Italy known as ‘IMU’).

About geographical distribution of PV systems in Italy, we find the highest share of installed PV plants in North Italy, roughly 54%, while shares of installed PV plants in Central Italy and South Italy (Sicily and Sardinia included) are respectively 17% and 29%.

Finally we can denote that growth of Italian PV market is driven by residential and commercial installations since they could benefit from feed-in tariff schemes, as Net Metering System.

Net Metering System, in Italy known as ‘Scambio sul Posto’ (SSP) could be adopted only by PV plants whose nominal power is lower than 200 kWp.

Since industrial PV systems could not exploit advantages of such incentive, they should increase their share of self-consumed power.

2.4.2 Evolution of Italian regulatory framework for PV sector

In this subparagraph we focus on evolution of Italian regulatory framework in the last ten years in which five regulation feed-in schemes, denominated ‘Conto Energia’, were introduced in order to promote the exploitation of renewable energy sources as solar, wind, wave, hydropower, etc.

Such incentive mechanisms allow Italy to become one of the world’s greatest producer of power through PV sources.

They improved generation of PV power through provision of premium tariffs to owners of PV systems for the 20 years following the investment.

However the aforementioned premium tariffs have been gradually reduced, so that yield of this type of investment has changed in the course of last decade: it ranged between 30 and 35% in 2007, then it declined to 15% in 2011.

After that we have discussed effects of introduction of this feed-in schemes, now we describe briefly each one of them.

1st 'Conto Energia'[25] entered into force in September 2005 and it was a revolution for PV sector in Italy since for the first time private investors could access to incentives for power generation through renewable sources.
Such feed-in scheme was successful.

2nd 'Conto Energia'[26]entered into force in February 2007 and introduced new criteria for installation of PV plants which were installed until December 2010.
The premium tariff was granted to the whole power generated and not only to self-consumed energy, which is power produced and then consumed on site.
Moreover this scheme simplified bureaucratic procedures to obtain such premium tariffs and it was introduced a diversification of tariffs considering also architectural integration of PV system.
Then such scheme was prorogued until June 30, 2011.

3rd 'Conto Energia'[27] was valid for PV plants that started to operate from January 1, 2011.
PV plants were divided in power classes, which were criteria to assign appropriate tariffs.
Such power classes were 'integrated', 'partially integrated', 'building integrated PV plants with innovative characteristics', 'concentrating PV plants' and 'technological innovative PV plants'.

4th 'Conto Energia' [28] is valid for all PV plants commissioned between June 1, 2011 and December 31,2016 with a minimum nominal power of 1 kW.
Until December 31, 2012 the so-called feed-in premium tariff was paid for power generated by PV plants, it covered a period of 20 years starting from commissioning date and it was composed by premium and price paid for electricity produced.
Then such tariff was composed by both value of power injected into the grid and incentives.
The goal set for such scheme was installation of 23,000 MW of PV capacity at national level.

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25. It was introduced with Ministerial Decree of 28th July 2005 in application of Directive 2001/77/EC on promotion of power produced through renewable sources.
26. Ministerial Decree February 19, 2007
27. Ministerial Decree August 6,2010
28. Ministerial Decree May 5, 2011

5th 'Conto Energia'[29] entered into force on August 27,2012 and then Italian electricity and gas regulator, AEEG[30], stated that this feed-in scheme would cease to have effect 30 calendar days after that cumulative cost of incentive would reach the sum of € 6.7 billion per year[31]. Such scheme is applied from commissioning date of PV plant and it will be paid 20 years.
It was introduced a new feed-in tariff that granted an all-inclusive feed-in tariff to amount of power fed into the grid and a premium tariff for self-consumed electricity.
Finally energy generated by PV plant whose nominal power was higher than 1 MWp will remain available to owner of PV plant.

2.4.3 Support schemes for sale and valorise power generated by own PV plant

Now we present the two main support schemes adopted by producers of PV power in order to sell or valorise such power self-produced.
These support schemes are purchase and re-sale agreements and net metering, but the first scheme allows PV plant's owner to sell power to GSE[32], while the second scheme allows PV plant's owner to have power generated by own PV plant valorised.
Before describing such support schemes, we want highlight that a the scheme of connection of a PV system is structured in such a way that at first power produced feeds PV owner's needs but if the quantity of power generated exceeds its needs, it is injected to the grid.
If quantity of self-produced energy is below user's needs, then user at first absorbs power produced by own PV plant and then it acquires the residual part of electricity from the grid.

1) Purchase and re-sale agreements

The first support scheme that we present is purchase and re-sale agreements, in Italy known as 'Ritiro Dedicato'.
This is an alternative way for private power producers to sell energy generated by own plant and injected into electrical grid to GSE[33] instead of selling such power through bilateral contracts or directly on the Italian Power Exchange Market (IPEX).[34]

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29. Ministerial Decree July 5,2012
30. AEEG stands for 'Autorità per l'energia elettrica ed il gas'
31. AEEG states the achievement of such threshold using data provided by GSE which is a company whose task is management of services aimed at implementing of exploitation of renewable energy sources.
32. GSE stands for 'Gestore dei Servizi Elettrici' and it an Italian company that withdraws power produced by private PV plants and allocate such energy on the market
33. GSE is the acronymous of 'Gestore dei Servizi Elettrici' and it a company that withdraws power produced by private PV plants and allocate such energy on the market

In according to this scheme, the power producer sells electricity to GSE at a predetermined price and GSE resell such electricity on the market.

The unit price applied by GSE for this amount of power bought from private users and resold on the market is the 'average zonal price', which is the average of monthly price per hourly band set on IPEX for market area where PV plant is located.

Moreover power producers which own PV plants, whose nominal power is up to 1 MWp, could sell self-produced power at 'guaranteed minimum prices' if 'average zonal price' is too low but this choice is not binding since they can get back selling power at 'average zonal price' if it rises again.

The 'guaranteed minimum prices' are stated yearly by AEEG.

Then GSE will transfer fees paid by producer for use of power grid, such as dispatch and transmission, to the distributors.

The eligible power producers for this kind of support scheme should own:

1) PV plants whose nominal apparent power is lower than 10 MWA[35] as renewable source plants (RES) or hybrid plants;

2) plants of any capacity that exploit renewable energy sources as solar, wind, waves, geothermal, tides and hydro;

3) plants whose nominal power is below than 10 MWA that exploit non-renewable sources;

4) plants whose nominal power is higher or equal to 10 MWA that exploit renewable sources different from sources mentioned at point "2).

2) Net metering[36]

The second support scheme that we are going to see is the Net metering, in Italy known 'Scambio sul Posto', that we will adopt to analyze the two investment projects dealt in the next two chapters.

This scheme could be considered as a mechanism of valorisation of power generated by private PV plants and sold to GSE that manage all activities linked to exploitation of power produced by PV plants owned by private customers.

GSE pays a contribution to power produced based on quantities of energy absorbed and injected into the electrical grid.

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34. IPEX is the Italian Power Exchange market and it is the place where possible to buy and sell wholesale power.
The aim of IPEX is to ensure transparency and equilibrium prices.

35. VA is acronymous of 'volt-ampere, which is the unit used to measure apparent power in an electrical circuit.

36. 'Lo scambio sul posto fotovoltaico: guida completa' from site 'www.fotovoltaiconorditalia.it'

Such contribution is based on features of PV plant and contractual conditions among private power producer and its energy supplier.
Now we describe as net metering process is articulated:

1. The owner of PV plant sells the power generated by its plant that exceeds its needs to GSE;
2. The owner of PV plant purchases the difference among power that it needs and self-consumed power from ENEL[37];
3. GSE returns to customers the minimum between cost of the electricity (COE), which the quantity of energy withdrawn from power grid times national unique price (NUP), and the value of electricity (VOE), which is the quantity of power injected into the grid times the hourly zonal price (HZP);
4. GSE returns the cost for usage of network of such customer, which is equal to minimum between quantity of power injected into the grid and quantity of power withdrawn from the electrical grid times the unit cost for exchange standard of electricity (UCes), which depends by annual amount of power bought from the power grid;
5. GSE returns the difference among value of electricity and cost of electricity if positive, otherwise the amount of such difference will be charged on its electrical bill.

Net metering is a bill mechanism that could be adopted only by owners of RES and cogenerated plants whose nominal power is up to 200kWp.

2.5 Conclusions

In this chapter we have seen the technical features of PV technology and we have denoted that PV market is dominated by silicon solar cells since they have higher energy efficiency with respect to thin-film solar cells.
Then we have observed the level of development of PV market at global, European and Italian level and the different level of development of three markets.
Furthermore we have learnt the importance of regulatory framework to support such sector.

37. ENEL is acronymous of 'Ente Nazionale dell'energia elettrica' is the main Italian provider of electricity.

About future development of global market, it was estimated that it will continue to grow even if at slower pace than in the last ten years: it is driven largely by investments in emerging Countries, as China and India, in this sector.
Future outlook for European PV market is characterized by uncertainty since structure of such market is changing: it is influenced by transition from feed-in tariff support policies toward a more market-based model.
Then there are Countries as UK and Germany where PV sector continues to grow while other Countries as Spain, Czech Republic and Bulgaria have adopted retroactive measures that discourage investments in this sector.
Finally we look at Italian PV market in which the end of feed-in schemes, introduced in the last ten years, has dampened the sharp growth of this sector seen in previous years.
Moreover the inclusion of PV systems in the tax basis for ‘IMU’ has reduced profitability of this type of investment.
However Net metering, in Italy known as ‘Scambio sul Posto’ (SSP), represents the best form of incentive for investments in medium-small sized plants since it allows power producers to be remunerated for charges paid in electrical bill for power bought.
Finally owners of PV plants whose nominal power is above 200 kWp and they could not benefit from advantages offered by such billing mechanism, they should increase the amount of self-consumed power.

CHAPTER 3

ECONOMIC VALUATION OF TWO PV PLANTS ISOLATED

In this chapter, we want to present the economic analysis of two investment projects in PV plants aimed to provide electrical power to two different users.
These PV plants are situated in the Western suburbs of Padua, at a distance of 20 metres from each other, but the first PV plant provides electricity to feed the shared facilities of a complex of four residential buildings while the second PV plant provides this commodity to a post office situated nearby the previous buildings.
The post office is classified as commercial user.
However before starting the economic analysis of each investment project, we think that it is necessary to describe the technical characteristics of each PV plant, as follows.

3.1 Technical features of these PV plants

These PV plants have the same technical characteristics but they serve users with different profile of power consumption.
Both PV plants are ground mounted and they are located in the outdoor areas surrounding each building, they are both South oriented and each of them has the an optimal inclination of 36 degrees.
Moreover they are composed by photovoltaic modules made with mono-crystalline silicon, while the total surface of such modules is 240 square metres for each PV plant.
Then it is possible to estimate the solar irradiation and the electrical energy produced by each PV system on daily and monthly basis using a particular software, known as PVGis database.
So it needs only to insert previous information, together with geographical coordinates of location:
-latitude 45°20’50’’North;
-longitude 11°53'18" East;
-13 metres of elevation.
The following table shows the estimates of solar irradiation and electricity provided on average by each PV plant on monthly and daily basis, relative for each month of the year.

Table 1. Estimates of daily solar irradiation and daily power provided on average by each PV plant

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly power produced (kWh)	1560	2370	3350	3500	3960	3870	4270	3970	3360	2540	1670	1550
Monthly irradiation (kWh/m2)	66.7	103	152	163	189	189	210	195	161	116	73.4	65.8
Daily power produced (kWh)	50.4	84.6	108	117	128	129	138	128	112	82	55.7	49.9
Daily irradiation (kWh/m2)	2.15	3.67	4.91	5.42	6.11	6.3	6.77	6.28	5.36	3.73	2.45	2.12

Source: ‘PVGis database’

In according to previous data, the potential annual production of power of each PV plant is estimated at 36000 kWh, net of technical system losses.

The percentage of combined technical system losses amounts to 28.5% and includes:

-the share of loss due to temperature and low irradiance, estimated at 9.8%;

-the share of loss due to shading and albedo, estimated at 2.8%;

-the share of other losses due deterioration of cables and inverter, estimated at 18.5%.

After that we present the main features of each PV plant, together with the estimated values of potential yearly power , net of operating losses, in the table below.

Table 2. Data of each PV plant

Classification	Ground mounted
Site	Padua, Italy
Latitude	45°20’50’’North
Longitude	11°53'18" East
Elevation	13 metres

Year of installation	2015
Useful life	25 years[38]
Material of modules	Mono-cristalline sylicon
Total surfece of modules	240 m^2
Total power	30 kWp
Yearly irradiation	1680 kWh/m^2
Technical losses	28.5 %
POTENTIAL YEARLY POWER	**36000 kWh**

Moreover for the economic analysis it needs to estimate the self-consumption percentage of electrical power by each user on daily basis, so we should apply the following formula:

$$\textit{Self consumption of electricity} = \frac{\textit{Self consumed daily electricity } (kWh)}{\textit{Daily production of electricity } (kWh)}$$

Since both PV plants are identical, they produce the same daily quantity of power, namely 98.6 kWh.

This is a mean value of daily power production of each PV plant which results from the simple division between estimated value of power production and number of days of the year. But each user has different electricity consumption habits, so it has been estimated that residential user consumes on average 40.08 kWh of their self-produced power every day while the post office (commercial user) absorbs on average 75.93 kWh of power generated by own PV plant daily.

Using previous data, we estimated the following percentages of self-consumption of electricity for each user:

Self-consumption percentage for residential user $= \frac{40.08\ kWh}{98.6\ kWh} =$ **41.38%**

Self-consumption percentage for commercial user $= \frac{75.93\ kWh}{98.6\ kWh} =$ **77.01%**

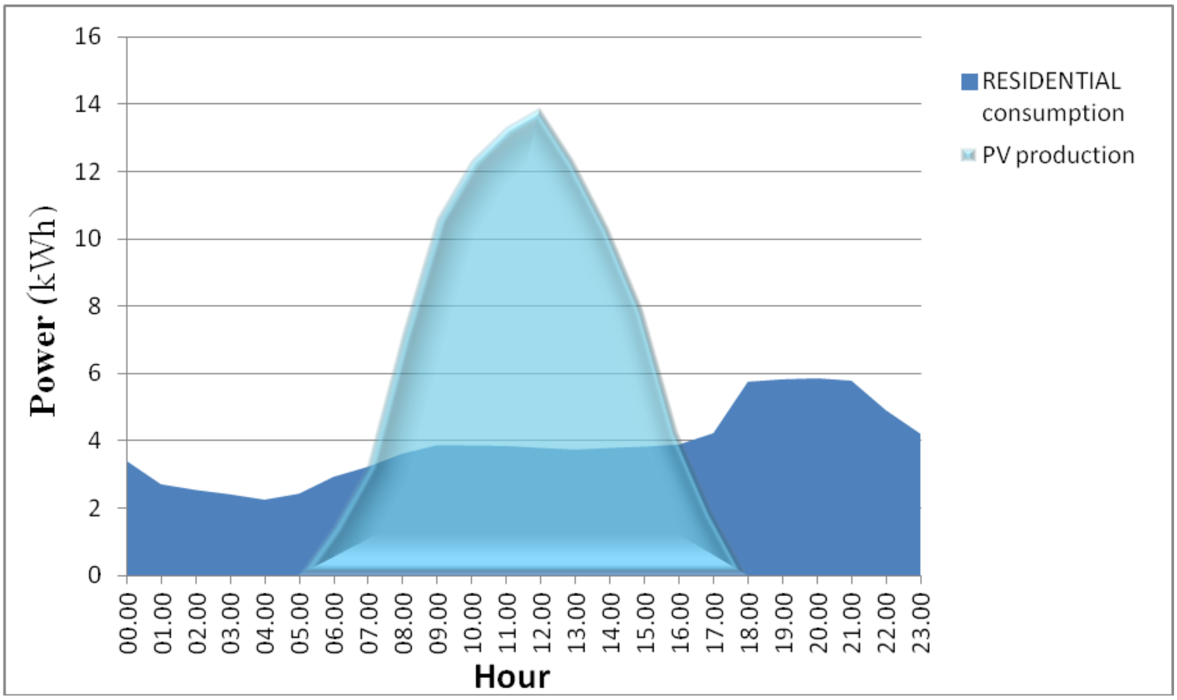
38. From site:'www.energy.gov'

For simplicity we will adopt for our economic analysis the estimates of average daily power consumption of each user and the estimates of average daily power generation of each PV plant, computed on yearly basis without considering monthly variability.

In fact we should observe that both daily power consumption and daily power production have a peak in July while daily power consumption of these users reaches the minimum in April but daily power production reaches the minimum in December.

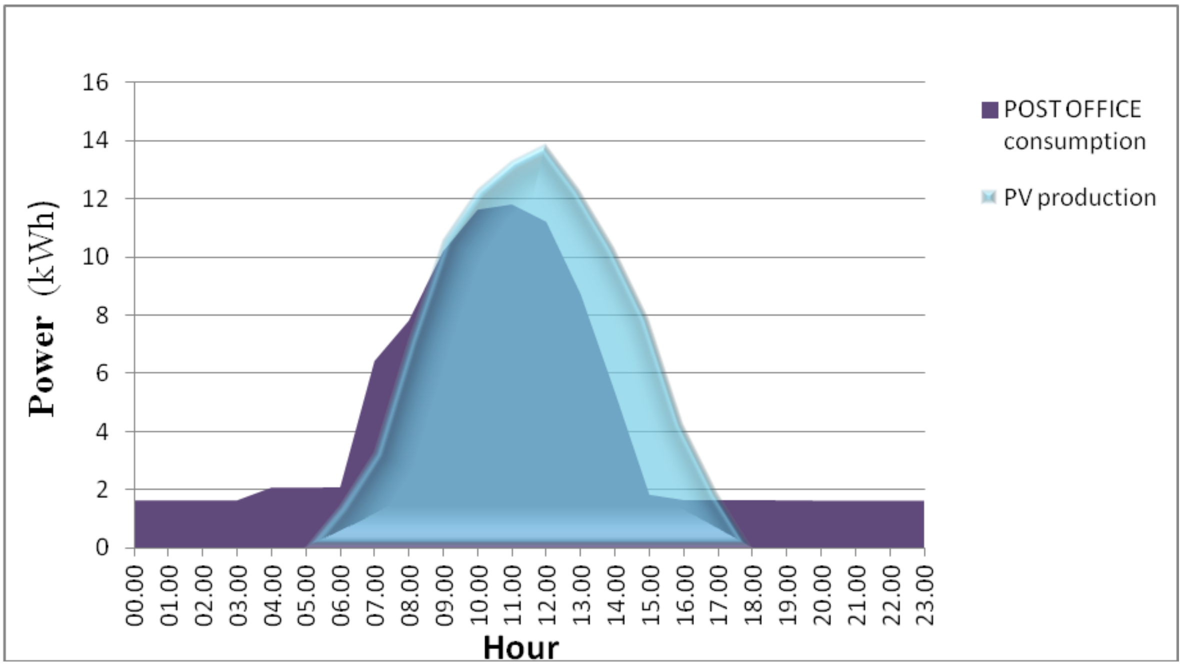
In the following figures we show the estimates of hourly power consumption of each one of previous users together with the estimates of hourly power production of their own PV plants during a day, based on daily average of production and consumption of energy during a year. Such estimates of daily power production and daily power consumption have been computed as in previous case: we have divided the annual amounts of power production and power production of each user by number of days that constitute a year.

Figure 1. RESIDENTIAL POWER CONSUMPTION vs PV POWER PRODUCTION



Source: ‘www.sunedisonenergysaverplan.com

Figure 2. POST OFFICE's POWER CONSUMPTION vs PV POWER PRODUCTION



Source : 'Analisi dei consumi energetici residenziali e vantaggi connessi all'utilizzo di un manager energetico',De Franceschi

The previous figures show that each user has a different habit of power consumption.

The residential user presents a daily profile of power consumption which is decreasing in the night hours, from 23.00 until 05.00, then it becomes increasing from 05.00 until 09.00, in which it stabilizes at a value that maintains almost unchanged up to 17.00.

Then residential energy consumption rises again and it reaches the peak of about 5.7-5.8 kWh from 18.00 until 22.00.

The commercial user (the post office) presents a steep growth of power consumption from 06.00 until 10.00, in which it reaches the peak of more than 11 kWh.

This peak of consumption is maintained for about three hours, because after 13.00 it decreases again until 15.00.

Then it remains almost stable at about 1.6-1.8 kWh for the rest of the day.

Peak of power consumption for residential user is in the time slot 18.00-22.00 since we think that time slot in which people returns home from work is 18.00-20.00, so that we register a massive use of condominium common services as autoclaves, staircase light and this high level of use of such appliances continues until 22.00 when people start to go to bed.

Since peak of consumption is placed in a time slot in which solar panels could not benefit from sunlight we observe that a great part of residential power consumption is not covered by energy produced by solar plant, so that both quantities of energy bought and sold from the grid are high while level of self-consumption remains low.

During the other diurnal hours we record an use of common services that is lower with respect time slot 18.00-22.00 while we reasonable believe that the minimum consumption of power is recorded during the night and dawn.

About commercial user we observe that peak of power consumption is concentrated in time slot 10.00-12.00 even if power consumption increases in time slot 08.00-10.00 since post office opens at 08.30, but power consumption of power decline in time slot 13.00-15.00 since post office closes at 13.30.

Moreover level of energy consumption remains stable from 15.00 to early morning of following day.

The difference among such users is that the peak of power consumption of post office is covered by power production of PV plant but this does not happen for residential user.

Then we have implicitly assumed that power consumption of each day is equal to power consumptions of working days: this is an useful simplification since consideration of differences of power consumption among week-ends and holidays with respect to working day would complicate this economic analysis.

Even if these two users have different daily profiles of power consumption, they are connected with PV plants characterized by the same level of nominal power, namely 30kWp. This could be the first reason why previous results show that such users present different percentages of daily self-consumption of electricity, more precisely this percentage is higher for the post office with respect to the residential complex.

3.2 Economic analysis of the two investment projects

Before entering in the core of such economic analysis, we want to describe the methodology used to evaluate these two investments: the NPV Methodology.

This methodology, also known as discounted cash flow method, is widely applied to assess the most part of investment projects since it is a very simple capital budgeting technique that provides fair estimates of values of such investment opportunities.

3.2.1 The NPV Methodology

This methodology allows to estimate the present value of an investment discounting the annual net cash flow with a particular rate, the Weighted Average Capital Cost (WACC). In according to this methodology, an investment is considered profitable if the NPV is positive.
The NPV formula is the following:

$$NPV = NCF_0 + \sum_{i=1}^{n} \frac{NCF_i}{(1 + WACC)^i}$$

where

$\boldsymbol{NCF_0}$ is the initial cost of investment;
$\boldsymbol{NCF_i}$ is the Net Cash Flow of year i
$\boldsymbol{WACC}$ is the Weighted Average Cost of Capital.

The **WACC** is a rate of opportunity cost, in fact it indicates the cost incurred by investor to forgo to employ his money in an alternative investment opportunity.
This rate allows to assess the value of capital invested since it allows to evaluate each one of the two capital cost components individually: debt and equity.
Then these two components are weighted with the respective share with respect to total cost of investment.
This is the formula of **WACC:**

$$WACC = \frac{E}{D+E}(k_e) + \frac{D}{D+E}(k_d)\,(1\text{-t})$$

where

$\boldsymbol{E}$ is equity;
$\boldsymbol{D}$ is debt;
$\boldsymbol{k_e}$ is the cost of equity;
$\boldsymbol{k_d}$ is the cost of debt;
t is the marginal tax rate applied in a Country.

The cost of debt (k_d) often is represented by yield-to-maturity of long-term government bonds.

The cost of equity (k_e) is computed through the Capital Asset Pricing Model (CAPM), so it indicates the minimum expected rate of return demanded by an investor who wants to invest in a risky asset.

The CAPM formula adopted to estimate such parameter, which coincides with the expected return of equity E(r_e), is the following:

$$E(r_e) = r_f + \beta_e [E(r_m) - r_f]$$

where

$\boldsymbol{r_f}$ is the return of a risk-free asset;

$\boldsymbol{\beta_e}$ is the unlevered beta of equity;

$\boldsymbol{E(r_m)}$ is the expected market return;

$\boldsymbol{E(r_m) - r_f}$ is the equity risk premium.

The unlevered beta of equity (β_e) , which is the beta of an investor who finances his project without borrowing money, indicates the sensitivity of investment return to market movements and it is defined as below:

$$\beta_e = \frac{Cov\ (r_m; r_e)}{Var(r_m)}$$

where

$\boldsymbol{Cov\ (r_m; r_e)}$ is the covariance between the market return $(\boldsymbol{r_m})$ and return of equity (r_e);

$\boldsymbol{Var(r_m)}$ is the variance of market return $(\boldsymbol{r_m})$.

In this economic analysis, the WACC for each investment project was estimated in the following way:

-both projects has been financed totally with equity, so WACC will be equal to cost of equity (k_e);

-the risk-free rate (r_f) used is the rate of return of AAA rated bonds with 20-years-to-maturity traded in Euro area in 2015[39];

-the market return (r_m) used is the monthly rate of variation of FTSE MIB Index in the period 2013-2015[40];

-the covariance between return of equity and market return, $Cov\ (r_m; r_e)$, was approximated to covariance among the monthly rate of variation of FTSE MIB Index in the period 2013-2015 and the monthly rate of variation of Hourly Zonal Price (HZP) of electricity in Northern Italy in the same period[41].

We have chosen to represent the market return with the FTSE MIB Index since such index indicates the return of a portfolio composed by stocks issued by 40 companies, quoted at Stock Exchange of Milan, which have the highest level of capitalization among quoted companies at such stock exchange.

Moreover $Cov\ (r_m; r_e)$ was approximated to covariance between the monthly rate of variation of FTSE MIB Index and the monthly rate of variation of Hourly Zonal Price (HZP) of electricity in the period 2013-2015 since we believe that the return of this type of investment depends by monthly variation of HZP because of the adoption of a billing mechanism which enhances the energy fed by each user into the power grid in according to such price.

In the next table let's present all values estimated for all these parameters together with the estimate of WACC:

Table 3. WACC rate

Risk-free rate	1.21 %
Unlevered beta	0.404
Expected market return	9.78 %
Equity risk premium	7.57 %
Cost of equity	4.68 %
WACC	**4.68 %**

39.From site 'www.ecb.europa.eu.'
40.From site 'www.investing.com'
41.From site 'www.gse.it'

Note. We assume that initial cost of investment will be financed totally with equity since the sum of money necessary for this investment is modest for these two users in order to apply for a loan to the bank: residential user includes a residential condominium complex of 50 families while post office is a subsidiary of society ‘Poste Italiane s.p.a.’ listed on Italian stock exchange.

3.2.2 Economic analysis of the RESIDENTIAL PV PLANT

After that we have computed the WACC, let’s proceed with the economic analysis of the investment project inherent the PV plant connected with the complex of residential buildings. As I have said before, we assess this investment project through the NPV Methodology considering a time horizon of 20 years from 2015,even if each PV plant has an estimated useful life of 25 years.
The reason for choice of such time horizon is that each investor has taken out an insurance which immunizes each PV plant for 20 years against the following types of risk:
-risk of outages of the PV plant due to mistakes in installation procedures or routine maintenance of the same plant;
-risk of damage of solar panels due to weather conditions such as snow and hail;
-risk of an annual decay of solar panels higher than 1%.

We should denote that this investor has preferred an insurance coverage for its PV plant of 20 years, instead of 25, since an insurance policy of 25 years would be too expensive because of insurance companies require a very high premium in order to provide this additional insurance coverage.
In fact in the last five years of life a PV plant has a very high probability to incur in outages and it could have an annual decay higher than 1%.
So that residential user pays an unique premium of 6,000 € to have insured its PV plant for 20 years against the aforementioned risks instead of paying 20 annual premia[42] for the same insurance coverage.

The starting point of such analysis is the analysis of costs , which is identical to cost analysis related to the PV plant of the aforementioned post office since both PV plants have the same technical features.

42.From site ’www.consorziocaes.org’

First of all we should know that the total cost of a generic PV plant is about 2,500 € per kWp, so the total cost of such PV plant amounts to 75,000 € (without insurance policy).
Such total cost is composed by the following cost percentages:

- 47%, PV modules;
- 11%, inverter;
- 12%, infrastructure;
- 7%, circuit panels and cables;
- 23 %, project and installation.

So we will report in the table below the cost items, including insurance costs, that compose the total expense incurred by residential user for this investment, together with the respective monetary amounts:

Table 4. Initial cost of investment for residential user

Description	**Costs** (Euro)
PV modules	35250
Inverter	8250
Infrastructure	9000
Circuit panels and cables	5250
Project and installation	17250
Insurance costs	6000
TOTAL	**81000**

Source: site www.enerpoint.it,

Moreover we should add to previous initial investment expense other two costs that occur during the useful life of plant, which are:
-the cost of ordinary maintenance of PV plant, which is 210 €for the first year after installation, but we estimate an increase of such amount of 1.7% per year; [43]
-the cost of inverter substitution, which will be reduced to 6300 € in the next 5 years.
About the annual cost of ordinary maintenance we assume that it will increase by 1.7% per year in according to the average annual rate of inflation[44], estimated as the average of annual rates of inflation occurred in Italy in the last ten years.

43. From site 'www.viacavoimpianti.it'
44. From site 'www.Istat.it'

Nowadays the duration of useful life of inverter could range between 5 years and 15 years[45], it depends by quality of inverter.
However we are considering a useful life of 10 years for such device but we believe that within five years new inverters will have a duration up to 15 years while the reduction of inverters' price is estimated at 25% in the same period of time[46].
So we believe that an inverter for a PV plant with nominal power of 30 kWp will cost 6,300 € at the beginning of 2020s instead of the current price of 8,250 €.
The next step to compute the NPV of this project is the revenue analysis.
First of all we should consider that this residential user has chosen to access a billing mechanism, the Net Metering, in Italy knows as 'Scambio sul Posto' (SSP).
This last data is important to assess the so-called SSP revenues.
So the revenues of such investment are:

1) the electrical bill savings due to auto-consumed energy;
2) the SSP revenues;
3) the tax deductions on the cost of the initial investment.

We should notice that we have based our computation of revenues on the mean daily consumption of energy by residential user and the mean daily production of this commodity by PV plant, estimated on the course of the year.
This is an useful simplification for our economic analysis, even if we do not consider the variability of mean daily consumption and mean daily production of energy which occurs during the months of the year.
The first type of revenues is based on the annual quantity of energy auto-consumed and the average power tariff applied on Italian market on each kWh of electricity sold by power companies.The following table shows how this kind of revenues is estimated:

Table 5. Electrical bill savings for residential PV plant

Estimated power produced	36000 kWh
Auto-consumption percentage	41.38 %
Auto-consumed power	14896.8 kWh
Power tariff (taxes included)[47]	0.1852 €/kWh
Electrical bill savings	**2758.89€**

45.From site 'www.consulente-energia.com'
46.'Studio Fraunhofer' from site 'www.assoelettrica.it'
47. Power tariff 2016 stated by 'Autorità per l'energia elettrica, il gas ed il sistema idrico'.

So the value of electrical bill savings is estimated at 2758.89 € per year, which is a considerable amount of money.

The second type of revenues is the SSP revenues, which are computed through the following formula:

SSP revenues= SSP contribution+ VOE-COE - Fee

where

SSP contribution is the sum of money paid by GSE to user in according to quantity of electricity exchanged (EE) among the user and GSE itself;

VOE is the value of electricity, it is equal to quantity of electricity sold by the user to GSE[48] times the hourly zonal price (HZP);

COE is the cost of electricity, it is equal to quantity of energy absorbed by user itself from the grid times the unique national price (NUP);

The **fee** paid yearly by electrical user to GSE depends by nominal power of PV plant, so that it is fixed at 30 € if nominal power of PV plant is less or equal to 20 kWp, but if nominal power is higher than 20 kWp the amount of this fee is the sum between a fixed sum of 30 € plus a variable amount that depends by power of PV plant: this variable cost is 1€ per kWp.

The **SSP contribution** is computed as follows:

SSP contribution= min(**COE;VOE)+UCes×EE**

where

UCes is the unit cost for exchange standard of electricity;

EE is the electricity exchanged and it is equal to the minimum quantity between the energy sold by user and the energy absorbed by user through the power grid.

The table below shows the estimated value of SSP contribution, obtained through the computational procedure above:

Table 6. SSP revenues for residential PV plant

Electricity yearly sold	21103.2 kWh
Electricity yearly bought	18958.1 kWh
Hourly zonal price (HZP)[49]	0.05681 €/kWh

48. GSE is the acronymous of 'Gestore del Servizio Elettrico' which is an Italian company, held by Italian Government, which provides incentives to private producers of power through renewable sources.
49. It was estimated as the average of monthly HZPs of Northern Italy occurred in the period 2013-2015. **Source**: site 'www.gme.it'

Unique national price(NUP)	0.05208 €/kWh
Value of electricity (VOE)	1198.87 €
Cost of electricity (COE)	987.34 €
Unit Cost of electricity (UCes)[50]	0.20302 €/kWh
Electricity exchanged (EE)	18958.1 kWh
SSP contribution	4836.21 €
VOE-COE	211.63 €
Fee[51]	60 €
SSP revenues	**4987.75 €**

The third type of revenues is represented by tax deductions on the initial cost of investment. The current Italian law about the installation of PV plants provides fiscal deductions on Italian income tax, known as Imposta sul reddito delle persone fisiche (IRPEF), that amount to 50% of total costs of investment in photovoltaic energy for anyone who decides to install a PV plant by December 31, 2016.

Obviously fiscal deductions do not cover insurance costs incurred by investors.

The eligible beneficiaries of these tax incentives are both natural persons and entrepreneurs.

These tax deductions are credited to the beneficiaries in ten equal annual instalments.

So the residential user will get tax credits of 3,750 € per year from 2016 until 2025.

Now we have all necessary data to assess the NPV of such investment.

As we have said before, the WACC was estimated at 4.68%.

Then we have prudentially considered an annual depreciation of 1% for electrical bill savings and SSP revenues because we assume that such PV plant has an annual decay of 1%.

Moreover we assume an annual growth of power tariff of 3%, since we have estimated that the mean level of power tariff growth in Italy was 3% per year[52].

The annual growth of power tariff will affect only the computation of electric bill savings since parameters necessary to compute SSP revenues have controversial trends.

For this reason we have considered only an annual depreciation of 1% for SSP revenues.

The table below shows the estimate of NPV of this investment project, together with the Internal Rate of Return (IRR).

50.It was estimated as the average value of UCes in 2013, reported by ‘Autorità per l’energia elettrica, il gas ed il sistema idrico’.

51. From site’www.gse.com’

52. This estimate of annual average growth rate of power tariff has been made using annual power tariff for period 2005-2015, whose data have been collected from site ‘www.gse.com’.

Table 7. NPV and IRR of residential investment project

Time horizon	20 years
NPV	**42106.58 €**
IRR	**10.90%**

About dynamics of internal rate of return (IRR) we can see that it grows rapidly in the first years following the investment and it reaches the final value of 10.9% at the end of such time period.

We denote a variation in growth level of IRR from 11th year following installation of PV plant, which becomes less marked since this time period is characterized by a significant fall of NCFs because fruition of fiscal inflows is concentrated in the first ten years of life of this project.

However initial value of IRR is low but it becomes positive 7-8 years after that investment is made.

Since the final value of IRR is higher than the WACC, we could say that such investment is profitable.

The final NPV of such project is 42106.58 € which is a great sum of money for a low-risk investment, while the amount of money invested will be recovered after 8-9 years, since at the 9th year the NPV starts to be positive.

About dynamics of NPV in the course of years we can say that also growth level of this last indicator is modified from 11th year of useful life of PV plant because of end of fruition of tax inflows.

The figures below show dynamics of NPV and IRR in the course of time period that we are considering whose duration is 20 years.

Figure 3. Dynamics of NPV for residential PV plant

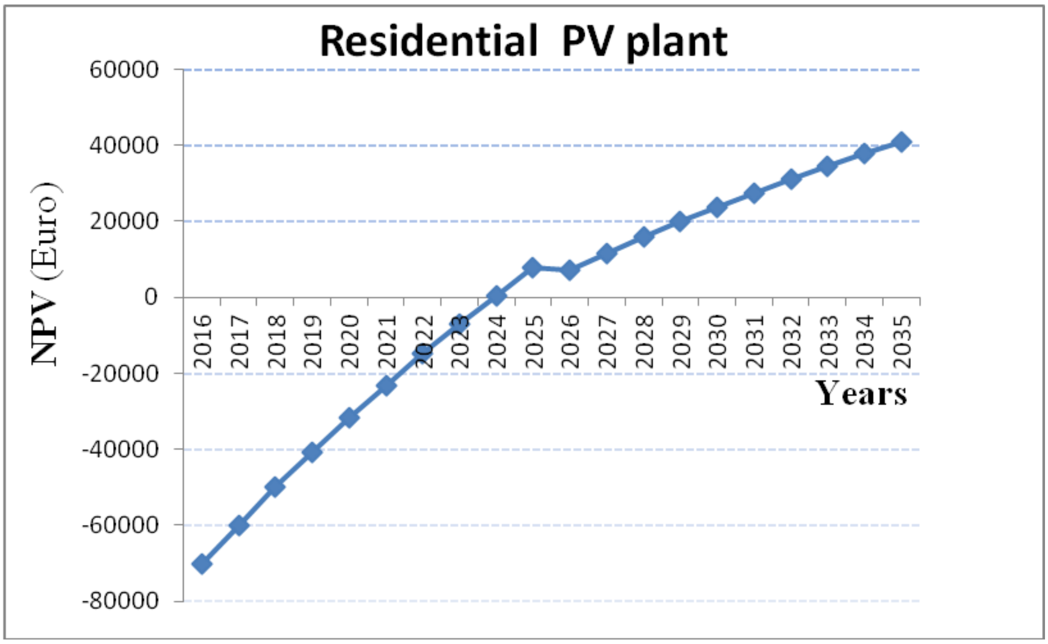
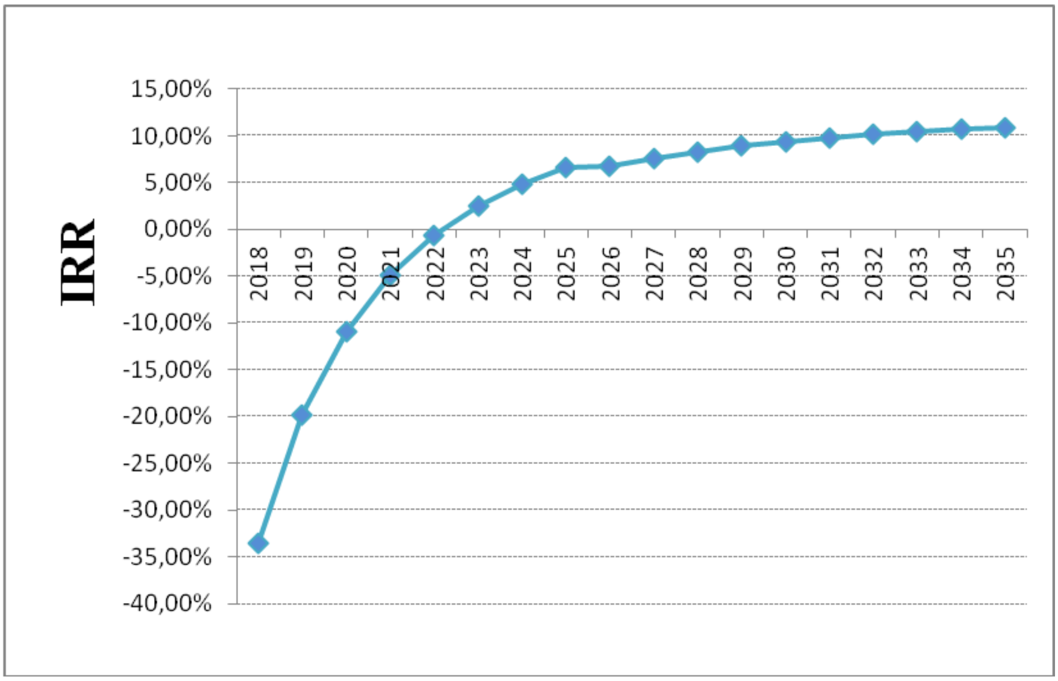


Figure 4. Dynamics of IRR for residential PV plant



3.2.3 Economic analysis of the POST OFFICE's PV PLANT

In this paragraph we will expose the economic analysis of the investment project concerning the PV plant that provides electricity to the aforementioned post office.

This PV plant presents the same technical features of the previous one, but the economic analysis will provide different results since this user has a different profile of power consumption.

Also in this case we assess this investment project through the NPV Methodology and we consider a time horizon of 20 years, starting from 2015.

The reason of choice of such length of time horizon is the same: the duration of insurance coverage for this investment is 20 years.

The beginning of this analysis is the cost analysis that produces the same monetary values of previous cost analysis, since this PV plant has the same nominal power as the previous one.

In the following table, all components of total cost of investment are summarized:

Table 8. Cost of initial investment for Post Office

Description	**Costs** (Euro)
PV modules	35250
Inverter	8250
Infrastructure	9000
Circuit panels and cables	5250
Project and installation	17250
Insurance costs	6000
TOTAL	**81000**

Source: site ‘www.enerpoint.it

As in the previous case, also this investment project includes the following costs , namely:

- the annual cost of ordinary maintenance of PV plant;
- the cost of inverter substitution, which will occur in 2026.

As we have said in the previous paragraph, the annual cost of ordinary maintenance will be 210 € in 2016 but we assume that it will grow by 1.7% per year, in according to the average of Italian annual inflation rate of the last ten years.

Moreover we assume that the cost of inverter will be 6300 € in 2026 since in the first half of 2020s the cost of all components of a PV plant will be reduced by 20-25 % in ten years.

Before starting the revenue analysis of such investment project, we should denote it is based on mean daily consumption of power by such user and mean daily power production of his PV plant, computed during the course of the year.

We do not consider the monthly variability of consumption and production of electricity of such user.

Instead the revenue analysis of this projects produces different results with respect to the previous one, since the quantity of energy sold and absorbed by the post office is different. Also in this case, the first item of revenue is the electrical bill savings which are reported in the following table:

Table 9. Electrical bill savings for Post Office

Estimated power produced	36000 kWh
Auto-consumption percentage	77.01 %
Auto-consumed power	27723.6 kWh
Power tariff (taxes included)[53]	0.1852 €/kWh
Electrical bill savings	**5134.41€**

As we can see, the amount of electrical bill savings is 4879.35 € which is bigger with respect to the previous investment.
This is due to the higher self-consumption percentage of power of commercial user with respect to the self-consumption percentage of residential user.
The second item of revenue is the SSP revenues, whose we will report the estimated value in the following table:

Table 10. SSP revenues for Post Office

Electricity yearly sold	8276.4 kWh
Electricity yearly bought	9073.9 kWh
Hourly zonal price (HZP)[54]	0.05681 €/kWh
Unique national price(NUP)[55]	0.05208 €/kWh
Value of electricity (VOE)	470.18 €
Cost of electricity (COE)	472.57 €
Unit Cost of electricity (UCes)[56]	0.20302 €/kWh
Electricity exchanged (EE)	8276.4 kWh

53. Power tariff for 2016 stated by 'Autorità per l'energia elettrica, il gas ed il sistema idrico'.
54. It was estimated as the average of monthly HZPs of Northern Italy occurred in the period 2013-2015. **Source**: site 'www.gme.it'
55. It was estimated as the average of monthly UNPs occurred in Italy in the period 2013-2015. **Source**: site 'www.gme.it'.
56. It was estimated as the average value of UCes in 2013, reported by 'Autorità per l'energia elettrica, il gas ed il sistema idrico'

SSP contribution	2150.45 €
VOE-COE	- 2.39 €
Fee	60 €
SSP revenues	**2088.06 €**

The third item of revenue is represented by tax deduction on Italian income tax, knows as IRPEF, which amounts to 3,750 € per year for the first ten year after the installation of the PV plant.

Now we have all data necessary to compute the NPV of this investment project are available, but we should make the following assumptions:

-the WACC adopted is 4.68% as in previous case;

-the electric bill savings and SSP revenues has been depreciated by 1 % since solar panels have an annual decay of 1%;

-about electric bill savings we have considered an annual increase of energy tariff of 3%, since this tariff has grown by 3% per year on average in these last ten years.

Then I will present in the following table results of estimates of NPV and the IRR for this investment project.

Table 11. NPV and IRR of commercial investment project

Time horizon	20 years
NPV	**43565.19 €**
IRR	**10.86%**

The tables above shows how IRR increases during time until it reaches the percentage value of 10.86% which is not much lower than IRR related to residential PV plant.

This is due to the fact that annual NCFs of commercial user (post office) are below the NCF of residential user until 2025 because of the annual SSP revenues of the latter are so higher that the greater electric bill savings of the former do not offset them until 2025.

The financial situation is reversed in 2026 after the end of tax deduction and the payment of expense for inverter substitution.

About dynamics of growth of IRR we observe the same features that we already seen in previous case: this rate has a market growth at the beginning of useful life of such project, it becomes positive 7-8 years after the initial expense for the investment.
As we have already seen for residential PV plant, we observe a contraction of pace of growth of this indicator from 2026 because time period characterized by fruition of fiscal benefits will end that year: in fact fiscal deductions on initial expenses for investment are spread for the 10 years of operation of such PV system.
However the final NPV of such investment is equal to 43565.19 €, which is an amount of money a bit higher than in the previous case.
About NPV we observe a pronounced reduction of path of growth from 2026 for the same reason whose we have already discussed plus increase of discount rate on annual NCFs.
Since yearly growth of power tariff is 3% per year this will affect positively electrical bill savings, so that commercial user which has a higher level of self-consumed energy per year than residential user will be more advantaged with respect latter user.
Since commercial user (the post office) has a lower NCF with respect to residential user until 2026, the payback period of former user is longer than payback period of latter user.
The post office will recover the amount of money invested in 9-10 years.
In the following pictures it is shown the path of NPV and IRR related to such investment project during the 20 year after the PV plant installation.

Figure 5. Dynamics of NPV for Post Office’s PV plant

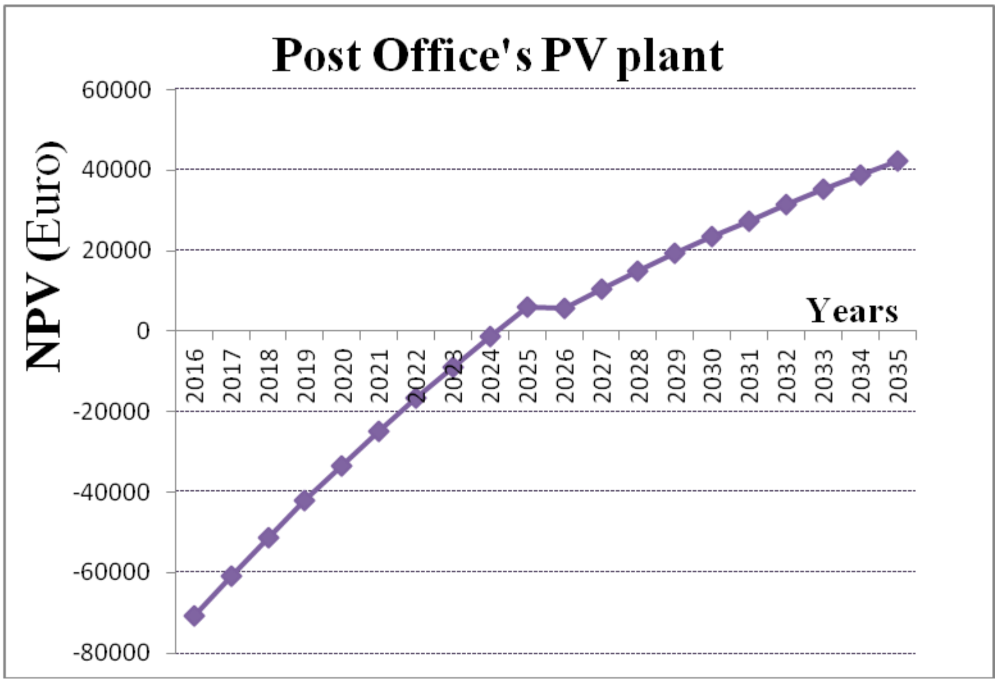
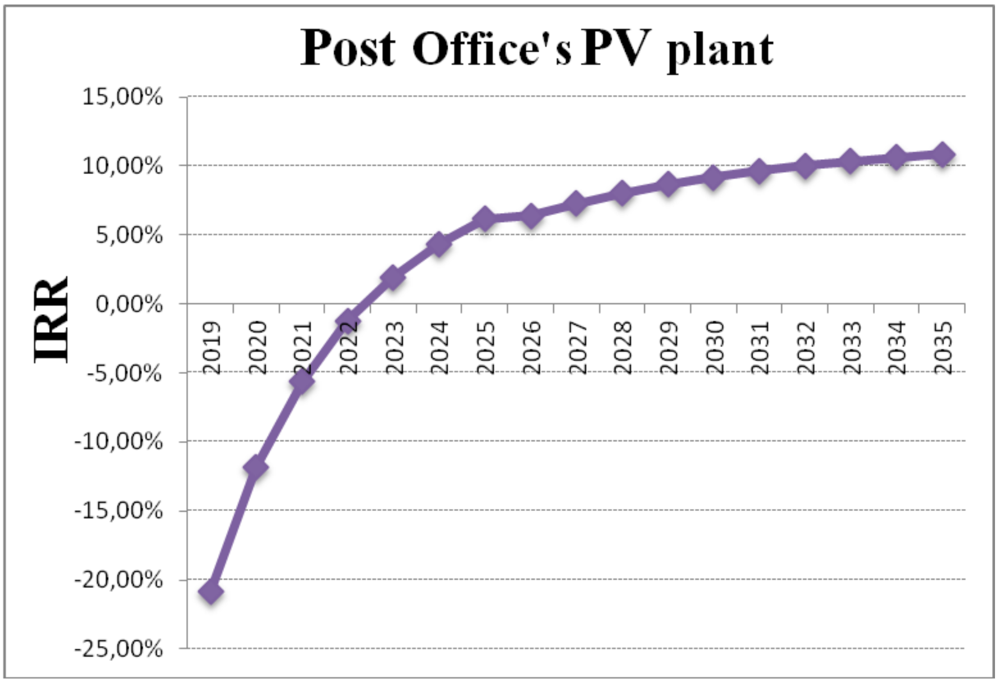


Figure 6. Dynamics of IRR for Post Office's PV plant



3.2.4 If we consider the whole duration of useful life of both PV plants: how will NPV and

IRR change?

a) Residential PV plant

If we consider a time horizon of 25 years for this investment project we will have a greater NPV, which will be 55983.69 €, and IRR will grow as well: it will increase up to 11.60%. As we can see, as duration of time horizon increases the growth of NPV and IRR will be lower because of actualized cash flow will be reduced as duration of time horizon increase. However trend of such indicators continue to be affected by end of period of fiscal incentives from 11th year of useful life of this PV system.

In the last 15 years of its residual life we denote a slower pace of increase with respect to previous time period.
Notwithstanding this moderate increase of annual NCF is driven by annual growth of power tariff, estimated at 3%.

b)Post office's PV plant

Also in this last investment project if we consider of time horizon of 25 years, we observe an increase of both NPV and IRR: so that NPV will be 60010.78 € and IRR will be 11.65%.
When we have considered a time horizon of 20 years we have noticed that IRR of commercial user was lower than residential user's one, while now we observe the opposite situation.
This is due to the fact that annual growth of NCF is driven by annual growth of power tariff, so that commercial user, whose auto-consumed power is bigger than energy auto-consumed by commercial user, has an higher growth of annual NCF with respect to other user.
About time paths of these two indicators of profitability we report the same features that are already known, namely NPV and IRR present a marked upward trend in the first ten years of PV system's operation but this trend for both indicators is dampen by end of period in which this user has fiscal inflows due to tax deductions on half of initial expense for this investment.

CHAPTER 4

ECONOMIC VALUATION OF TWO PV PLANTS CONNECTED THROUGH A SMART GRID

4.1 Installation of smart grids: changes in costs, savings and power production

In the previous chapter we have considered each PV plant as a stand-alone plant, but now we consider the possible economic advantages that would be if these two plant was connected through a smart grid.

The installation of this new technology constitutes an additional cost of 10,000 € which will be shared equally within the two users.[57]

However this new system reduces the operating losses of each PV plant and increases the safety of electrical systems of each user, allowing a cut of annual cost of ordinary maintenance for these two electrical systems equal to 300 € per capita the year after the installation of this new technology.

In fact we estimate an annual growth by 1.7% of this amount of money saved, in according to the average of Italian annual inflation rate of the last ten years.

We have estimated that the introduction of smart grids will produce a 40% saving on the annual expense for ordinary maintenance of electrical system of each user.

This quote of maintenance savings is composed by[58] [59] :

- 20.5% , outage detection;
- 4.5%, service outage management;
- 3%, integrated Volt/VAr Control, which improves power quality;
- 2%, for remote meter reading;
- 3 %, for tamper detection;
- 7% ,for renewable generation integration.

Since the current annual cost for ordinary maintenance of an electrical system of a building is about 750 €, we have estimated that a reduction of 40% of such expense represents a saving of 300 €.

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57. From site 'www.genitronsviluppo.com'.
58. 'Operation and Maintenance Savings from Advanced Metering Infrastracture-Initial Results' from US Department of Energy.
59.'Smart Grid Economic and Environmental Benefits' from site 'smartgridcc.org'.

Then we have indexed this amount to the estimated annual inflation rate, which is 1.7%, in order to assess the future savings in maintenance of electrical system.
Moreover these new technologies generate a fall in technical system losses of each PV plant, since they tend to minimize power losses of cables and inverter.
About the reduction of technical losses of each PV plant generated by application of smart grids, we assume that technical losses due to cables and inverter are about 15%[60], while in the previous case they amounted to 18.5 %.
So that combined technical losses fall from 28.5% to 25.5%[61].
However it has been estimated a growth of annual energy production of 1,500 kWh, since in previous case annual production of energy was estimated at 36,000 kWh while now it reaches the threshold of 37,500 kWh, net of technical system losses.
The following table shows all estimated values about solar irradiation and power provided by each PV plant for each month of year, on monthly and daily basis.

Table 1. Estimates of daily solar irradiation and daily power provided on average by each PV plant

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly power produced (kWh)	1630	2470	3500	3650	4130	4040	4450	4140	3510	2650	1740	1610
Monthly irradiation (kWh/m2)	66.7	103	152	163	189	189	210	195	161	116	73.4	65.8
Daily power produced (kWh)	52.5	88.2	113.0	122.0	133.0	135.0	144.0	134.0	117.0	85.6	58.1	52.0
Daily irradiation (kWh/m2)	2.15	3.67	4.91	5.42	6.11	6.30	6.77	6.28	5.36	3.73	2.45	2.12

Source: PVGis database

60.'How Utility Electrical Distribution Networks can Save Energy in the Smart Grid Era' by Michel Clemence, Renzo Coccioni and Alain Glatigny.
61. Results from 'PVGis database'

Since the power production of each PV plant has grown because of smart grids but profile of consumption of each user has remained unchanged, the percentage of self-consumption of electricity of each of them has fallen as we can see below:

Self-consumption percentage for residential user = $\frac{40.94\ kWh}{102.75\ kWh}$ = **39.84 %**

Self-consumption percentage for commercial user = $\frac{76.41\ kWh}{102.75\ kWh}$ = **74.37 %**

Instead in the previous case the self-consumption percentage for residential user and commercial user were respectively 41.38 % and 77.01%.

In the next two pictures it is possible to look at hourly power consumption of each one of previous users together with the estimated values of hourly power production of their own PV plants during a day.

Figure 1. RESIDENTIAL POWER CONSUMPTION vs PV POWER PRODUCTION

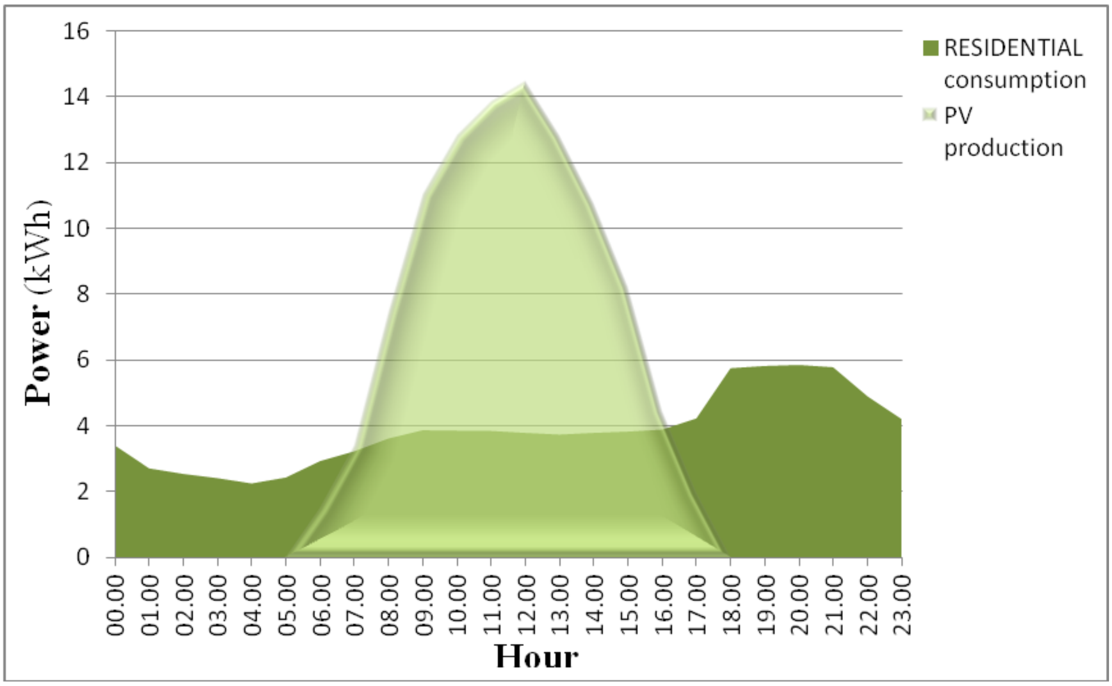
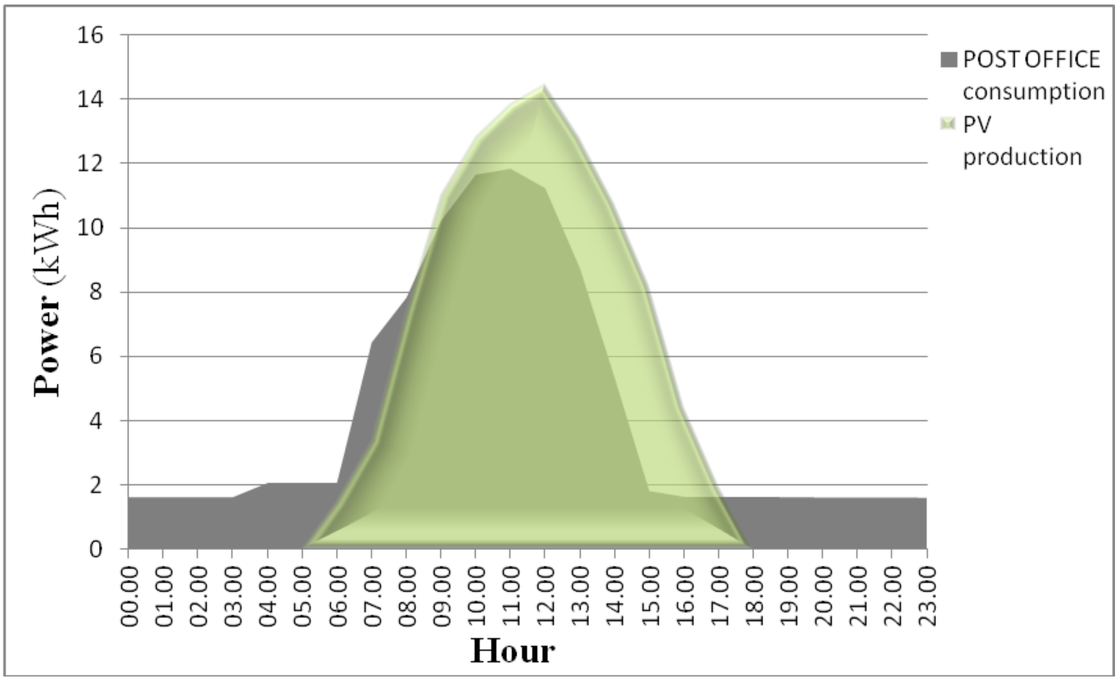


Figure 2. POST OFFICE's POWER CONSUMPTION vs PV POWER PRODUCTION



Since the profile of energy consumption of each user is not changed, we see the same features of consumption already known, which are:

-**the residential user** has the minimum of power consumption during the night while it has the peak of consumption of 5.7-5.8 kWh from 18.00 to 22.00;

-**the commercial user** has the a constant consumption of this commodity of 1.6-1.8 kWh during the night and after the 15.00, while the peak of consumption of 11 kWh, has been recorded from 10.00 until 13.00 on every business day.

One more time reasons that explains such power consumption are the same.

Families tends to consume more power in time slot 18.00-22.00 since most part of people return home from work in time slot 18.00-20.00 so that it is recorded a greater use of condominium common service in previous time slot since we predict that people go to bed after 22.00.

While post office presents a peak in power consumption in time slot 10.00-12.00 when flow of customers to this type of office is more intense.

For simplicity we adopt as pattern of our analysis the profile of power consumption of each user in a working day, neglecting week-ends or holidays, and we consider as daily energy consumption the average value of daily consumption of this commodity by each user computed dividing estimate of their annual power consumption by number of days in a year.

After the description of changes in power production of each PV plant because of installation of smart grids, it is possible to proceed to economic analysis of each investment project.
But in the next case of analysis we assume that both users do not exchange electricity among themselves.

4.2 Economic analysis of the two investment projects

The economic value of each investment has been assessed through the NPV Methodology, that we have already seen before.
Also in this case it has been considered a time horizon of 20 years for each investment projects since the duration of insurance coverage lasts 20 years.
As we have already seen in the 3rd chapter, the basis of these economic analyzes of such investments are the quantities of energy consumed by each users and produced by respective PV plants on average during a day.
These averages of power consumption and production has been estimated on yearly basis, exactly as we have seen before.
The first project that will be analyzed is the residential PV plant.

4.2.1 Economic analysis of the RESIDENTIAL PV PLANT

The starting point of this analysis is the cost analysis, which will produce the same results for both PV plants since they have the same nominal power, which is 30 kWp, and the additional cost to introduce smart grids will be equally shared among the two users.
As we have said before, this additional cost is 5,000 € per capita.
So the total expense incurred by each investor amounts to 86,000 €.
The following table reports all cost items of such investment opportunity.

Table 2. Initial cost of investment for residential user

Description	**Costs** (Euro)
PV modules	35250
Inverter	8250
Infrastructure	9000
Circuit panels and cables	5250
Project and installation	17250

Additional cost for smart grids	5000
Insurance costs	6000
TOTAL	**86000**

Sources: www.enerpoint.it, www.genitronsviluppo.com

Moreover during time horizon of such investment project we have to add other two costs which are the annual cost of ordinary maintenance of such PV plant, which amounts to 210 € in 2016, and the cost of inverter substitution, equal to 6300 €, which will probably occur in 2026 since actual inverters have an useful life of ten years, on average.

Also in this cost analysis we have made two assumptions:

-annual costs of ordinary maintenance of PV plant will increase by 1.7 % per year, in according to the mean of annual inflation rate estimated in Italy for the last ten years;

-in literature there is an analysis, made by Studio Fraunhofer, which forecasts a reduction of inverter substitution cost by 25% within five years and an increase of useful life of such device up to 15 years, so that the cost of an inverter substitution for a PV plant with 30 kWp of nominal power will amount to 6300 € in the second half of 2020s, instead of the current price of 8250 €.

The next step of this analysis is the revenue analysis.

We remember that each user adopts the billing mechanism of 'Net Metering', in Italy known as 'Scambio sul Posto' (SSP).

In synthesis, the revenue items are:

1) the electrical bill savings due to auto-consumed energy;
2) the SSP revenues;
3) the savings on annual cost of ordinary maintenance of electrical system;
4) the tax deductions on the cost of the initial investment.

The first revenue item is electrical bill savings whose estimated value has been recorded in the next table .

Table 3. Electrical bill savings for residential PV plant

Estimated power produced	37500 kWh
Auto-consumption percentage	39.84 %
Auto-consumed power	14940 kWh
Average power tariff (taxes included)	0.1852 €/kWh
Electric bill savings	**2766.89 €**

As we can see, electrical bill savings are about 2766.89 € per year but the increase of value of such item generated by the contribution of smart grids is about 8 €: in previous case electrical bill savings amounted to 2758.89 €.

The reason for which this increase of electrical bill savings is so modest is that the growth of power production generated by this new system is concentrated above all in the hours of day in which the consumption of electricity was already below power production of PV plant.

The second revenue item is the SSP revenues which are reported in the following table.

Table 4. SSP revenues for residential user

Electricity yearly sold	22560 kWh
Electricity yearly bought	18907 kWh
Hourly zonal price (HZP)	0.05681 €/kWh
Unique national price(NUP)	0.05208 €/kWh
Value of electricity (VOE)	1281.63 €
Cost of electricity (COE)	984.68 €
Unit Cost of electricity (UCes)	0.20302 €/kWh
Electricity exchanged (EE)	18907 kWh
SSP contribution	4823.18 €
VOE-COE	296.96 €
Fee	60 €
SSP revenues	**5060.13 €**

The estimated value of SSP revenues is 5060.13 € per year and also in this case the variation of such item with previous case is quite modest, it is about 70 €, and it is driven by the growth of quantity of energy sold to GSE.

Now this last quantity amounts to 22560 kWh per year versus 21103.2 kWh of case in which the two PV plant were not connected through the smart grids.

The third revenue item is new with respect to previous case.

As we have said before, the savings on cost of ordinary maintenance for each one of these two electrical systems are estimated at 300 € only for year 2016, since we have assumed a growth by 1.7% per year of such revenue in according to estimate of Italian inflation rate.

The last revenue item is the tax deduction on the cost of initial investment.

Since also the cost of installation of smart grids is involved in this form of deduction granted by Italian Government, we should consider a total tax deduction of 4000 € per year which covers a period of ten years: from 2016 to 2025.

Now it is possible to estimate the NPV of such investment project, in which we have applied a WACC of 4.68% as in previous economic analysis.

Moreover it has been considered an annual depreciation of 1% on electrical bill savings and SSP revenues because of PV plants have an annual decay of 1%.

Then we have assumed that price of electricity paid on electric bill will increase by 3% per year since it was the mean growth rate per year of such tariff.

In this table we show final results about assessment of NPV and IRR for this investment project.

Table 5. NPV and IRR of residential investment project

Time horizon	20 years
NPV	**44461.76 €**
IRR	**10.86%**

We denote that the installation of smart grids increases the NPV of such investment, which reaches the sum of 44461.76 €, while in the case without smart grids the NPV of such project was 42106.58 €.

While the IRR of this investment reaches the percentage of 10.86% which is lower than previous case, probably because of initial expense of investment is increased from 81000 € to 86000 €.

As we can see in the following figure, the payback period remains unchanged with respect to previous case, namely 8-9 years, as well as the path followed by NPV.

The path followed by NPV and IRR is similar, one more time we denote that both NPV and IRR have a sharp growth in the first years after PV plant installations but then they tend to reduce their own pace of growth for various reasons: higher discount rates applied on NCFs, end of fiscal revenues that they are paid to such investors only for the first ten years following the initial expense for investment.

The following figures show paths followed by NPV and IRR for residential user’s investment.

Figure 3. Dynamics of NPV for residential PV plant

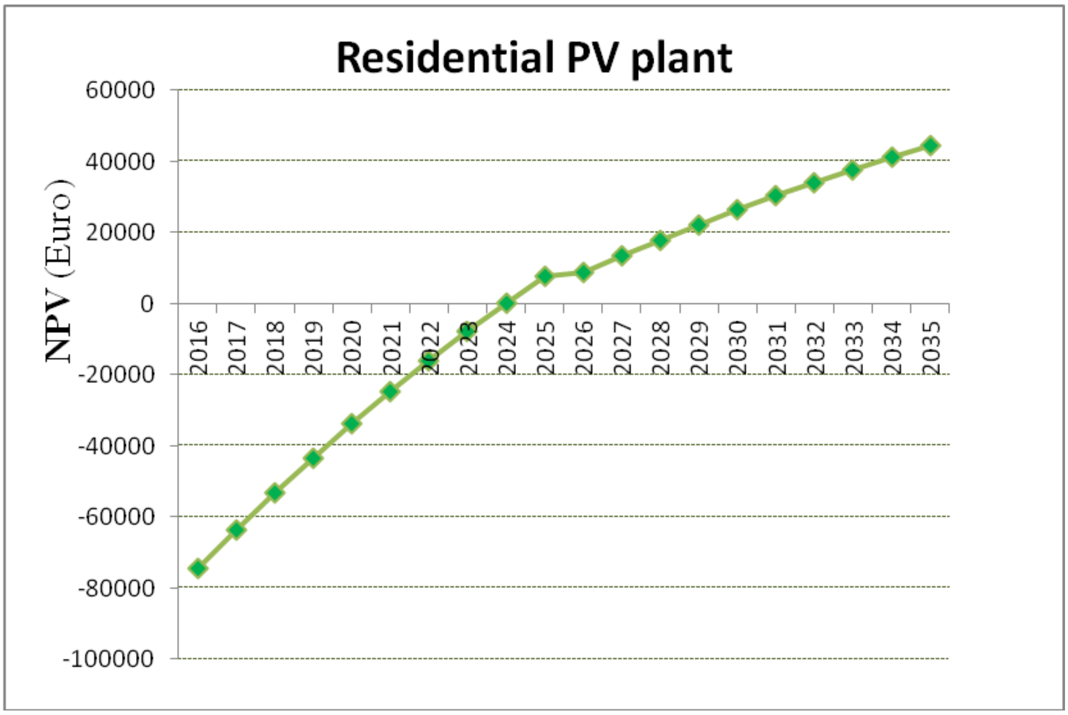
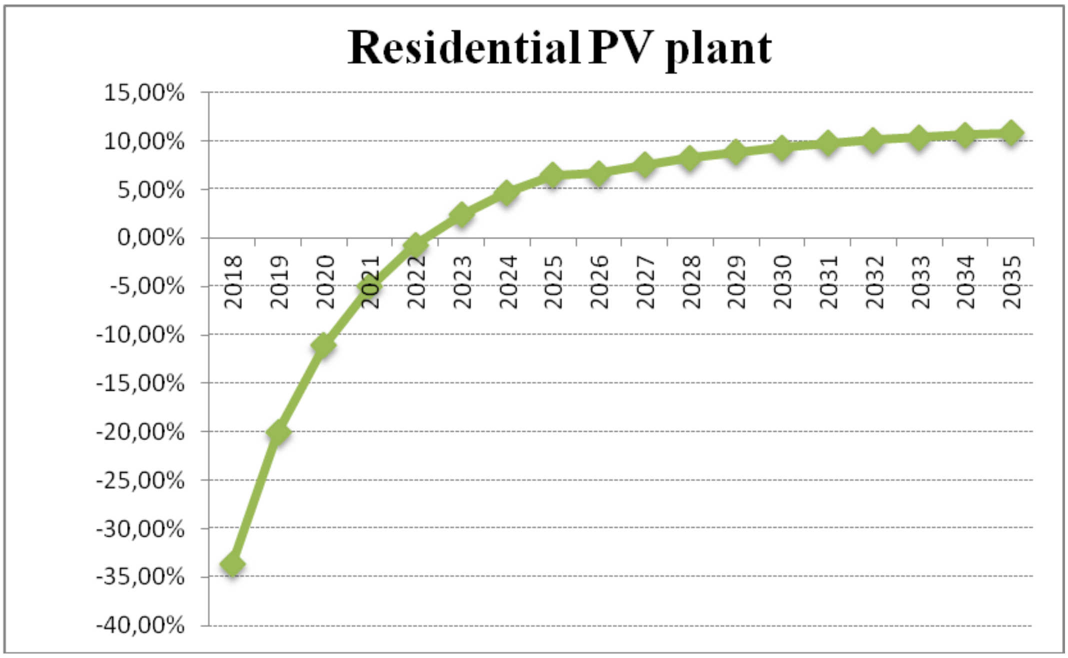


Figure 4. Dynamics of IRR for residential PV plant



4.2.2 Economic analysis of the POST OFFICE's PV PLANT

The cost analysis of such investment project is identical to the cost analysis that has been described before for the residential PV plant as well as values inherent each cost item.
In the following table we summarize each cost item together with the corresponding monetary value.

Table 6. Initial cost of investment for Post Office

Description	**Costs** (Euro)
PV modules	35250
Inverter	8250
Infrastructure	9000
Circuit panels and cables	5250
Project and installation	17250
Additional cost for smart grid	5000
Insurance costs	6000
TOTAL	**86000**

Sources: www.enerpoint.it, www.genitronsviluppo.com

Moreover we should add the annual cost of ordinary maintenance of PV plant, which is 210 € the first year following the installation but we assume that it will grow annually by 1.7 %, and the cost of inverter substitution.
The cost of inverter substitution, that will probably occur in 2026, will not be 8250 € as now but it will be reduced by 20-25 years within 5 years, as Studio Frenhaufer has forecasted.
So it will be reduced to 6300 €.
About the revenue analysis, since this commercial user adopts the billing mechanism of 'Scambio sul Posto' (SSP), we have the same revenue items as in the residential PV plant but only the values of electrical bill savings and SSP revenues change.
The value estimated for electrical bill savings has been recorded in the table below.

Table 7. Electrical bill savings for Post Office

Estimated power produced	37500 kWh
Auto-consumption percentage	74.37 %

Auto-consumed power	27888.75 kWh
Power tariff (taxes included)	0.1852 €/kWh
Electric bill savings	**5165 €**

From the table above it results that electrical bill savings are about 5165 € per year, while in the case dealt in the 3rd chapter electrical bill savings were 5134.41 €.

The increase of such revenue is not high because even if the quantity of electricity generated by this PV plant has grown, passing from 36,000 to 37,500 kWh per year, the share of self-consumed electricity has fallen, passing from 77.01% to 74.37 %.

So that growth of auto-consumed power has been slightly with respect the case without smart grids, passing from 27723.6 kWh per year to 27888,75 kWh per year.

This explains why the increase of electrical bill was so low, about 30 €.

Now let's present in the next table the value assessed for SSP revenues.

Table 8. SSP revenues for Post Office

Electricity yearly sold	9611.25 kWh
Electricity yearly bought	8898.7 kWh
Hourly zonal price (HZP)	0.05681 €/kWh
Unique national price(NUP)	0.05208 €/kWh
Value of electricity (VOE)	546.02 €
Cost of electricity (COE)	463.44 €
Unit Cost of electricity (UCes)	0.20302 €/kWh
Electricity exchanged (EE)	8898.7 kWh
SSP contribution	2270.06 €
VOE-COE	82,57 €
Fee	60 €
SSP revenues	**2292.63 €**

In this case SSP revenues are 2292.63 € while the SSP revenues of post office's PV plant seen in the previous chapter were 2088.06 €: so smart grids have implemented this revenue item of about 204 €.

As we have seen for PV plant connected to a complex of residential building at the beginning of the chapter, this increase in SSP revenues with respect the case without connection through smart grids, has been driven by growth of quantity of electricity sold to GSE.

The amount of last two revenue items is identical to investment in residential PV plant and they are:

- savings in cost of annual ordinary maintenance of electrical system, which are 300 € for the first year after installation of PV plant;

-tax deduction of 4,000 € per year for the period 2016-2025.

As we have seen before, forecasts of annual costs for ordinary maintenance of electrical system has been indexed to Italian inflation rate of the last ten years, which is 1.7% per year on average.

One more time we have applied a WACC of 4.68%, we have considered an annual depreciation of 1% on electric bill savings and SSP revenues because of annual decay of 1% of PV plant and an annual growth by 3% of power tariff paid in electric bill, so that this last increase of power tariff will affect only electric bill savings.

All estimates of NPV and IRR of such investment are reported in the following table.

Table 9. NPV and IRR of commercial investment project

Time horizon	20 years
NPV	**47825.31 €**
IRR	**11.05%**

The NPV estimated for such investment project is 47825.31€ while NPV of PV plant without smart grids was 43565.19 €, so this new technology has brought an added value on this project of more than 4260 €.

The duration of payback period has remained unchanged: 9-10 years.

The IRR has grown up to 11.05%, while in previous case it was 10.86 %.

Also in this case IRR becomes positive between the 7th and 8th year following realization of such project and we denote again that pace of growth of these two indicators shows the same features whose we have already discussed: they increase sharply in the first ten years of operation of this PV plant but then this pace of growth is less marked.

The reasons that explain this trend of such indicators are already known and they have greater discount rates for time period far from entry into operation of PV plant and end of inflows due to fiscal incentives.

In fact each user benefits of revenues deriving from tax deduction only for the first ten years of life of PV plant, then lack of this revenue item will reduce annual NCFs.

The increase of NPV and IRR of this commercial user equipped with smart networks was driven by a growth of amount of power available for sale which affects the SSP revenues.
In the figures below it is possible to look at path of NPV and IRR for such investment project.
In the following two pictures it is possible to look at dynamics of two previous indicators of profitability for this investment project.

Figure 5. Dynamics of NPV for Post Office's PV plant**.**

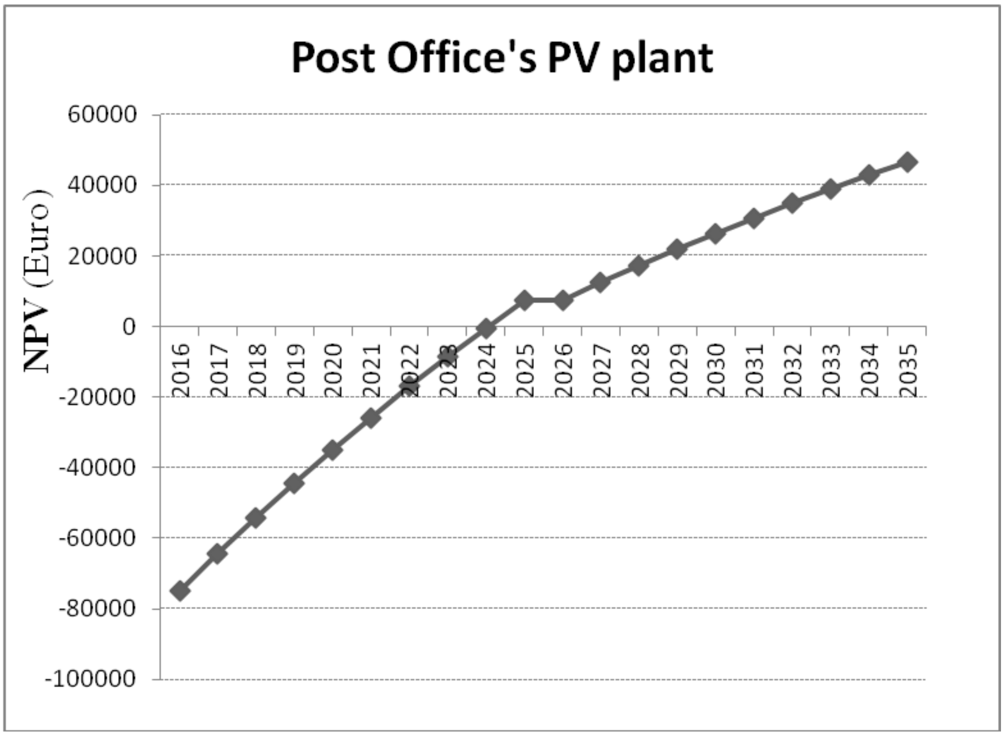
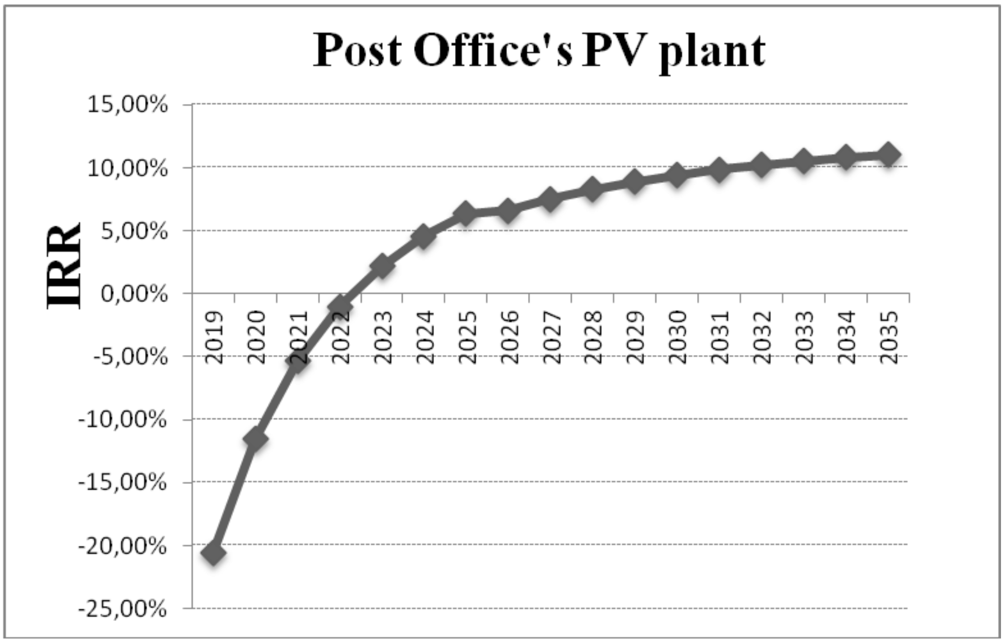


Figure 6. Dynamics of IRR for Post Office's PV plant



4.3 An alternative scenario: both users exchange electricity among them

Now let's examine the case in which the aforementioned users decide to exchange electricity among them in order to reduce amount of power bought by each one from ENEL.
We premise that since both users have PV system with equal nominal power installed and they have energy surplus and energy deficit in the same hours of day, the possibilities of power interchange are quite limited.
Moreover we should remember that both users adopt billing mechanism of 'Scambio sul Posto' and each one of them injects a greater quantity of power to electrical grid with respect to power absorbed by these user from the same grid.
In this scenario it has been estimated that they would exchange a quantity of power equal to 0.33 kWh per day, namely 120 kWh on annual basis.

This exchange is articulated in the following way:
-the residential user would sell 0.33 kWh of own power production to post office from 6.00 until 8.00 of each day;
-the commercial user would give back such amount of electricity from 16.00 to 17.00 of each day.

But this type of exchange would generate a symmetric result among these two investors, since:
-the residential users would obtain a reduction of both power sold and bought of 0.33 kWh per day;
-the commercial user would obtain a reduction of both power sold and bought of 0.33 kWh per day.

Obviously this agreement of power exchange among such users will not change the total cost supported by each one for the investment, that is 86,000 €, as well as it will not change neither savings on maintenance of their respective power systems neither the amount of tax deductions obtained by each of these two investors.
However this type of agreement will modify only the amount of bill savings and SSP revenues of each user, as we see in the following tables.

Table 10. Electrical bill savings for residential user

Auto-consumed power plus power received by post office	15060 kWh
Average power tariff (taxes included)	0.1852 €/kWh
Electric bill savings	**2789.11 €**

Table 11. SSP revenues for residential user

Electricity yearly sold	22440 kWh
Electricity yearly bought	18787 kWh
Electricity exchanged (EE)	18787 kWh
SSP revenues	**5028.95 €**

While the amount of electrical bill savings and SSP revenues related to post office (commercial user) have been reported in the following tables:

Table 12. Electrical bill savings for post office

Auto-consumed power plus power received by residential user	28008.75 kWh
Average power tariff (taxes included)	0.1852 €/kWh
Electrical bill savings	**5187.22 €**

Table 13. SSP revenues for post office

Electricity yearly sold	9491.25 kWh
Electricity yearly bought	8778.7 kWh
Electricity exchanged (EE)	8778.7 kWh
SSP revenues	**2261.45 €**

From this values, we will obtain the following estimates for NPV of each investment project:
-the NPV for PV plant of residential user is 44427.35 €.
-the NPV for PV plant of commercial user is 47790.94 €.
In order to compare the estimates of NPV for residential user and commercial user obtained so far, let's present in the following tables the estimated values of NPV and IRR for each investment project.

RESIDENTIAL USER

Table 14. NPV of residential user

	Without smart grids	With smart grid but without power exchange among users	With smart grid and power exchange among users
NPV	**42106.58 €**	**44461.76 €**	**44427.35 €**

Table 15. IRR of residential user

	Without smart grids	With smart grid but without power exchange among users	With smart grid and power exchange among users
IRR	**10.90 %**	**10.86 %**	**10.85 %**

COMMERCIAL USER (Post Office)

Table 16. NPV of commercial user

	Without smart grids	With smart grid but without power exchange among users	With smart grid and power exchange among users
NPV	**43565.19 €**	**47825.31 €**	**47790.94 €**

Table 17. IRR of commercial user

	Without smart grids	With smart grid but without power exchange among users	With smart grid and power exchange among users
IRR	**10.86 %**	**11.05 %**	**11.04 %**

Looking at previous results inherent NPV of each user it is clear that the optimal investment choice for both investors is to invest in smart networks but they should avoid to exchange electricity among them.

The main reason for which it is not convenient to exchange power among such users is that the Unit Cost for exchange standard (UCes) is higher than price of unit power bought on the market.

So that if an user has increased the quantity of auto-consumed energy and reduced the quantity of energy bought from the electrical grid, in case of value of electricity bigger than cost of electricity, the decrease of SSP revenues caused by reduction of energy bought from electricity provider is not offset by the increase of electrical bill savings, due to growth of auto-consumed power.

About paths followed by NPV and IRR, we find the same features that we have already found namely they present a marked increase in the first ten years of life of PV plants in which both users receive fiscal inflows deriving from reimbursement of half of initial expense of investment, excluded insurance costs, in form of tax deductions on Italian tax of individual incomes.

4.3.1 If we consider a time horizon as long as useful life of both investment projects with smart grids: how will NPV and IRR change?

a) Residential PV plant

As we have seen in the 3rd chapter an increase of duration of time horizon will produce a growth of both final NPVs even if this growth is less sharp as duration of this time horizon increase.

So that if we consider a time horizon of 25 years, the NPV of this investment will be 59221.69 € if residential user is equipped with smart grids but it does not exchange electricity with commercial user, while if it exchanges power with this last user NPV will be 59203.13 €. Also in this case it has no incentive to exchange electricity with the other one, even if the difference in NPV between the options to exchange/not to exchange is reduced with respect the case with a time horizon of 20 years.

About IRR of residential user, if time horizon is 25 years it will be 11.56 % in case of such user forgo to exchange electricity with the other one, otherwise it will be 11.55%.

They are still lower levels of IRR with respect the case without smart grids, in which IRR for residential user was estimated at 11.60 %: this reduction of IRR could be motivated by the fact that this user has a low level of self-consumption of electricity, so the annual increment of electric bill saving is not so high.

Paths of NPV and IRR have same trends that we have already faced for same investment project but with a lower duration of time horizon.

b) Post office's PV plant

In a time horizon of 25 years, the NPV of commercial user will be 65135.85 € if it forgoes to exchange electricity with other user, otherwise it will be 65117.34 €.

Also in this case commercial user has no incentive to exchange own self-produced power with power self-produced by its neighbour, even if the difference in NPV between these two options is less than the case with a shorter time horizon.

While IRR of this user if it invests in smart grids will be 11.81% in case of no exchange of power and 11.80% in the alternative case: these are still higher values with respect of IRR of the case without smart grids, which was 11.65%.

Also in this case features of trend over time inherent NPV and IRR do not change with respect situation in which we consider a time horizon of 20 years.

4.4 If residential user would choose to reduce the nominal power of its PV plant to 25 kWp: how will its NPV and IRR change?

Now we hypothesize a new scenario in which residential user chooses to install an PV plant with less nominal power, namely 25 kWp.

The main purpose of analyzing this scenario is to pick the positive effects of interchange of electricity among such users.

We have chosen to analyze the scenario in which only the nominal power of residential PV plant is reduced since only residential user has a very low share of self-consumed power in case the nominal power of its PV plant is 30 kWp, in fact it was only 39.84 % (with smart grids).

But if it reduced the nominal power of its PV plant to 25 kWp the share of self-consumed energy will grow up to 46.43%.

However a PV plant with such nominal power would generate a situation in which the quantity of energy sold to power grid is smaller than the quantity of energy bought from electricity provider, while in previous cases the situation was reversed.

So that residential user has incentive to decrease the amount of power absorbed through power grid, buying more electricity from its neighbour user, but it has no incentive to sell own energy to post office since the quantity of energy exchanged with power grid would reduce and the SSP revenues would fall as well.

As we have operated until now, also in this case we will develop our economic analysis on the basis of daily average of energy requirements of each user and of energy generation of its PV plant, computed in the course of the year neglecting monthly variability of such quantities.

Moreover we continue to consider a time horizon of 20 years since residential user has signed an insurance contract which guarantees insurance coverage for 20 years following installation against various types of risks as snow, hail, annual decay greater than 1% and outages caused by mistakes in procedures of installation and routine maintenance.

Notwithstanding we will add also estimates of NPV and IRR relative to both investors in case the time horizon considered is long as useful life of both PV plants, namely 25 years.

Then this user has signed an agreement with the commercial user which will sell to the former an annual quantity of energy equal to 600 kWh at unit price of 0.10 €/kWh.

In this way residential user could increase the amount of power sold to GSE while commercial user (the post office) could sell a part of self-produced energy at a price higher than average value of HZP, which is 0.05681 €/kWh.

Since the quantity of energy purchased by residential user from ENEL is higher than quantity of energy sold by itself to GSE, it has incentive to resell the whole amount of energy bought from its neighbour to GSE rather than self-consume this additional quantity of electrical energy.

This happens because nowadays the sum between HZP and UCes is higher than unit cost of electricity paid in electrical bill, which 0.1852 €/kWh.

Now let’s proceed with economic analysis of this investment project.

The first step of this economic analysis is the cost analysis.

In the next table we will summarize all cost items which compose the initial expense for such investment, which amounts to 72500 €.

Table 18. Initial cost of investment for residential user

Description	**Costs** (Euro)
PV modules	29375
Inverter	6875
Infrastructure	7500
Circuit panels and cables	4375
Project and installation	14375
Additional cost for smart grids	5000
Insurance costs	5000
TOTAL	**72500**

About costs incurred during the aforementioned time horizon we should consider:
-the annual costs of ordinary maintenance of PV plant;
-the cost of inverter substitution, which is expected in 2026.
-the cost of energy bought from commercial user.
The annual costs of ordinary maintenance of PV plant are estimated at 175 € in 2016 but we believe that such costs will grow by 1.7% per year in according to expected Italian inflation rate.
We assume that the cost of inverter substitution will be 5300 € in 2026 instead of actual cost of 6875 € because the expected fall of costs of components of PV plant is estimated at 25 % within five years[62].
Finally we estimate that monetary sum paid by residential investor to other investor for power purchase is 60 € per year from 2016 until 2040 when its PV plant will cease to be operational.
The next step of this economic analysis is the revenue analysis.
The first two revenue items that we are going to see are the electric bill savings and SSP revenues whose estimated values are recorded in the table below.

Table 19. Electrical bill savings of residential user

Auto-consumed power plus power received by post office	14713.15 kWh
Average power tariff (taxes included)	0.1852 €/kWh
Electric bill savings	**2724.88 €**

Table 20. SSP revenues for residential user

Electricity yearly sold	17279.9 kWh
Electricity yearly bought	19136.95 kWh
Electricity exchanged (EE)	17279.9 kWh
SSP revenues	**4459.02 €**

The other two revenue items of this type of investments are savings in maintenance costs of electrical system and tax deductions.
One more time we assume that the first revenue item will be 300 € for the first year after installation of PV plant but it will increase by 1.7% per year in according to expected Italian inflation rate.

62. Studio Fraunhhofer, from site 'www.assoelettrica.it'

While tax deductions will cover half of total cost of PV plant and smart grid, so they will amount to 3375 € per year for the period 2016-2025.

The last parameter necessary to proceed to compute the NPV and IRR of this investment project is WACC which has been estimated at 4.68% as we have seen so far.

In the following tables we report the results inherent NPV and IRR of residential user, who owns a PV plant equipped with smart grids, in time horizons of two different durations: 20 years and 25 years.

Then we add another table that records the estimated values of IRR and NPV of the same user, with the same time horizons that we already seen in paragraph 4.2 in order to compare these new results with previous ones.

Table 21. NPV and IRR of residential PV plant of nominal power of 25 kWp

Time horizon	**20 years**		**25 years**	
Interchange of power among users	**Yes**	**No**	**Yes**	**No**
NPV	**44842.62 €**	43362.22 €	**58500.47 €**	56858,27 €
IRR	**11.89%**	11.68%	**12.55%**	12.34%

Table 22. NPV and IRR of residential PV plant of nominal power of 30 kWp

Time horizon	**20 years**		**25 years**	
Interchange of power among users	**Yes**	**No**	**Yes**	**No**
NPV	44427.4 €	**44461.76 €**	59203.28 €	**59221.69 €**
IRR	10.85%	**10.86%**	11.55%	**11.56%**

As we can understand through comparison previous results, the optimal solution for residential investor is to maintain a PV plant of nominal power of 30 kWp and this makes not convenient for none of two counterparties to trade power, as we have seen before.

Table 23. Post Office's PV plant, with nominal power of 30 kWp

Time horizon	**20 years**		**25 years**	
Interchange of power among users	**Yes**	**No**	**Yes**	**No**
NPV	**48900.46 €**	47825.31 €	**66352.37 €**	65135.85 €
IRR	**11.18%**	11.05 %	**11.93%**	11.81 %

If we look at situation of commercial user we see that it prefers sell power to residential user in case this user chooses to reduce nominal power of its PV plant to 25 kWp, but since for its neighbour it is more convenient to keep a PV plant whose nominal power is 30 kWp, it has to keep a PV plant with the same nominal power but it could not exploit benefits of power interchange.

4.5 Conclusions

In this chapter we have elaborated the economic analysis of the two investment projects that we have presented in previous chapter but we have considered the case in which PV systems owned by such users are equipped with smart grids.
We have developed such economic analyzes in two different scenarios: in the first scenario we assume that previous users do not trade power among themselves while in second scenario we consider the possibility of power interchange among users.
Since we have seen that it is convenient for both users not to trade power among themselves, we have tested hypothesis of reduction of nominal power of residential PV plant to 25kWp in order to allow these users to exploit benefits brought by possibility of energy trade among themselves.
Results of such test have been disappointing for residential user in case it reduces nominal power of its plant, even if profitability of commercial user's project would be improved if its neighbour would accept such reduction of nominal power.

We have neglected the case in which only nominal power of post office's PV plant is reduced since this last user has a high self-consumption percentage of power: thus surely it is not willing to decrease nominal power of its PV plant.

From what has been said, it results that both users will choice to have PV plants whose nominal power is 30 kWp but they will not interchange power among themselves, even if each user would be advantaged by power interchange in case its own neighbour decreased nominal power of its own PV system.

Then we summarize in the following tables all results about NPV and IRR that we have found in these last two chapters related to each user for time horizon of 25 years.

Table 24. NPV and IRR of RESIDENTIAL PV PLANT

Nominal power	30 kWp			25 kWp		
Installation of smart grids	No	Yes		No	Yes	
Power interchange	No	No	Yes	No	No	Yes
NPV	**55983.69 €**	**59221.6 €**	**59203.13 €**	**51355.38 €**	**56858,27 €**	**58500.47 €**
IRR	**11.60 %**	**11.56 %**	**11.55%.**	**12.23 %**	**12.34%**	**12.55 %**

Table 25. NPV and IRR of POST OFFICE's PV PLANT (with nominal power of 30 kW)

Power interchange	No		Yes	
Installation of smart grids	No	Yes	Yes	
Nominal power of residential PV plant	-	-	30 kWp	25 kWp
NPV	**60010.78 €**	**65135.85 €**	**65117.34 €**	**66352.37 €**
IRR	**11.65 %**	**11.81 %**	**11.65 %**	**11.93 %**

CHAPTER 5

OPTION TO POSTPONE SMART-GRID INVESTMENT AND ECONOMIC ANALYSIS OF BENEFITS BROUGHT BY SMART GRIDS

This chapter is a completion of previous analysis of the two investment projects in PV plants equipped with smart grids since it explores other two aspects related to such projects, namely the possibility to postpone this investment and the quantification of benefits generated by implantation of this technology in terms of revenue due to power interchange among private users and savings in electric bill and expenses for maintenance of own electrical plant.
In the first paragraph we evaluate the option of investing in this technology over the next five years while in the second paragraph we analyze additional revenues brought by smart networks in order to understand how much such improvement of profitability for this type of investment depends by new possibilities for power interchange among private users.
Since this analysis of additional profitability is focused on both present and future perspective, we have specifically decided to discuss about option of postponement of this investment project before the development of the aforementioned analysis.

5.1 Value of option to postpone the two investments in PV plants

Now we deal with temporality of these two investment choices in order to assess if it is convenient to invest this year or postpone such investments of five years.
The value of the option to wait for investing is based mainly on estimates of future changes of unit power tariff paid on electric bill by users and future changes of components of a PV plant and the attached smart grids.
However we continue to index cost of ordinary maintenance of PV plants and electrical systems of both users to average of Italian inflation rate, which is 1.7%.
Then we consider the hypothesis of end of tax incentives for this kind of investments, so that this future scenario is characterized by absence of tax deductions on initial expense for investment and it is compared with a current scenario, in which we assume that investors irrationally forgo to aforementioned fiscal incentives, in order to evaluate such time option.
The hypothesis of future elimination of such tax incentives is quite realistic since we observe that Italian Government intends to reduce share of tax deduction on Italian income tax offered as reimbursement for initial cost of investment year by year.

But the main reason for which we test scenarios characterized by lack of fiscal incentives is that we want to know if this kind of investment is still profitable even if tax benefits granted by governments are not longer available, as it is predictable.
Now we proceed to analyze the Net Present Value (NPV) of the two investment projects in case we postpone them of five years.
Obviously estimated NPVs have been discounted with respect to Weighted Average Cost of Capital (WACC) since decision to invest now or later should be taken now.
These estimated values of NPV will be compared to current values of NPV for the same investments with the same condition in order to estimate the value of wait for investing.
We consider the same two different scenarios that we have already seen in the previous chapter.
In the first scenario we suppose that both residential PV plant and post office's PV plant have the same nominal power of 30 kWp but they do not interchange power among themselves, which was the optimal scenario for both users.
In the second scenario we assume that the two counterparties involved in power interchange are a residential PV plant with a nominal power of 25 kWp and a commercial PV plant with a nominal power of 30 kWp.

1st scenario

As we have said before in this scenario we assume that both residential and post office's PV plant have a nominal power of 30 kWp, so it is not convenient to either users to trade energy with the other.
Moreover we assume that both users adopt the billing mechanism of 'Scambio sul Posto' for valorisation of power sold to national power grid.
About cost analysis we suppose that cost of components of PV plant and attached smart grids will be reduced by 25% in five years[63] while insurance premium for such structures are subject both to a decline of 25% within five years, in according to forecasted reduction of cost for these technologies, and an annual growth of 1.7% in according to Italian inflation rate.
Moreover we compute final value of NPV of each investment project on a time horizon of 30 years, instead of 25 years, since new generation solar panels will have an useful life of 30 years while new generation inverters will last 15 years[64].

63. From site: 'www.assoelettrica.it'.
64.'The ugly side of solar panels' from 'Low tech magazine'.

Cost for inverter substitution, which depends by nominal power of PV plants, it is 6300 € for each one of such plant.

So that initial expense for investment, included expense for the unique insurance premium, will be 65550 € for each one of them while annual cost for ordinary maintenance for each PV plant it will be 230 € the year following installation but it will increase by 1.7% in according to Italian inflation rate.

About revenue analysis we continue to apply the estimated growth rate of 3% for unit price of electricity bought by users from ENEL as well as the estimated growth rate of 1.7% for savings in expense for routine maintenance of own electrical system.

One more time we consider a depreciation of 1% for both electric bill savings (together with previous appreciation of 3%) and SSP revenues in according to annual decay of 1%, while WACC is fixed at 4.68%.

Now we show discounted estimates of final NPV for both projects whose realization is postponed by five years.

Then we report in another table the estimated values of NPV for such investment projects realized in current times, excluding tax incentives for both users, in order to compare such data with previous ones.

So it is possible to assess the value of option to postpone the realization of such projects.

Table1. Discounted value of NPV for investment in residential and post office's PV plant (in case such projects has been postponed by five years)

Type of project	Residential PV plant	Post Office's PV plant
Final NPV[65]	**55863.93 €**	**68830.13 €**

Table 2. NPV for current investment in residential and post office's PV plant (without fiscal incentives for both investments)

Type of project	Residential PV plant	Post Office's PV plant
Final NPV	**27849.01 €**	**33763.25 €**

65. The final values of NPV have been discounted with WACC since we want to know actualize the expected value of NPV within five years since we should decide now if it is convenient to invest this year or postpone such investment.

As previous tables show, the discounted values of NPV to invest in five years for both projects are higher than NPV of both projects, depurated by tax deduction on initial investment expense, in case we suppose to invest this year.
So it is possible to compute the value of option of wait for investing which is equal to the difference, if positive, among discounted value of NPV to invest within five years and NPV to invest this year otherwise it is equal to zero.
It results that in both investments it is convenient to postpone realization of both PV plants and values of options to delay such investments are 28014.92 € for residential investor and 35066.88 € for commercial PV plants.
These high levels for option to delay these investments are due to fall of costs of photovoltaic investment whose we have noticed a downward trend over the last ten years.
In fact forecasts about future decline of cost for PV plants made by Studio Fraunhofer are based just on this trend, which is caused by incessant technological progress which allows to produce solar modules at lower and lower prices.
This is the main reason for which Italian Government is trying to gradually fiscal incentives, which have been granted in order to reduce dependence on fossil fuels for power generations not only to improve the quality of environment but also in anticipation of a future increase of traditional energy sources whose future depletion is expected.
This difference in the value to wait for investing among these two users mainly depends by consumption profile of each one of them.
Post office has higher value to postpone such investment since it is characterized by higher level of self-consumption of power, so if power tariff will increase in the future its electric bill savings will grow as well while SSP revenues remain unchanged with respect current case.
Moreover we observe that NPV of residential user in the current case, in which we assume the absence of fiscal incentives, has a greater reduction with respect to NPV of commercial user in the same case: so we denote that residential user is more penalized by lack of tax incentives for this type of investments with respect to post office.

2nd scenario

In this second scenario we assume that residential user, which owns a PV plant with 25 kWp of nominal power, interchanges electricity with commercial user, whose PV plants has a nominal power of 30 kWp.

We suppose that residential user purchases 600 kWh per year of power at unit price of 0.10 €/kWh for 30 years from post office and it resell this amount to GSE applying the conditions provided by billing mechanism 'Scambio sul Posto', adopted by both users.
We choose to fix the price of power traded among these two users at 0.10 €/kWh again, in order to compare results of this analysis with scenarios dealt in previous chapter, with the only difference that in this case we hypothesize the absence of fiscal incentives for this type of investments.
The assumptions relative at both investments are similar to assumptions made in previous scenario.
About the initial expense for investment we continue to forecast a reduction by 25% for cost of PV plant and attached smart grids so that that initial cost for residential investment is 55750 € while initial cost for post office's PV plant is 65550 €.
Moreover cost of inverter substitution is estimated at 5300 € for the former and 6300 € for the latter.
Then the estimate of electrical bill savings is based on forecasted growth by 3% for unit price of electricity paid by each user to ENEL.
Both cost for ordinary maintenance of PV plants and savings for ordinary maintenance of electrical systems are indexed to the average of Italian inflation rate, which is 1.7% per year.
One more time we consider an annual depreciation of 1% for both electrical bill savings and SSP revenues in order to keep into account the annual decay of 1% of solar panels while we continue to adopt a WACC equal to 4.68%.
Now we proceed to present discounted estimates of final NPV for both projects whose realization is postponed by five .
This table is followed by another table in which we can look at estimated values of NPV for these investment projects realized in current times, assuming that two users do not require tax deduction provided for these investments, in order to compare such data with previous ones.
So it is possible to calculate the value of option to postpone the realization of such projects.

Table 3. Discounted value of NPV for investment in residential and post office's PV plant (in case such projects has been postponed by five years)

Type of project	Residential PV plant	Post Office's PV plant
Final NPV	**55350.01 €**	**69203.59 €**

Table 4. NPV for current investment in residential and post office's PV plant (without fiscal incentives for both investments)

Type of project	Residential PV plant	Post Office's PV plant
Final NPV	**32029.83 €**	**34185.34**

As we can see in previous tables, also in this case we have higher values for (discounted) NPVs related to possibility to invest within five years with respect to NPVs estimated for decision to invest this year in such projects.

So we surely obtain positive values for options to delay these two investment: in fact for residential PV plant the value to postpone investment is 23320.18 € while for post office's PV plant this value amounts to 35018.25 €.

Also in this case we see that value of option of wait for investing is higher for commercial investor with respect to residential one but we observe that the differential of value among such options in increased in this last scenario with respect to the first one.

We can denote that benefits of delay this kind of investment are increased for post office, probably because of combination of self-consumption share and increased demand for power by residential user so that commercial user could sell its neighbour an amount of 600 kWh per year of energy at price, 0.10 €/kWh, which is higher than remuneration granted by 'Scambio sul Posto' for energy sold to national power grid.

Finally we can denote that residential user is penalized by reduced power generation of its PV plant which causes a greater dependence towards ENEL or commercial user for energy provision while decline of power given to national power grid causes a loss of part of advantages granted by access to billing mechanism of 'Scambio sul Posto' whose aim is valorization of energy sold by private users to power grid.

In the following tables we summarize value of options to wait for investing for residential user and commercial user in the two scenarios that we have seen before.

Table 5. Value of option to wait for investing for residential user

RESIDENTIAL USER		
Scenario	1st scenario	2nd scenario
Nominal power of residential PV plant	30 kWp	25 kWp
VALUE of OPTION	28014.92 €	23320.18 €

Table 6. Value of option to wait for investing for commercial user

COMMERCIAL USER		
Scenario	1st scenario	2nd scenario
Nominal power of residential PV plant	30 kWp	25 kWp
VALUE of OPTION	35066.88 €	35018.25 €

5.2 Added value provided by smart-grid to PV plant investment

In this paragraph we present the two components of added value provided by smart grids to value of PV plant at which they are attached, which are savings in electrical bill and additional gains given by new possibilities for power interchange among private owners of PV plants.

Moreover increment of value of investment in PV plant given by installation of smart grids has a third component which is linked indirectly to such plant: it is savings in annual routine maintenance for electrical system.

We assess this added value brought by smart grids to PV plant through comparison of NPVs of previous PV plants (residential and post office's) computed for three different cases:

-PV plants do not adopt smart grids;

-PV plants are equipped with smart grids but their owners do not trade power among themselves;

-PV plants are equipped with smart grids and there is power interchange among their users.[66]

4.In this case we suppose that PV plants involved in power interchange have a different nominal power otherwise none of their users is interested to trade power with its neighbour.

We estimate potential values of NPV in case both users interchange power among themselves, even if we have already seen in previous analyzes that hypotheses of power interchange are less profitable for each one of this investors with respect to possibility to invest in a PV plant of nominal power of 30 kWp and avoid private trading of energy.
After that we make our estimates of additional value generated by installation of smart grid on the basis of the previous scenario in which we hypothesize that both users, whose PV plants have a different nominal power, decide to trade electricity among themselves.
In this scenario residential PV plant has a nominal power of 25 kWp while post office's PV has a nominal power of 30 kWp.
Then we consider two different time framework for such assessment: the current time framework and the future time framework (postponement of investment in five years).
Let's start from current time context.

5.2.1 Added value of smart-grid investment in current time framework

We hypothesize that both investors decide to invest this year in PV plant equipped with smart grids which allow these users to trade power among themselves.
The first investment project that we analyze is the residential PV plant, whose power is 25 kWp.
This user consumes 14523.35 kWh per year of energy produced by its solar plant and buys 19326 kWh per year of power from ENEL at unit price of 0.1852 €/kWh for the first year following installation of PV plant while in the case in which we consider the possibility of power interchange among users we assume that it buys an addition share of power that amounts to 600 kWh per year from commercial user at unit price of 0.10 €/kWh for the whole useful life of its investments.
In the case in which this amount of energy purchased from its neighbour is sold together with part of power surplus produced by PV plant but not absorbed by its owner, so that the total quantity of power given by residential user to national power grid 17357.15 kWh per year while in the case in which we do not consider such possibility, this quantity declines to 16757.13 kWh per year.
Then we present in the following table all estimated values of NPV for residential user for each case in order to assess added value brought by smart grids to such investment.

Table 7. NPV of residential PV plant with 25 kWp of nominal power

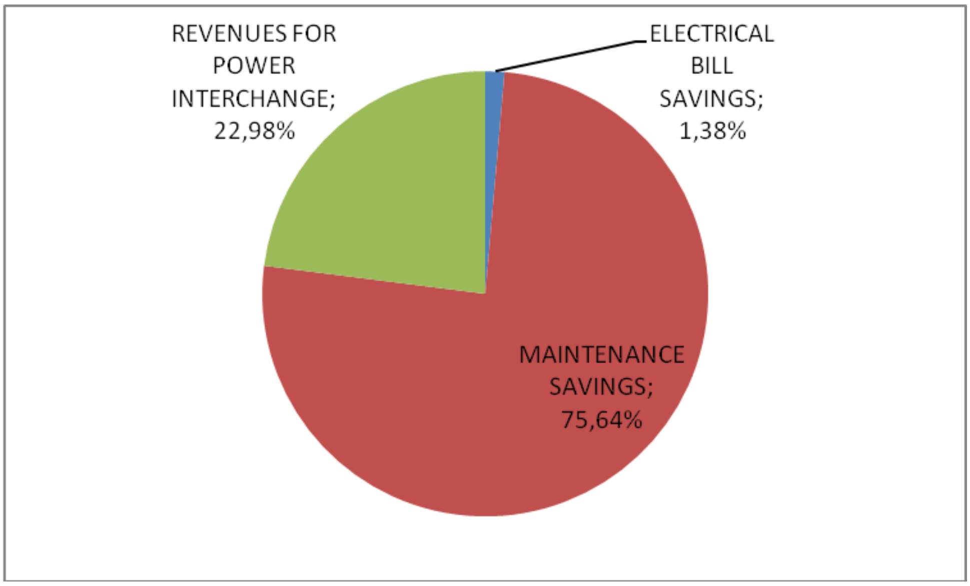
Cases	**NPV**
Without smart grid	51355.38 €
With smart grid but without power interchange	56858.27 €
Power interchange among two users	58500.47 €

In this three cases we see that installation of smart grids increases value of investment in PV plant and this increase is higher if residential user has the possibility to trade power with its neighbour.

So that added value given by introduction of smart grid to such investment is 7145.09 € if residential user could exploit possibility of power interchange with commercial user which owns a PV plant whose nominal power is 30 kWp.

The following figure shows the relative weight of each one of previous three components in this added value.

Figure 1. Percentage of contribution provided by improvement of each revenue item to added value of residential PV plant through adoption of smart grids



As we can denote in graphic above the most part of added value given by smart grids to this investment is represented by maintenance savings while other contributions to increase of value of such investment are less significant.

The lowest share of this added value is represented by electrical bill savings since smart grids reduce by 3% technical losses of PV plant at which they are attached but the percentage of electric bill savings depends also by percentage of self-consumed power.
So that we have estimated the increment of electric bill savings due to smart grid, weighting the share of reduction of technical losses caused by implantation of this technology with the percentage of energy self-consumed by residential investor.
The share of revenues for power interchange is not so high since the quantity of power traded among such users is quite modest, since commercial user could not sell a bigger amount of power to its neighbour at unit price of 0.10 €/kWh.

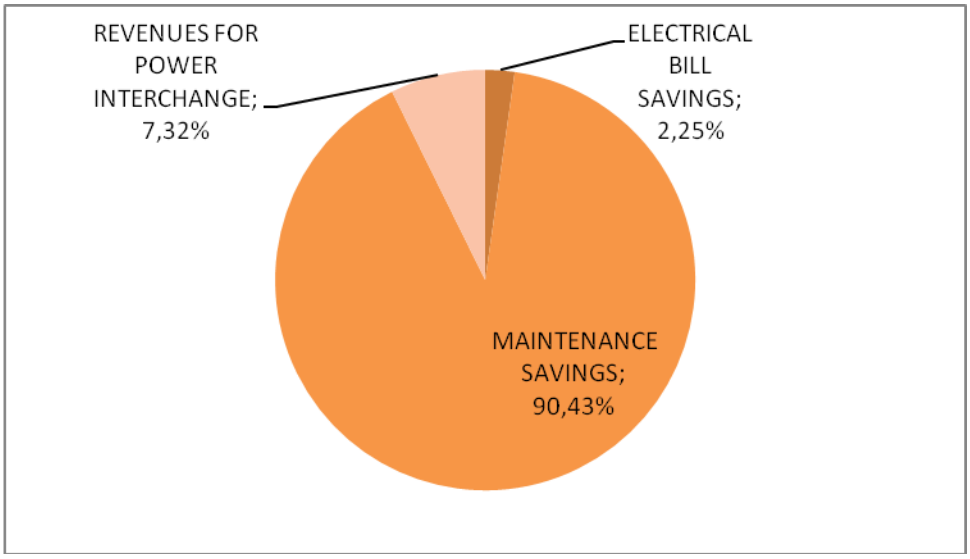
Now we consider the situation of commercial user whose PV plant has a power of 30 kWp. This user self-consume 27888.75 kWh per year of energy generated by its PV plant and absorbs 8898.7 kWh per year of power from national power grid.
In the case in which we allow both users to trade power, the amount of this commodity produced by its PV plant but not self-consumed is divided in this way: it sells 9011.25 kWh per year to GSE and 600 kWh to its neighbour and unit price of energy traded among these two users is 0.10 €/kWh.
Otherwise this users will sell 9611.25 kWh per year of electricity only to GSE.
In the next table we present all estimated value for NPV of commercial user for the same three cases that we have seen before.

Table 8. NPV of post office's PV plant with 30 kWp of nominal power

Cases	NPV
Without smart grid	59746.66 €
With smart grid but without power interchange	65132.85 €
Power interchange among two users	65557.95 €

Also for this user we see that added value given by investment in smart grids is higher if this user accepts to sell power to residential user.
If post office trade electricity to its neighbour, added value for investment in PV plant amounts to 5811.29 € which is lower than added value that we have met for residential investment.
Now we show in the following graphic the contribution of each one of three items of added value to investment in post office's PV plant.

Figure 2. Percentage of contribution provided by improvement of each revenue item to added value of post office's PV plant through adoption of smart grids



In previous picture we see how savings in annual expense for ordinary maintenance of electrical system of commercial user dominates the sum of money estimated as added value of smart grid to investment in photovoltaic technology.

This greater share of maintenance savings, which constitute 90.43 % of added value brought by smart grid to such investment, is due to low profits deriving from sale of part of self-produced power to residential user.

In fact we quantify this margin of profit as a difference among unit price of power sold to residential user, namely 0.10 €/kWh and HZP, which is unit price at which GSE pays power purchased from private users.

HZP is estimated at 0.05681 €/kWh.

Finally we denote a slight increase of share of electric bill savings with respect previous case since we have an higher percentage of self-consumed power.

For this user share of self-consumed power amounts to 74.36 % while for residential user it amounts to 46.43%.

5.2.2 Added value of smart-grid investment in future time framework

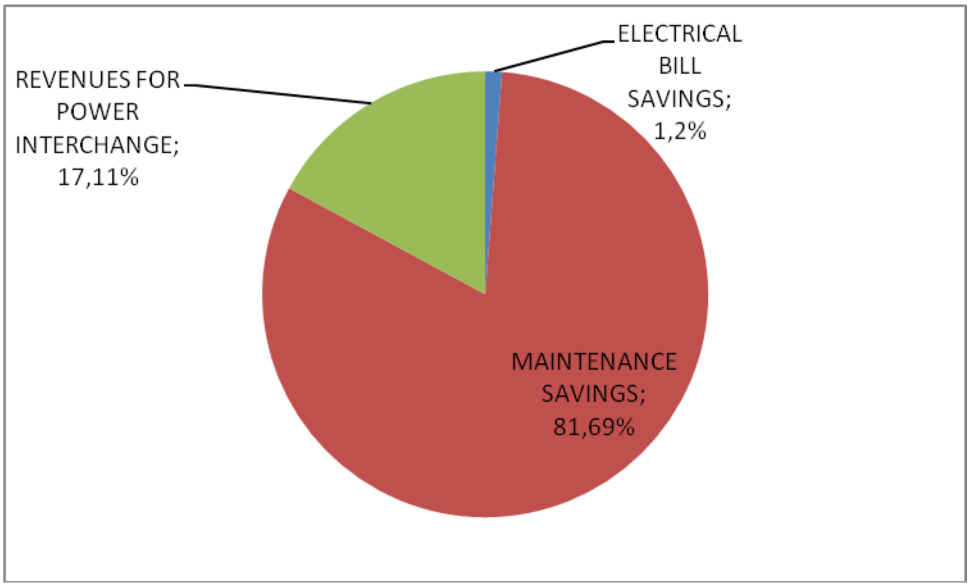
Now we deal with smart-grid investments for both PV plants under the assumption that both users have decided to postpone own investments by five years.
The first investment that we examine is the investment in residential PV plant.
One more time we assume that such PV plant has a nominal power of 25 kWp and it interacts with post office's PV plant whose nominal power is 30 kWp.
The annual amount of energy self-consumed is 14523.35 kWh per year and it purchases 19326 kWh per year of power from ENEL at unit price of 0.1852 €/kWh.
If we consider the possibility of power interchange with commercial investor, this user purchases an additional quantity of power , equal to 600 kWh per year paying different unit price, 0.10 €/kWh to residential investor.
However this additional amount of power received by post office's PV plant is resold to GSE in according to condition stated in billing mechanism of 'Scambio sul Posto'.
So that if residential investor does not trade with its neighbour, the quantity of energy given to electric power grid is 16757.13 kWh per year, otherwise it is 17357.15 kWh per year.
Then we proceed to NPV for this kind of investment for the same three case:
-PV plant is not equipped with smart grids;
-PV plant is equipped with smart grid but users do not interchange power;
-both users trade powers.
In the following table we illustrate all estimates of NPV for each one of previous cases.

Table 9. NPV of residential PV plant with 25 kWp of nominal power

Cases	NPV
Without smart grid	47165.32 €
With smart grid but without power interchange	53949.51 €
Power interchange among two users	55350.1 €

If we look at previous table we denote that smart grids provide an added value to such investment which is 8184.78 € in case residential users accepts to buy energy from its neighbour otherwise it amounts to 6784.19 € so the contribute of smart grid to power interchange is equal only to 1400.59 €.
If we want to see the respective percentage of components of this added value, we present in the following figure all components of such added value together their respective shares.

Figure 3. Percentage of contribution provided by improvement of each revenue item to added value of residential PV plant through adoption of smart grids



In the previous figure we denote a greater predominance of maintenance savings in the added value generated by smart grids with respect to case of investment made in current time.

Such growth of share for maintenance savings is due to expected increase of this expense that we have indexed with respect to inflation rate of 1.7% per year.

Moreover we see a reduction of NPV in future investment with respect to investment made in current time because of expected abolishment of fiscal incentives for investments in 'clean energy' for the future, so that if NPV declines but SSP revenues and share of added value due to increase of electric bill savings remain unchanged and savings in routine maintenance of electrical system continues to grows, it is clear that weight of this last item grows significantly.

Then we denote a decline for share of revenues for power interchange since this value is linked to SSP revenues that do not changes over time.

The second investment project whose we evaluate added value brought by smart grids is the investment for post office's PV plant.

This PV plant has a nominal power of 30 kWp while its neighbour owns a PV plant was nominal power is 25 kWp.

The amount of self-consumed power is 27888.75 kWh per year while the annual amount of power bought from national energy provider is 8898.7 kWh.

Moreover we should distinguish two cases: the first case in which this investor does not interact with residential user for power interchange and the second case in which both investors trade power among themselves.

In the first case post office will sell 9611.25 kWh per year of electricity to GSE in according to mechanism of valorisation of energy sold, namely ‘Scambio sul Posto’.

In the second case the annual quantity of energy sold by commercial user to GSE is 9011.25 kWh per year while residential user purchases by this investor 600 kWh of power per year paying an annual sum of money equal to 60 €.

The following step is the estimate of NPVs for this investment project for the same three cases that we have already defined before.

In this table we could look at results of this estimation procedure.

Table 10. NPV of post office’s PV plant with 30 kWp of nominal power

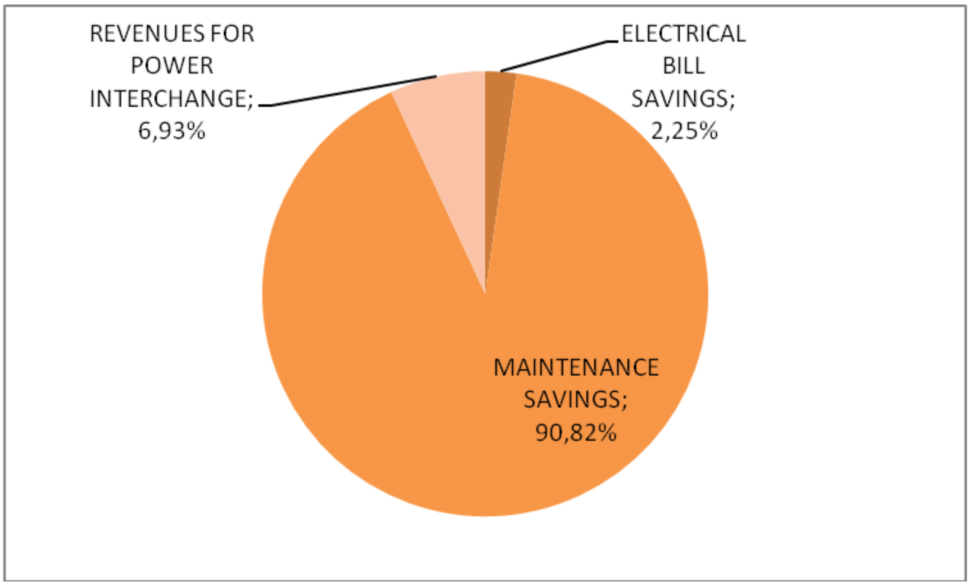
Cases	NPV
Without smart grid	63812.88 €
With smart grid but without power interchange	68830.13 €
Power interchange among two users	69203.59 €

Data of table above say that added value of installation of smart grids is 5390.71 € in case commercial user chooses to interchange power with the residential one, otherwise added value of smart grids in case this user forgoes to trade energy with its neighbour is 373.46 €.

This time we observe that benefits of power interchange due to implantation of this technology are lower than all other cases that we have faced so far.

However we illustrate in the following figure the measures of contribution given by each one of these three components to added value of smart grid on investment.

Figure 4. Percentage of contribution provided by improvement of each revenue item to added value of post office's PV plant through adoption of smart grids



In the last figure we observe a slight increase of percentage of savings in cost for routine maintenance of electrical system with respect to case in which investment in such commercial PV plant is set in the present temporal framework.

This is due to expected increase of cost for ordinary maintenance for electrical system that valorises more and more smart grids that allows to save money for this type of expense.

The share of electrical bill savings is unchanged since the percentage of self-consumed power does not change as well as the reduction by 3% of technical losses of PV plant due to such technology.

Finally we denote a slight decline of contribution of revenues for power exchange to this added value: the reason is that SSP revenues and monetary amount received by neighbour for energy sold do not change in absolute value over time while NPV increases because of smart grids.

In this way the contribution of benefits generated by power interchange among private users tend to decline over time

5.3 Conclusions

In the first part of this chapter we have seen the value of option to wait for investing in two PV plants that provided power to a residential and a commercial user.
From such analysis it results that both investors should continue to invest in PV plants whose nominal power is 30 kWp and avoid to trade power among themselves, as we have seen in previous chapter, but the option to invest has a positive values for both users.
So that they should invest in 5 years since initial cost of investment has been reduced by 25% while maintenance savings and electrical bill savings tend to maintain an increasing trend.
Finally we have demonstrated that the highest share of added value of smart grids to PV plants at which they are installed is represented by savings in annual cost for ordinary maintenance of electrical system.
It is expected that this share will increase in the future because annual expense for routine maintenance of electrical system will grow by 1.7% per year in according to Italian inflation rate while SSP revenues tends to remain unchanged.
The share of revenues for power interchange is higher for users which purchase power from other users and resell such electricity to the market in according to aforementioned mechanism 'Scambio sul Posto'.
We do not forget that starting condition of greater quantity of energy bought with respect to energy sold for an users improves share of added value to NPV due to revenues for power interchange since this user obtains more benefits of power interchange that could be exploited only if such investor finances the building of such system.

CONCLUSIONS

The purpose of this study is to evaluate if installation of smart grid to two medium-small sized PV plants increases the value of such PV investments through exploitation of benefits brought by this new technology as possibility to interchange power among private producers, reduction of technical losses of PV plants and reduction of expenses for ordinary maintenance of electrical systems of such users.

At first we have described technical features of this technology and its crucial role in order to improve quality of power provision and implement exploitation of renewable sources for generating power with low environmental impact.

Then we have dealt with PV technology, describing its technical features and level of development of PV markets but we have focused on regulatory framework of Italian PV market in order to see the main support schemes currently available for investors in such technology.

The part of Italian regulatory framework concerning support schemes available for investment in PV sector constitutes an useful tool for evaluating the effects of combination between such support schemes and smart-grid technology.

In all scenarios that we have analyzed, we denoted that anyway smart grids improve value of investments in PV plants but to understand the benefits brought by smart grids in terms of new possibility of power interchange among private users, we should differentiate nominal power of both PV plants.

In this last scenario we have denoted that owner of greater PV plant benefits more from such possibility of power interchange while owner of smaller PV plant records a net fall of profitability for its investment since benefits of power interchange do not offset the loss of profitability due to reduction of nominal power of its PV plant.

Since the best solution for these two investors is to avoid both reduction of nominal power of own PV plants and interchange of power among themselves, it results that the greatest contribution of such technology to profitability of PV investments is given by savings in expenses for ordinary maintenance of their electrical systems, which are connected to PV plants.

Moreover we have observed that share of contribution to profitability given by savings in routine maintenance of electrical system is higher in case we postpone by five years such investment, because cost of investment in PV plants equipped with smart grid will fall by

25% in five years while we estimate an annual increase by 1.7% of expense for ordinary maintenance of electrical systems of previous users.
So we learn that the benefits provided by incentive mechanism of net metering are not compatible with new possibilities of power interchange provided by adoption of smart grids. It seems that net metering is structured so as to discourage power trading among private users in order to favour injection of surplus power produced by private user to national power grid. However this technology provides economic benefits in terms of increased reliability and safety of electrical systems of private owners that could be quantifiable in terms of savings in yearly cost of routine maintenance.
The share of saving in such costs has been estimated at 40%.
The results of economic analysis of such investment project could be interpreted as a proof that potential installation of smart grids on large scale would produce great economic benefits as reduction of potential outages on power grids and improvement of quality of power provided, since growth of digitalization presses for a better quality of electricity.
We can say that development of smart grids is complementary to development of production of power through renewable sources since it reduces waste of power due to technical losses of plants fed with renewable sources and it allows to equilibrate demand and supply of power in order to avoid overloads in power grid.
Moreover it favours integration of national electricity markets, which is a necessary condition to support growth of sector of ‘clean energy’.
However development of smart grids on large scale requires an adequate regulatory framework and the support of government policies.

BIBLIOGRAPHY & SITOGRAPHY

BIBLIOGRAPHY

- Analisi dei consumi energetici residenziali e vantaggi connessi all'utilizzo di un manager energetico, De Franceschi
- Building a National Clean-Energy Smart Grid, Wired for Progress 2.0
- Directive 2001/77/EC
- Energy infrastructure-priorities for 2020 and beyond-a blueprint for an integrated European network
- Electricity Network Investment and Regulation for a Low Carbon Future, Pollit and Bialek
- Global market outlook for Solar Power 2015-2018
- How does photovoltaic work?, GIL KNIER, www.science.nasa.gov
- How Utility Electrical Distribution Networks can Save Energy in the Smart Grid Era, Michel Clemence, Renzo Coccioni and Alain Glatigny
- Lo scambio sul posto fotovoltaico: guida completa, www.fotovoltaiconorditalia.it
- Micro-inverters from string inverters,www.completesolar.com
- Ministerial Decree February 19, 2007
- Ministerial Decree August 6,2010
- Ministerial Decree May 5, 2011
- Ministerial Decree July 5,2012
- Operation and Maintenance Savings from Advanced Metering Infrastructure-Initial Results from US Department of Energy
- Photovoltaics Report, www.ise.fraunhofer.de
- Progress in PV: Research and Application 2015
- Rapporto Statistico 2014, solare fotovoltaico, www.gse.com
- Smart Grid Economic and Environmental Benefits, a Review and Sinthesis of Research on Smart Grid Benefits and Costs
- Studio Fraunhofer, www.assoelettrica.it
- The Future of Electricity (and Gas) Regulation in a Low-carbon Policy World, Michael Pollit (2008)
- The Future of Electricity (and Gas) Regulation in a Low-carbon Policy World, Michael Pollit (2008)
- The ugly side of solar panels, Low Tech Megazine

SITOGRAPHY

- www.logismarket.it
- www.science.nasa.gov
- www.cleanenergyreviews.info
- www.completesolar.com
- www.ise.fraunhofer.de
- www.solarcellcentral.com
- www.solarbusinesshub.com
- www.gse.com
- www.fotovoltaiconorditalia.it
- www.ecb.europa.eu
- www.investing.com
- www.enerpoint.it
- www.viacavoimpianti.it
- www.Istat.it
- www.consulente-energia.com
- www.assoelettrica.it
- www.genitronsviluppo.com
- smartgridcc.org