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SMART GRIDS, ENERGY PRODUCTION AND PRIVATE INVESTMENTS

A REAL OPTION APPROACH

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SMART GRIDS, ENERGY PRODUCTION AND PRIVATE INVESTMENTS

A Real Option Approach

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Alla mia cocciutaggine
A chi me l’ha trasmessa
A chi la condivide
A chi la sopporta, e un po’ l’apprezza

I

Building the Smart Grid

A literature review

1. Towards a *Smart Grid*

In the last years, a wide development of distributed generation took place, with a relevant role of intermittent energy sources. The development of distributed generation and, in particular, of intermittent energy power plants (mainly wind farms and photovoltaic power plants) determined new critical issues for design and management of the overall energy system and electric grid.

A new issue was raised, stimulated by the new features introduced by distributed generations for electricity systems, but also by the other structural problems that affected local grids, such as inefficiencies, congestion rents, power outages, and line losses (Cook et al., 2012).The issue was the need to make the energy system “smarter”, particularly as regards electric grids (IEA Workshop report, 2011; European JRC Report on Smart Grid, 2012): this is made possible through innovative devices and rules for energy supply and demand, involving power transmission, distribution and consumption. The set of adaptations, both hardware and software, are commonly collected in the general definition of Smart Grids. The adaptations are to be improved on the actual electric network and new designs are to be shaped for markets and new rules to be issued to improve grid reliability and security.

The large number of applications and tools labelled as “Smart Grid” do not allow for a single definition of the topic, but what is relevant for all of them is the common purpose of improving the electric grid from the technical and managerial point of view.

Analyzing the actual condition of the electric grid, and considering its possible future developments towards a *smarter* grid, it relevant to consider some critical aspects that play an important role in evaluating the opportunity of investing in such a complex development program.

In the following paragraphs, a brief description of the main economic, social and policy themes connected to the smart grid evaluation is provided. The initial review paves the way to the second part of the article, which aims at suggesting an economic evaluation approach for investments in the sector. The smart grid goal is in need of an accurate economic evaluation of the effects connected to the implementation of new tools and mechanisms. The method we suggest for the economic evaluation of investments in a Smart Grid scenario is the real option analysis, which can capture both the effect of risk and of new flexibility opportunities in a changing environment, characterized by high levels of uncertainty.

1.1.Distributed generation

At the basis of the Smart Grid “revolution” there is the great development of distributed generation of intermittent energy sources.

Economic evaluation, by now, has mainly focused on the profitability of distributed generation, considering each plant as a single and separate investment, paying only little attention to the impact on the grid and to possibilities for a smart integration.

Distributed power plants economic performance results are deeply influenced by the integration degree with the transmission and distribution grid, since only integration can assure, time to time, a complete use of low-cost energy: technical integration must allow for system coordination and for its automatic adaptation depending on usage and production levels in different system nodes.

Together with technical integration, market integration is needed: priority of dispatching (as for the Italian case) and incentives systems make renewable energy not comparable with the rest of the market, creating disparities among sources that at present are hardly managed by the system and that generate costs to be divided among all agents.

Mitsher and Ruther (2012) analyzed the economic sustainability of small photovoltaic investments and described the role that these plants can have in Brazil, considering them a great resource for the country: in case of lack of energy,these plants can supply energy and avoid grid underperformances. What is relevant to notice from the Smart Grid point of view is that these plants are useful because of the great presence of hydropower generation among Brazilian sources: hydropower and solar power are complementary, and their integration generates a smart compensation for production, limiting increases in rates. Also Sivaraman and Moore (2012), considering the carbon abatement potential of photovoltaic plants, state a use of photovoltaic power at peak and intermediate loads, paving the way to considerations about a smart use of the generation mix depending on the photovoltaic production: in their study, however, the intermittency problem of photovoltaic and its costs are not taken into consideration.

As an early user of intermittent energy sources, Denmark is a good set for studies on distributed power plant, and in particular wind farms. Agnolucci (2007) studied the influence of politics on the development of plants, explaining with the regulatory risk investment trend and underscoring that recent incentive policies will bring turbine renovations. From the regulatory point of view, Mc Laren Loring (2007) deepened the importance of public planning with the participation of local population in the regions of Wales, England and Denmark. An interesting contribution for the integration of wind production – referring particularly to Denmark - is given by Zugno et al. (2012): they give an example of demand response retail market functioning as a Stackelberg game, where we have consumers at the lower level, and a retailer equipped with wind power generation at the upper level. This paper also embodied the concept of consumers' participation, which is particularly relevant for the smart grid to perform successfully.

1.2.A new role for consumers

Distribution and production optimization tools are one important aspect of the Smart Grid structure: on the other hand it is necessary to involve agents on the consumption side.

Electric energy consumers can be industrial, commercial or residential: all of them can play a big role in balancing the grid, in optimizing overall consume and in a more efficient use of energy, by shaping and shifting usage patterns, following the energy variable availability of intermittent energy sources. This service can have a significant role on capacity market, reducing the need for overall power capacity and, as a consequence, its cost. In an uncertain environment the optimal capacity size is higher than the amount needed in a perfect information framework (see de Vries and Heijnen, 2008): adding the "collaboration" of loads to the balancing, we can improve the efficiency of the system.

These goals can be achieved by signaling to the customer grids necessities, and connecting an adequate incentive to the signal to compensate their effort. These techniques are listed under the category of the demand side management, and according to a wide consolidated literature (Gellings, 1985 – among others) we can identify the following strategies:

- "Peak clipping", by shutdown of consumer equipment of with distributed generation inflows;
- "Filling the valleys", encouraging off peak consumption;
- Conservation strategies, by increasing energy efficiency;
- Load building, which means control seasonal energy demand increase for buildings;
- Load shifting, translating consumption from time to time;
- Flexible modeling, by integrating planning between the concessionary and the consumer needs.

Loads can be driven by prices and contracts that optimize grid performances and through real time pricing.

Industrial customers – especially the most energy intensive ones - could heavily impact on distributors optimizing function and moreover, some of them could change their loads pattern by programming industrial processes with different timing. Some of them, indeed, have the possibility to offer availability for disconnections in case of necessities (ARG/elt 212/10), that can be seen as a form of capacity service. Other firms do not have this possibility because they have a constant need for energy: given the good predictability of these industrial loads, the optimization process could be activated *ex ante* (and regulated by contracts).

Residential customers, on the other hand, do not usually have a relevant role in determining the demand, if taken as individual loads, while they do matter if taken as a whole. Private consumption needs are only partially fixed – and the fixed amount depends from the single loads, because elasticity differs from one customer to another.

Consumers' side evaluation seem to be particularly interesting, since consumers, by directly reacting to energy instantaneous prices, may gain advantages from energy savings and smoothing demand peaks (Alcott, 2009; Gans, Alberini and Longo, 2011; Ito 2012). In particular, Gans et al. (2011) produced an interesting study that gives evidences from real market in Ireland, where information on consumption seem to reduce total load by 15-20%.

For this kind of loads, interaction could be realized by trying to empower customers with information on electricity prices, so that they could decide to adapt their electric consumption depending on price signals obtained from the grid.

In this sense, the electricity market could be compared to any other market, where the consumer chooses the quantity to consume basing his/her evaluation on marginal prices.

To do this, it is necessary to implement one of the most important aspects of the "Smart Grid revolution", represented by the high information flow required for its functioning.

While in some cases this information flow is almost automated, the "last mile" for Smart Grids creation calls for an active interaction between end consumers and electric grid. End users shall receive information through the grid regarding the optimal instantaneous consumption, signaling if in that moment the system is burdening a lack or an excess of energy, and consequently deciding whether to adapt their behavior to the grid's request or not. In a market, price is the vehicle for signals.

Price information for domestic electric demand is a long time issue for economists.

Jeong-Shik Shin (1985) argued that the consumer, while evaluating electric energy optimal demand, does not perform a maximization using marginal price, but he/she compares average prices perceived from the electricity bill. This happens contrary to the theory of a well – informed consumer behavior, and this fact is justified by the cost of discovering what the marginal price is for electric energy (i.e. the assumption of perfect information fails). The author considered four relevant points as main causes for lack of information: customers ignorance about price structure (that was, in Shin's case, determined by declining blocks); difficulties connected to marginal price calculation, due to rate structure (over or under estimation in case of switch in marginal blocks); the complicated structures of rate schedules, that do not allow for response to price changes until they are shown on the energy bill; the ex post information of adjustments due to rate schedule shifts.

This study enlightens some typical aspects that have to be considered while trying to induce optimal energy consumption: the electric energy consumer cannot process the price information in the correct way because of informational barriers that make it impossible to directly link it to quantities.

The barriers we could identify while relating electric energy consumption levels and prices are mainly:

- Temporal barriers: often, we are aware of our total expenditure only after we have decided the consumption level; instantaneous expenditure is unaffordable, making it impossible to link energy cost to our decisions on consumption patterns and timing;
- Technical barriers: we simply do not know how much the single electric device is affecting our bill, because we only have an intuitive idea of how much energy it is consuming – to this aspect, learning costs can also be addressed;
- Information costs barrier: even in case of information availability, it is somehow too costly: we do not have the possibility to observe prices in a simple way, since in most cases we do not know how and where to observe them.

From the identified issues, we argue that the consumer needs to improve his/her behavior on the following points:

- Real time information on consumption and price; since the price is connected to grid utilization, forecasts on optimal patterns could be useful to shift consumption;
- Indications on what is worth switching off and turning on later: improvement in energy use depends on my ability to focalize on energy intensive loads;
- Consumer friendly devices for price reading and grid interactions, with a consequent fall in information costs.

These are the main concepts of a Smart Grid applied to consumers’ participation.

If we want customers’ help to optimize the grid’s use, we must drive them through their utility function, and make it possible for them to get closer to its classical maximization.

The big challenge of involving consumers in grid regulation passes through the possibility for the consumer to have real time information of its impact on the grid through consumption measurements and linked prices. Among different tools and devices that can contribute to creating a Smart Grid system, smart meters are on top of the list.

The electricity usage is measured by electric meters, that are commonly installed for every customer of the electric grid: to allow people to take advantage from these devices, we need to make them “smart”.

On the metering operator side, a devices that allows for “readings to be taken frequently enough for the information to be used for network planning” results to be particularly interesting for grid optimization. Loads predictability allows for a reduction in total system capacity and for a better integration of intermittent renewable resources energy production, that is one of the relevant issues of the smart grids paradigm, and smart meters are an important step to gain this result. Cook et al. (2012) tried to quantify the benefits of a smart meter implementation in the United States of America, and they concluded that benefits could be relevant both short-term and long-term.

Investments in this particular Smart Grid device could solve some grid inefficiencies such as congestion, power outages, net losses and energy waste, that causes high prices: a better knowledge of the energy demand allows for better fitting in providing it, reducing capacity needs and losses.

Following the dispositions identified in the “Guidelines for cost benefit analysis of smart metering deployment”, published by the European JRC (2012), a smart meter is an electric meter – digital, not mechanical – that at least allows the following points:

1) On the customer side:

a. Providing readings directly to the customer and any third party designated by the consumer;

b. Updating the readings referred to in the previous point frequently enough to allow the information to be used to achieve energy savings.

2) On the metering operator side:

a. Allowing remote reading of meters by operator;

b. Providing two-way communication between the smart metering system and external networks for maintenance and control of the metering system;

c. Allowing readings to be taken frequently enough for the information to be used for network planning.

3) On the commercial aspects side:

a. Supporting advanced tariff systems;

b. Allowing remote on/off control of the supply and/or flow power limitation.

4) On security and data protection side:

a. Providing secure data communication;

b. Fraud prevention and detection;

5) For distributed generation

a. Providing import and export and reactive energy;

Observing the five sectors pointed out by the European JRC in the report, it is possible to highlight some particularly relevant characteristics that a smart metering system shall have to guarantee to be really defined as “smart”.

On the consumer side, we already noticed (Shin, 1985) how much it is relevant for consumer maximization to have the possibility to know relevant data connected to energy consumption. Smart metering systems empower the consumer with data, and also call for information flows frequently enough to guarantee the possibility of achieving energy savings: this characteristic paves the way to new rate systems, it is possible to apply real time pricing tariffs and to deliver precise price signals to the consumers. This aspect is taken into consideration in the “commercial side” of the smart metering infrastructure.

It is important to have a double communication flow (from the load to the distributor, and vice versa) because only this way we can achieve the interaction that could lead to efficiency and grid optimization: single way communication is not a “smart” communication because one of the parts cannot receive the information instantaneously and react to it.

In 2002, the Italian “Telegestore” project allows for the installation of 32 million automated meters, which guarantee the Distributor remote access to residential consumption data: in this way, the distributor is able to immediately assess the energy demand of the single load and consequently regulate its service.

This project has been registered by the European JRC Report on Smart Grid (2012) as the most important smart meter European installment: Telegestore meters, indeed, do not allow the consumer to read information on price and react to distributors signals, so they still neglect one of the most important conditions for a “smart” metering system.

An example of two way communication deployment is the project that Enel Distribution company presented a boosting scheme for the AEEGSI (“Autorità per l’Energia Elettrica, il Gas natural e il Sistema Idrico”, Italian national Authority for electric energy, natural gas and water supply services). The scheme includes the supplying of a demand response tool for 8.000 customers in the town of Isernia, where the project is in motion. Demand response was not a mandatory field of the AEEGSI call for tender, but it was mentioned among possible optional interventions: in this way, the distribution society created the possibility to evaluate the introduction of real time pricing information for a set of customers in the pilot program framework.

In conclusion, interactions among consumers have also been analyzed. An example of analysis in this particular field is given by choosing a multi-agents storage system framework (Vytelingum et al., 2010) that showed that agents reduce peak demand through the Nash equilibrium.

1.3.Challenges and policy issues

Singh (2012) noticed how the Enel Telegestore project advantages are mostly due to the utility in terms of non-technical losses, automated meter reading and remote disconnection, while it is not clear when and how the consumer will start to benefit from the new infrastructure.

We have to carefully manage different market powers, since the development of smart metering systems and real time pricing could lead to different cost and benefits shares, depending on the business model (Tahon et al., 2012). Actually, we have to consider that the distributor could optimize the management of the grid by reducing the service: balancing the grid by remotely limiting consumers' loads allows for less costs from the distributor side, but it increases costs for the consumers, in terms of adaptation. It is true that distributor/aggregator shall offer some kind of remunerations for load shifting service, but the consumer does not have the real possibility to control how much he/she is contributing to grid balancing, and there is no control on the distributor's costs. In this way the distributor can offer a limited remuneration, moreover, it can penalize who does not accept this condition (with high on peak prices – and the consumer cannot monitor the price, presently). Remote control seems to not be so convenient for consumers, unless the regulator react and decide for a more effective benefits sharing.

Moreover, the great amount of real time data collected by the smart meters gives – potentially, at least - the possibility to create heavily different rates depending on the time of electric energy consumption. This possibility can be an advantage for some customers, but it is particularly critical for those loads characterized by a rigid demand, that cannot react to the price signal: this poses equality problems on a fundamental service.

The high exchange of information in the Smart Grids raises many problems for practical appliances, since it may generate legal problems related to the preservation of individual privacy (Mohesenian-Rad et Al., 2010; McKenna, 2011), that might be overcome thanks to common regulation implemented on ICT market. Also, Mohesenian-Rad et al. (2010) show that, by applying a game theory approach, a group of customers could adopt the best strategy for loads as a Nash equilibrium, having cost minimization as a target. Playing the game, data are visible to the supplier only on an aggregate base, so the privacy issue no longer exists. Anyway, this aspect shall not be underestimated, because since information on consumption is substantial information, people may not agree to share it even in case of economic price advantages: loss of consent in this segment of the Smart Grid could impede its successful development.

Data collection and their delivery on time are the pillar of the Smart Grid development, but this informations to be considered in view ofthe privacy issue and also ofthe security issue, to which point 4 of the JRC list is totally dedicated. The huge amount of data that has to be exchanged and elaborated must be delivered in a reliable way: technical problems or external hacker attacks could not only dissolve programming benefits, but also cause great damage, both technical and economic. As regards the private load sector, technical damages could definitely be realized by directly manipulating data aggregation and disturbing prediction on loads, but perhaps the greatest danger can be caused by hackering on prices.

Slightly manipulating price signals – remaining in a cautious interval of variation - it is possible to affect at first the commercial aspect of the system, disturbing rate calibration and causing loss in profits (for the distributors) or in consumers' utility.

Intense manipulations of data, on the other hand, can drive the system to dangerous dysfunction and black outs, causing high economic and technical damages to the grid, but also social and political issues: the great part of the devices we use (and need) in everyday life rely on electric energy.

1.4. Summarizing

It is impossible to ignore that the implementation of Smart Grid tools will introduce a new and more relevant role of information – that from an economic point of view is one of the most interesting and influencing theme in balancing agents relationships: in absence of a proper regulation, those who are "obliged" to reveal their preferences (i.e. consumption or production pattern) are exposed to disadvantages.

The implementation of a smart metering system increments the predictability power of operators and allows for grid optimization. Distributors, the agents that dialogue directly with consumers, can better manage their loads, both interacting with the transmission system operator and the consumers: in this way they reduce grid losses, they optimize energy use by shifting loads and signaling – through prices - when to consume.

Consumers are directly involved in grid optimization, and by responding to different prices they can save money, while consuming the same amount of energy; moreover, by simply knowing how much they are consuming, they could adopt virtuous behaviors, that can be modified in a peer effect context.

On the consumer side, indeed, the impact of new devices for consumption regulation opens more views and possibilities. First, the good (electric energy) is not exactly the same good if consumed in different hours of the day: it can be more or less needed (different elasticities in different time of the day), and price variations can have different effects if performed in different time ranges.

Electric energy is not only perceived as different in different times because of individual needs, but it is also substantially different because it is produced by different energy sources: can we really consider a photovoltaic kWh exactly equal to a thermoelectric kWh? Increasing environmental awareness of consumers makes these “products” different, because there are energy mix preferences. A Smart Grid system could help to fit consumer preferences and modulate the price in a more efficient way.

Then, for the electric system, energy production often has a different impact depending on the sources’ characteristic: kWhs we consume along the day and that come from different sources are really different, because distributed power plants are not fully integrated in the system, they are costly and treated in a special way. Smart Grid system will allow for their integration both from a technical and an economical point of view.

Also, Smart Grid has critical problems to be handled:

- Market power regulation, since the actual framework will be unbalanced with the introduction of Smart Grid tools;
- Redistribution issues, since some agents will have to bear more cost deriving from the Smart Grid implementation (consumers with rigid demand)
- Privacy issues and public consent, meaning that regulation shall guarantee secure treatment data, using them as an aggregate and setting clear rules on property. Then, good communication on Smart Grid themes must be delivered, avoiding people to be against them without proper knowledge on the issue.

Throughout different studies and research fields, regulation seems to be the right answer at different stages and for different issues (market power and data treatment above all - see also “The Smart Grid, entry, and imperfect competition in electricity markets”, Alcott, 2012), but it must be sustained by an economic evaluation.

It is hard to cover all the different research field connected to the development of the Smart Grid, but if we want to succeed in finding applicable conclusions in one of the different topics, it is essential to be aware of the assumptions and limits that characterize the specific field we are analyzing. A more mature research experience on this topic shall lead to a coordinated vision of the Smart Grid environment.

Although, looking at technical aspects and the related research, the implementation of Smart Grid technology seems to be feasible, at present we are still in a deployment phase of the technology. Smart Grid development seem to be slow in coming: this is mainly due to some persistent uncertainty on the technological side, but also on the investment side, where the development is likely to stall in absence of a proper economic and financial analysis.

To guarantee energy system sustainability and reliability, Smart Grids seem to be definitely needed, but in a context of limited financial resources and high uncertainty, investment boosting seems to be unavoidable: the question is how to reach this target in a sustainable way.

Economic evaluation of private investments could be an effective guide for incentive schemes and regulation frameworks, since only with an in-depth analysis of investors' utility can we know how they will react to regulatory inputs.

Strong interest for economists derives from the fact that there is an opportunity for increases in efficiency. What is necessary to analyze from an economic point of view are all the potentials of the Smart Grid in terms of value creation and destruction, and the overall distribution of costs and benefits among the agents. This analysis seems to be particularly complex and must be run at various levels and from different points of view.

It is necessary to evaluate costs and benefits, but these depend on the choices made on technology: looking at Smart Grid applications, it is important to recognize that some investments are alternative while other are complementary, and different strategies could have different performances depending on the environment in which they are set. The cost benefit analysis of the system shall be conducted on different scenarios and shall guide the long-term investment strategy.

After having shaped the system objectives and possible strategies, it is necessary to identify the agents that gain benefits from the Smart Grid paradigm and those who have to bear costs from this implementation. This analysis must consider different market power owned by agents, since some of them are empowered with the possibility to shift investment costs on other agents or, symmetrically, jeopardize benefits by taking advantage of their position.

After having understood the framework, it could also be possible to find out who shall invest on Smart Grid: looking at different cost and benefit sharing and different market power, it could emerge that some agents have an interest on the realization of investments and could pay for having a Smart Grid, but they are not empowered to produce them and, even in case of realization, there are no possibilities to keep the rent deriving from them. Others have the possibility to invest, but they have no interest in doing so: it is the case of agents that can transfer inefficiency cost to other market agents. In other cases, there is an investment that creates value, but, since it is developed on the basis of private utility functions, given the current regulations it is not fully exploiting the potential of the Smart Grid (see Shin 2012) on Italian smart metering infrastructure).

These complex set of analysis will lead to a redefinition of market rules and regulatory tools (i.e. incentives, taxation, price regulation…) aiming at reaching a general efficiency target.

2. Evaluating investments in Smart Grid

In a period of great enthusiasm for the topic, the concept of “smartness” is often confused with the concept of simple improvements in grid efficiency. By investing in Smart Grid, we will improve the efficiency of the system too – and with a good potential – but not all efficiency improvements can be addressed as “Smart Grid” measures. To guide the analysis, we can identify Smart Grid measures thinking about the difference between “inertial” investments, meaning with this definition all that can be done to renovate the system in the actual framework, and “dynamic” investments, that, if put in place, will allow for new function of the system.

As an example, we can consider inverter substitution in a photovoltaic plant: we could decide to substitute the inverter with a new one because we can have a gain in its efficiency and better performances – but if the new inverter is a “traditional” inverter, we cannot say we are investing for Smart Grids. If the new inverter is a “smart inverter”, then, we are doing something more, acting not only on system obsolescence, but also allowing for new improvements in its functioning.

Moreover, while evaluating these “smart investment” we shall put them in the right framework, where all their functionalities can be fully used: investments for Smart Grid need to be coordinated in the whole system since their value sensibly changes depending on the context in which they are placed.

Henriot (2013) looks at the investment needed by the European transmission grid in the next two decades based on what was stated by the European Commission together with the European TSOs. Investments aim at integrating renewables and guaranteeing grid reliability – objectives that could be addressed for the creation of a smarter European grid. During his evaluation, the author considers a cost plus system to remunerate investments and reasonable conditions for debt collection, keeping as a boundary the maintenance of a good rating level for the TSOs. Given the current financial situation and considering the historical trends of rates, Henriot concludes that investment objectives would not be met without an increase in rates paid by customers.

This analysis can be interesting because it states some of the problems we find in grid investment evaluation.

First, the study aggregates all the European TSOs, creating a single operator, and considers all the investment designed by them. This assumption could be coherent with the tendency of considering Europe as a single market with a single system, but looking at all the investments as a whole we cannot have a proper evaluation of single initiatives: different lots have different ex ante efficiency degrees, and the value of new investments changes significantly from one area to another. Grid investment evaluation meets a certain difficulty, that derives from the nature of the object of our analysis itself: the Smart Grid involves all the stages of electricity production, distribution and consumption. During the evaluation, we have to keep in mind the overall performance of the system, but without forgetting the principle that we must find the remuneration of the investment seen as a single step.

Secondly, an investment on the grid can have different values for each agent connected to it: given the fact that, in the analyzed framework, investment decisions are set by the European Commission together with the European TSOs association, it is reasonable to assume that the decisions are heavily biased by agents involvement. Moreover, we cannot control internal cost of the TSOs, and a cost plus remuneration is not a good incentive to invest in an efficient way. In Henriot’s study, it is assumed that investments shall be made by the TSOs, but we do not know if it is the right solution: it can be a starting point for new analysis, keeping in mind that the same results could be reached with different people investing in the same program or in a different one.

Finally, transferring all costs to the costumer is not a smart solution, not only because it will generate public protests, but mainly because this solution seems to reflect traditional system’s rule, that does not fully exploit new possibilities given or that will be given by a Smart Grid system, including all costs and benefits generated by new investment opportunities and their sharing among agents.

Summing up, while evaluating investments in electric grid it is almost essential to assess them in a dynamic context, that is supposed to move towards different market structure, government regulation and agents participation; in other words, it is no longer possible to evaluate these kind of investments outside of the Smart Grid view.

Evaluating these investments is challenging, both because of the presence of the network effect of each intervention and because of the possibility to develop different network structures. A careful analysis of the single investment opportunity is necessary, and it shall be completed by an integration of the single investment in the system, also applying scenarios conditions given by the environment.

2.1.Choice of the method: Real Option Analysis

The first step for a reliable evaluation is a careful context analysis, to identify possible variables influencing our investment and possible events occurring during its development. The evaluation model shall include those elements considered relevant to determine investment value, after having set a clear panel of assumptions.

This preliminary approach to the investment – that could appear quite intuitive – is often underestimated. Practitioners mostly apply traditional evaluation methods because they are widely recognized and trusted; academics have to deal with the risk of making experiments and keeping them too far from real applications: this attitude strongly contributes to maintaining the separation between the two approaches – whilst damaging both.

Analyzing Smart Grid application and framework, it is possible to find out that flexibility is one of the main characteristic of the future energy system: real time pricing, dynamic managing of assets, different possible policies, agents interaction and customers empowerment create an environment where flexibility values really matter. Given this evidence, it is necessary to choose a proper methodology to conduct the evaluation process.

Real Option method has been added (Dixit and Pindyck, 1994) to well-known traditional methods, such as NPV and Monte Carlo simulations, , borrowing techniques from the financial investment evaluation to overcome some limits of the real ones.

In particular, while evaluating the investment we want to incorporate in its value both the uncertainty that affects the cash flows and the possibility for the investor to be flexible and react to different states of nature, obtaining upside for the investment value (Yeo and Qiu, 2003).

Real option analysis founds its natural application in those fields in which flexibility opportunities are present: this evaluation method detects an extra value for the investment – not identified by the simple NPV evaluation – when options and flexibility opportunities do exist. Otherwise, the option value is equal to zero and there is no difference between traditional methodologies and real option analysis.

Real option analysis has been recently used to evaluate investment in energy field, where we often have to deal with a high level of uncertainty, particularly when choosing strategies for development of new energy technologies (Siddiqui and Fleten, 2010) and taking decisions in energy production, when option value is generated both from the technical side (Stokes et al., 2008; Di Corato and Moretto, 2011) and from the regulatory framework (Monjas-Barroso and Balibrea-Iniesta, 2013): Martìnez Ceseña et al. (2013) provide for an interesting review of real option analysis in electricity generation process.

After having reviewed the main characteristics of the Smart Grid, we understood that one of the most relevant improvements with respect to the previous electricity network is the possibility to manage it in a more flexible way. This new value for flexibility must be captured in investment evaluation: real option analysis shall be the way to achieve this.

Looking at the literature, indeed, we noticed that real option analysis is mostly concentrated on the production side, and only marginally explored in other stages of the system, such as transmission, distribution and consumption, and this is also proved by the study of Fernandes et al. (2011). This is probably due to the fact that, by now, private investment can easily be put in place if referred to traditional production plants and, with the recent growth of renewable generation market, to distributed production plants: we could state that there is a stronger “demand” for this sort of evaluation.

However, with the development of new tools that allow for the consumer’s participation in the management of the electric system, it is reasonable to expect a development for real option analysis also for consumption models, since it will be influenced by new technological potentials. An important extension of the consumer’s view, has been provided by the possibility to be a consumer and a producer at the same time, becoming the so called *prosumer*, that embodies the change in relationships between agents of the electric system, and whose economic role shall be deepened in further researches.

Moreover, investment on the transmission and distribution networks, aiming at the Smart Grid, will require a careful analysis since they are irreversible, they have a long duration and are characterized by high levels of uncertainty, deriving from the variability both in production and in consumption that influenced the service.

2.2.The option of having options

When considering the electric system and investments in Smart Grid, it is often difficult to say if we are looking at investments in Smart Grid or in a Smart Grid framework. The difference seems little, but it is relevant: the risk is that we keep looking beyond Smart Grid implementation without considering how to invest in its development.

As an example, if we look at the *prosumer* level, we can recognize that it will be possible for this agent to invest in power generation with the higher value deriving from the option to switch its behavior between self-consumption and electricity grid selling, depending on the electricity price. If we considered a market for ancillary services (i.e. those technical services needed for grid balancing), the *prosumer* could also take into account their remuneration in consumption/production decisions. Moreover, changing the configuration of the market and imagining the *prosumer* in a micro grid, the agent could also decide to switch markets, selling electricity both in the micro grid and in the main one, depending on differences in electricity prices in the two environments. In some cases, storage could also be a solution to enhance flexibility and investment value.

These possibilities are typical of a Smart Grid framework, and relevant for the investment decision: for the evaluation, we are imagining being in a Smart Grid, but to actually create it for real we need somebody to activate it and choose among different development alternatives.

From the investor’s point of view, the value of the investment will be different depending on the Smart Grid scenario developed for the system: what is really needed for the activation of the investment is a Regulator.

The Regulator shall set the rules and the policies to develop the scenario that maximizes overall system surplus: to do this, it is essential for the Regulator to know how the agents will react to the new framework, and that is why it is necessary first to analyze all possible operations and investments at different stages. After having discussed possible implementation and their implications for the agents, the Regulator has the possibility to aggregate them in a network context, choosing the best strategy and setting clear and stable rules to create it (see also Monjas-Barroso and Balibrea-Iniesta, 2013).

In this sense, the Smart Grid value can be seen as the sum of the values it generates all along the electric system: costs and benefits are distributed among the operators and the agents at different stages, and only the integrated vision can move investments in this field.

Moreover, the Smart Grids embedded more value than the simple sum of single investment values: this is not only connected to the effect within the electric system, but also to a more general management of an integrated energy system. Having a Smart Grid system means the possibility to make decisions on future investment strategies, since by making the electric grid more efficient and flexible, we reduce the need for new power, and we have the option to postpone investment in generation –this refers not only to electricity generation, but also to different sources of energy. Given the high technological risk of this field and the uncertainty in future sources, this aspect is crucial, and shall not be underestimated.

3. Conclusion

Energy in all its forms plays an essential role in many fields: its management is critical not only for efficiency reasons, but also to guarantee continuity and safeness of other human activities.

Facing new challenges of energy supply pushed the governments and the market agents to look for new ways to produce, manage and consume it.

In particular, electric energy management states some peculiar criticalities given by the fact that supply and demand need to be balanced real time, while respecting technical parameters. Electric energy is difficult and costly store, many agents are involved in the grid, and all this generates a great role for forecasts and information.

In recent years, the electric grid has been deeply investigated by different researches from different points of view, that all share the target of making the grid more efficient, reliable, adaptable to different necessities and capable to respond to new challenges: we can gather all these studies in a set of works aiming at realizing the so-called Smart Grid. Since different disciplines are involved, and many tools for the Smart Grid are required, we still do not have a unique definition for this system, but we can identify some fundamental elements to recognize it.

The Smart Grid will be an active grid, characterized by a huge number of information delivered real time and a high participation of customers in its balancing and management. This new configuration of the grid will help to manage our resources, in a context of great uncertainty in traditional energy sources and considering the difficult integration of distributed generation, mostly provided by intermittent sources. The need for a new paradigm is, on the one hand, unavoidable, since the actual transmission and distribution system is no longer suitable for the new generation system. On the other hand, there are important efficiency issues – fundamental in a framework of constrained resources - that could be solved thanks to the adaptation of the grid, also involving the consumers in the overall management of the system.

To define, circumscribe and evaluate the Smart Grid is particularly challenging, given the number of interactions between different levels and fields it implies: it is necessary to identify regulatory issues and possible distortions on energy markets, since adaptations towards a Smart Grid are both hardware and software, and these shall imply new rules for electricity markets to balance different market forces, that rise particularly from the role of the consumer in grid management. Huge information and data exchange, that paves the way to the possibility for the consumer to respond to grid’s inputs (i.e. basically, price signals), calls for economic studies aiming at quantifying consumer’s value in participating to a Smart Grid and “playing” as an active agent for grid management: consumer’s value, however, is strictly connected to its market power, since other agents can jeopardize all the gain in responding to prices. An evaluation of profits and losses for the agents in the system seems to be critical, since it allows for a grid design to delivery an overall improvement.

Private investment evaluation in a Smart Grid environment seems to also be particularly interesting, since Smart Grid could significantly modify energy investment management, extending flexibility opportunities connected to power plant operational phase. Flexibilities can enhance investment value and modify private agent’s investment decisions, and that is why it is important to introduce in the evaluation model proper instruments to capture them and quantify private values generated by the Smart Grid framework.

Agents interactions, profits and losses connected at a global level to the Smart Grid system are undoubtedly relevant for the Regulator acting as a public agent in the energy field: only with a deep understanding of the agents’ interests in the system, and with a clear view on possible externalities landscape, can the Regulator adopt the best strategies in managing the whole system.

Evaluation, both at private and at public level, is therefore a critical aspect for the Smart Grid future development phase, and, aiming at reaching a high level of investment value awareness, it cannot forget Smart Grid peculiarities: evaluation instruments and procedures must be strictly bound to real application mechanisms and technical issues.

Real option analysis seems to be particularly performing in such an environment, since it is able to capture the value of flexibilities in the presence of high levels of uncertainty and dynamism: both on the private and the public side many scenarios must be taken into account while deciding investments in the sector, and the choice of the method appears to be a critical factor for success.

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II

The Italian electric system

A survey

1. Introduction

Growing concern about GHG[1] emissions and future availability of traditional energy sources motivated several countries to promote renewable energy distributed generation: this measure has been carried out in different ways by national governments, with remarkable impacts on present electric systems.

In Italy, the last decade was characterized by a large development of distributed generation power plants, and particularly biomass and photovoltaic power plants: private investments in these sectors have been facilitated and boosted through incentives, which made them particularly attractive for institutional, large and small investors. Other investments in main renewable energy sources (hydropower generation and wind generation) have also been encouraged and boosted, but they do not seem easy to handle for small investors: this is a consequence of some relevant investment characteristics, and particularly of dimension and location boundaries, that made them less developed by residential investors. Hydro-power generation history is long, since it provides for stable flows of energy, with a nearly guaranteed return that made it financially convenient: institutional large operator acting as monopolist chose them in the past. Nowadays, revamping process of big hydro-power plant is connected to a specific license that makes the market more rigid; “micro” and “mini” hydro-power generation could be a good sector for private investors, because investments opportunities are many and smaller in size, with highly predictable cash flows: difficulties in finding a proper location and environmental boundaries could limit the market, but for a satisfactory analysis of these markets we shall wait for the effects of D.M. July 6th, 2012[2]. Investments in wind farm have similar limitations: investments’ size could be affordable by a number of operators, but finding a place where to install wind turbines is not easy in Italy, where only part of the national territory owns proper environmental characteristics to make the investment profitable[3], and often it is not available because of landscape and environment safeguard necessities.

Looking at biomasses and photovoltaic, on the other hand, we find a lively market at different levels: both the technology, finding a building location is relatively easy, and the investment size can be adjusted to different investor typology. Private participation to small and diffused production energy market have been heavily boosted with monetary incentives, and especially for the photovoltaic sector, which took advantage of high feed in tariff remuneration. On one hand, these

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[1] Green-house gases. GHG are gases that have an impact on global warming: CO_2, CH_4, N_2O, SF_6, HFC_5, PFC_5 are covered by the international decree on global warming known as “Kyoto Protocol” (Bosetti, Paltsev, Reilly and Carraro, 2012).

[2] D.M. July 6th, 2012 established the new boosting schemes for smaller sizes of hydropower plants.

[3] See “GSE - Atlante eolico Italiano - Interactive Wind Atlas - http://atlanteeolico.rse-web.it/viewer.htm”

incentives allowed for developing photovoltaic technology faster, guaranteeing payoffs for huge initial investments; on the other hand, incentives caused an increase in public costs, regarding both monetary disbursement to pay guaranteed tariffs and electric system costs connected to the management of a number of energy sources not efficiently integrated.

Photovoltaic plants, actually, have a relevant responsibility for grid costs: in 2012, the installed photovoltaic capacity reached a power amount of more than 16,4 GW, split into 478.331 different plant, with an increase in power of 28,5% with respect to 2011 (GSE, 2013). The other not dispatching energy source - wind - provides for less than half of photovoltaic power capacity (8,1 GW) in 807 plants.

High penetration of photovoltaic technology, total installed power and its fragmented distribution into several power plants have a considerable impact on the electric system, especially in terms of management costs. Provided that the grid was not designed to support peripheral inflows, and especially those instable coming from unpredictable production, photovoltaic production forced the system to sustain new costs, derived from the need of new predictions on production, loads and overall balancing.

Despite the increasing system costs, it is undeniable that photovoltaic and other renewable sources shall have a considerable role in future energy supply, which calls for "green" energy sources: it is now necessary to find out how to allow the development of these sources for energy production in a sustainable way from the system point of view. This objective can be reached by implementing tools and mechanisms forming the so called Smart Grid.

The Smart Grid environment will allow important improvements in grid management, such as self-healing mechanisms, instantaneous information on grid status, decentralized control, instantaneous interaction between the agents connected to the grid and the grid itself; depending on its "needs", the grid could send signals to the agents, and the agents will have the possibility to respond to the signals, changing the load path or supplying ancillary services. In this way, the system can allow a better integration of renewables - which collaborate in keeping the grid stable - and work for their development without costly monetary incentives: by having the possibility to gain revenues by helping grid management, the investor could find the investment profitable even in absence of further incentives.

Analyzing the agents’ perspective and reactions in a possible future Smart Grid environment is a fundamental step in detecting the effects that the new system could have on private investments in the distributed generation sector, and, implicitly, in going towards the definition of the Smart Grid value.

The target of this work is to provide a glimpse of the Italian electric system and of its market, in order to pave the way to the analysis of possible Smart Grid's scenarios for the Italian case, with a specific focus on possible integration strategies for photovoltaic production.

In the following analysis we briefly describe the Italian electric system, indicating the main agents operating in it and involved in its functioning: from energy production to transmission, and from transmission to the distribution system, towards energy final consumption. We particularly underline the photovoltaic contribution to electricity production and its impact on the system, being the solar source interesting for the Italian market, since it is widely developed, productive, although badly integrated. We recall structures and mechanisms of the Italian electricity market, pointing out which agents are involved in the balancing activity, that is one of the most critical aspects in renewable integration. We describe relevant prices in the market, such as the Prezzo Unico Nazionale – PUN (the unique price for the national Italian territory) and the zonal prices that we can find at local levels.

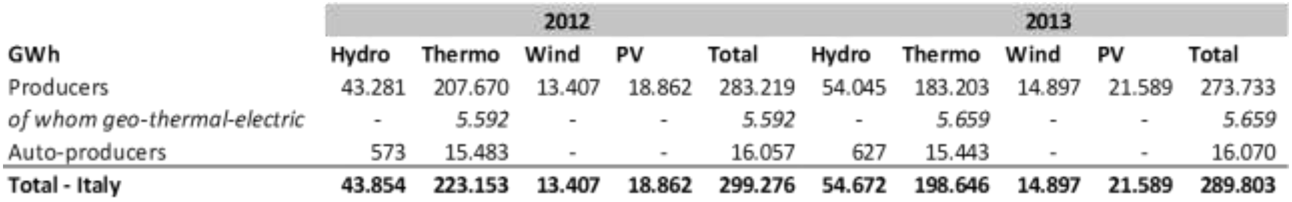
2. The Italian electric system

The electric system is the sum of physical infrastructures and coordinated phases that allow us for using electricity in everyday activities; it can be divided into three main areas: production, transmission and distribution (Terna, 2014).

2.1. Production

In Italy, electric energy production is a liberalized activity, carried out by pure producers and by auto-producers.

According to Terna[4], the Italian electric energy production amounted to 289.803 GWh in 2013: 13.407 GWh generated by wind farms, 18.862 GWh by photovoltaic power plants, 43.854 GWh by hydro power plants, and 223.153 GWh generated by thermoelectric power plants (of whom 5.592 from geothermal plants).



	2012					2013				
GWh	**Hydro**	**Thermo**	**Wind**	**PV**	**Total**	**Hydro**	**Thermo**	**Wind**	**PV**	**Total**
Producers	43.281	207.670	13.407	18.862	283.219	54.045	183.203	14.897	21.589	273.733
of whom geo-thermal-electric	-	*5.592*	-	-	*5.592*	-	*5.659*	-	-	*5.659*
Auto-producers	573	15.483	-	-	16.057	627	15.443	-	-	16.070
Total - Italy	**43.854**	**223.153**	**13.407**	**18.862**	**299.276**	**54.672**	**198.646**	**14.897**	**21.589**	**289.803**

Table 1 - Electric energy generation in Italy, sorted by source, year 2012 - 2013 (Terna, 2014).

Thermo-electric generation covers the largest production quota, but between 2012 and 2013 it is the only energy source that decreased its production, both in absolute terms (from 223.153 GWh to 198.646 GWh) and in percentages over the total production (from 74,6% to 68,5%), while other sources increased their contribution. In 2013, hydro-electric production represented nearly the 20% of overall production, wind farms contributed for 5,1% and photovoltaic power plants for 7,4%.

	2012	**2013**
Hydro	14,7%	18,9%
Thermo	74,6%	68,5%
Wind	4,5%	5,1%
PV	6,3%	7,4%

Table 2 - Electric energy generation in Italy (%), sorted by source, year 2012 - 2013 (Terna, 2014).

Total production decreased by 3% between 2012 and 2013: the production from hydro increased by 25%, wind production by 11% and photovoltaic production by 14%, while thermoelectric production complexly decreases by 12% (thermoelectric production by geothermal source slightly increased its contribution).

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[4] See paragraph 2.1.2

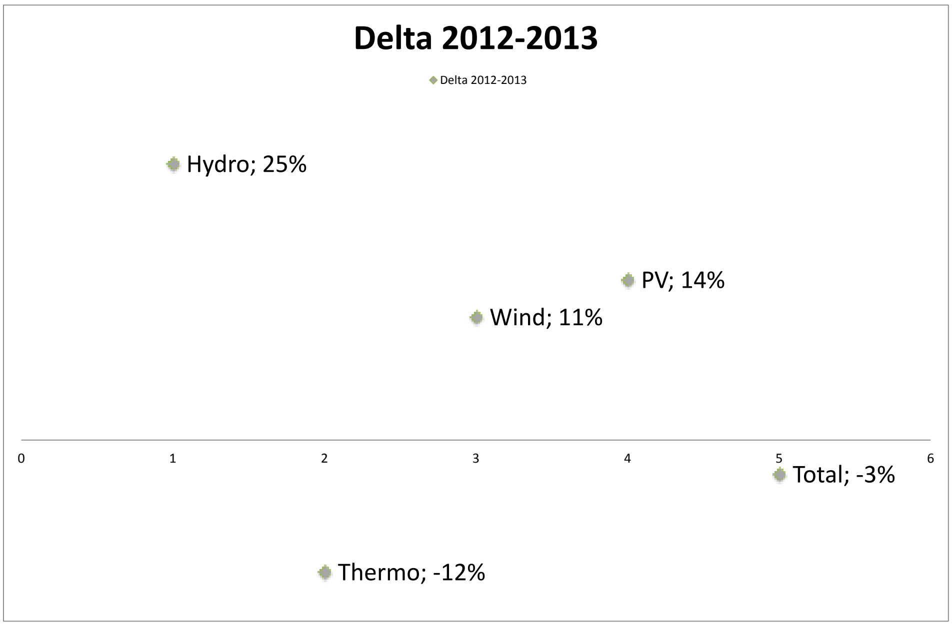

Figure 1 – Differences in electric production between 2012 and 2013in Italy, sorted by source (%);(data provided by Terna, 2014).

Some producers are classified as producers, other as auto-producers: a producer is defined as "auto-producer" when at least the 70% of the energy produced by the plant is directly used by the owner, being the owner a single person, a firm or other recognized entities (GSE, 2014).

Auto-producers in 2013 represented the 7,8% in the thermoelectric sector, about 1% of hydro-electric sector, while there were no auto-producers in wind and solar generation. This can be explained with high incentives dedicated to the renewable production, that make more convenient to sell energy to the grid rather than auto-consume it.

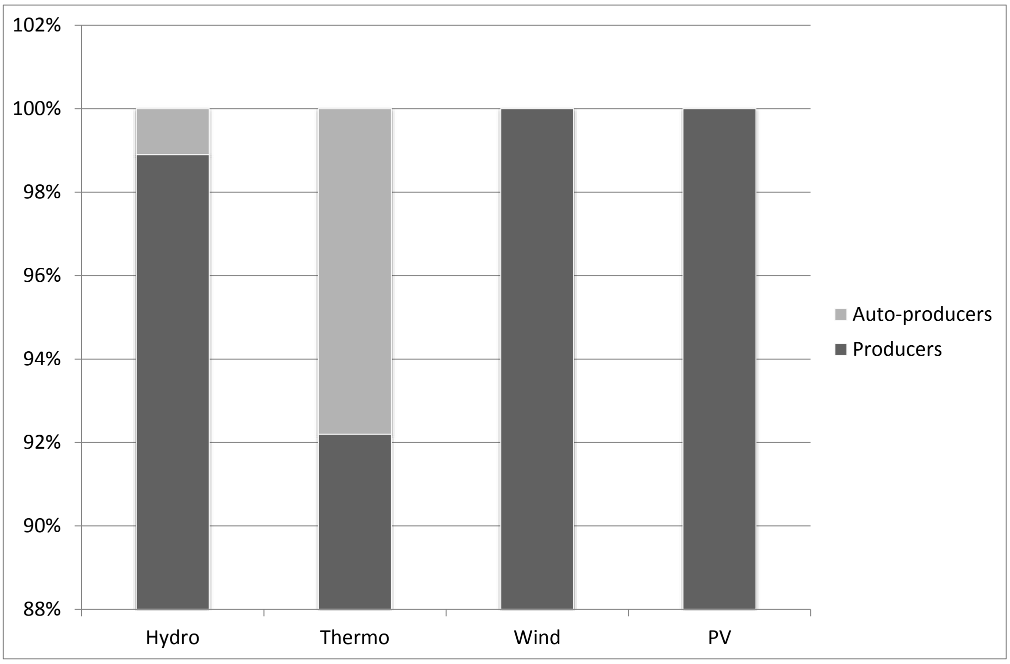

Figure 2: producers and auto-producers percentages, sorted by source; (data provided by Terna, 2014).

2.2. Renewable production

As mentioned in the introduction of this work, in the latest years the electric energy production from renewable sources has strongly increased its contribution to the overall Italian production.

Hydropower holds a great quota of electric energy production: looking at the GWh production between 2006 and 2013, it is clear that the hydro source is the major renewable contributor to energy supply.

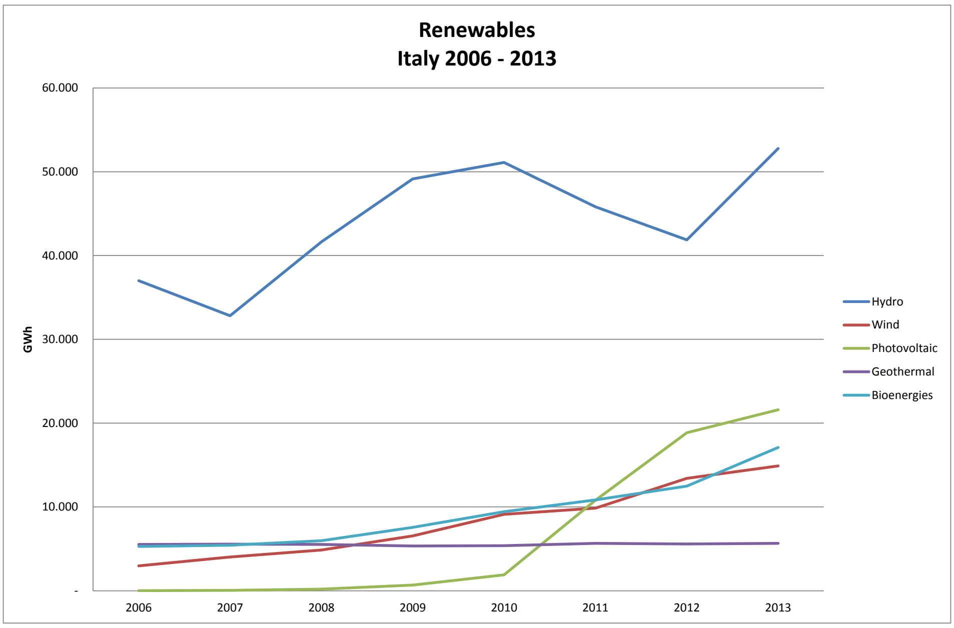

Figure 3: Renewables energy production, 2006-2013 data (Terna, 2014)

The photovoltaic production, actually, strongly reacted to incentives schemes issued by Italian government, reaching in 2012 the second position of the renewable sources. National decrees for the execution of the first “Conto Energia” were issued between 2005 and 2006, after the European Directive 77/2001, and it started the development of photovoltaic investments in Italy; the second “Conto Energia” started in 2007, and was supposed to end on December 2010, but its tariffs were applied until June 2011 thanks to the so called “Salva Alcoa” decree (l. 129, August 13th, 2010): this disposal was particularly successful, especially in its last phase, when it is possible to recognize a huge increase in photovoltaic energy production. The subsequent decrees (third and fourth “Conto Energia”) had shorter duration and started the decrease of the incentives; at the moment, the fifth “Conto Energia” will be in force until the maximum expenditure of 6,7 billion € per year for incentives is reached (GSE, 2014).

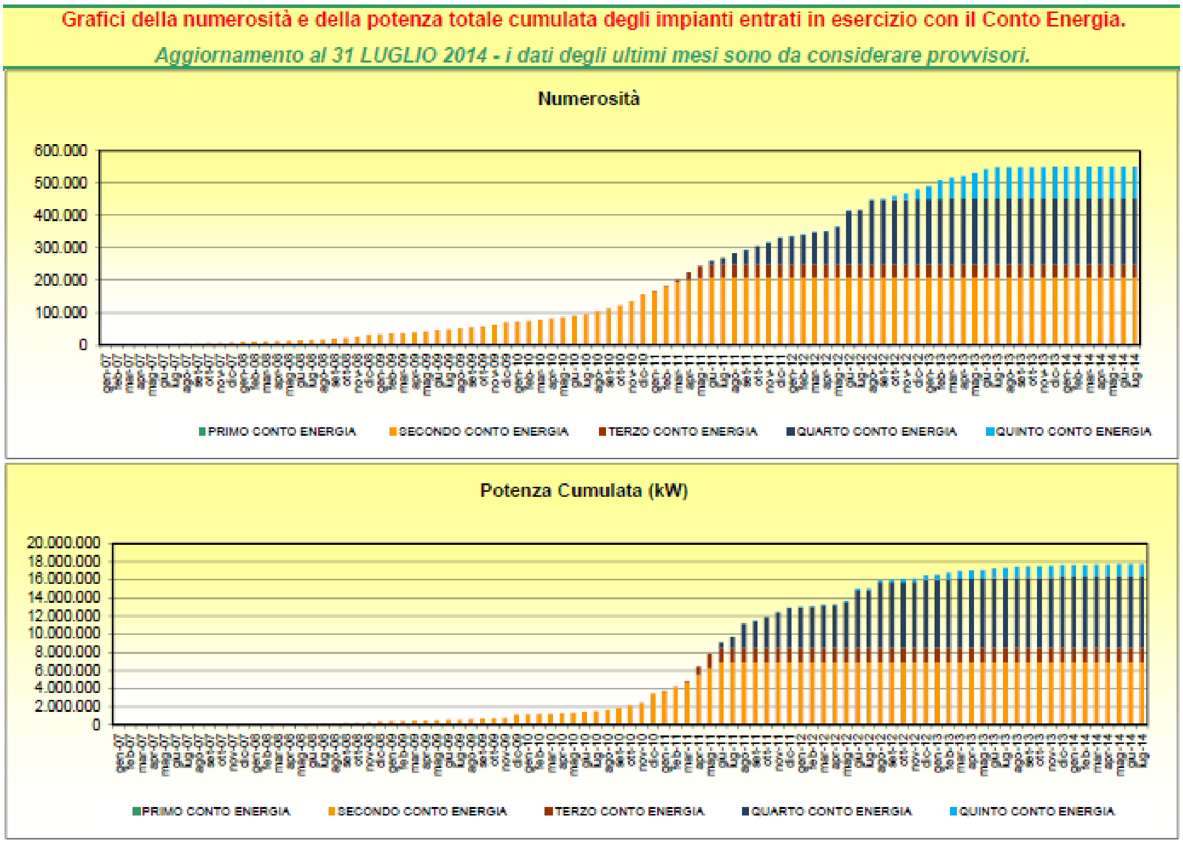

Figure 4: number and power of photovoltaic plant, sorted by Conto Energia (GSE, 2014)

What is relevant, indeed, is the “shock” suffered by the grid due to this great increase: the graph represents the percentage increase of photovoltaic and wind production - with respect to the preceding year – between 2007 and 2013.

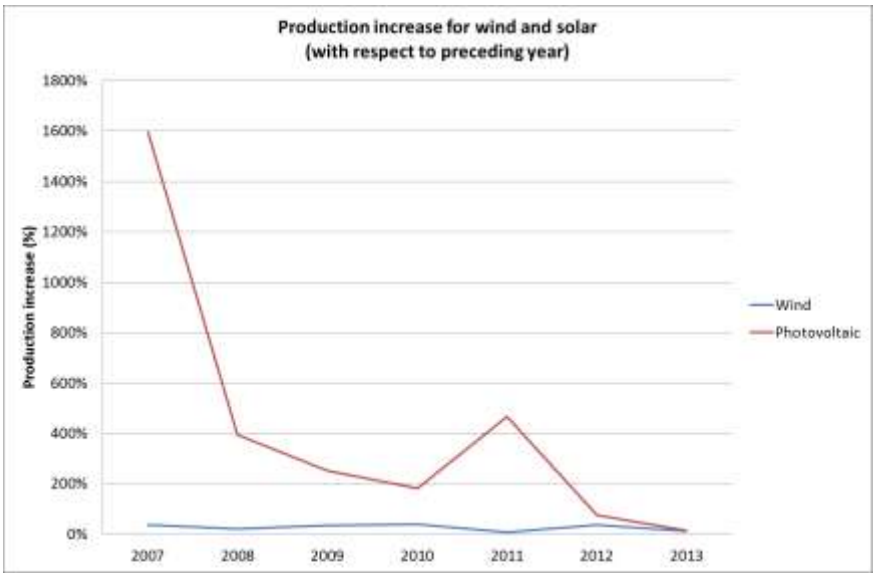

Figure 5: Renewable non-dispatching energy production, percentage increases between 2007 and 2013 (Terna, 2014)

According to the AEEGSI[5] (281/2012/R/efr decree, July 5th, 2012), intermittent and not-dispatching production is mainly represented by wind production, connected to the high voltage network, while photovoltaic production is connected to the low voltage network: these two sources mainly originated the need for a Smart Grid.

We consider wind and solar sources, since their productions are unpredictable and highly fluctuating: as a consequence, their impact on managing the grid and on the instantaneous balancing between production and loads is much higher with respect to other productions. Photovoltaic production, in particular, is affected by weather conditions and it suffers not only from seasonality, but also from an hourly variation that can be really large in presence of clouds or other temporary obstacles to solar radiations.

As reported by Terna data on historical production, wind production remained quite stable, even if production trend is slightly positive during the time interval. As pointed out in the introduction to the work, photovoltaic highly increased its presence in the production: in 2006 only 2,3 GWh were produced from photovoltaic, that became nearly 40 GWh in 2007 – which explains the +1.600% increase registered in 2007. Between 2010 and 2011 (II Conto Energia) we registered a +466% increase in photovoltaic production, from 1.906 GWh to 10.796 GWh: the EU directive 77/2001 – which started the promotion of renewable energy production in member states – also reaffirmed the priority of dispatching for the new sources, forcing the grid to take charge of a fast increase of unpredictable production.

The presence of intermittent and unpredictable production is a challenge for the system, because:

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[5] See paragraph 3.1.1. for a brief description of the AEEGSI activity in the Italian market

- It influences the protection system of the electric grid;
- It influences the provision of energy for dispatching service (AEEGSI, PAS 21/2011), increasing the costs of the balancing activity carried out by the operator.

2.3. Transmission

We identify with the term “transmission” the transportation of electricity between one of the production sites to the distribution grid at a high voltage level (380 kV - 220 kV - 150 kV, as specified by Terna website): this activity is carried out by the Transmission System Operator (TSO) in a condition of natural monopolist, since the grid is unique on the national territory.

The TSO is Terna. Terna started its activity as a separate and independent company on October 1999, after having been constituted in May 1999 by Enel as a consequence of the decree for electricity market liberalization. At the beginning of its history, Terna was endowed with the operations and management activities related to the transmission infrastructure: in 2005 Terna acquired also the property of infrastructures for electric transmission and changed its name in Terna – rete elettrica nazionale S.p.A..

Terna is responsible for the transmission grid management, included the planning of new lines and the rationalization on the existing connections. It is responsible for the functioning of the electricity system and guaranteeing the equilibrium between electric energy supply and demand at each time of the day. The dispatching service is a fundamental activity carried out by Terna, which has the responsibility to maintain the system balanced. The balance is obtained by coordinating energy inflows from different production plants spread on the national territory, borders connections, transmission and auxiliary services: as highlighted in the description of renewable energy production, high levels of unpredictability and intermittency make the balancing activity challenging for the operator.

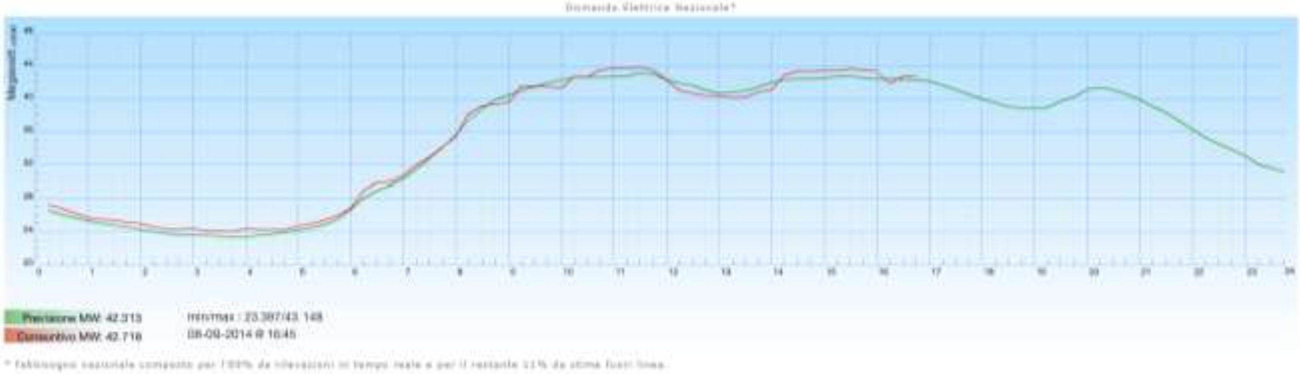

Figure 6: National demand for electricity, real time data VS forecast (Terna, September 8th, 2014)

2.4. Distribution

Through the distribution service, electricity is delivered to consumers at medium and low voltage, and it is carried out by Distribution System Operators (DSOs), which operate in a regime of local monopoly.

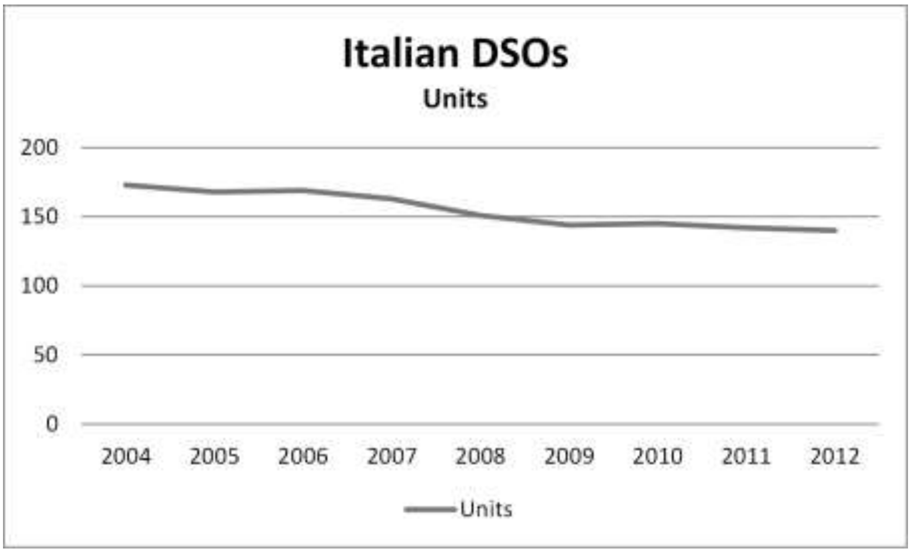

Figure 7: Number of Italian DSOs (Terna, 2014)

The national TSO provides data on all the market player of the sector, and, having 2012 as last year of survey, we can learn that there were 140 DSOs – whose activity is subject to license - recorded at the end of the year, constantly decreasing since 2004 (when they were 173).

Among these, only 10 DSOs serve more than 100.000 customers, covering the 97,8% of all customers (and corresponding to 97,6% of power): Enel is the biggest operator and distributes nearly the 86% of the electric power; other big operators concentrate their service on specific geographical areas, such as Hera and Acegas-Aps in the north-eastern part of Italy (and they recently merged in a unique operator which plays a relevant role in the territory).

Year 2012 - Main DSOs (Societies)

	Withdrawals (n.)	Withdrawals (GWh)
ENEL	31.689.259	239.733
Acea	1.623.209	9.158
A2A	1.117.898	10.971
IREN	692.359	3.881
Dolomiti Energia	300.642	1.979
HERA	259.730	2.216
AGSM VERONA	164.658	1.760
Acegas-Aps	141.749	761
Azienda Energetica - Etschwerke Bolzano	137.891	962
Compagnia Valdostana delle Acque	136.321	912
	36.263.716	**272.333**

Table 3: Main DSOs in Italy, 2012. (Annual voluntary survey of regulated sectors, Terna 2014)

Withdrawals (n.) - Classes	**DSOs (n.)**	**Distributed amount (GWh)**	**Withdrawals (n.)**	**Distributed amount/operator (GWh)**	**Withdrawals (n.) per operator (on average)**
> 500.000	4	263.739	35.121.400	65.935	8.780.350
100.000 - 500.000	6	8.590	1.140.991	1.432	190.165
50.000 - 100.000	3	3.084	228.279	1.028	76.093
20.000 - 50.000	9	1.727	264.645	192	29.405
5.000 - 20.000	21	1.354	212.542	64	10.121
1.000 - 5.000	41	471	90.164	11	2.199
< 1.000	49	108	20.955	2	428
Total	**133**	**279.073**	**37.078.976**	**2.098**	**278.789**

Table 4: Italian DSOs' activity details, year 2012. (Annual voluntary survey of regulated sectors, Terna 2014)

DSOs in Italy have three tasks:

- distribution of electric energy;
- connection between plants and grids;
- measurements and data management

Looking at small operators, it is worth to look at the Trentino Alto Adige case: 68 DSOs operate in the region, and this number is an outlier looking at the Italian scenario. This presence can be explained both considering the morphological characteristics of the territory (high mountains, a number of valleys and small villages to be served), but also the wide development of distributed generation, which rose both from natural characteristics and from cultural attitude of local population towards renewable sources.

In the process of liberalization for market competition in energy sectors, the European Union imposed company separation between producers and distributors for electricity and natural gas markets: this aspect is known as “unbundling”, and it regards only big distributors with more than 100.000 customers.

Unbundling legislation in Italy have been issued by the Authority in 2007 with the decree 11/071, regarding administration and accountability separation duties for the firms operating in the electricity and gas sectors. In its planning documents the Authority underscores its willingness to monitor the strict appliance of the rule: it is reasonable to expect a great attention to major operators, having some firms a consistent inheritance coming from the previous condition of monopolist, and covering an important role in all market segments.

2.4.1. The DSOs and the Smart Grid

Being in charge of managing measurements and data on the grid, DSOs seem to be good candidates for an important role in improving grid efficiency and developing smart grids. A step toward the new system was made in 2010 when the Italian authority issued a decree (ARG/elt 39/10 "Incentives applicable to some forms of production and distribution of energy efficiency") that states procedures and criteria for the selection of pilot projects for the Smart Grid deployment at the distribution level, to be boosted and realized on the national territory: projects were mainly presented by distributors, among which we can find some relevant big players. The decree states the most important national initiative for the deployment of private Smart Grid project in Italy. The document declares that, even in absence of a clear definition of the Smart Grid, it can be possible to distinguish it from the traditional infrastructure because it's "active" and it works with different penetrations of communication and control technologies. The attribute "active", referring to the CEI 0-16, is given to a MT grid in which there is power flow from the medium voltage grid to the high voltage grid for at least a 5% of the functioning time in the year: this aspect comes from the assumption that the presence of distributed generation leads to a production that exceeds local consumption and asks for an inversion of the power flow from the medium voltage grid to the high voltage. The actual Italian system is not used to this kind of events, that started with the diffusion of distributed generation, and the design of a Smart Grid with new communication and control procedures will allow a better integration of all the active and passive users of the grid. The key selection criteria identified by the Authority to assign funds were:

- The project must be a field project that involves a medium voltage grid;
- The grid treated in the context must be an active grid with at least a 1% yearly flux inversion;
- Presence of control and/or regulation system for grid tension and an automated registration of relevant indicators;
- Use of non-owned communication protocols.

Through the selection the Authority chose eight projects that will be boosted with an increase in the Weighted Average Cost of Capital (WACC): this was a first step to boost innovative investments for the distribution grid, but it surely need for improvements that allow also for investment efficiency (increasing WACC, indeed, could lead to over-expenditure).

Despite the great attention to the theme, and the actual need for a new system, Smart Grid development seem to be hard to be carried on: a political sign in this sense is given by the Italian National Energy Plan (*Strategia Energetica Nazionale - SEN*) approved in March, 2013 that collocates investments for Smart Grid development in the long period scenario: waiting for them, since 2012 Terna started to plan not-dispatching energy plants disconnection to guarantee grid stability (as a consequence of 281/2012/R/efr, July, 5th 2012), and that increases the attention to different issues such as balancing, energy losses and market forces regulation.

In future years, we expect DSOs' role will be carefully evaluated and redesign. As a first step, the national authority should collect results and feedbacks from the pilot project financed by the ARG/elt 39/10, to detect positive and negative aspects of the experimental implementation for active networks. Then, further legislation shall focus on the new tasks for the DSOs' coming from technological and managerial changes for grid improvements:

- Grid investments shall be boosted, but in such a way that allows for efficiency, impeding "easy" revenues coming from opaque costs' structures;
- Innovation, and not only simple efficiency on present technology, must be a priority;
- Data management seems to be a natural task for DSOs, but new, big amount of data could make them too powerful, putting at risk market equilibria;
- DSOs' new tasks shall be accompanied by a strict respect of unbundling rules, to reach roles clear definition and separation.

Summing up, the authority shall recognize DSOs' role, maybe also extend it, but always investigating market equilibria and keeping a strict control on rules' respect.

2.5. Consumption

In 2013, total electric energy demand in Italy amounts to 318.475,1 GWh, that include 21.187,5 GWh spent for system losses; as already mentioned, total internal production was about 289.803 GWh, that implied deficit of 42.137,6 GWh that were imported: about 80% of imported energy proceeds from France and Switzerland (Terna 2014).

The Italian system has been affected by a systematic deficit of electricity since 1970's, and this condition has been confirmed also in the latest years, when the economic crisis reduced both energy demand and energy internal production.

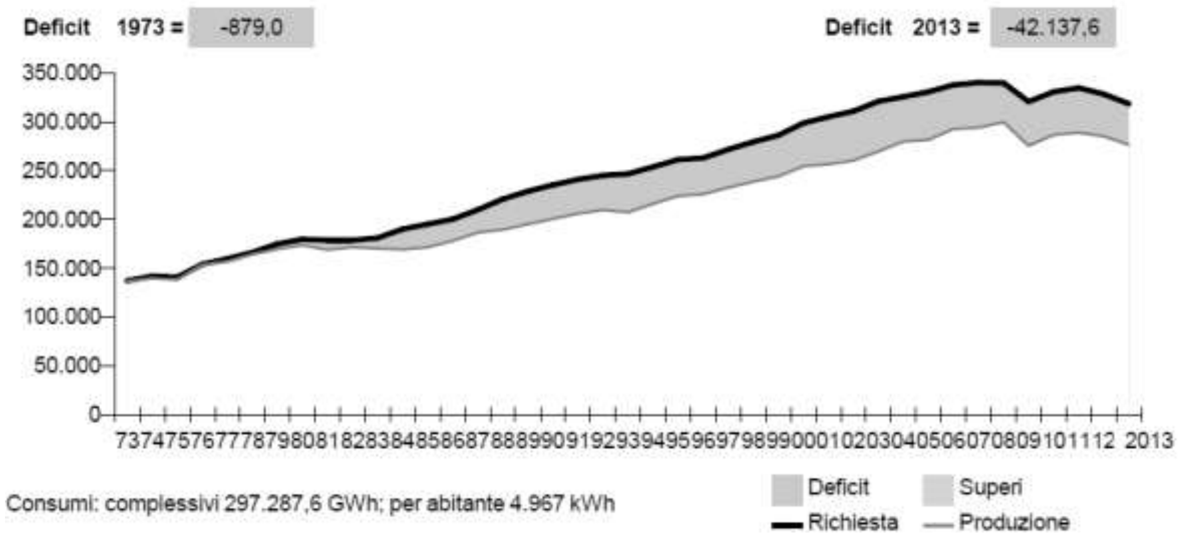

Figure 8: energy production and consumption, historical data (Terna, 2014).

In 2009, the Authority analyzed residential loads, aiming at collecting relevant information to introduce different prices for different time slots.

The time slot price differentiation aimed at decreasing electrical limitations to residential load shifting from peak hours to low demand time intervals, allowing for a better use of the resource. In order to forecast load shifting opportunities, the Authority made a list of all residential consumption typologies, identifying a number of services: heating and cooling, big appliances (e.g. washing machine), electronic devices (e.g. television), ICT devices (e.g. monitors, modem), lighting systems, small appliances (e.g. micro-wave oven, toaster) and other common devices (e.g. electric iron, hair drier). For each device, the Authority shaped a load curve, defined a typical usage (in the morning, in the evening, during the week or in the weekends, etc.) and made hypothesis on the possibility to shift the load connected to the specific service: as an example, house lighting, cooling and heating systems were assumed fix loads; some devices like hair drier and PC were classified as "partially" flexible loads; big appliances like washing machines and dish washers were assumed flexible loads.

Given load characteristics in terms of power and consumption habits, the Authority made hypothesis on the possibility of sending price signals to reduce the load during the day (when the industrial demand is higher) and to increase consumption in the evening and during the night: this analysis brought to the actual time slot division F1, F2 and F3[6].

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[6] See paragraph 3.2.1

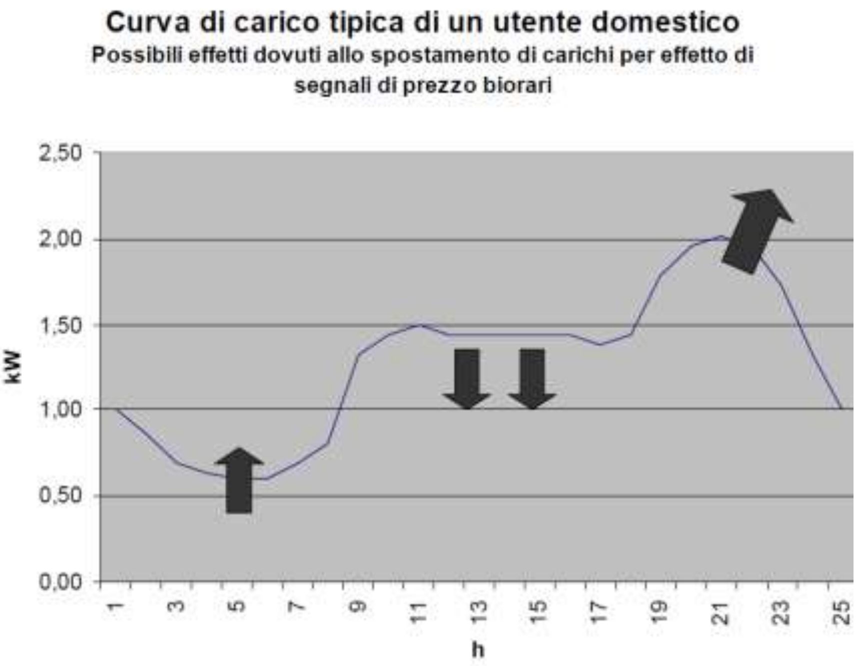

Figure 9: load curve for residential consumer (AEEGSI, 2009)

This approach aimed at a better use of the electric resource, given production and consumption characteristics at the time: the introduction of time-of-use prices gave a first incentive to an energy management approach for residential loads, and increased consumers' consciousness, even if shifts in load have been tiny (see Maggiore et al., 2013).

Looking at residential load, however, it is worth to note that daily consumption can be relevant in the hours when photovoltaic production is active: this time interval has been penalized by time-of-use prices defined by the Authority, while for a photovoltaic *prosumer* it could be profitable (especially in absence of monetary incentives) to concentrate residential loads during the hours when solar radiation is available for the plant.

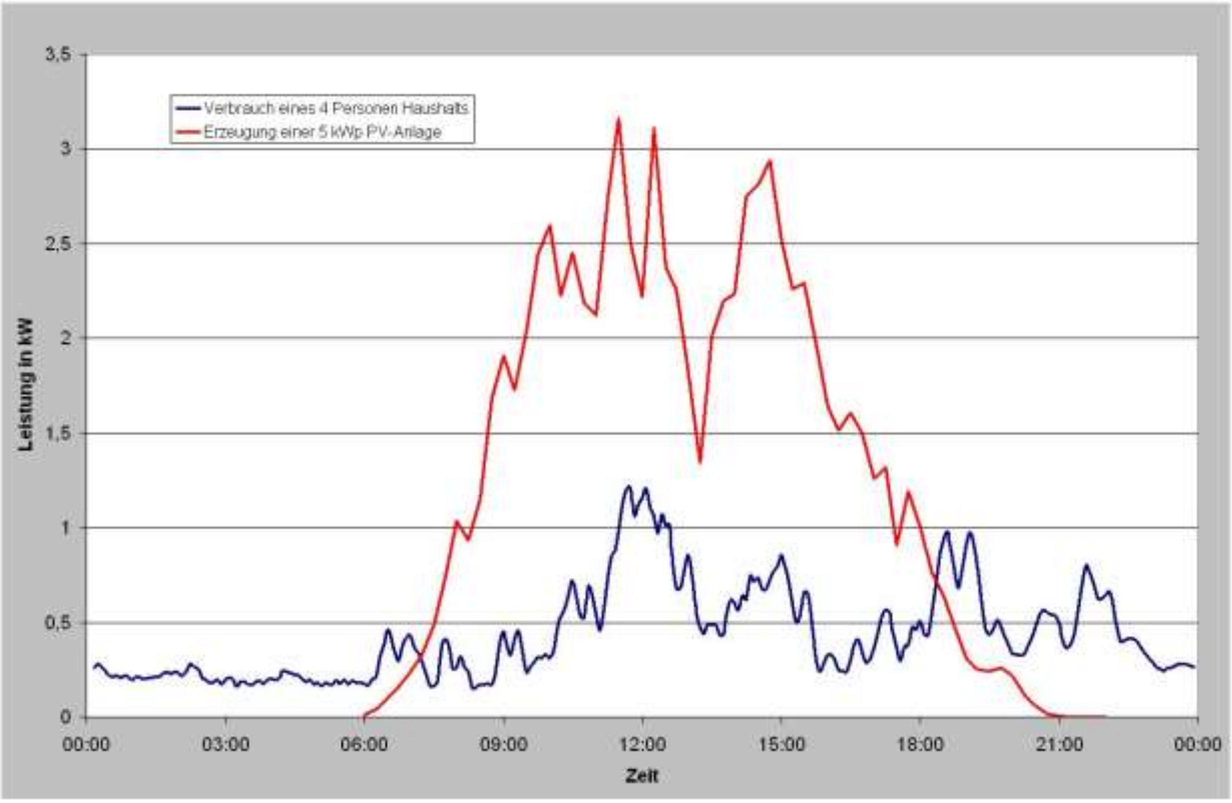

Figure 10: Average consumption for a four-member family in a typical summer day VS photovoltaic power generated by a 5kWp plant (from http://www.sma-italia.com)

Figure 10 shows an example of residential load for a four-member family in a summer day, while photovoltaic production is active: photovoltaic power is higher than requested load during all the daylight time slot. Changing plant power and looking at different season and weather conditions we will surely find considerable differences in production pattern (and consumption pattern too), but what is relevant is that, at yearly level, investing in smart load management tools to take advantage of photovoltaic production can be valuable. This private behavior could be a resource for the grid too, if properly regulated to respond to system needs: private production and private consumption could be – jointly – a new energy resource for the system.

3. Italian electricity market

The Italian electricity market has been managed as a monopoly from 1962 to 1992, when the liberalization process started with the transformation of Enel (the state-owned monopolist company) in a limited company: its privatization, indeed, started in 1999, with the legislative decree n.79, March 1999. According to the GME (GME, 2009) the Italian electricity market was born with the publication of the decree 79/99 (also known as "Decreto Bersani"), since the reform was aimed at promoting competition on the production side and on the selling market, and to increase transparency and efficiency in the dispatching – that is managed in a regime of natural monopoly (GME, 2009).

Electricity trading is organized into different markets. The first market is the "day ahead market", where electricity market operators make bids about energy that they will be able to supply during the next day. In a second phase, immediately after the closing of the day ahead market, market operators are can adjust their bids, on the basis of new information and forecasts. The third market is the dispatching market, that is aimed at perfectly equilibrating energy supply and energy demand time to time; in this market energy traded is paid as bid by the operators. If the market is negatively unbalanced, i.e. there is less energy on the grid than the requested, more energy must be bought to compensate the gap; if the market is positively unbalanced, energy exceeds the local load.

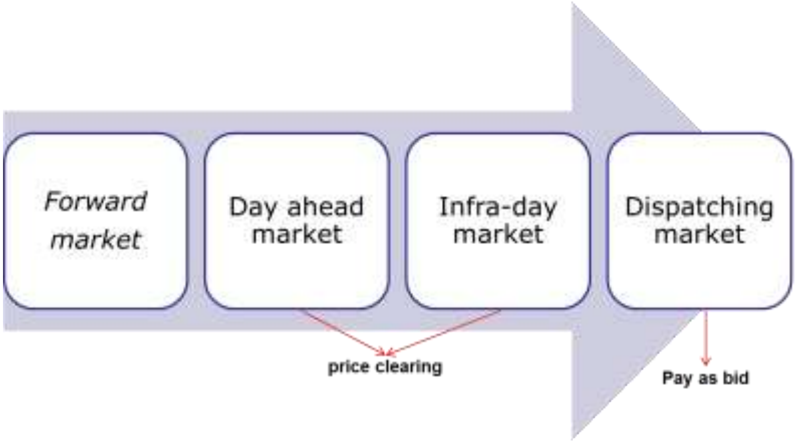

Figure 11: Electricity markets.

The dispatching market is organized by the Manager of energy Markets (*Gestore dei servizi energetici - GSE*) where authorized operators can bid their offers the day ahead: the GME collects the data and communicates market results. Terna, that is responsible for market balancing, operates as a natural monopolist and it can use energy from the dispatching market as a reserve for real time balancing.

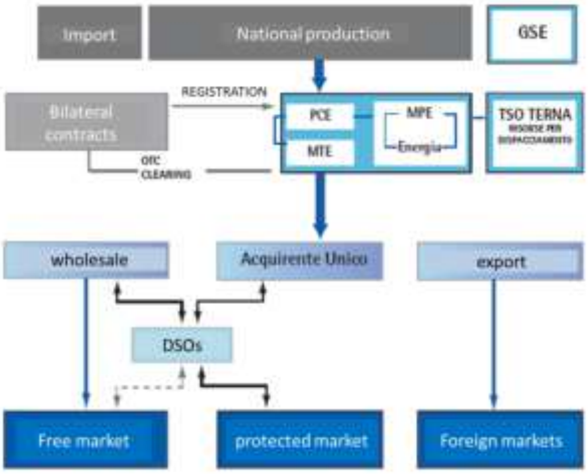

Figure 12: The organization of electricity market (Terna, 2014).

3.1.Autorità per l’Energia Elettrica, il Gas e il sistema Idrico (AEEGSI)

The national authority for the electricity sector was founded in 1995 and, given its work areas, it’s now called “Authority for electric energy, gas and water system” (Autorità per l’Energia Elettrica, il Gas e il sistema Idrico - AEEGSI).

The AEEGSI is an independent entity that has the duty to protect consumers, promote market competition, efficiency and the diffusion of services on the territory (AEEGSI, 2014). We already recall the project for Smart Grid development the Authority promoted in 2010, and this can be taken as a general example for the activity of promoting competition and service accessibility; among its activities, also collection of data on market operators and monitoring activities are really relevant.

The Authority is entrusted with the ruling of the three sectors, and it performs this task issuing specific decrees and directives: particularly interesting for our work have been those related to the management and the sharing of system burdens generated by not dispatching sources.

Authority decree 281/2012, recalling the process of progressive worsen of system burdens due to the presence of fluctuating energy sources on the production side, introduces the right for the GSE to divide among different producers system burdens deriving from system unbalancing – that is due to the mismatch between forecasts and effective production. After this decree, producers associations called for a cancellation of burdens for unpredictable energy sources and the Administrative Tribunal of Lombardia region (TAR Lombardia) answered to the appeals, cancelling the effects of the decree in June 2013. The Authority asked the Consiglio di Stato to suspend the decision of the TAR Lombardia, but the Consiglio di Stato confirmed the sentence in June 2014, forcing the Authority to redefine the mechanism in a way that shall be not penalizing solar and wind power plants: this principle guided the Authority in the formulation of the decree 522/2014/r/eel issued on October, whose effects still have to be verified.

Balancing burdens issue is still far to be solved, and it’s worth to note that – at the time of writing – no mechanisms of dynamic response to grid status from small production units have been designed, but only a penalty system with different shore leaves. The possibility to actively integrate small renewable producers must be deeply investigated, aiming at increasing system efficiency and at avoiding the reduction of energy investments’ value.

3.2.Italian market prices

3.2.1. The PUN

Looking at prices on the Italian market, the reference variable to be followed to understand the evolution of electricity market price is the PUN (Prezzo Unico Nazionale).

The PUN is the Italian national price for electric energy, calculated as the mean of the different prices originated at a zonal level, weighted by the volume of effective exchanges, net of purchases for pumping and from foreign regions[7]. The PUN is used as a national purchase price, meaning that each Italian energy consumer can buy at this price no matter where he/she is connected to the grid.

According to data provided by the GME, the mean value of the PUN in 2013 was 63 €/MWh. Looking at the graph reported in Figure 13, it is possible to see that recently the PUN seems to have registered a negative trend, probably mostly deriving by drop in energy demand due to the economic crisis and the contemporaneous availability of higher distributed energy generation: however, further future observations are needed to confirm this trend, extending the time series.

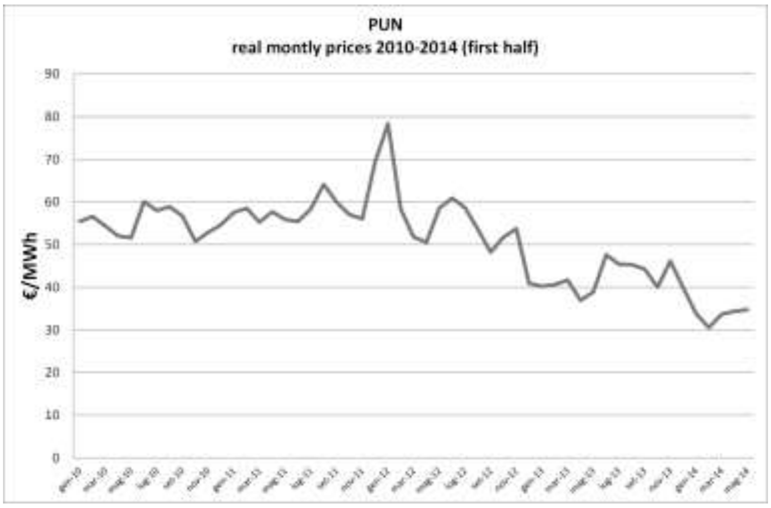

Figure 13: The PUN, 2010-2014, first half. (Author’s elaboration on data from Gestore Mercati Energetici (GME))

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[7] The PUN is defined by art. 30, comma 4, letter c) of the Italian Authority (AEEGSI). See Resolution n. 111/06 June 13th, 2006 (Condizioni per l'erogazione del pubblico servizio di dispacciamento dell'energia elettrica sul territorio nazionale e per l'approvvigionamento delle relative risorse su base di merito economico, ai sensi degli articoli 3 e 5 del decreto legislativo 16 marzo 1999, n. 79) .

The PUN, indeed, is not the end consumer can buy electricity on the national market, because it faces an higher price level due to the presence of grid costs, general costs and taxes.

The Italian Authority AEEGSI provides an analysis of the final electric energy cost for the typical final residential consumer in Italy, characterized by an average yearly consumption equal to 2.700 kWh, and a maximum power of 3 kW.

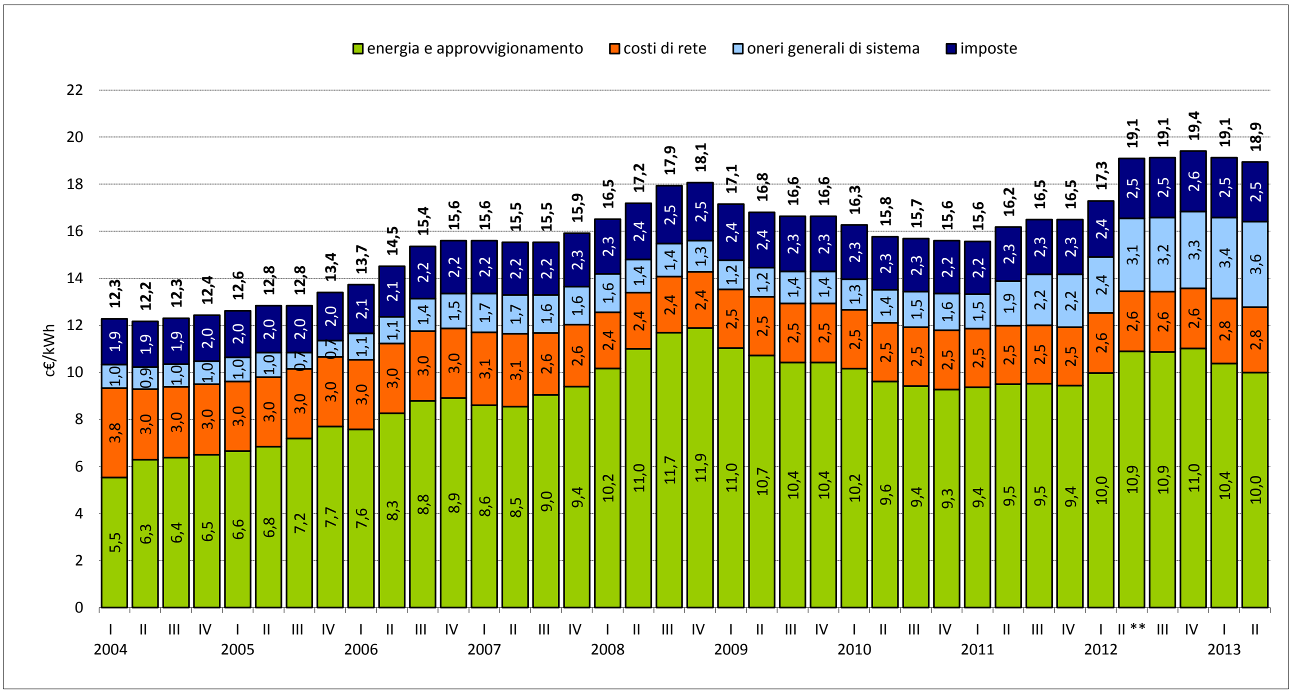

Table 5: *Energy costs for end consumers, 2004-2013. (AEEGSI, 2014)*

Looking at Table 5, it is possible to see that energy price is only part of the final cost that have to be paid by the domestic end consumer: we take as example the second trimester 2013 (that can be considered not different with other time intervals), where energy price and supplying represents half of the total energy cost. Other voices composing the final price are connected to the electrical system, being attributable to grid costs nearly for the 15%, to general cost for the 19%, and to taxes (13,23%).

End consumer energy price, % composition - 2013, II trimester	
Energy and supplying	52,91%
Grid costs	14,81%
General costs	19,05%
Taxes	13,23%

Table 6: Author elaboration on AEEGSI data (2014).

The average electric energy price paid by the end consumer in the 2013 second trimester was 189 €/MWh, and according with the percentages provided by the national authorities, this price is the sum of:

- 99,99 €/MWh for energy and supplying services;

- 27,99 €/MWh for grid costs;
- 36,00 €/MWh for general costs;
- 25,00 €/MWh for taxes.

Considering the average value of the PUN in that period, it is possible to see that the contribution given by this component to the final price is tiny: as reported in the table 7, the average value of the PUN for the months of April, May and June 2013 was 57,39 €/MWh (included in the 99,99 €/MWh corresponding to "energy and supplying" voice), that correspond to a weight of 30% on the final price paid by the end consumer.

Monthly averages, PUN 2013 (€/MWh)

Month	Monthly average	Time slot - F1 (average)	Time slot - F2 (average)	Time slot - F3 (average)	On peak (average)	Off peak (average)
January	64,487	75,367	72,045	52,450	75,430	58,034
February	62,970	71,074	70,422	52,537	72,375	57,746
March	63,975	70,248	74,670	53,493	73,059	59,313
April	61,033	66,489	78,084	49,138	65,875	58,229
May	54,893	62,793	69,727	41,195	62,140	50,619
June	56,236	62,214	66,543	46,328	63,253	52,727
July	66,857	70,764	71,968	60,756	71,626	64,044
August	65,014	64,825	73,162	60,553	65,290	64,863
September	64,721	66,193	74,004	58,755	68,414	62,732
October	64,367	69,486	75,251	54,005	72,879	59,358
November	61,733	73,456	67,939	50,182	73,649	55,317
December	69,281	80,804	78,603	57,992	78,922	63,978
Year	62,986	69,457	72,641	53,126	70,267	58,934

Table 7: The PUN, montly data sorted by time slot (AEEGSI, 2014).

It appears clear that not considering supplying costs, system costs and taxes will determine a strong underestimation of the real energy price paid by the Italian end consumer; moreover, it can be said that PUN variations are hardly perceived by the end consumer, being just one third of the overall final price.

Analyzing the PUN, it is worth to remember that actual tariff schemes divide the hours of the day into portions with different prices: time slots F1, F2 and F3, identified on the basis of typical national loads.

In the graph, monthly averages of the PUN in different daily portion are reported (2009-2014 first half):

– F1 corresponds to the high demand portions, 8.00 a.m.- 7.00 p.m. between Monday and Friday;

– F2 corresponds to intermediate hours, 7.00 a.m. - 8.00 a.m. and 7.00 a.m.- 11.00 a.m. during the week, 7.00 a.m.- 11.00 p.m. on Saturday;

– F3 corresponds to the off peak hours: 00.00 - 7.00 a.m. and 11.00 p.m. - 12.00 p.m. from Monday to Saturday, and all the hours of Sunday.

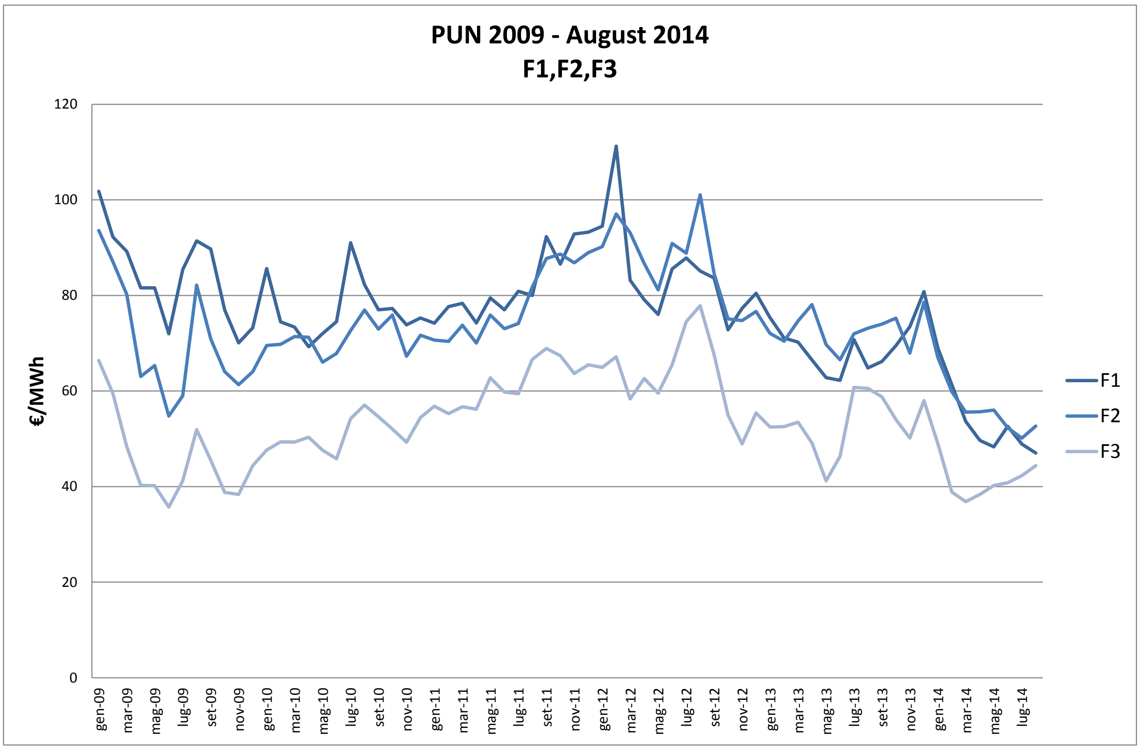

Table 8: Authors elaboration on GME data (2014).

Recalling production characteristics, it is worth to note that photovoltaic production is concentrated during the high demand hours F1 (with the exception of the Sunday production, which is addressed to the F3 time slot because of lack of industrial demand), so the photovoltaic producer if called to play in the market (and having no batteries) will always play in the hours in which the peak price is on. Different price slots have similar patterns, and recently have decrease differences in price, as it can be noticed in the 2014's values in the graph.

Looking at the differences between on-peak prices and off-peak prices in table 10, indeed, it is possible to argue that there is a tendency to reduce the difference between the two values of the PUN: this can be seen in the table reporting the mean monthly average of the PUN on and off peak, but it is also more evident from the graph of differences between on and off peak in the same period: the tendency of the past five years is clearly negative. This phenomenon - that shall be verified and proved in the long run with a longer time series - can be justified, on one hand, by the reduction of the industrial demand in the years of the ongoing economic crisis, reduction which is reinforced by the strong boosts given to energy efficiency investments in latest years; on the other hand, photovoltaic production during the day is contributing to the overall production, inflowing energy in the grid when the daylight is available.

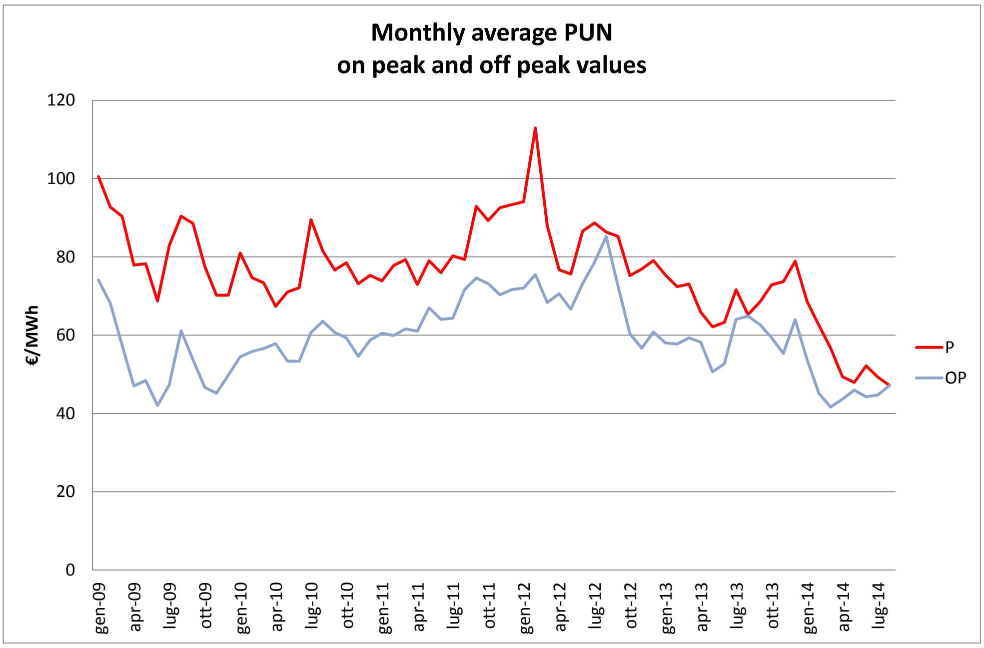

Table 9 PUN, on peak and off peak values, monthly averages (GME data, 2014)

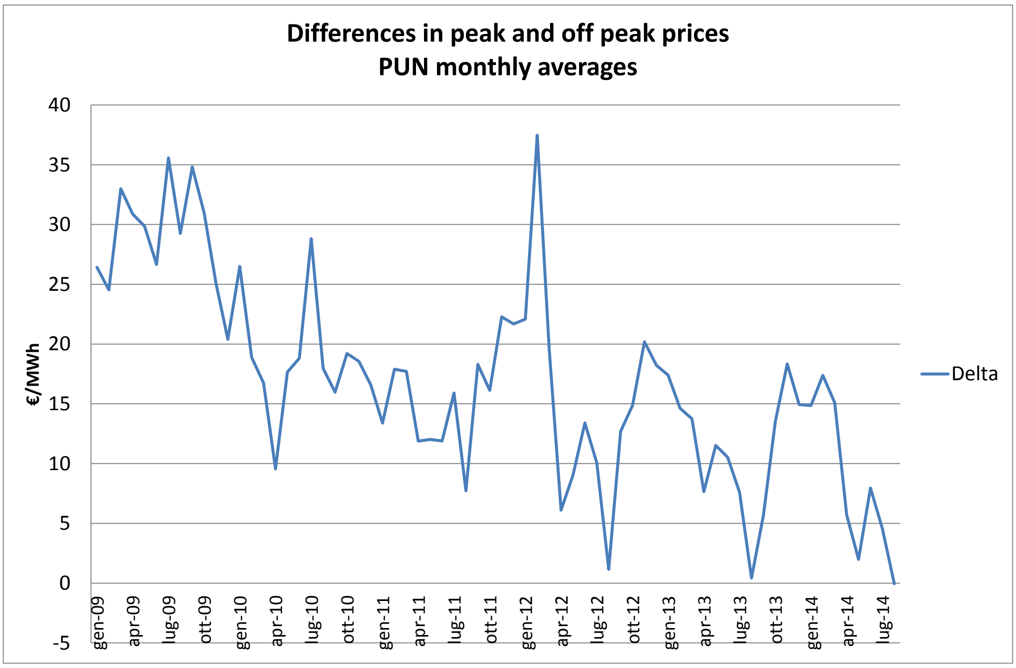

Table 10: PUN, differences between on peak and off peak values, monthly averages (GME data, 2014)

To conclude the brief overview on PUN characteristics, another interesting phenomenon can be highlighted looking at differences between F1 and the other two portions, F2 and F3: the graph shows how in the past two years the on peak price went lower than the intermediate price of F2, and this evidence – that shall be deepen in dedicated analysis- could be addressed to the high renewable production, that fill the market with energy during the F1.

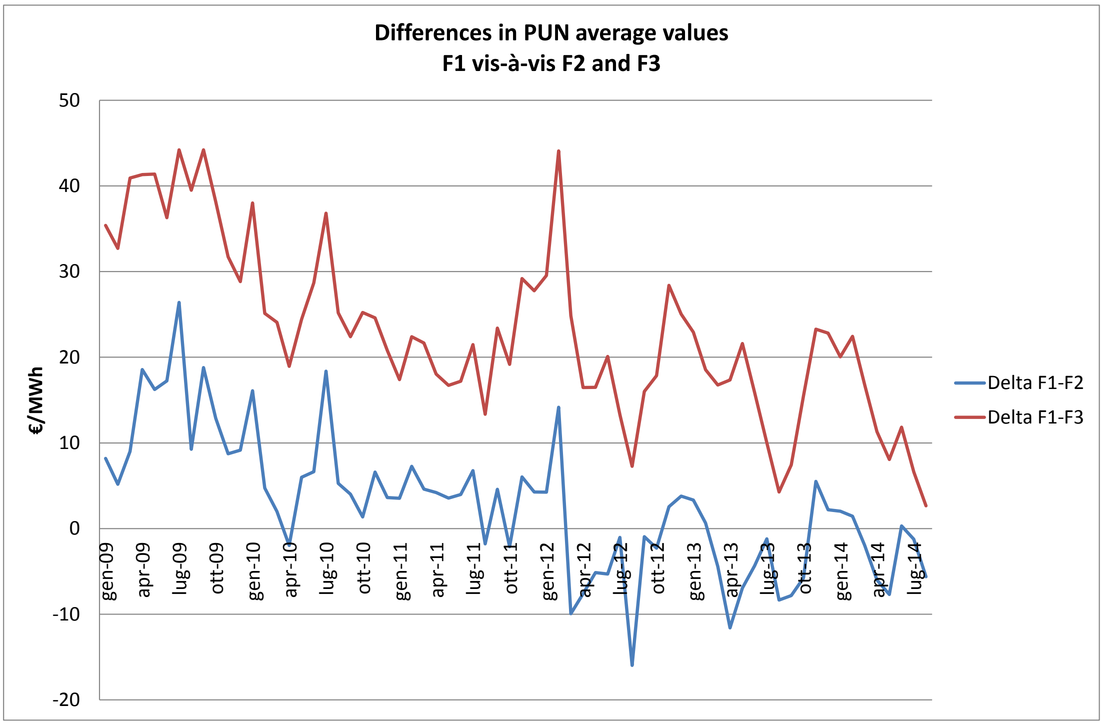

Table 11 PUN, differences in time slot prices, monthly averages (GME data, 2014)

3.2.2. Zonal prices in the Italian market

Actual system designed for renewable energy distributed production plants provides for the inflows of the photovoltaic energy in the national grid, with a remuneration that varies between different incentives schemes: the grid always accepts renewable energy inflows, no matter if they are useful for the system or not, because they have the privileged regime of priority of dispatch. Depending on the year of connection of the plant, different levels of feed - in - tariff remuneration have been applied to the plants (depending on the *Conto Energia* edition, as illustrated in paragraph 2); some customers have also the possibility to ask for the local exchange mechanisms (*scambio sul posto*), in which the *prosumer* has the possibility to let into the grid the energy surplus produced, and to consume it back when it is needed, paying a price that is lower than that on the market: in this case, the *prosumer* is not asked for contributing to the grid management in an active way, but price differentials represent a fee that the grid asks for providing the consumer with the service. Most of the time, power plants also receive a payment for energy sold to the grid, and the price of this energy is related to the area where the plant is located.

Italian electric system is divided into different zones, among whom physical energy exchanges are limited due to system security needs. The GME glossary provides a brief summary of the zones we can consider in the Italian market, that are:

- Geographical zones, representing a geographical portion of the national grid: north, north-central, south, south-central, Sicily, Sardinia;

- National virtual zones, that represent a limited production pole: Monfalcone, Rossano, Brindisi, Priolo and Foggia;
- Foreign virtual zones, representing connecting points with adjoining countries: France, Switzerland, Austria, Slovenia, BSP (a Slovenian electricity market zone, connected to IPEX with the market coupling mechanism), Corsica, Corsica, and Greece;
- Market zones, that are aggregations of geographical and virtual zones in which energy flows respect limits defined by the Italian Transmission System Operator, Terna.

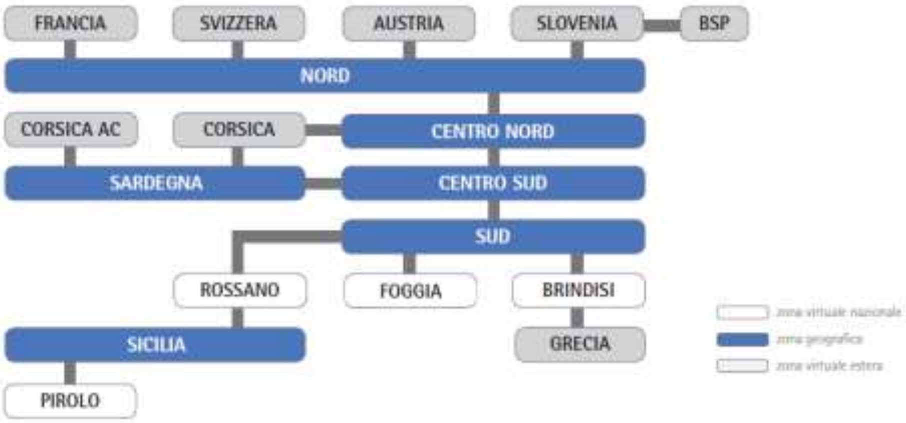

Table 12: Italian electricity market zones (GME, 2014).

We analyze zonal prices from the six geographical zones registered between 2010 - that can be considered as one of the first relevant year for photovoltaic diffusion in Italy - and first semester 2014 - that is the last period available on the GME website at the writing time.

As mentioned above in PUN description (paragraph 3.2.1), zonal prices determines PUN level, because the final PUN of each hour of the day is the result of zonal prices averages, weighted for energy exchanges.

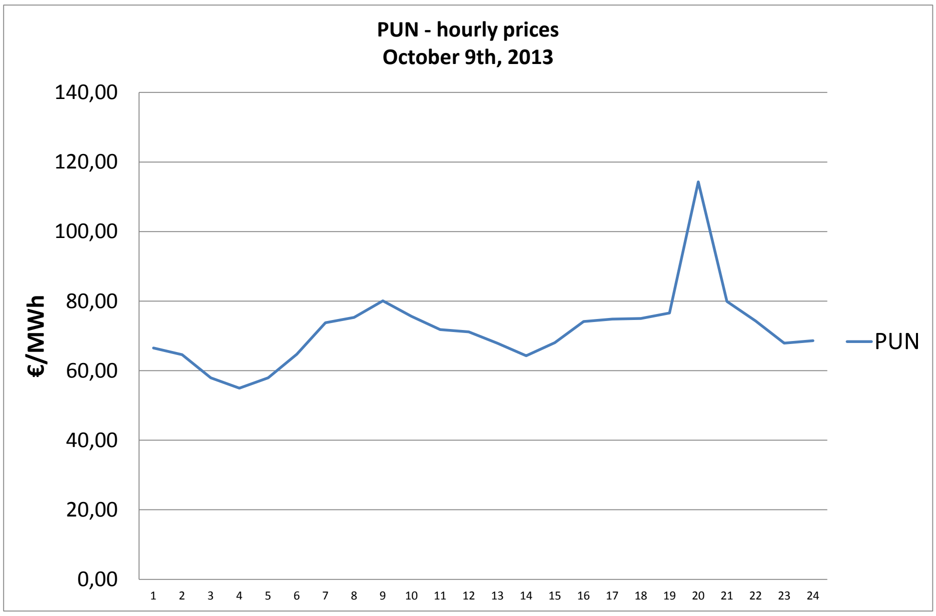

Table 13: PUN on October 9th, 2013 - GME data elaboration.

The graph in table 13 shows the shape of the hourly PUN registered a standard day (Wednesday, October 9th, 2013). As it can be clearly seen, the price, which on average is about 72 €/MWh, presents large variations during the day: the maximum price is 114, 29 €/MWh, registered around 8 p.m., and the minimum is 54,97 €/MWh, with a difference of 59, 32 €/MWh.

Similar shapes are reported also for the each zonal price, with heavy differences for some particular geographical areas.

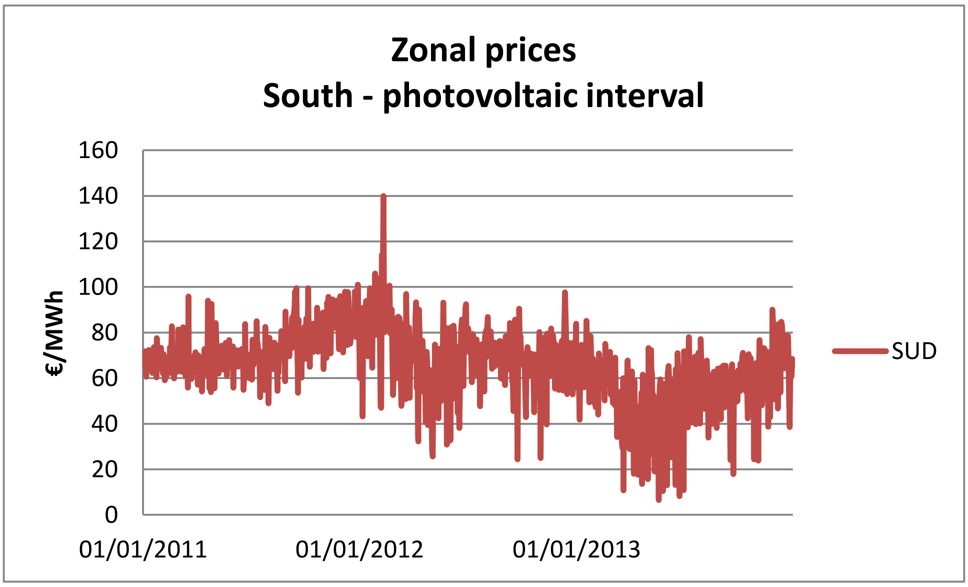

Table 14: Zonal photovoltaic price for South, 2011-2013. Source: elaboration from Gestore Mercati Energetici (GME, 2014)

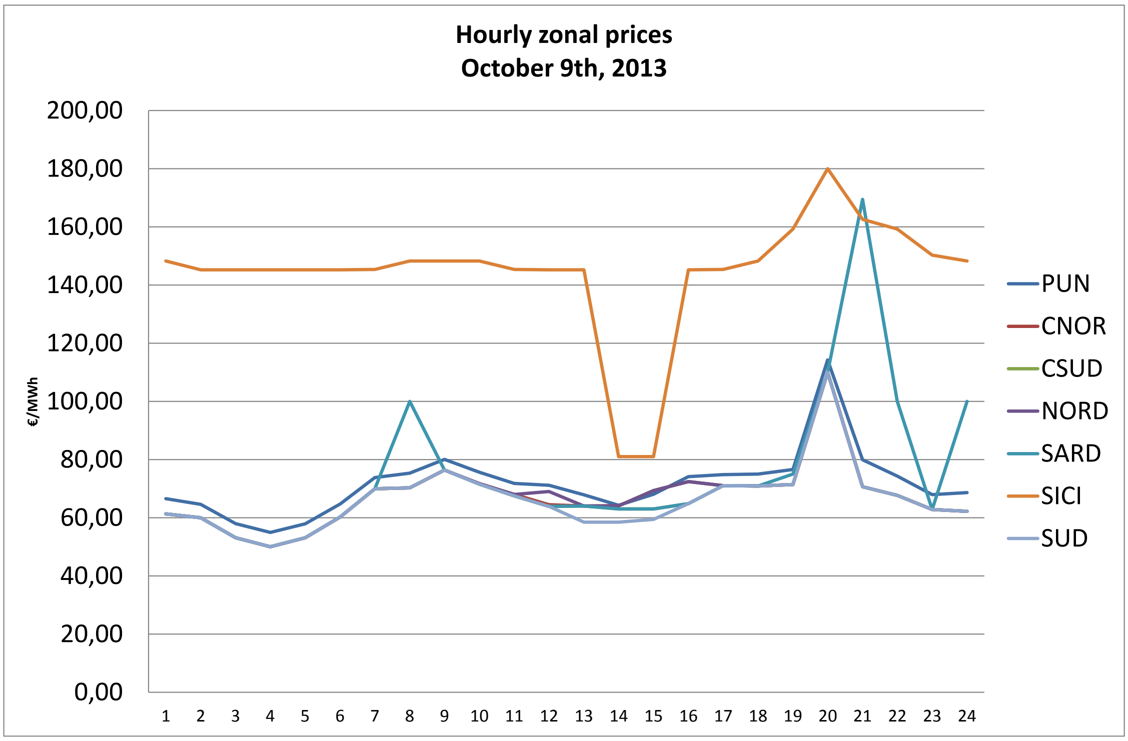

Table 15: Zonal prices on October 9th, 2013 - GME data elaboration.

Looking at different geographical areas, it is evident that some areas suffer from an higher variability if compared to the others: Sardinia (light blue) presents "overreactions" of the zonal price during price peaks (8 a.m. and 8 p.m.); Sicily has a peculiar situation, with really high prices and strong peaks and drops.

Differences in zonal prices are determined by differences on transmission capacity, consumer's behavior (Gianfreda and Grossi, 2009) and different distributed production patterns, that have increased their importance in the latest years: it can be assumed that zonal prices give a measure of the local congestion of the grid in every time of the day.

Difficulties in managing grid connections with the islands are a well-known issue for the Italian system (GME annual report, 2012). As an example, systematically higher prices in Sicily are due to the obsolescence and the inefficiency of the local production system, and to the difficulties in the connections with the rest of the Italian territory: in the October 2013 this problem was stressed by some speculative actions that cause a substantial increase in price differentials between Sicily and the rest on the nation, with local prices higher than 200 €/MWh . Lacks in connection for Sicily should be managed through the building of a new line between Sorgente and Rizziconi, that was scheduled by Terna in 2011, and whose works will start in 2015: Terna's calculations in the Sorgente-Rizziconi economic evaluation reported that the Sicilian congestion causes, on average, higher electricity bills for about 800 million euro every year. With the new cable between Sicily and the mainland, a drop in prices is expected, having as a reference point the effect of the SA.PE.I cable between Sardinia and the mainland that leaded to a drop in price differences with the south area of about 45%. Difficulties in dispatching also call for Authority interventions to re-equilibrate, or to ask Terna for accurate forecasts to reduce system burdens (as an example, 239/2013/r/eel, May 30th, 2013).

4. Conclusion

In this work we present a brief survey on the Italian electricity system and electricity market. In the description, we want to point out the relevance of the impact of renewable resources on the system: at production level, in the latest years renewables highly increased their contribution, and this phenomenon is mainly due to boosting schemes and incentives provided by the national government to fulfill the suggestions given by European directives.

Renewable, however, deeply impact on actual electric system, that was not designed to support peripheral inflows coming from generation plants spread on the territory, that are now connected with a "fit and forget approach", perceived by the system as "negative loads" and unable to react to system necessities. Particularly, the electric system suffers from the presence of intermittent and not-dispatching plants, like wind-farms connected at high voltage grid and photovoltaic plants connected to medium and low voltage grid. These plants affect system stability influencing both system protection mechanisms and forecasts on productions and loads: as a consequence, balancing activity is more costly.

New plants on the production side generated the need for a Smart Grid, that shall be able to better integrate and use all system resources, making renewable interact with the system, responding to grid signals.

Consumers and *prosumers* contribution shall be encouraged, with the use of smart energy management devices that could help the residential loads to adapt to grid necessity, shifting to those hours when the demand is low and production high: this approach has been somehow started with the introduction of time-of-use tariffs, but the tariff system determined just a limited shift in load, while smart tools could enable residential load to better adapt and react to signals.

Prosumers could take advantage of small private plants (like residential photovoltaic plants), contributing to keep the grid stable. In a future Smart Grid scenario, consumers and *prosumers* could also be directly involved in the electricity market, that is now unified under the PUN: zonal prices, however, show some criticalities deriving from system congestions and unbalances that could be solved at nodal level with the participation of local agents.

Looking at actual system structure and agents, it is reasonable to expect that the new Smart Grid environment will call for a deep renovation of market roles, schemes, and equilibria – especially thinking to new data management and balancing responsibilities – but increase in system efficiency and adaptability can be worth to make the effort.

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III

Flexible and integrated

A photovoltaic investment evaluation in a Smart Grid scenario

1. Introduction

The future of the electric system and the related markets will be smart: the new environment will include new agents, markets and relationships.

To better fit consumption necessities and to improve efficiency in the use of energy resources, the system needs for new technologies to improve production, transmission and distribution management. A deeper involvement of ICT will allow functional communications, but it also need for a proper regulation that shall balance new equilibria and provide for penalties and incentives if necessary. All these features are currently included in the idea of Smart grid, a theme whose importance has grown with the development of distributed and intermittent energy sources, and it is still growing due to the need for efficiency in energy management.

A unique definition or a single strategy for the development of Smart grid do not exist. According to the first "Smart grid Executive Report 2012" (2012, Energy and Strategy Group, Politecnico di Milano), smart grid technological solutions can be classified into:

- Smart generation solutions, including smart inverters and asset optimization systems;
- Smart network, including control, automation, and demand-response management systems;
- Smart meters and active demand, including advanced metering infrastructures and home management systems;
- Storage systems, that can be applied throughout the whole energy production and consumption chain.

Regardless the way in which the Smart grid will be realized (preferring batteries or dynamic energy management; centralizing or decentralizing system controls; etc.), what will be relevant for its success is the presence of smart agents using it. This study aims at analyzing an investment decision in a Smart grid scenario: the investor will evaluate new elements influencing the investment decision, acting in an environment where the energy system in general, and the electric grid in particular, is characterized by new tools that allow for managerial flexibilities.

In the following analysis, we want to focus on the Smart grid tools that are needed to improve participation to the electric grid of small production plants - and in particular photovoltaic plants - giving the plant owner the possibility to play on an active market.

With the pervasive presence of intermittent energy sources connected to the system, energy flows on local grids become highly unpredictable: photovoltaic production reaches different levels within the day and suffers from seasonality; moreover, it can be reduced or interrupted depending on weather conditions, or simply being affected by clouds. This makes it not possible to trust photovoltaic plants to supply energy demand: electric energy has the technical limit that it cannot be stored, and production and consumption are nearly contemporaneous (and the farer the consumption point, the lower the efficiency of energy delivery) so, as we have a lack in photovoltaic energy inflows, we must call for the power capacity of stable power plants that are always at disposal to fix the balance. Photovoltaic production, thus, is presently a huge cost in terms of balancing needs, that are filled on the balancing market.

Looking at the local grid segment, photovoltaic production is placed side by side with other small - medium producers, a number of private and industrial consumers and also a growing presence of prosumers (that is the result of the joint condition of "producer" and "consumer"), that are often part of the photovoltaic generation: as a whole, the different agents and loads could be organized and coordinated in order to locally balance the grid segment, consuming energy in a short distance (limiting wastes) and limiting bad effects on the entire system.

Looking at a single agent, indeed, it is also possible to take advantage of personal flexibilities in electric energy consumption, letting the agent interacting with the grid and shifting consumptions depending on price signals.

In the work that follows, we want to analyze the private investment decision in a residential photovoltaic plant, that will be managed by a prosumer. As a first step, we briefly discuss the role of the prosumer in the Smart grid, and we define some characteristic of the agent we chose for the discussion.

Once identified who makes the investment decision, we assume that the Smart grid that will be the environment of our analysis, and to which the agent will be connected, is adapted for:

- Instantaneous detection of the optimal energy consumption level that can be technically sustained by the system, at the node (or local grid portion);
- Instantaneous communication - through energy prices - of the optimal energy flow that has to be given/taken by the single agent.

That are just a small part of the set of tools that could be put in place by the smart grid system. In this study we also avoid the discussion about data management and system security, that surely are a relevant aspect for future development of Smart grid and shall be investigated by researchers in the ICT field, in deep coordination with public economists.

Signals about optimal energy flows are delivered from the grid to the agent through prices. If energy price at local level is high, then it could be convenient to suspend the consumption and sell energy to the grid; *viceversa*, if the energy price at local level is low, it's better to consume, concentrating the load in those hours in which for a set of possible causes (high not dispatching production, strikes that stops industrial production, vacancy, etc.) there is an excess of energy on the grid.

It is important to note that smart grid technologies are sometimes complementary and sometimes substituted, so it's critical to define a main strategy to be followed in developing it. In particular, storage systems, that are a cardinal aspects of the research on Smart grid and, in general, on electric energy use and management, have a decrease in value if introduced in a system with high penetration of other balancing tools, such as plants virtual coupling, demand-response and smart home management systems. In the model we are describing in the following analysis, storage systems are not include: actual storage system, indeed, are still quite expensive and they have an heavy impact on initial investment costs; moreover, batteries' cost do not end with the initial buying costs, because the it must be considered the cost of battery substitution during the plant life: photovoltaic production oscillations do not allow for an optimal use of the battery -- that decreases faster its efficiency level - and technological improvements are needed. The main motivation to the choice of not including batteries in the model, indeed, is that in this way it is possible to enlighten the power of flexibility while acting in a "real time" market, and in a condition of uncertain production: the inclusion of power storage will extend system flexibility (also reduce the impact of unpredictable flows on the grid) increasing even more investment value due to energy management opportunities.

In paragraph 3 we present the evaluation model, that takes into account the value for flexibility through a real option approach: decisions on optimal investment's size and optimal conditions for the investment complete the model. Paragraph 4 presents a possible application to the Italian market, taking as a proxy for price signals prices registered in four geographical price zones (north, north central, south and south central) in Italian electricity market. Conclusion follows.

2. The prosumer[8] as a critical agent in the new scenario

The energy prosumer embodies the new paradigm of the energy system, which moves from a centralized management and control to a more wide and participated system. Building a "participated" system for energy management means that different agents connected to the grid could be called to act in favor of it, shaping loads patterns depending on grid necessities, providing ancillary services and, in general, reacting to grid requests.

Considering this approach, and building a proper legislation to make it effective, grid managers could manage not dispatching plants together with the producers, that can react to grid signals. As an example, it is possible to encourage consumption of energy during the periods of low demand or of unexpected overproduction, or to avoid energy inflows in the grid by finding a way to store it; following the same mechanisms, also the consumers can contribute to grid management, by adapting their load pattern responding to the necessity of a general equilibrium. The new grid environment could be regulated and balanced with incentives, but a market solution seem to be feasible, and shall be investigated.

Renewable integration and participation in grid management are two cardinal aspects in the Smart grid system, and the target of this work is to suggest a model where both of them find application. In the following analysis, we consider an investment decision in a photovoltaic power plant from an energy consumer point of view: with the investment, the consumer becomes a prosumer.

This double condition of consumer and producer perfectly fits the framework we described, where this kind of investments are no more boosted by incentives: for our prosumer, the choice of investing in energy production is not oriented to making profits, but it is justified by the need for energy consumption and the possibility to reduce energy expenditure. The investment decision strictly depend on private energy consumption, and not on the possibility to gain further remunerations by the plant.

Joint evaluation of energy production and load curves forces the agent to a more careful evaluation of the relationship between the new plant and the electric grid. That is, we are abandoning the "fit and forget" approach, both from the producer's and from the grid's side, moving towards a setup where the investor increases his awareness about the impact of the plant on the grid and can consequently react.

In terms of investment decision, the prosumer is empowered with more flexibility in managing costs and profits, because he has the possibility to take choices regarding both consumption and

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[8] While referring to the prosumer, we will use prosumption to identify production with the consequent consumption of the energy produce by the prosumer himself, and the verb to prosume to express prosumer's activity

production: the prosumer can decide to change energy consumption path, but also to change the source of the energy consumed, that can come from the photovoltaic plant or from the general grid (and *viceversa*) to satisfy private energy need.

As a producer, the prosumer suffers from the non-programmability of its energy production, that is one of the most important problem in the integration process, but in a smart context there is the possibility of managing the moments in which production is present.

3. Model set up

We consider an agent that has to decide when and whether to invest in a photovoltaic plant. The agent has as a primary target to cover his own energy load but, being connected with the smart grid, it also has the possibility of selling, totally or partially, the energy produced by the photovoltaic plant. In our model, taking advantage of energy management flexibility given by the Smart grid, the prosumer can take choices on how to use energy: he can decide whether to directly use it in *prosumption* (being both the producer and the consumer) or to sell it. From the selling point of view, he decides to sell energy to the grid only when the grid is sending a favorable price signal: in this way, while selling, the prosumer is providing a service to the grid.

The decision to sell to the grid is taken only when it is profitable: in this latter case, the agent keeps the option to call for energy from a national grid at a contractually fixed price. It is not possible for the agent to buy energy from the grid at the price at which he could sell the energy, and this is motivated by the fact that the agent is de facto acting into two separate markets: as a consumer, the agent can buy energy from the grid at the fixed price or *prosume* the energy the photovoltaic plant is providing; as a producer, the agent can be called for a collaborating to grid equilibrium, selling price when the profitable signal price arrives.

Since prosumer's objective is to minimize energy costs, the investment decision will depend on its energy demand and on the ratio between the buying and selling price of energy.

Let introduce some simplifying assumptions:

Assumption 1: Agent's demand of energy per unit of time $t > 0$ (i.e. day, week, month, year...), is normalized to 1 (i.e. 1 KWh, 1 MWh, etc..). This is can be represented as:

$$1 = \xi\alpha_1 + \alpha_2 \quad (1)$$

where $\alpha_1 \geq 0$ is the expected production of the power plant per unit of time, $\xi \in [0,1]$ is the production quota used for *prosuming* and $0 < \alpha_2 \leq 1$ is the energy bought from the national grid.

For example, if we are considering an interval of 24 hours then $\xi\alpha_1 + \alpha_2 \equiv \int_0^{24} l(s)ds = 1$ where $l(s)$ denotes the consumption of energy at time $s \in [0,24]$. In this case α_2 is the quota of the energy demand that must necessarily be bought from the national grid, since it is required during the interval of plant inactivity (i.e. when solar radiations are not available), while $\xi\alpha_1$ is the *prosumed* energy, when the plant is working and producing. This also implies that $(1-\xi)\alpha_1$ is the quota the agent can sell on the local energy market.

Assumption 2: The prosumer is connected to the local market through a smart grid. The prosumer receives information of the selling price at the beginning of each time interval t and, on the basis of this information, it makes the decision on how much of the produced energy to consume and how much to sell in the local market.

Although the smart grid could allow for instantaneous exchange of energy flows and information on energy prices, given the small dimension of the agent, it is reasonable to assume that it's not possible to rapidly changing the consumption pattern $l(s)$, while investing in a PV plant is a long-run decision: this assumption simplify the analysis and does not seems overly restrictive.

Assumption 3: The prosumer cannot buy energy from the local grid.

Again, this is a crucial assumption in our analysis. Although, the possibility that agents produce energy and inject it in the grid is actually one of the reasons for allowing smart grid technologies, here we assume that the reverse is not possible. The market behind the local grid that we are considering is not for direct consumption but for the general management of the electric system. Since there are events in which the demand for power is higher than the supply, i.e. there is less energy on the grid than the requested, the prosumer is called for increase the level of reliability of the system by selling its energy. This helps to reduce system costs caused by unpredictable energy inflows coming from distributed and intermittent energy sources, that made more challenging system balancing activity. Information on grid needs are delivered through the buying price to solve balancing needs, local congestions or sudden black outs.

Assumption 4: Storage is not possible.[9]

According to Assumptions 1-4, if we indicate by c the per-unit fixed contract price (buying price) of energy, a the per unit cost paid to produce energy by the PV plant and v the per unit selling price of energy, we can write the prosumer's net cost of energy per unit of time as:

$$\begin{aligned} C &= \min\left\{c - \alpha_1(v-a),\ \ \xi\alpha_1 a + (1-\xi\alpha_1)c - (1-\xi)\alpha_1(v-a)\right\} \\ &= c - \alpha_1(v-a) + \min[\xi\alpha_1(v-c),\ \ 0] \end{aligned} \tag{2}$$

The first term is the net cost in the absence of self-consumption (i.e. energy is totally sold in the market), the second term indicates the net cost in the presence of self-consumption. Notice that the energy costs paid by the agent depends on the possibility of choosing between selling energy in the

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[9] This is consistent with $\alpha_2 > 0$. In other words, no batteries are included in the PV plant. This reduces managerial flexibilities, since energy must be used as long as produced. Further analysis will investigate the investment decision in the presence of batteries, that generates new investment opportunities for the producer.

market or *prosuming* photovoltaic energy. In the first case, the agent pays c and earns $\alpha_1 v$, minus the production cost of α_1, and the prosumer sells production from photovoltaics in the local market; in the second case, part of the energy produced by the plant is *prosumed* ($\xi\alpha_1$, at the production cost a), part of the energy required $\alpha_2 = 1 - \xi\alpha_1$ is bought at the contract fixed price c and the energy produced but not consumed is sold in the local market at price v.

Since it is always possible for the agent to switch from one mix to the other, depending on energy prices, we can distinguish two cases. Whenever $v > c$ the agent minimizes energy costs by selling to the local grid the entire production, i.e. $\xi = 0.$ Whereas, whenever $v < c$ the agent minimizes energy cost via a positive *prosumption* quota $\xi > 0$.

Further, we assume the marginal cost of internal production of energy $a = 0$ and the buying price c constant over time, while the selling price $v(t)$ is stochastic and driven by the following Geometric Brownian Motion[10]:

$$dv(t) = \gamma v(t)dt + \sigma v(t)dz(t) \qquad \text{with } v(0) = v_0 \tag{3}$$

where $dz(t)$ is the increment of a Wiener process, σ is the instantaneous volatility of the selling market price and γ is the drift, lower than the market discount rate r, i.e. $\gamma \leq r$ .11 By (3), we implicitly assume that $v(t)$ does not depend on the agent's demand, this is again justified by our emphasis on the investment decision of a small prosumer, unable to influence the market.

Finally, we conclude the set up by introducing two more assumptions:

Assumption 5: We assume that $c - \alpha_1 v(t) > 0$ for all $t.$

Assumption 6: The maximum energy demand's quota that can be satisfied by the photovoltaic production is given by $\bar{\alpha} \in [\xi\alpha_1, 1).$

Assumption 5 excludes the possibility that the photovoltaic plant can be used to make profits. In other words, if $v(t)$ is such that $\alpha_1 v(t)$ becomes higher than c the agent will become a producer selling all the energy on the market, not a prosumer, i.e. $\xi = 0,$ and setting α_1 as much high as possible. We assume that the probability for this to happen is negligible.

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[10] Alternative dynamic frameworks may be used, such as mean reverting process. Conclusions would not change, but it would not be possible to determine a closed solution.

[11] The process $dz(t)$ has mean $E(dz) = 0$ and variance $E(dz^2) = dt.$ Therefore, $E(dv(t))/v(t) = \gamma dt$ and $E(dv(t)/v(t))^2 = \sigma^2 dt,$ i.e. starting from the initial value $v_0,$ the random position of the price $v(t)$ at time $t > 0$ has a normal distribution with mean $v_0 e^{\gamma t}$ and variance $v_0^2(e^{\sigma^2 t} - 1)$.

Although households energy management is widely recognized[12] as a priority to reach an overall cost-saving by photovoltaic generation systems, nowadays consumers' load during the day is still particularly high during the evening13 while the quota of energy consumed in the morning and/or in the afternoon is still quite low. Then, if we take the day as unit measure, it is reasonable to assume that $\bar{\alpha}$ will not exceed 30% of total energy demand. This represents a limitation when the agent has to decide the optimal size of the plant: we take into account agent's load curve by setting $\bar{\alpha} = \xi\alpha_1,$ i.e. by fixing $\bar{\alpha},$ the production quota used for *prosumption* ξ is endogenously determined by choosing the plant size $\alpha_1.$ Plant's sizes greater than $\bar{\alpha}$ allow for an increase in the photovoltaic production that can be sold in the market at price v . Active households energy management may increase $\bar{\alpha}$, that may consequently induce investors to install higher size plants.

3.1.The value of the PV plant

According to (2) once installed, the plant allows for a flexible choice between two polar cases:

1. If $v(t) < c$, the prosumer decides to *prosume* part of the energy produced according to its load.
2. If $v(t) > c$, the prosumer decides to satisfy the entire energy demand buying from the national grid provision, and selling the whole energy produced in the local market;

Therefore, for any given $\xi > 0$, the present value of energy costs with the embedded flexibility to switch form self-consuming to "total" selling, is given by the solution of the following dynamic programming problems (Dixit and Pindyck, 1994; Hu and Oksendal, 1998; Moretto, 1996):

$$\Gamma C^0(v(t);\xi,\alpha_1) = -[c - \alpha_1 v(t) + \xi\alpha_1(v(t) - c)], \qquad \mathit{for}\ \ v(t) < c \tag{4.1}$$

and

$$\Gamma C^1(v(t);\xi,\alpha_1) = -[c - \alpha_1 v(t)], \qquad \mathit{for}\ \ v(t) > c, \tag{4.2}$$

where Γ indicates the differential operator: $\Gamma = -r + \gamma v\frac{\partial}{\partial v} + \frac{1}{2}\sigma^2 v^2 \frac{\partial^2}{\partial v^2}$. The solution of the differential equations (4.1) and (4.2) requires two boundary conditions:

$$\lim_{v \to 0}\left\{C^0(v(t);\xi,\alpha_1) - \frac{(1-\xi\alpha_1)c}{r} + \frac{(1-\xi)\alpha_1 v(t)}{r-\gamma}\right\} = 0 \tag{5.1}$$

and

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[12] Ciabattoni et al., 2014, among others.

[13] Looking at the analysis performed by the Italian National Authority in 2009, it is possible to note that the higher peak load asked by the residential demand is concentrated in the evening, between 8.00 and 10.00 p.m. (AEEGSI, 2009)

$$\lim_{v\to\infty}\left\{C^1(v(t);\xi,\alpha_1) - \frac{c}{r} + \frac{\alpha_1 v(t)}{r-\gamma}\right\} = 0, \qquad (5.2)$$

In (5.2.) the term $\frac{(1-\xi\alpha_1)c}{r} - \frac{(1-\xi)\alpha_1 v(t)}{r-\gamma}$ represents the present value of operating costs meanwhile the prosumer uses the PV for self-consumption, wihile in (5.2) the term $\frac{c}{r} - \frac{\alpha_1 v(t)}{r-\gamma}$ indicates the present value of operating costs when selling the whole energy produced. By the linearity of (4.1) and (4.2) and using (5.1) and (5.2) we obtain:

$$C(v(t);\xi,\alpha_1) = \begin{cases} C^0(v(t);\xi,\alpha_1) = \frac{(1-\xi\alpha_1)c}{r} - \frac{(1-\xi)\alpha_1 v(t)}{r-\gamma} + \hat{A}v(t)^{\beta_1} & \text{if } v(t) < c \\ C^1(v(t);\xi,\alpha_1) = \frac{c}{r} - \frac{\alpha_1 v(t)}{r-\gamma} + \hat{B}v(t)^{\beta_2} & \text{if } v(t) > c. \end{cases} \qquad (6)$$

where $\beta_2 < 0$ and $\beta_1 > 1$ are the negative and the positive roots of the characteristic equation: $\Phi(\beta) \equiv \frac{1}{2}\sigma^2\beta(\beta-1) + \gamma\beta - r$ respectively.

The additional terms $\hat{A}v(t)^{\beta_1}$ and $\hat{B}v(t)^{\beta_2}$ represent the value of the option to switch from self-consumption to energy selling if $v(t)$ increases, and the value of the option to switch the other way round if $v(t)$ decreases respectively. Therefore, the constants $\hat{A}$ and $\hat{B}$ must be negative. Finally, when $v(t) > c$, assumption 5 rules infinite profits.

Imposing the value matching and the smooth pasting conditions at $v(t) = c$, we obtain:

$$\begin{cases} \hat{B} = \xi\alpha_1 cB \equiv \xi\alpha_1 c\frac{1}{(r-\gamma)}\frac{r-\gamma\beta_2}{r(\beta_2-\beta_1)} \\ \hat{A} = \xi\alpha_1 cA \equiv \xi\alpha_1 c\frac{1}{(r-\gamma)}\frac{r-\gamma\beta_1}{r(\beta_2-\beta_1)}. \end{cases} \qquad (7)$$

which are always non-positive and both linear in $\xi\alpha_1$.

3.2.The optimal size

Now that we have determined the value of the plant, we are able to calculate its optimal dimension. The opportunity to invest in a photovoltaic system must be considered *vis-à -vis* the alternative that in our case is to satisfy the whole energy demand by buying it from the national grid at the contracted price c. The agent will invest if and only if the plant generates a payoff (in term of lower costs), greater than the status quo. In our case this payoff is simply given by:

$$\Delta C(v(t);\xi,\alpha_1) \equiv \frac{c}{r} - C(v(t);\xi,\alpha_1) = \begin{cases} \frac{\xi\alpha_1 c}{r} + \frac{(1-\xi)\alpha_1 v(t)}{r-\gamma} - \hat{A}v(t)^{\beta_1} & \text{if } v(t) < c \\ \frac{\alpha_1 v(t)}{r-\gamma} - \hat{B}v(t)^{\beta_2} & \text{if } v(t) > c. \end{cases} \quad (8)$$

The agent's problem is to choose the optimal size by maximizing (8) with respect to α_1, net of the investment cost. In addition, since we focus on a prosumer that invests mainly for *prosumption*, i.e. $v(t) < c$, the optimal size is given by:

$$\alpha_1^*(v(t)) \;= \arg\max[\Delta C^0(v(t);\xi,\alpha_1) - I(\alpha_1)] \quad (10)$$

where $I(\alpha_1)$ represents the sunk costs of the plant. We model the cost of the technology as a Cobb-Douglas with increasing cost-to-scale which is quadratic in α_1 , i.e.:[14]

$$I(\alpha_1) = \frac{K}{2}\alpha_1^2. \quad (11)$$

Generally the cost of a PV plant is related to the maximum power of the plant at standard conditions (i.e. power at peak measured in kWp [15]). However, referring to the agent's load curve and the main characteristics of the panel production curve, it is possible to switch from kWp to the average kWh produced16. Therefore, the function (11) captures capital costs (costs of the panels, inverters and cables), the on-going system-related costs (operating and maintenance costs) and insurance, along with the (estimated) amount of electricity produced during the lifetime of the plant, and converts them into a common metric. In addition, to take into account the efficiency losses caused by the

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[14] The sunk cost is assumed to be quadratic only for the sake of simplicity. None of the results were altered if the investment cost is represented by a more general formulation $I(\alpha) = K\alpha^{\delta}$ with $\delta > 1$.

[15] kWp stands for "kilowatt peak", and indicates the nominal power of the plant (or of the panel). It is calculated with respect to specific standard environmental conditions: 1000 W/m^2 light intensity, cell positioned at latitude 35 ° N, reaching a temperature of 25 ° C. (International IEC standard 904-3, 1989)

[16] Continuing with the example of a day, $\alpha_1 = \int_{t_0}^{t_1}[(l \circ s)(t)dt,$ where $(l \circ s)(t)$ is the energy self-consumed and sold at each time t, and (t_1,t_0) is the interval in which the solar plant produces. If we calculate the power at peak as $p = \arg\max(l \circ s)(t)$ and the output load of a panel is sufficiently smoot in (t_1,t_0) we can approximate α_1 by $p(t_1 - t_0)$.

decay of the system during its life -- that can be assumed less than 1% per year [17]- we assume that (11) is convex in α_1

By substituting (11) in (10) and assumption 6, we get:

$$\alpha_1^*(v(t)) \;= \arg\max\left[\frac{\bar{\alpha}c}{r} + \frac{(\alpha_1 - \bar{\alpha})v(t)}{r-\gamma} - \bar{\alpha}cAv(t)^{\beta_1} - \frac{K}{2}\alpha_1^2\right]$$

or:

$$\alpha_1^*(v(t)) \;= \frac{\frac{v(t)}{(r-\gamma)}}{K}, \qquad (12)$$

According to (12), the optimal size is given by the ratio between the expected discounted flow of revenues by an additional unit of capacity (i.e. kWh), divided by the marginal cost of this additional unit. It is worth noting that as α_1 is a function of the current value of the selling price $v(t),$ this should be sufficiently high to make profitable for the prosumer to invest in a plant di dimension higher than $\bar{\alpha}$. Otherwise, since the plant 's size is given by the consumption load pattern (assumption 6), the optimal choice will be setting $\xi = 1$.

3.3. The optimal time to invest

Let's now turn to the optimal investment policy. Denoting by v^* the selling price triggering the investment, the agent's ex-ante value of the plant is given by the solution of the following dynamic programming problem:

$$\Gamma F(v(t)) \;= 0, \qquad \text{for } v_0 < v(t) < v^* \qquad (13)$$

where v^* is the threshold that makes it profitable to invest.[18]

The standard method used in section 4 can also be applied to find the general solution of (13). In particular, assuming that the current value of $v(t)$ is sufficiently low so that immediate investment is not optimal, we obtain:

$$F(v(t)) \;= Mv(t)^{\beta_1} \quad \text{for } v_0 < v(t) < v^* \qquad (14)$$

where $\beta_1 > 1$ is the positive root of $\Phi(\beta)$ and M is a constant to be determined. Imposing the value matching and the smooth pasting conditions at $v(t) = v^*$, we can prove that:

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[17] See Lorenzoni et al., 2009.

[18] Whenever $v_0 < v^* < v(t)$ it would be optimal for the prosumer to invest immediately (i.e., the agent follows the *NPV* rule and the value of the option to wait is null).

Proposition Provided that $v^* < c$, and $\beta_1 < 2,$ the optimal investment trigger is given by:

$$\frac{v^*}{r-\gamma} = \frac{\beta_1 - 1}{\beta_1 - 2}\left(\frac{1}{2}\bar{\alpha}K\right) + \sqrt{\left(\frac{\beta_1 - 1}{\beta_1 - 2}\right)^2\left(\frac{1}{2}\bar{\alpha}K\right)^2 - \frac{\beta_1}{\beta_1 - 2}\frac{\bar{\alpha}c}{r}K} \qquad (15)$$

while the plant's size is:

$$\alpha_1^* = \max\left[\frac{\frac{v^*}{(r-\gamma)}}{K},\ \bar{\alpha}\right]$$

Proof: See Appendix A.

It is important to stress that a necessary condition to induce the agent to invest as a prosumer is that the optimal entry trigger v^* is lower than $c.$ In other words, at the investment time the contracted price of energy (buying price) must be higher than the selling price, otherwise it would be optimal to switch immediately to selling the entire production.

In addition, if v^* is such that $\frac{v^*}{(r-\gamma)}/K < \bar{\alpha},$ the agent will invest in a plant whose dimension is calibrated on the *prosumption* capacity, deciding to sell energy when $v(t) > c.$

Finally, if $\beta_1 > 2,$ the option to sell energy and participate to the local market is so high, that will never be optimal for the agent to became a prosumer, it would be optimal to enter as producer.

4. Possible applications to Italian market: a simulation

4.1. The setting

As described in the previous section the agent can buy electricity at the contracted price c and this price is considered as constant and fixed during the entire investment life. In other words we assume that the prosumer has signed a not modifiable contract with the grid energy provider at the beginning of the period. We also assume that c is fixed over the time, i.e. whenever the prosumer decides to invest, price c doesn't change. These simplifying assumptions partially limit the potential of the model in showing the influence of time in the investing decision.

To complicate the analysis, and better capture the value of time in the investment decision, it is possible to consider c as a stochastic variable, and let it vary over time. If expectations on price c enter the analysis, they might strongly affect the decisions whether or not to undertake the investment and the time to invest. On the one hand, if the energy price c is expected to increase in the future, the opportunity to invest, *ceteris paribus,* becomes more valuable, due to increasing savings obtained by *prosumption*; on the other hand, if price drops are expected, the prosumer might decide to wait and see future price realizations -- and not to kill the waiting to invest option.

In this paragraph, we present model simulation results, taking into account some variables from the Italian market.

- c , fixed buying price, must be representative of the average price paid by residential end consumers.

Referring to year 2013, the average electric energy price paid by the end consumer in the 2013 second trimester was 189 /MWh, and according with the percentages provided by the national authorities (this price is the sum of 99,99 /MWh for energy and supplying services; 27,99 /MWh for grid costs; 36,00 /MWh for general costs; 25,00 /MWh for taxes). Deducing taxes - that are not considered in the model structure - the average price is 163,98 /MWh.

- v is the price at which the prosumer has the possibility to sell energy to the grid: to perform the model, we use as proxy for v Italian zonal prices. We built a dataset starting from hourly data provided by Terna S.p.A.:
  - From each day we extract the interval between 8 a.m. and 7 p.m., assuming that - on average - it can be considered as the interval of photovoltaic activity19 and, as a consequence, the activity interval for the prosumer;
  - We calculate the average price of the "photovoltaic interval" for each day;
  - We calculate the average photovoltaic monthly price from the photovoltaic daily averages.

Before performing the simulations, we tested the series for lognormality and for the Dickey Fuller test for unit root, whose results are needed to apply the model [20]. Considering 59 monthly seasonally adjusted[21] observations of the zonal prices between 2010 and 2014, and following the method described by Chen (2012), we estimated γ and σ for the four geographical areas that are reported in the table.

Variable	**σ**	**γ**
North	32,07%	5,14%
North central	30,35%	4,60%
South	31,12%	4,84%
South central	29,83%	4,45%

Table 1: estimations

Sicily and Sardinia are excluded from the analysis because, being islands, limited connections and peculiarities make price behavior not compatible with the model.

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[19] That corresponds to F1 time-of-use tariff.

[20] See Appendix for test's results.

[21] i.e. Obtained by the residuals of the regression of the variable on 2 monthly dummies, intercept excluded.

- a is the photovoltaic marginal production cost. The minimization of prosumer' s cost function impose to consider the marginal production cost of the produced energy coming from the photovoltaic power plant in case the agent decide to invest: the production input for photovoltaic production - solar radiations - is for free, and marginal production costs for the photovoltaic power plant can be considered close to zero.

Even if no costly inputs are needed to guarantee the production, other costs not included in the initial physical investment, but fundamental along plant life shall be considered: insurances, maintenance, washing and general managing costs influence operations of the plant even in absence of production inputs. The presence of operational costs for the photovoltaic plant will be taken into account in the calculation for the photovoltaic LCOE - levelized cost of energy, a measure that allows for a comparison between different energy sources[22].

- K is the result of the investment costs equation. It strictly depends on the LCOE level we estimate for the territory on which the plant is installed; being solar irradiation one of the critical values to estimate the LCOE level, it's worth to note that for different geographical zones in Italy we should use different LCOE levels. However, many factors impact on LCOE definition, so we assume the same value for the four zones.
- $\bar{\alpha}$ represents the percentage of electric energy consumption that can be concentrate during the photovoltaic by the prosumer, that is obliged to keep the connection with the main grid due to the technical limit that impose to buy energy consumption when the plant is not functioning. The value of $\bar{\alpha}$ could be increased by further smart grid technologies that help to improve energy management.
- T, is photovoltaic investment life, and can be set between 20 and 25 years
- r, can be estimated at a level of about 7%, in a market where:
  - the BTP rate is 2,82% for investment duration equal to 20 years and 3,07% for duration equal to 25 years;
  - market risk is evaluated at 5%;
  - the beta of the photovoltaic sector is estimated at a world level to 0,623, while Italian energy companies normally register higher betas[24].

Considering the investment typology we investigate in the analysis, CAPM is not a proper method to evaluate the rate, but if we start from its result (6%), and consider an increase due to market

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22See, among others, Fraunhofer (2013).

[23] Bloomberg, 2014

[24] See Yahoo finance; "Il Sole 24 ore".

conditions in Italy and investor typology (small residential plant not for profits) we can set the rate between 6% and 8%.

4.2.Plant value and optimal size

In order to test the model, we perform the analysis on the areas of the Italian market north, north central, south and south central, where:

- c , fixed buying price, is set at 160 (/MWh);
- K is the result of the investment costs equation, provided a levilised cost of energy produced by the PV plant equal to 180 /MWh and to 250 /MWh[25];
- γ is equal to the specific value estimated for each area, as reported in paragraph 4.1.

In different scenarios, we shift the parameters:

- $\bar{\alpha}$, Simulations are made for $\bar{\alpha}$ values of 30%, 50% and 70%: the smaller value is quite near to actual percentage of daily energy usage; 50% and 70% will give a measure of the effects of smart tools for energy management, that could enable the prosumer to shift load to the photovoltaic interval;
- T, investment life, equal to 20 or to 25 years;
- r, the interest rate, is set at 7%;
- σ , volatility of the selling price v, that assumes the values 30%, 35% and 40%

Depreciation rate is assumed to be equal to zero.

We perform the simulations after having calculated the K values reported in table 2.

		K			
	t (year)	**North**	**North central**	**South**	**South central**
LCOE=180	20	3.874,64	3.874,64	3.874,64	3.874,64
	25	4.249,16	4.249,16	4.249,16	4.249,16
LCOE=250	20	5.381,45	5.381,45	5.381,45	5.381,45
	25	5.901,61	5.901,61	5.901,61	5.901,61

Table 2: K values for the four geographic areas, T=20, 25, LCOE=180,250 €/MWh

The following table summarizes the values we obtained for v^* and α_1^* for different scenarios in different areas:

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[25] These value are consistent with the related literature for Italy (Fraunhofer 2013, JRC 2013)

NORTH

LCOE=250 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,40	39,56	0,39	38,97	0,39	38,48
20	0,5	0,50	49,96	0,50	49,37	0,50	48,89
20	0,7	0,70	58,07	0,70	57,54	0,70	57,09
25	0,3	0,38	41,28	0,37	40,68	0,37	40,19
25	0,5	0,5	52,08	0,5	51,50	0,5	51,02
25	0,7	0,7	60,48	0,7	59,97	0,7	59,55

LCOE=180 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,47	33,96	0,46	33,39	0,46	32,93
20	0,5	0,60	43,03	0,59	42,43	0,58	41,93
20	0,7	0,70	50,14	0,70	49,55	0,70	49,07
25	0,3	0,45	35,45	0,44	34,88	0,44	34,41
25	0,5	0,57	44,88	0,56	44,28	0,56	43,79
25	0,7	0,70	52,27	0,70	51,69	0,70	51,21

NORTH CENTRAL

LCOE=250 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,41	52,84	0,40	51,73	0,39	50,85
20	0,5	0,51	66,24	0,51	65,15	0,50	64,27
20	0,7	0,70	76,53	0,70	75,54	0,70	74,75
25	0,3	0,39	55,07	0,38	53,96	0,38	53,07
25	0,5	0,50	68,94	0,50	67,87	0,50	67,01
25	0,7	0,70	79,56	0,70	78,63	0,70	77,87

LCOE=180 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,49	45,53	0,48	44,47	0,47	43,63
20	0,5	0,62	57,33	0,61	56,21	0,60	55,32
20	0,7	0,72	66,47	0,70	65,38	0,70	64,51
25	0,3	0,47	47,49	0,46	46,41	0,45	45,56
25	0,5	0,59	59,72	0,58	58,61	0,57	57,71
25	0,7	0,70	69,18	0,70	68,11	0,70	67,25

SOUTH

LCOE=250 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,40	46,89	0,40	46,04	0,39	45,35
20	0,5	0,51	58,98	0,50	58,13	0,50	57,45
20	0,7	0,70	68,32	0,70	67,56	0,70	66,93
25	0,3	0,38	48,90	0,38	48,04	0,37	47,34
25	0,5	0,50	61,43	0,50	60,60	0,50	59,92
25	0,7	0,70	71,09	0,70	70,36	0,70	69,77

LCOE=180 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,48	40,34	0,47	39,52	0,46	38,86
20	0,5	0,61	50,93	0,60	50,07	0,59	49,37
20	0,7	0,71	59,19	0,70	58,34	0,70	57,66
25	0,3	0,46	42,09	0,45	41,26	0,44	40,59

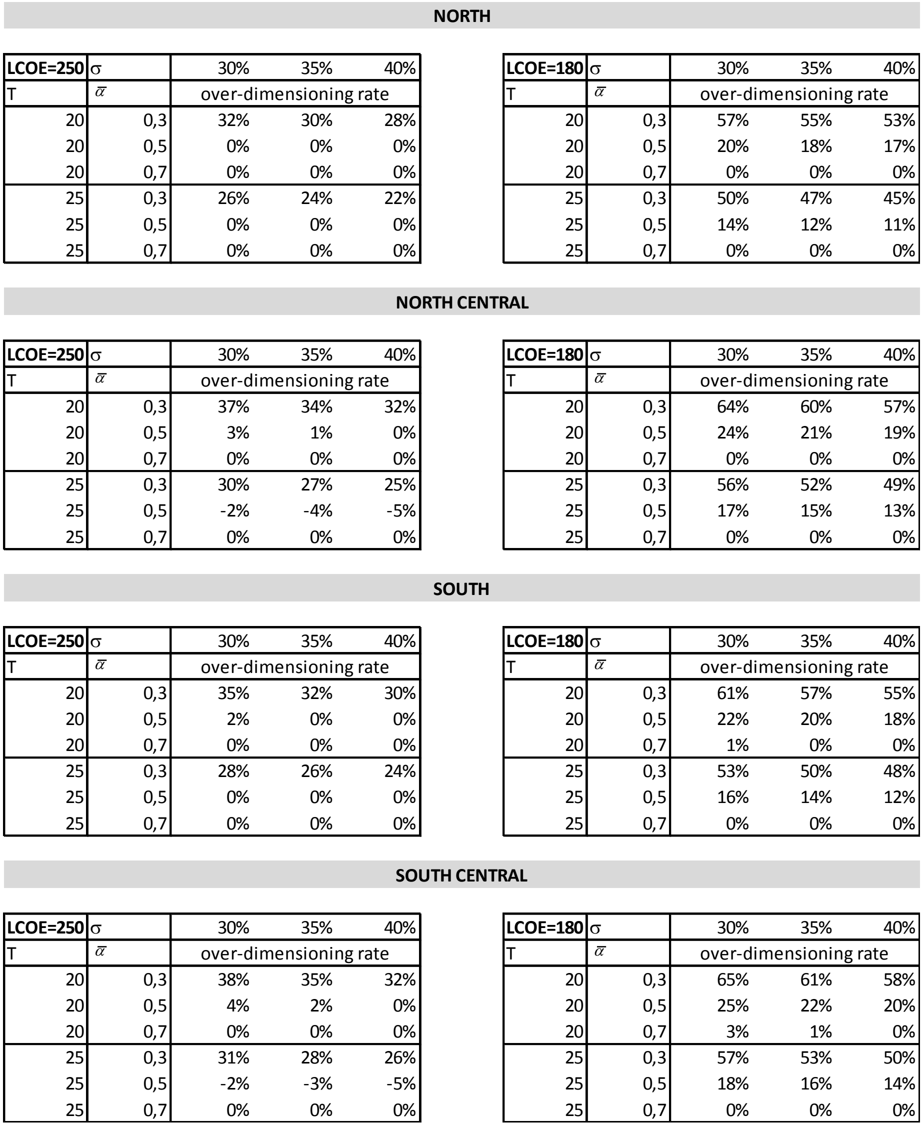
Table 3: optimal size and trigger v – simulations' results

Grey cells represent the cases in which the optimal size of the plant exceeds the capacity of satisfying prosumer's load with the photovoltaic plant (the *prosuming* capacity), meaning that the prosumer is pushed to invest in a bigger plant to participate to the market; when it is profitable to invest, the minimum size is set at the level of $\bar{\alpha}$.

Looking at the results we can observe that:

1. Increasing variance - and, consequently, increasing uncertainty on future revenues coming from energy selling - reduces investment size, forcing the agent to keep the investment smaller, internalizing in the investment decision possible worst case scenarios (low prices due to high uncertainty in the market);
2. Increasing variance, on the other hand, pushes the agent to accept lower entry prices, accelerating the entrance into the market, even if investment size in this case is lower: high variance, indeed, corresponds to high uncertainty that could lead to high selling prices, and that's why the agent can decide to bet on the investment, weighting the risk by investing less.

Measuring as $\frac{\alpha_1^* - \bar{\alpha}}{\bar{\alpha}}$ the over-dimensioning rate in investment decision, decreasing in over-dimensioning is strongly relevant changing $\bar{\alpha}$: for low levels of $\bar{\alpha}$, the over-dimensioning rate is relevant, between 30% and 65%, while increasing $\bar{\alpha}$ the result for over-dimension rate tends to be equal to zero.



NORTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	32%	30%	28%
20	0,5	0%	0%	0%
20	0,7	0%	0%	0%
25	0,3	26%	24%	22%
25	0,5	0%	0%	0%
25	0,7	0%	0%	0%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	57%	55%	53%
20	0,5	20%	18%	17%
20	0,7	0%	0%	0%
25	0,3	50%	47%	45%
25	0,5	14%	12%	11%
25	0,7	0%	0%	0%

NORTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	37%	34%	32%
20	0,5	3%	1%	0%
20	0,7	0%	0%	0%
25	0,3	30%	27%	25%
25	0,5	-2%	-4%	-5%
25	0,7	0%	0%	0%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	64%	60%	57%
20	0,5	24%	21%	19%
20	0,7	0%	0%	0%
25	0,3	56%	52%	49%
25	0,5	17%	15%	13%
25	0,7	0%	0%	0%

SOUTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	35%	32%	30%
20	0,5	2%	0%	0%
20	0,7	0%	0%	0%
25	0,3	28%	26%	24%
25	0,5	0%	0%	0%
25	0,7	0%	0%	0%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	61%	57%	55%
20	0,5	22%	20%	18%
20	0,7	1%	0%	0%
25	0,3	53%	50%	48%
25	0,5	16%	14%	12%
25	0,7	0%	0%	0%

SOUTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	38%	35%	32%
20	0,5	4%	2%	0%
20	0,7	0%	0%	0%
25	0,3	31%	28%	26%
25	0,5	-2%	-3%	-5%
25	0,7	0%	0%	0%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	over-dimensioning rate		
20	0,3	65%	61%	58%
20	0,5	25%	22%	20%
20	0,7	3%	1%	0%
25	0,3	57%	53%	50%
25	0,5	18%	16%	14%
25	0,7	0%	0%	0%

Table 4: plant over-dimensioning rate

This result can be partially explained with the tendency to reduce investment size in uncertain environment, and being the level of *prosumption* high (50% or 70%) it is hard to exceed it; the result, however, points also out that increasing in smart energy management decreases the participation to the smart grid. We already mentioned the "substitution effect" between the real time demand-response and batteries, and the simulation results give the possibility to underline that energy management is a rival for active participation to the grid: the more energy "independent" becomes the prosumer, the less he wants to participate to the grid.

The opportunity to be connected to the smart grid, however, represents the major part of the investment value: the ratio between the value coming from flexibility - represented by $-\bar{\alpha} c A v^{t\beta_1}$ - and the total net present value shows that the flexibility value always represents more than the 90% of the total investment value.

NORTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	93,46%	94,69%	95,45%
20	0,5	95,24%	96,14%	96,69%
20	0,7	96,22%	96,93%	97,37%
25	0,3	93,81%	94,98%	95,70%
25	0,5	95,52%	96,37%	96,89%
25	0,7	96,46%	97,13%	97,53%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	92,09%	93,57%	94,49%
20	0,5	94,14%	95,25%	95,93%
20	0,7	95,27%	96,16%	96,71%
25	0,3	92,50%	93,90%	94,77%
25	0,5	94,47%	95,51%	96,15%
25	0,7	95,55%	96,39%	96,90%

NORTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	94,94%	95,71%	96,20%
20	0,5	96,08%	96,67%	97,04%
20	0,7	96,70%	97,19%	97,49%
25	0,3	95,17%	95,90%	96,36%
25	0,5	96,26%	96,82%	97,17%
25	0,7	96,85%	97,32%	97,61%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	94,06%	94,97%	95,54%
20	0,5	95,38%	96,08%	96,52%
20	0,7	96,10%	96,68%	97,05%
25	0,3	94,32%	95,19%	95,73%
25	0,5	95,59%	96,26%	96,67%
25	0,7	96,28%	96,83%	97,18%

SOUTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	93,82%	94,87%	95,52%
20	0,5	95,21%	96,02%	96,52%
20	0,7	95,97%	96,64%	97,06%
25	0,3	94,10%	95,10%	95,72%
25	0,5	95,43%	96,20%	96,68%
25	0,7	96,16%	96,80%	97,19%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	92,75%	93,97%	94,74%
20	0,5	94,35%	95,31%	95,90%
20	0,7	95,23%	96,03%	96,53%
25	0,3	93,06%	94,24%	94,97%
25	0,5	94,61%	95,52%	96,09%
25	0,7	95,45%	96,21%	96,69%

SOUTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	95,25%	95,92%	96,34%
20	0,5	96,26%	96,78%	97,10%
20	0,7	96,81%	97,24%	97,51%
25	0,3	95,45%	96,09%	96,49%
25	0,5	96,42%	96,91%	97,22%
25	0,7	96,94%	97,35%	97,61%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	94,46%	95,25%	95,74%
20	0,5	95,64%	96,25%	96,63%
20	0,7	96,28%	96,79%	97,11%
25	0,3	94,69%	95,44%	95,92%
25	0,5	95,82%	96,40%	96,77%
25	0,7	96,43%	96,92%	97,23%

Table 4: "Smart" weight on total NPV – simulations' results

If we look at the net present value without the possibility to interact with the grid, evaluating the opportunity of investing at current prices (entering the market with the average v value in 2013[26]), we find out that the optimal plant size has a trigger (NPV=0) that is far lower that the *prosumption* rate.

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[26] See appendix for the average values.

	Optimal dimension without flexibility			
$\bar{\alpha}$	North	North Central	South	South central
0,3	0,10	0,03	0,04	0,01
0,5	0,17	0,06	0,06	0,01
0,7	0,23	0,08	0,08	0,02

Table 5: α** at NPV=0, no flexibility opportunities*

4.3.The role of time

Once calculated optimal investment size and the trigger for the selling price for the three levels of energy management, we compare the net present value at the optimal price and the net present value at current zonal prices, taking as reference of each v the average value for the related zone in 2013. As reported in the table, in the north area the trigger v price was already been reached in 2013 and the difference in net present values is zero. For what regards other geographical zones, energy management opportunities matter in determining optimal trigger price, that is higher than the current price: this makes the net present value at optimal v higher than the net present value at current v levels.

NORTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	0,00	0,00	0,00
20	0,7	0,00	0,00	0,00
25	0,3	0,00	0,00	0,00
25	0,5	0,00	0,00	0,00
25	0,7	0,00	0,00	0,00

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	0,00	0,00	0,00
20	0,7	0,00	0,00	0,00
25	0,3	0,00	0,00	0,00
25	0,5	0,00	0,00	0,00
25	0,7	0,00	0,00	0,00

NORTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	3.421,28	2.931,93	2.383,68
20	0,7	15.615,35	16.319,00	16.582,01
25	0,3	0,00	0,00	0,00
25	0,5	5.432,72	5.197,28	4.837,07
25	0,7	18.860,23	19.992,36	20.574,65

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	0,00	0,00	0,00
20	0,7	5.028,58	4.373,48	3.628,13
25	0,3	0,00	0,00	0,00
25	0,5	0,00	0,00	0,00
25	0,7	7.854,27	7.556,22	7.075,31

SOUTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	1.923,27	1.616,77	1.243,99
20	0,7	10.903,50	11.815,86	12.348,25
25	0,3	0,00	0,00	0,00
25	0,5	3.448,87	3.388,49	3.208,88
25	0,7	13.365,90	14.689,52	15.546,06

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	0,00	0,00	0,00
20	0,7	2.873,71	2.473,71	1.974,65
25	0,3	0,00	0,00	0,00
25	0,5	0,00	0,00	0,00
25	0,7	5.016,86	4.962,88	4.735,40

SOUTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	9.430,84	9.207,59	8.811,06
20	0,7	26.142,99	27.190,09	27.594,95
25	0,3	0,00	0,00	0,00
25	0,5	11.835,06	11.859,40	11.637,17
25	0,7	30.020,42	31.490,12	32.195,10

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$	NPV*-NPV^t		
20	0,3	0,00	0,00	0,00
20	0,5	1.621,26	615,48	-330,36
20	0,7	13.488,58	13.205,23	12.670,63
25	0,3	0,00	0,00	0,00
25	0,5	3.700,60	2.900,12	2.098,22
25	0,7	16.866,10	16.930,99	16.641,58

Table 6: Differences in NPV, comparison between v and v(t). v(t)is equal to average 2013.*

Given the result of the simulation it seems clear that in some zones photovoltaic investments with smart grid participation opportunities will be immediately profitable for the prosumers. It's worth to remember, however, that zonal prices are just proxies for v that will represent a set of system needs - that in the case of zonal prices are mainly connected to congestions.

5. Conclusions

The development of distributed power plant, in the future, shall be managed through a system that allow for a better integration of renewable energy plants, calling for private actions helping grid management. The smart grid environment allows for an instantaneous interaction between the agent and the grid: depending on its needs, the grid can send signals (through prices) to the agents, and the agents have the possibility to respond to the signals having a monetary gain. In this way, the system can allow for better integration of the renewable -- that collaborate in keeping the grid stable -- and for a photovoltaic development without costly monetary incentives.

In this work we want to provide a model for photovoltaic investment evaluation in a Smart Grid scenario. The agent we analyze is a consumer, that shall decide whether to invest in a residential power plant, having *prosumption* as a main target, but having also the possibility to react to grid price signals when profitable. In this way, the grid can take advantage of intermittent plants, and the photovoltaic investor can add a new revenue line to his investment.

Looking at model calibration, we can observe that the threshold selling price v^* and the investment size α_1^* move towards different directions while increasing the expected variance of the selling price: this aspect shall be taken into account while considering how to implement a new market in the smart grid, because the agents could enter the market relatively early, but with low size investments, that allow for low participation of the agent to the new market for managing local grid needs. It is reasonable to expect that in those area where the grid suffers from congestions or high degrees of production unpredictability, the involvement of the prosumers in the grid management could push investments, making agents do an extra effort to provide the grid with private services on response to price signals: in these zones, actually, the prosumer expects to be called more frequently to contribute to grid management i.e. higher prices/higher volatility are expected. On the other hand, we expect zones where energy inflows in favor of the grid are not expected not to be frequent - or poorly remunerated - shall face less private investments in distributed generation, leading to a sort of "optimal positioning" of private investment. This aspect shall be deepen in further analysis, to understand if the Smart Grid could also help investment planning both in regarding optimal location decisions and opportunity to postpone capacity investments.

It is evident that the possibility to participate to grid management represents a big component for the net present value of the photovoltaic investment in the smart grid, and this shall be taken into account to evaluate the Smart Grid itself. The Smart Grid, actually, is made up by a number of improvements in efficiency and values for agents, but for a complete evaluation we need to consider all the effects for the system: this aspect is difficult to handle, but at policy level it could be interesting to evaluate if it is more efficient to build a market where small producers can work for grid stability or to keep the actual market, reinforcing system assets.

Another relevant aspects emerges from model simulations, and it regards managerial flexibility: increasing managerial flexibility, the agent has the possibility to shift its residential load and increase *prosumption* quota. This aspect cause a drop in over-dimensioning rate, making agents reducing the participation in grid management and becoming more "independent": this can also be a solution for the future energy system , with a lot of small agents with their own energy to be managed, but system stability must be preserved.

Especially in the case of photovoltaic prosumers, increasing independence during the production time corresponds to the risk of high peaks in demand when the solar radiation is absent, obtaining exactly the opposite result from the connection to the smart grid. This danger is particularly high where photovoltaic production represents a large component of the *prosumption* activity: this problem shall be investigated in an environment where different sources work together (e.g. photovoltaic and biomass power plants), balancing loads in a virtual grid - finding solutions for equilibria in a micro grid environment.

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7. Appendix

Appendix A - Proof

In order to determine the optimal trigger v^*, we impose the following matching value and smooth pasting conditions:

$$Mv^{*\beta_1} = \frac{\bar{\alpha}c}{r} + \frac{(\alpha_1(v^*) - \bar{\alpha})v^*}{r-\gamma} - \bar{\alpha}cAv^{*\beta_1} - \frac{K}{2}\alpha_1^2(v^*) \tag{A.1}$$

$$M\beta_1 v^{*\beta_1-1} = \frac{(\alpha_1(v^*) - \bar{\alpha})}{r-\gamma} - \bar{\alpha}cA\beta_1 v^{*\beta_1-1} \tag{A.2}$$

where the second equality follows from the fact that $\alpha_1^*(v^*)$ is given by (10). Substituting (12) in (A.1) and (A.2) we obtain:

$$\begin{aligned} Mv^{*\beta_1} &= \frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)^2 + \frac{\bar{\alpha}c}{r} - \frac{\bar{\alpha}v^*}{r-\gamma} - \bar{\alpha}cAv^{*\beta_1} \\ M\beta_1 v^{*\beta_1-1} &= \frac{2}{K}\left(\frac{v^*}{r-\gamma}\right)\frac{1}{r-\gamma} - \frac{\bar{\alpha}}{r-\gamma} - \bar{\alpha}c\beta_1 Av^{*\beta_1-1} \end{aligned}$$

or

$$\begin{aligned} Mv^{*\beta_1} &= \frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)^2 + \frac{\bar{\alpha}c}{r} - \frac{\bar{\alpha}v^*}{r-\gamma} - \bar{\alpha}cAv^{*\beta_1} \\ Mv^{*\beta_1} &= \frac{2}{\beta_1 K}\left(\frac{v^*}{r-\gamma}\right)^2 - \frac{\bar{\alpha}v^*}{\beta_1(r-\gamma)} - \bar{\alpha}cAv^{*\beta_1}. \end{aligned}$$

Consequently:

$$\begin{aligned} \frac{2}{\beta_1 K}\left(\frac{v^*}{r-\gamma}\right)\frac{v^*}{r-\gamma} - \frac{\bar{\alpha}v^*}{\beta_1(r-\gamma)} - \bar{\alpha}cAv^{*\beta_1} &= \frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)^2 + \frac{\bar{\alpha}c}{r} - \frac{\bar{\alpha}v^*}{r-\gamma} - \bar{\alpha}cAv^{*\beta_1} \\ \frac{2}{\beta_1 K}\left(\frac{v^*}{r-\gamma}\right)\frac{v^*}{r-\gamma} &= \frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)^2 + \frac{\bar{\alpha}c}{r} - \frac{\bar{\alpha}v^*}{r-\gamma} + \frac{\bar{\alpha}v^*}{\beta_1(r-\gamma)} \\ -\frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)^2 + \frac{2}{\beta_1 K}\left(\frac{v^*}{r-\gamma}\right)\frac{v^*}{r-\gamma} &= \frac{\bar{\alpha}c}{r} - \frac{\beta_1-1}{\beta_1}\frac{\bar{\alpha}v^*}{(r-\gamma)} \\ \frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)\left[-\left(\frac{v^*}{r-\gamma}\right) + \frac{2}{\beta_1}\frac{v^*}{r-\gamma}\right] &= \frac{\bar{\alpha}c}{r} - \frac{\beta_1-1}{\beta_1}\frac{\bar{\alpha}v^*}{(r-\gamma)} \\ -\frac{1}{K}\left(\frac{v^*}{r-\gamma}\right)\left[\frac{\beta_1-2}{\beta_1}\frac{v^*}{r-\gamma}\right] &= \frac{\bar{\alpha}c}{r} - \frac{\beta_1-1}{\beta_1}\frac{\bar{\alpha}v^*}{(r-\gamma)} \end{aligned}$$

Defining $y = \frac{v^*}{r-\gamma}$ we can reduce the above expression as:

$$f(y) \equiv \frac{\beta_1-2}{\beta_1}y^2 - \frac{\beta_1-1}{\beta_1}(\bar{\alpha}K)y + \frac{\bar{\alpha}c}{r}K = 0 \tag{A.3}$$

From (A.3) we identify two possible solutions:

1) if $\beta_1 - 2 > 0$, the quadratic function $f(y)$ has an upside concavity. Also $f(0) = \frac{\bar{\alpha}c}{r}K > 0$, $f'(\tilde{y}) = 0 \rightarrow \tilde{y} = \frac{\beta_1-1}{\beta_1-2}\bar{\alpha}K > 0$ and $f(\tilde{y}) = \frac{\bar{\alpha}c}{r}K > 0.$ Therefore the graph does not cross the horizontal axis in any points.

We can interpret this result by saying that if the option to sell energy and participate to the market is too high, then the prosumer becomes a PV producer and keeps buying energy from the grid, and maintaining as well the possibility to switch to *prosumption* if selling prices decrease.

2) If $\beta_1 - 2 < 0,$ the parabola has a downside concavity. Yet, $f(0) > 0,$ $f'(\tilde{y}) = 0 \rightarrow \tilde{y} = \frac{\beta_1 - 1}{\beta_1 - 2}\bar{\alpha}K < 0$ and $f(\tilde{y}) = \frac{\bar{\alpha}c}{r}K > 0.$ Therefore, one of the roots is positive and its value is:

$$y^* = \frac{\beta_1 - 1}{\beta_1 - 2}\left(\frac{1}{2}\bar{\alpha}K\right) + \sqrt{\left(\frac{\beta_1 - 1}{\beta_1 - 2}\right)^2\left(\frac{1}{2}\bar{\alpha}K\right)^2 - \frac{\beta_1}{\beta_1 - 2}\frac{\bar{\alpha}c}{r}K}$$

Appendix B - tests

In the model we apply the real option analysis to evaluate the investment in the photovoltaic technology for a prosumer: before performing the simulation using the Italian zonal prices, we must check some characteristics of the monthly photovoltaic prices distribution, to find out whether it is possible to consider their behavior as a Brownian motion.

Lognormality tests

Since the number of our observations is quite small (59 monthly averages for each zone), it is better to check graphical tests representing the distance between the distribution of the logarithm of the variable and the normal distribution. This test is automatically provided by statistic software: here we present those performed by Stata on the monthly averages calculated on the photovoltaic interval between 2010 and the first half of 2014 for the geographical zones North, North-central, South, South-central, Sicily and Sardinia.

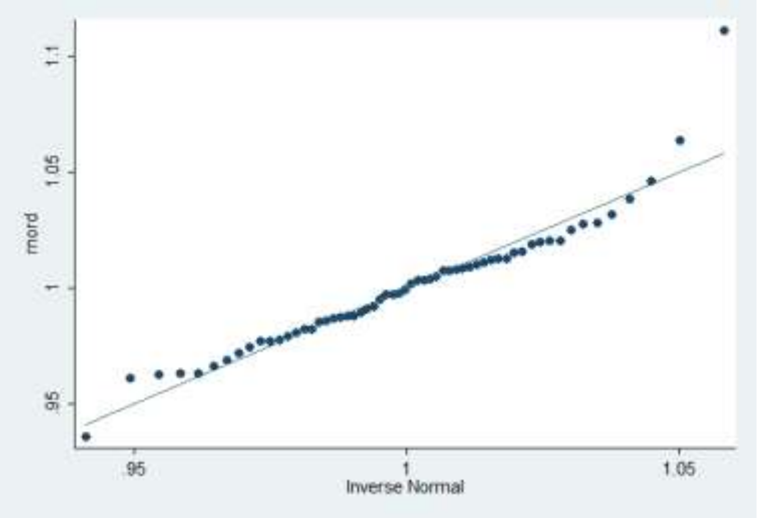


Figure 1.A: normality graphical test for ln of prices in North area

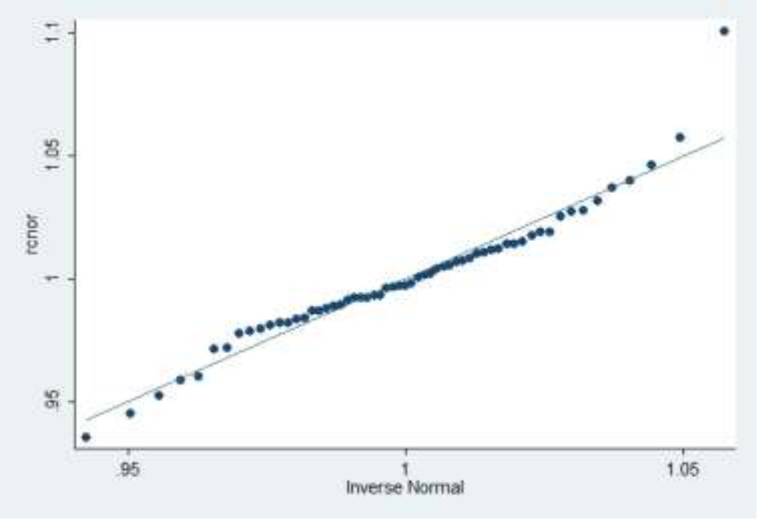


Figure 2.A: normality graphical test for ln of prices in North central area

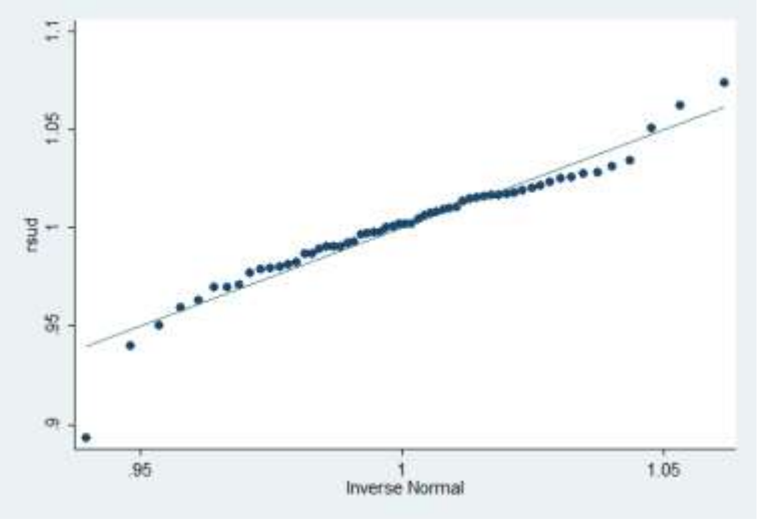


Figure 3.A: normality graphical test for ln of prices in South area

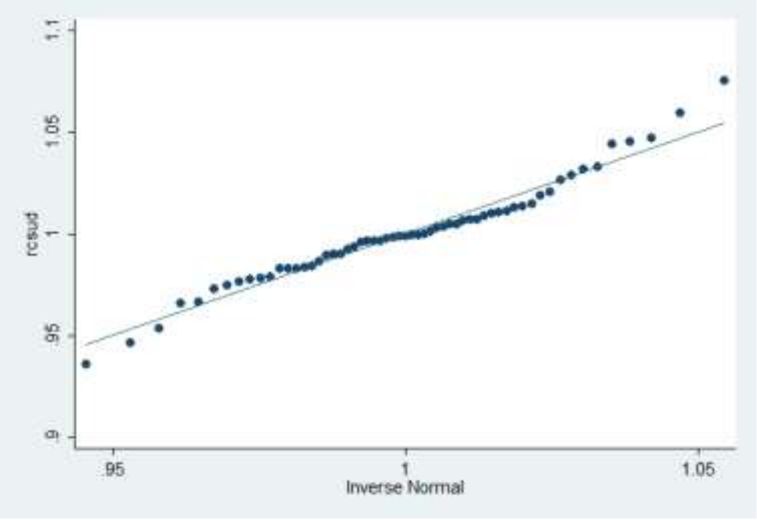


Figure 4.A: normality graphical test for ln of prices in South central area

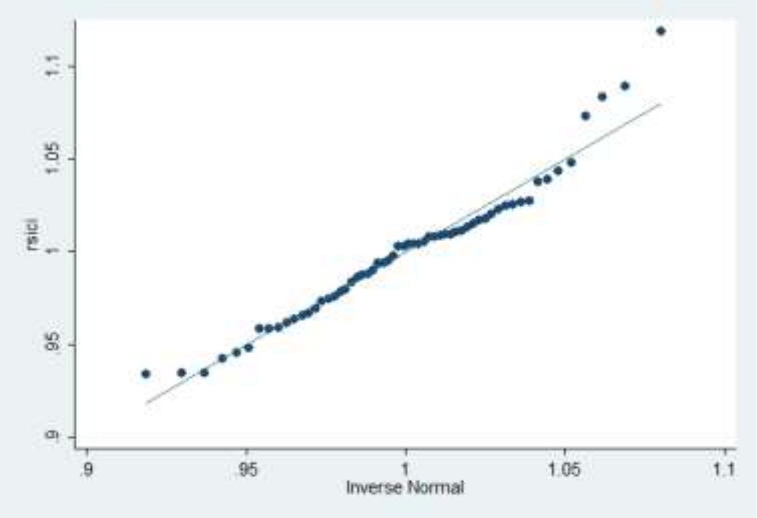


Figure 4.A: normality graphical test for ln of prices in Sicily

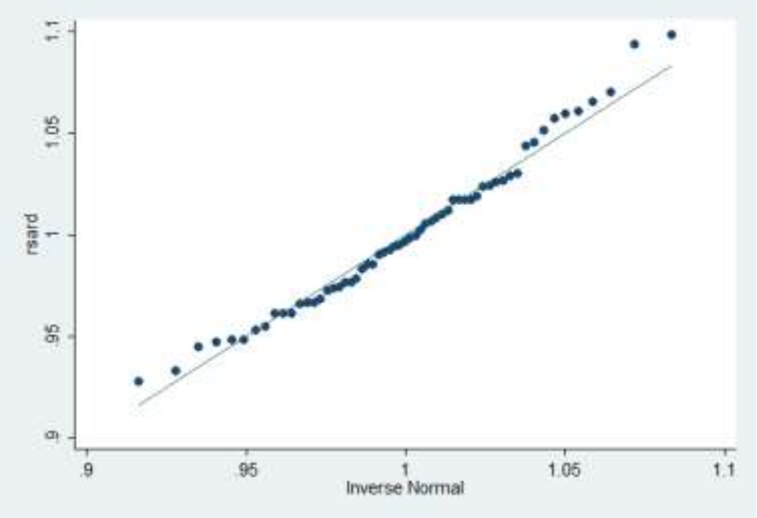
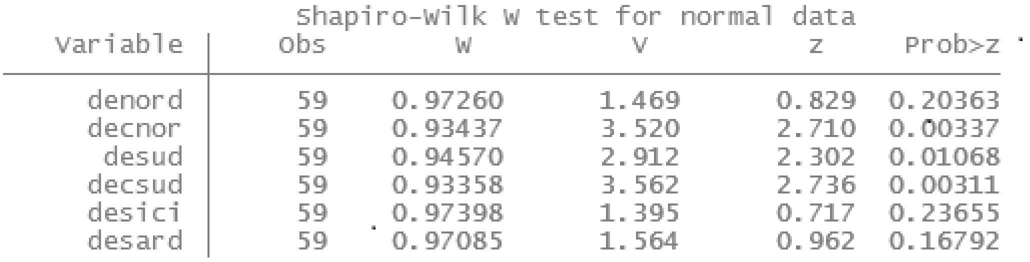


Figure 4.A: normality graphical test for ln of prices in Sardinia

Graphical evidences generally support the hypothesis of lognormality for the variables, even if some of them presents scattered tails. Using the test of Shapiro – Wilk test for normality, graphical evidences has been confirmed.



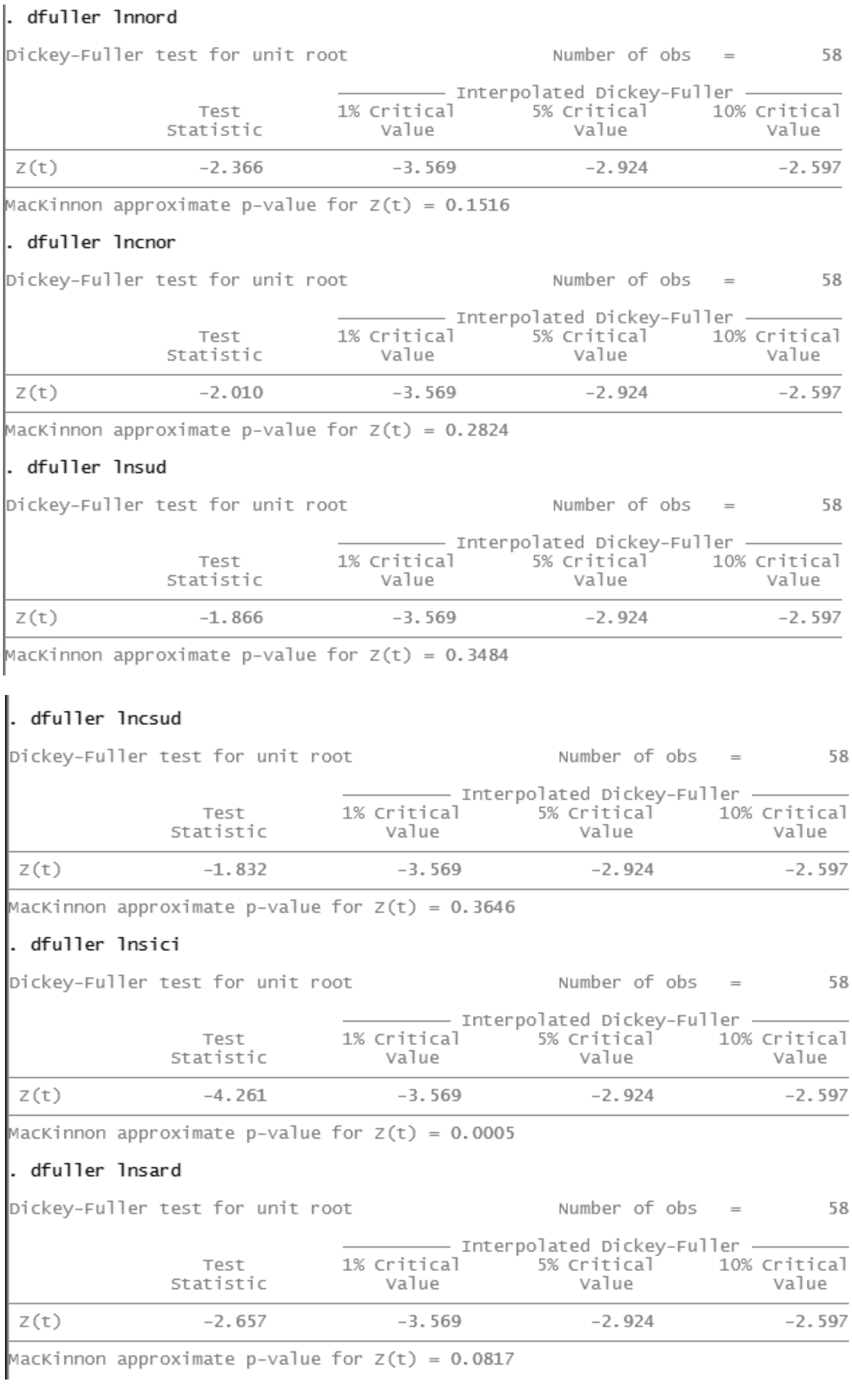
```
                   Shapiro-Wilk W test for normal data
    Variable |    Obs         W           V          z     Prob>z
-------------+-----------------------------------------------------
      denord |     59    0.97260      1.469      0.829   0.20363
      decnor |     59    0.93437      3.520      2.710   0.00337
       desud |     59    0.94570      2.912      2.302   0.01068
      decsud |     59    0.93358      3.562      2.736   0.00311
      desici |     59    0.97398      1.395      0.717   0.23655
      desard |     59    0.97085      1.564      0.962   0.16792
```

Table 1.A: Shapiro-Wilk test: results.

The test shows high value of W (0<W<1), which support the hypothesis of normality. It’s worth note that Sicily, Sardinia and Northern area’ s results are weaker: these can be explained – on one side - with the isolation of Sicily and Sardinia, while for the North it can be hypnotize a strong influence from the neighborhoods.

Dickey Fuller test for unit root

We test the presence of the unit root with the Dickey Fuller test (Table 6.A), automatically provided by the statistic software STATA.



```
. dfuller lnnord

Dickey-Fuller test for unit root                   Number of obs   =        58

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -2.366            -3.569            -2.924            -2.597
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.1516

. dfuller lncnor

Dickey-Fuller test for unit root                   Number of obs   =        58

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -2.010            -3.569            -2.924            -2.597
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.2824

. dfuller lnsud

Dickey-Fuller test for unit root                   Number of obs   =        58

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -1.866            -3.569            -2.924            -2.597
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.3484

. dfuller lncsud

Dickey-Fuller test for unit root                   Number of obs   =        58

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -1.832            -3.569            -2.924            -2.597
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.3646

. dfuller lnsici

Dickey-Fuller test for unit root                   Number of obs   =        58

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -4.261            -3.569            -2.924            -2.597
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0005

. dfuller lnsard

Dickey-Fuller test for unit root                   Number of obs   =        58

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -2.657            -3.569            -2.924            -2.597
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0817
```

Table 2.A: Dickey Fuller test: results.

The results shows that North, north central, South and south central areas can be treated as Brownian motions, while Sicily doesn’t. Sardinia could be accepted, but we decide not to analyze it because of the lack of connections with the rest of the market.

Appendix C - betas

As pointed out in appendix A, when $\beta_1 - 2 > 0$ the *prosumer* invests for profits and starts presuming only if prices go down.

In the simulations we presented, the β_1 is always smaller than 2, and the consumer is interesting in acting as a *prosumer*.

North			
σ	30%	35%	40%
beta1	1,18	1,15	1,13
beta2	- 1,56	- 1,14	- 0,88
North central			
σ	30%	35%	40%
beta1	1,24	1,20	1,17
beta2	- 1,56	- 1,14	- 0,88
South			
σ	30%	35%	40%
beta1	1,21	1,18	1,15
beta2	- 1,56	- 1,14	- 0,88
South central			
σ	30%	35%	40%
beta1	1,25	1,21	1,18
beta2	- 1,56	- 1,14	- 0,88

Table 3.A: Betas calculated for simulations

Appendix D – Different LCOE levels

We report results for a lower LCOE level (100 /MWh), to strengthen the evidence that progress in technology (increase in panels' efficiency) and cost reductions will help the development of bigger plants, at very low trigger prices.

NORTH

LCOE=100 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,61	7,49	0,61	7,45	0,60	7,42
20	0,5	0,78	9,63	0,78	9,59	0,78	9,55
20	0,7	0,92	11,36	0,92	11,31	0,92	11,27
25	0,3	0,58	7,89	0,57	7,85	0,57	7,82
25	0,5	0,74	10,15	0,74	10,10	0,74	10,06
25	0,7	0,88	11,97	0,87	11,92	0,87	11,87

NORTH CENTRAL

LCOE=100 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,70	36,16	0,68	35,11	0,67	34,31
20	0,5	0,89	45,84	0,87	44,65	0,85	43,73
20	0,7	1,04	53,45	1,01	52,19	0,99	51,21
25	0,3	0,66	38,00	0,64	36,92	0,63	36,09
25	0,5	0,84	48,13	0,82	46,91	0,80	45,97
25	0,7	0,98	56,07	0,96	54,79	0,94	53,80

SOUTH

LCOE=100 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,73	44,57	0,70	42,94	0,68	41,72
20	0,5	0,92	56,27	0,89	54,43	0,87	53,03
20	0,7	1,07	65,40	1,04	63,45	1,01	61,97
25	0,3	0,69	46,80	0,66	45,12	0,65	43,86
25	0,5	0,87	59,02	0,84	57,14	0,82	55,71
25	0,7	1,01	68,52	0,98	66,55	0,96	65,06

SOUTH CENTRAL

LCOE=100 **rate 7%**

	σ	30%		35%		40%	
T	$\bar{\alpha}$	α_1*	v*	α_1*	v*	α_1*	v*
20	0,3	0,73	45,70	0,71	43,99	0,68	42,70
20	0,5	0,92	57,68	0,89	55,73	0,87	54,27
20	0,7	1,07	67,00	1,04	64,95	1,02	63,40
25	0,3	0,69	47,99	0,67	46,22	0,65	44,89
25	0,5	0,87	60,48	0,84	58,50	0,82	57,00
25	0,7	1,01	70,19	0,98	68,12	0,96	66,55

Table 4.A: LCOE =100, Simulations' results

Appendix E – v(t) prices

In the simulations we considered the yearly average zonal price as v at time zero.

Yearly average zonal prices				
€/MWh	North	North central	South	South central
2013	63,66	61,60	55,88	59,69
2014	53,21	50,88	47,00	49,65

Table 5.A: Yearly average zonal prices, 2013 and 2014

In table 6.A we present the same simulation with yearly averages calculated for 2014: “smart” component still prevails, while differences between NPV at v* and NPV at v(0) increase, since v(0) is now lower.

NORTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	93,46%	94,69%	95,45%
20	0,5	95,24%	96,14%	96,69%
20	0,7	96,22%	96,93%	97,37%
25	0,3	93,81%	94,98%	95,70%
25	0,5	95,52%	96,37%	96,89%
25	0,7	96,46%	97,13%	97,53%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	92,09%	93,57%	94,49%
20	0,5	94,14%	95,25%	95,93%
20	0,7	95,27%	96,16%	96,71%
25	0,3	92,50%	93,90%	94,77%
25	0,5	94,47%	95,51%	96,15%
25	0,7	95,55%	96,39%	96,90%

NORTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	94,94%	95,71%	96,20%
20	0,5	96,08%	96,67%	97,04%
20	0,7	96,70%	97,19%	97,49%
25	0,3	95,17%	95,90%	96,36%
25	0,5	96,26%	96,82%	97,17%
25	0,7	96,85%	97,32%	97,61%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	94,06%	94,97%	95,54%
20	0,5	95,38%	96,08%	96,52%
20	0,7	96,10%	96,68%	97,05%
25	0,3	94,32%	95,19%	95,73%
25	0,5	95,59%	96,26%	96,67%
25	0,7	96,28%	96,83%	97,18%

SOUTH

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	93,82%	94,87%	95,52%
20	0,5	95,21%	96,02%	96,52%
20	0,7	95,97%	96,64%	97,06%
25	0,3	94,10%	95,10%	95,72%
25	0,5	95,43%	96,20%	96,68%
25	0,7	96,16%	96,80%	97,19%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	92,75%	93,97%	94,74%
20	0,5	94,35%	95,31%	95,90%
20	0,7	95,23%	96,03%	96,53%
25	0,3	93,06%	94,24%	94,97%
25	0,5	94,61%	95,52%	96,09%
25	0,7	95,45%	96,21%	96,69%

SOUTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	95,25%	95,92%	96,34%
20	0,5	96,26%	96,78%	97,10%
20	0,7	96,81%	97,24%	97,51%
25	0,3	95,45%	96,09%	96,49%
25	0,5	96,42%	96,91%	97,22%
25	0,7	96,94%	97,35%	97,61%

LCOE=180	σ	30%	35%	40%
T	$\bar{\alpha}$			
20	0,3	94,46%	95,25%	95,74%
20	0,5	95,64%	96,25%	96,63%
20	0,7	96,28%	96,79%	97,11%
25	0,3	94,69%	95,44%	95,92%
25	0,5	95,82%	96,40%	96,77%
25	0,7	96,43%	96,92%	97,23%

Table 5.A: plant over-dimensioning rate.

NORTH

LCOE=250	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	0,00	0,00	0,00
20	0,5	0,00	0,00	0,00
20	0,7	3.441,82	3.669,60	3.743,49
25	0,3	0,00	0,00	0,00
25	0,5	0,00	0,00	0,00
25	0,7	5.158,59	5.747,65	6.122,93

LCOE=180	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	0,00	0,00	0,00
20	0,5	0,00	0,00	0,00
20	0,7	0,00	0,00	0,00
25	0,3	0,00	0,00	0,00
25	0,5	0,00	0,00	0,00
25	0,7	0,00	0,00	0,00

NORTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	833,82	408,51	0,00
20	0,5	11.091,28	11.581,30	11.760,17
20	0,7	26.297,08	28.373,75	29.656,22
25	0,3	1.788,48	1.478,88	1.140,10
25	0,5	13.091,00	13.835,34	14.202,56
25	0,7	29.528,15	32.033,74	33.635,87

LCOE=180	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	0,00	0,00	0,00
20	0,5	4.599,35	4.281,02	3.862,35
20	0,7	15.765,13	16.481,20	16.753,86
25	0,3	0,00	0,00	0,00
25	0,5	6.327,48	6.221,86	5.960,32
25	0,7	18.574,49	19.648,16	20.185,69

SOUTH

LCOE=250	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	0,00	0,00	0,00
20	0,5	7.296,68	7.857,91	8.166,49
20	0,7	18.375,85	20.504,50	21.992,00
25	0,3	687,58	436,35	160,69
25	0,5	8.811,78	9.619,44	10.121,44
25	0,7	20.825,86	23.366,13	25.178,07

LCOE=180	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	0,00	0,00	0,00
20	0,5	2.374,80	2.149,21	1.841,05
20	0,7	10.395,19	11.210,04	11.664,92
25	0,3	0,00	0,00	0,00
25	0,5	3.685,85	3.667,78	3.522,21
25	0,7	12.523,70	13.685,01	14.411,82

SOUTH CENTRAL

LCOE=250	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	3.424,76	3.107,21	2.747,29
20	0,5	17.311,81	17.943,53	18.158,40
20	0,7	37.126,04	39.371,94	40.634,20
25	0,3	4.565,31	4.359,36	4.077,67
25	0,5	19.705,56	20.585,25	20.974,72
25	0,7	40.991,13	43.660,06	45.222,79

LCOE=180	σ	30%	35%	40%
T	$\overline{\alpha}$	$NPV^{*}-NPV^{t}$		
20	0,3	0,00	0,00	0,00
20	0,5	9.543,78	9.391,43	9.055,77
20	0,7	24.520,64	25.434,30	25.755,70
25	0,3	718,25	139,29	0,00
25	0,5	11.610,74	11.664,15	11.472,79
25	0,7	27.883,55	29.145,99	29.713,00

Table 6.A: Differences in NPV, comparison between v and v(t). v(t)is equal to average 2014.*

IV

Abandoned productive areas: a *smart* way to resettlement

Preliminary analysis[27]

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[27] Developed with the support of the "Radicanti e Ruzantini" foundation in Este (Padova).

1. Introduction

In 2004 in Italy there were about 5.000 sites that needed to be reclaimed, and 7.000 were judged potentially polluted (APAT, 2006). Following the definition of the CLARINET project[28] (in APAT, 2006), brownfield areas are "*sites that have been affected by the former uses of the site and the surrounding land; are derelict or underused; have real or perceived contamination problems; are mainly in developed urban areas; require intervention to bring them back to beneficial use*". Abandoned areas, actually, are much more than those strictly declared polluted.

In 2004, in the Veneto region were registered 42.300 hectares dedicated to production plants, corresponding to 11.503 sites, with an average dimension of 4 hectares that decreases to 2,88 hectares in the Province of Padova (Moccia and De Leo, 2007).

These data give a measure of how much the phenomenon is widespread and scattered on the territory. Limiting the dissertation of the problem to the big criticalities on the territory – the Porto Marghera area, above all - do not allow for a coordinated and effective solution for the issue. What is needed is surely, on one hand, a focused approach to main polluted industrial areas, but also on the other hand, a systematic strategy to handle small abandoned productive areas on the territory, bringing them back to activity and targeting local requalification.

In this work we want to make a preliminary step on the way to resettlement strategy design, looking at abandoned areas as a public resource to be revamped.

Looking at the issue from the public side, a good strategy could be fund in the current of the so called "Smart City" projects, which are registering a lot of success and a wide set of possible applications – even if often just theoretical and vague – that call for a wide use of new technologies and infrastructures for services.

An application that will be able to solve such a big issue, will deserve for sure the definition of *smart*: given the complexity of the problem, the dissertation must be considered as a first preliminary attempt in this sense.

This work starts analyzing the decision process that shall lead public agent's choices while deciding whether to promote the settlement of new productive firms in green sites or to push the same firms to settle on previously abandoned industrial area to be recovered.

Changing industrial configuration, land use issues, and growing concern about environmental sustainability of urban and industrial development have increased the interest for re-using of dismissed industrial areas.

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[28] From the project website: "CLARINET is a Concerted Action of the European Commission's Environment and Climate Research and Development Programme. It's primary objectives are to develop technical recommendations for sound decision making on the rehabilitation of contaminated sites in Europe and to identify research and development needs, in particular in relation to the EC Fifth Framework Programme (FW5)"

Actual economic situation suggest for measures that encourage new settlements, but the need of asking for re-settlement on abandoned areas seems to call for significant subsidization that are not affordable for the most of public entities. On the other hand, asking to entrepreneurs to bear recovery costs heavily limits the economic initiative of the territory.

Being concerned about the economic crisis, looking for recovery of local firms, and being the local authority itself limited on the financial side, there is the risk to push the productive sector "no matter how", conceding the use of land without a serious evaluation of the consequences.

In the following discussion, we want to analyze differences in public value between the settlement of a firm in a green area and the settlement of the same firm in an abandoned productive area; then, private decision is considered too. In the first step of the analysis, we consider the public agent to be fully free of choosing the best place where to collocate the new firm, having in its "portfolio" both green and abandoned productive areas: the choice aims at creating the higher value for the community inhabitant the land controlled by the public decision maker.

Then, we introduce a private agent that wants to start a new firm: the decision-maker, on the basis of previous results, must pushed the private agent to choose the site where the settlement creates an higher value from the community point of view. At this step, distances between public and private view will be analyzed, pointing out critical aspects on which it is necessary to act. We are comparing the results of the analysis with the real situation, with particular reference to the role of different stages and actors involved in the public decision process and the time inconsistency problem affecting decisions.

Concluding, we collect some considerations about incentives and levers the public agent (i.e. the national or the regional government, or local public authorities) own to drive private firm settlement of the territory.

2. The public decision

The recovery of productive areas has become a primary necessity for urban and rural regulation, since land preservation issues and pollution concerns have grown their relevance at different policy levels. However, it must be clarified which process drives the public agent to promote such a policy.

The public decision maker makes the first choice about the settlement of productive firms by determining the destination of use of different sites on its land. In Italy, this moment can be identified with the zoning phase, committed to every municipality on its jurisdiction (Brasson M., 2015).

Among the land dedicated to productive scopes, we can state a distinction between:

- private sites dedicated to productive purpose, on which the regulator can express his will through the release or the denial of authorizations, the impositions of restrictive requirements for the private initiative (as an example, limits for GHG emissions, compulsory installation of purification plants,…), etc.;
- Public sites dedicated to productive purpose, which the public agent has the possibility to stimulate the private market by:
  - Selling the site to private agents;
  - Conceding the site to a private for a limited period of time, at the end of which the site goes back to the public authority (license).

The first critical phase of the decision process for the public agent is the very initial one, when the territory is divided into different zones, and each zone is dedicated to a specific purpose.

The reason why we shall consider as critical the initial phase (and not, as an example, the authorization phase) is that at this stage we already have the theoretical “killing” the options connected to the green areas (Bosetti and Messina, 2000). Deciding which areas to dedicate to productive scope means not only a potential realization, but it is something already happening and which will impede the realization of other different projects on the same area.

When we theoretically think about the process of public decision making, we imagine a public agent that is empowered with all the necessary tools to perform the best choice for its community.

1. The decision process is fully in the hands of the single public decision maker, that means that there is a single level in the public organization, and all the decisions are taken at this level;

2. The public decision maker is deciding where to optimally set a private productive unit which is interested to enter the market, and that considers the land on which the firm will be settled as an input for investment, at a specific cost (to be determined);
3. The decision maker is just positioning the firm, not starting the business – which will be carried out by a private agent;
4. There are no private lands on the market: the public agent must decide which site to sell (or concede) for the new production;
5. The problem is reduce to the decision between two sites:
    - A green site, empty and uncontaminated ("greenfield");
    - An abandoned productive site ("brownfield"), partially occupied by buildings connected to the previous activity and with a certain degree of soil contamination (that, in principle, could also be equal to zero).
6. Both greenfield and brownfield sites have the same "influencing power" towards the surrounding area, meaning that none of them is located at the borders of the influencing area, and positive/negative externalities coming from the sites affect the same amount of inhabitant population.
7. Population is equally distributed on the territory: there are no significantly differences between population neighboring the two sites. For sake of simplicity, we can say that the population is exactly the same in the two cases.
8. While considering the settlement on the abandoned site, we can imagine that the re-use could be carried out through different ways:
    - Re-settlement with total re-use of the existing buildings and productive structure, with costs for renovations;
    - Re-settlement with a partial re-use of existing buildings and structures, with costs for renovations, demolitions and disposals;
    - Re-settlement with no possibility of re-using buildings and productive structures, with full costs for demolitions, disposals and reclamation.

    The public agent considers only the third case, with total change of the site and no possibility for re-using what is still present on the abandoned site. This approach is coherent with the assumption of no business implications for the public decision maker.

    The possibility of re-using depends on business typology. It influences the willingness to pay for the area of a potential private investor. The assumption of total demolition and reclamation is taken to simplify the analysis, but it is not so far from the reality: technological progress, lack of information and asymmetric information, risk connected to renovations are all factors that play a relevant role, often impeding – in the *ex ante* analysis - the re-using of productive structures and existing buildings.

With the acquisition of the site, part of these obstacles to the re-using are eliminated (typically, all what is connected with information lack or asymmetry), but their influence on the positioning decision has already had effect on the decision, i.e. through the willingness to pay of the private agent or on the price offered by the public decision-maker, if it is taking into account risks connected to renovations.

Given the listed assumptions, we can now consider all the relevant elements for the public cost-benefit analysis, that shall drive the decision between promoting the productive initiative on the green area or on the abandoned area to be revamped.

2.1.Public cost benefit analysis

The public decision-maker has the right to promote a new production unit deciding where to settle it: in the following discussion we consider all the relevant elements for the decision between the greenfield ("new", uncontaminated site) and the abandoned productive site, both located on the reference area.

Physical transformation of the site and the productive activity itself will influence the neighboring area and the community inhabiting it, offering new opportunities and benefits, but also causing costs that, in some cases, could be really relevant.

The decision, thus, shall be taken considering the implied set of benefits and costs affecting the community connected to the new activity. The decision-maker shall consider, in the decision, the events affecting all the territory under its influence, and all the stakeholder connected to this territory; looking at the time interval during which the effects of the new activity will take place, it is possible to consider it as infinite, since the general public welfare shall have no limits.

Relevant elements on the benefits side are:

1. Monetary benefit (direct).

   The first aspect that can be identified is the direct monetary benefit coming from the assignment of the right of settlement to the private agent, that sees the site as an input of its productive activity. As all the other inputs, the land will have a price: this price becomes a direct monetary benefit for the public agent.

2. Indirect monetary benefits.

   Firm will be subject to local taxes: the local authority gains benefits from raising more taxes, that can be re-invested on the territory.

3. Positive externalities.

The presence of the firm will create value for the territory, like:

- Employment for local population;
- Call for the settlement of complementary productive activities, with consequent new job and employment opportunities;
- Request for new services.

Looking at the costs connected to the operation, the decision maker must consider:

1. Options killed.

   When the public decision maker decides to put a new green area on the market, it is renouncing to use that area for different purpose.

   A greenfield can become a productive area, but it could also - potentially – become a residential area, with flats or villas, a park, or simply remain a green area: all these alternatives have different values, which can vary depending on the events occurring on the reference area, on the market and on all the significant variables influencing the value. The option value must be considered as a cost in the zoning phase, because possibilities connected to other developments are killed (Bosetti and Messina, 2000).

2. Infrastructures' costs.

   The area must be endowed by infrastructural services, such as:

   - Streets
   - Aqueduct
   - Sewers and sanitation
   - Connections to electric grid
   - …

   These services are usually already present in brownfields, especially when abandoned areas are located close to urban centers or to other productive area.

3. Urbanization costs.

   After the supply of infrastructures, urbanization shall be implemented, providing the area with secondary urban infrastructures, like parking areas for workers. We assume that these costs will be bared by the public agent, even if often in practical cases they are a duty for the private investor: in this case, they will probably be detract from the private agent willingness to pay, reducing the direct monetary costs registered among benefits.

4. Negative externalities.

   Air pollution, soil contamination, noise, traffic and streets congestions, etc. are usually the main variables connected to productive settlements, with different weights, depending on business typology.

The decision between settling the productive firm in a “new” site or in an “abandoned” site must be taken comparing costs and benefits of the two alternatives, giving a measure to variables that are not easily measurable, like externalities. Options value are also an hard element to be investigated, since they strictly depend on future realizations which usually are unpredictable or characterized by high levels of uncertainty.

Comparing greenfield and brownfield, we can say that:

- Direct monetary benefit (price) will reasonably be higher for the greenfield area, because the willingness to pay of the private counterpart for a “new” site is – *ceteris paribus* - higher (see paragraph 3 for deeper comments on this);
- Indirect monetary benefits, in absence of specific policies, will be equal;
- Positive externalities connected to employment and request for new service can be assumed equal in the two case. Brownfield redevelopment causes additional gains in terms of redevelopment and requalification.

Direct monetary gain and positive externalities make the difference in benefits between the settlement in greenfield and brownfield area. Considering public agent time-horizon, the presence of positive externalities shall highly matter for the final balance: the possibility of redeveloping the abandoned area must be carefully appraised, even if it could be hard to let it make the difference in presence of high monetary benefits for the greenfield settlement (higher prices paid by the private investor).

Looking at the costs that occur in the two cases, we have:

- As already mentioned, options are killed in the case of greenfield occupation because all alternative uses are excluded once dedicated the land to the productive scope. The brownfield area, on the other hand, has already lost the original option value owned by the greenfield. Actually, alternatives exist also for redevelopment: as an example, we could decide to change destination from the productive to the residential, especially in case of urban integrated areas. Reconversions of brownfields, however, are usually costly and often affected by restrictions, so the option value is low.
- Infrastructures and urbanization are totally needed by the greenfield, while the brownfield could already be endowed with them. In some cases, infrastructures of the brownfield could be affected by obsolescence, or they could be unsufficient for the new development.
- Negative externalities connected to the productive activity can be assumed equal in the two cases, not changing the business typology for with we are choosing the optimal location.

Opportunity losses and the impossibility of taking advantages from existing infrastructures make the greenfield settlement more costly for the public side.

Results from the cost-benefit analysis strictly depends on the evaluation made on single case, and particularly on the value conferred to the not monetary costs and benefits. In particular, if redevelopment of abandoned areas is considered as a priority by the public agent, value associated to this externality shall overtake other elements in the cost-benefit analysis: public policy can directly drive the result of the evaluation, if the target of redeveloping is clear and strongly pursued.

Once made the evaluation, the public agent knows the value that the two alternatives have for public welfare: among benefits, expectation on direct monetary benefit – i.e. the price received by the private investor that want to settle down on the area must – are calculated. The public agent do not want to impede the productive settlement, but it must create value for collectivity: to send a signal on optimal location to the private investor, the public agent uses the price to buy the price, or the value of the license to use it for a limited period of time.

In determining the site price, from the public point of view:

- Option value lost with the greenfield use must be compensate by monetary benefits, and this makes the price for greenfield rise;
- Positive externalities generated by the redevelopment generate additional value for the public welfare, that compensate lower price for brownfield areas.

The tendency to set the greenfield price higher and the brownfield lower is choice shared by both public and private agents in the market, but with different motivations from the two sides, that often impede to take the best choice.

3. On the private side

Usually, the decision to settle a new firm in a productive site is originated by a private agent (an entrepreneur), that has the possibility to locate the firm on one of the free sites dedicated to the scope by a regulatory document produced by the policy – maker in the zoning phase.

The cost of the site where to settle down is critical in the positioning decision. Moreover, expectations about the preparation of the site, including contingent reclamation costs, and the building phase heavily influence private willingness to pay.

Reclamation costs are all the costs connected to the actions to be implemented on the area before starting the new investment. We address to the category costs for operations like demolitions, disposals, decontamination: these costs, indeed, shall not be confused with preparatory costs linked to any new settlement (digging, land smoothing).

By definition, these costs for new areas are equal to zero, since no polluting activities were set there before, and no existing constructions are present on the site. On the contrary, reclamation costs for abandoned productive areas could vary significantly, depending on the nature of the production previously settled on the area.

Reclamation costs represent a relevant source of costs for the investor and often represent the main obstacle to redevelopment of abandoned areas.

The private agent has expectations on the level of reclamation costs, that often suffer from lack of information about the real situation of the site: the presence of polluting abandoned areas affect also the market of “healthy” abandoned areas that are left outside of the market. The market of the abandoned areas becomes a sort of “Lemon” market, like the one designed by Akerlof (1970) to describe trading results in absence of proper information.

While setting the price for the greenfield and the brownfield, both private and public agent set the brownfield at a lower price and the greenfield at an higher price, but for different reasons:

- The public agent wants to recover the option value lost in dedicating the greenfield to a productive area, cancelling the possibility to use the site for different purpose; moreover, it evaluate the positive externalities coming from the redevelopment of abandoned areas, and this make it set even lower the price for brownfields;
- The private agent suffers from great uncertainty on possible reclamation costs: to determine private willingness to pay for the area, the private agent evaluates different costs scenarios, attributing probabilities to different levels of costs on the basis of the information it has. Private agent implicitly do an option analysis on costs, arriving to calculate the maximum price for the area. Lack of information deeply affect cost evaluation, lowering private willingness to pay, which sometimes determines the impossibility to redevelopment.

Being moved by different reasons in setting the price, private and public side can hardly come to a common result, especially in extreme cases when the option value lost by the public for the greenfield is evaluated to infinite, or and reclamation costs expected by the private for the brownfield tend to overtake investment value.

On the private side, however, decisions on where to set a production pole are influenced by some relevant factors, such as: economies of scale, transportation costs, unemployment rate. Institutions play a relevant role, since they can take decisions on both tangible and intangible infrastructures, that are critical in making economically interesting a specific area (Trigilia, 2006).

Assuming the *ceteris paribus* condition for what regards unemployment rate and economies of scale (i.e. the private investor has no specific interests coming from personal conditions in locating on one place or on the other), differences in infrastructures can make the difference in positioning decision. Schoenbaum (2002) analyzed the effect of redevelopment policies in Baltimora and funds that pollution do not have a systematic relationship with pollution rate, which apparently do not affect land use or land value: this result does not mean that pollution of potential pollution are not influencing locating decision, but it make us think that other elements can affect more firm positioning. Schoenbaum underlines that the presence of public services, transportation and labor force access were affecting land use and land value for firm: this aspect must be taken into account when we want to define policies that drive firm positioning on the territory.

Moreover, the value of infrastructures that we noticed in the public cost – benefit analysis could be the key to find a contact point between public needs and private issues in developing productive areas.

4. “Smart” infrastructures: a way for re-settlement?

Investors are attracted by infrastructure and services while deciding where to developed their business: if the public agent wants abandoned areas to be repopulated, it is necessary to make them more attractive for industries, endowing them with the characteristics that enable new businesses.

Broadband infrastructures, performing mobility, efficient use of energy and shared services that allow for operational savings can be the key for making abandoned areas attractive again.

The current of the so called “Smart City” project can be the right environment where to look for new opportunities for the redevelopment of abandoned productive areas. At the moment, the vocation to the “city” has limited the application focused on the industrial areas: this is particularly true if we think that the critical point is the integration of the services, that can represent the real value for revamped areas.

If, on one hand, reclamation costs have a negative impact on investors’ willingness to pay, the possibility to settle the firm in a “smart” environment where all services are integrated and technological opportunities are higher than in other territories represent a reduction in costs. In particular:

- Smart mobility allows for better connectivity between agents, improving economies of scale;
- Smart waste management services reduces costs related to the treatment of special waste, typical of some productions;
- Smart grid infrastructure, together with renewables integration can reduce energy costs, and this have a particular impact on highly energy-intensive productions;
- …

On the revenues side, broadband enables for the use of business-related tools that increase industrial competitiveness. Improvements can affect not only innovative firms, but also traditional productions, making business development more profitable: this additional profitability shall cover reclamation costs for re-settlement.

The first set of project financed by the Italian Ministry of University and Research (MIUR) show how research on the *smart* city is mainly moving on services to citizens, without caring about productive areas. *Smart* improvements must target productive areas in a strategic and coordinated way, caring about the specific vocation of the site and not providing services in a separate way, but offering a “package” of advantages to potential investors.

The case of 22@Barcelona project (cited in the monographic work of Cassa Depositi e Prestiti, 2013) is a good example of *smar city* requalification approach, with a mix of residential and productive destination, based on the presence of infrastructures for innovative sectors and a number of services that favor a diversified activities. The investment of 180 billion euro for the redevelopment of 200 hectares of land was financed by the local authority, that repaid the investment with real estate operations.

This is a positive example, but it does not fit our purpose. If compared with the scattered shape of abandoned productive areas in Italy, the Barcelona project arise some relevant questions:

- How to adapt a *smart* requalification project to small and scattered requalification needs?
- Is it possible to develop a *smart* requalification by relying on infrastructures and services, leaving to private investors the duty of real estate reclamation?

These aspects shall be deeply investigated, in order to promote a requalification process without having the public agent directly investing on reclamation, but giving the public side the role of facilitator for infrastructures and services.

This approach is needed because the number and the dimension of the abandoned productive areas in Italy will call for too much resources to be redeveloped with a direct intervention: smart replicable models can easily find successful application; moreover, a systematic approach that involves private economic evaluation can prevent the way back to the abandonment of the areas when new opportunities occur - private commitment is relevant for a successful redevelopment.

5. Conclusions

The presence of brownfield areas to be re-developed is a long-run issue for the Italian territory. Beside particularly critical and complex situations - addressed by the government as “location of national interest” for recovery – a great number of small and scattered abandoned areas is present. Provided that using new green areas for productive settlements can have considerable drawbacks in terms of land use, pollution and wasted option values, finding a way for resettlement has become a priority for local authorities.

Private investments in resettling are braked by high uncertainty about reclamation costs to be bared after the acquisition of the area, but can be positively influenced by other institutional factors and by the presence of good infrastructures.

Public authority could drive the settlement towards brownfield areas with a set of strategies.

Given high levels of uncertainty on the market of abandoned areas, the public agent can decide to help the market of brownfield by reducing the uncertainty degree connected to reclamation costs: this can be achieved by providing credible information on land status with studies and analysis, or by guaranteeing the existing information set, e.g. for the pollution degree of the areas.

Small abandoned productive areas, however, are often not affected by high degrees of pollution, but simply affected by obsolescence that make them less attractive for new firms, that want to start an activity that could be really distant to those previously settled. Decisions on positioning are positively influenced by infrastructures and services the private investor can obtain settling down on a certain site. Abandoned areas were originally chosen by industries because of strategic advantages they owned: a way for resettlement can be to create again the conditions for a comparative advantage for the areas.

A way to land re-use, then, is a *smart* application of the *smart* city concept, that is having a wide development and use – or abuse – in local programs can be applied to abandoned areas.

Abandoned industrial areas are often close to urban centers: some applications, actually, reconvert them in urban spaces, changing destinations. But to keep the industrial vocation of the area it is convenient to make it comfortable for industries that need for new infrastructures: investing in ICT infrastructures and services is what can make these areas useful for a kind of industry that could better evaluate to be insert in a urbanized and infrastructure context than in a greenfield, where all services still need to be put in place. Enabling abandoned areas with infrastructures make worth for new industries to bare reclamation costs.

Moreover, infrastructural investments are sunk costs for public agent that send a credible signal to the market, that could be moved to considered the resettlement an opportunity: once the first firms have settled down due to technological advantages, further firms could be attracted in the near sites, both because of the presence of shared services and because of market credibility created by the first investment.

Investments in *smart* infrastructures can give activation energy to the redevelopment process, but a careful political and economic strategy is needed: *smart* infrastructures are costly, and the redevelopment process must be worth to sustain such a cost.

The growing perspective of redevelopment can be a good motivation, since first firms – which bared reclamation costs to take advantage of infrastructures - can call new private investors. Once reclamation costs have been repaid, new firms could be ready to pay for sharing infrastructures: this possible strategy needs to be investigated to evaluate the trigger value of infrastructures compared with real reclamation costs in a limited area.

In a condition of limited resources, however, active investing policies are hard to be put in place: it must be deeply investigated the possibility to design a taxation strategy that drives the market to the use of brownfield areas, putting in place a redistribution scheme that helps redevelopment without suffocating private investors’ initiative.

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