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LOCAL TRADING TO COORDINATE PROSUMERS IN A VIRTUAL ENERGY DISTRICT

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Introduction

The environment, energy and climate change issues represent a huge and urgent challenge, and, therefore, it is essential to identify, in addition to the basic strategy, even the most appropriate instruments to achieve it.

Research in the energy sector is perhaps, the most strategic tool for the worldwide energy policies. Indeed, if properly directed, research and technological progress will induce the changes needed to make economic development compatible with environmental protection. The main research areas to be developed are primarily those which can help to reduce dependence on fossil fuels, to reduce CO_2 emissions and to increase the efficient use of energy. In addition to the development of energy research, it is necessary to integrate and coordinate the strategy of every single Nation and the tools used in the European dimension.

An effective approach may be to assist in the process of European liberalization, currently under construction, specific investment priorities (and/or regulatory and market issues) and adequate tools for their implementation [1].

In this regard, the aim of this Ph.D. thesis fits the current world and national energy situation, explains how the energy sector is evolving towards new scenarios. Indeed, this Ph.D. thesis offers a new vision to better manage an aggregation of user, composed of consumers and small-size producers (able to generate energy for less than 10 MW). The aggregation creates an "energy district", managed in a coordinated way by an aggregator, called City Energy Provider, who organizes the "local market" to optimize the rational use of energy and to integrate very well the renewable resources. The core of this thesis will provide different models to describe the functionalities of the local market: firstly, a simple model will present the idea of “local market”, then, different degree of constraints (limits on transport capacity of lines, cuts on production, use of storage systems with their technical constraints) will be considered. All the models will be tested on practical cases, providing results in terms of amounts of energy managed on local market, recovered from the cut, sold/bought in/out the energy district, stored, with the corresponding economic value for each chosen action.

The core is divided into three sections. In the first section, the current world and Italian energy situation and transformations that the energy sector needs to face will be descripted. Then, in the second section, a description of the Project RES NOVAE thanks to the Ph.D. 3-years period research has been brought, is provided. The last section shows the innovative management strategy for an aggregation of users, especially referring to the possibility to create an energy local market: models and results of the application of these models to real cases will be presented.

1. First Section – Start Points

1.1. World Energy Configuration

It is about from fifty years that attention to environmental issues significantly affect planning policies and development of many countries all over the world. On one hand, more and more different nations participate in worldwide thematic groups and engage in ambitious targets for the pollution reduction and rational and efficient use of resources, to face the climate changes [2-3]. On the other hand, the welfare of a nation is still too often linked exclusively to the industrial development, the objectives of which are often in the opposite direction to the environment care.

In this context, more and more scientists actively promote a 100% renewable energy vision. According to the Intergovernmental Panel on Climate Change (IPCC)'s latest assessment report [4], human population have already used almost 2/3 of carbon budget. At the current and projected rate of consumption, this entire budget will be used by 2040. According to the IPCC, the remaining carbon budget is identified: humankind cannot emit more than 1,000 gigatons of CO_2 from now.

The world's most rigorous scientific bodies agree on climate change, due to a build-up of greenhouse gases, especially carbon dioxide, in the atmosphere caused by human activity. The greenhouse effect is a natural process, in which the atmosphere traps some of the sun's energy, warming the earth and moderating our climate. Increase in 'greenhouse gases' from human activity has enhanced this effect, artificially raising global temperatures and disrupting our climate.

According to the IPCC [4], the United Nations forum for established scientific opinion, the world's temperature is expected to increase over the next hundred years by up to 4.8° Celsius if no action is taken to reduce greenhouse gas emissions - much faster than anything experienced so far in human history [5].

Globally, most fossil fuel is used to generate energy, either electricity, heat, or motor fuel. It is worth to underline that, if unchanged, the growth of fossil energy will lead to unmanageable impacts on the global population. If the world population remains dependent on fossil fuel in the pursuit of energy security, the result will be a potentially catastrophic spiral towards increasing greenhouse gas emissions and more extreme climate impacts [5]. So it is essential that humankind moves rapidly towards a new form of energy supply – one that delivers 100% renewable energy by 2050 [5]. The International Energy Agency (IEA) published an evaluation of the current development of the energy sector in May 2015 (IEA – TCEP 2015) [6], which concluded that the implementation of renewables and energy efficiency is successful but too slow to meet the 2°C target. Here are some of the IEA's conclusions:

- costs: Increasingly, renewables are competitive with new fossil fuel plants, and the cost gap between renewable electricity and fossil power from new plants is closing worldwide.
- policy: Power markets must be redesigned to accommodate variable, distributed renewables.
- technology: Cogeneration and renewable heat, storage,
- mobility: Electric vehicles
- buildings: energy-efficient renovations.

1.2. Demand supply

Fossil fuels are still the primary source providing about 80 % of overall energy needs. They are divided as follows: 34 % oil, 26 % coal and 22 % natural gas [7-12].

The most significant factors that determine the energy demand are on the one hand, the population growth and on the other, the economic growth, as well as the increasing industrialization and urbanization in emerging countries and in those developing. Between 2010 and 2040, the world population will increase from 7.5billions to 9billions of individuals, (Fig.1). This increase will take place exclusively in emerging and developing countries. At the same time, the economy in non-OECD[1] countries will increase by 4.4 % while in OECD countries only 2%. In

[1] Organisation for Economic Cooperation and Development

non-OECD countries, there is enormous need to catch up in economic development and the standard of life resulting in inevitable increase in energy demand. A particularly significant example: while in the US, Eurozone and Japan a data among the 428 and 470 cars per 1,000 inhabitants is reported, in China this data is recorded to 57 and India only 18. In the non-OECD countries, the energy use per capita is considerably lower than the OECD countries. If an American consumes 7 tons of energy a year, an Indian consumes only 0.6.

According to the latest forecasts from 2010 to 2040, the world's energy needs will increase by 35% [7-12]. The increase of energy will register only in emerging countries China and India as well as in developing countries because of the population growth, the economic pulse, the increase of industrialization, urbanization and therefore well-being (Fig.1). In non-OECD countries, however, it is expected, by 2040, a slight recession provided to increase energy efficiency (thanks for example to the production of cars with a reduced fuel consumption).

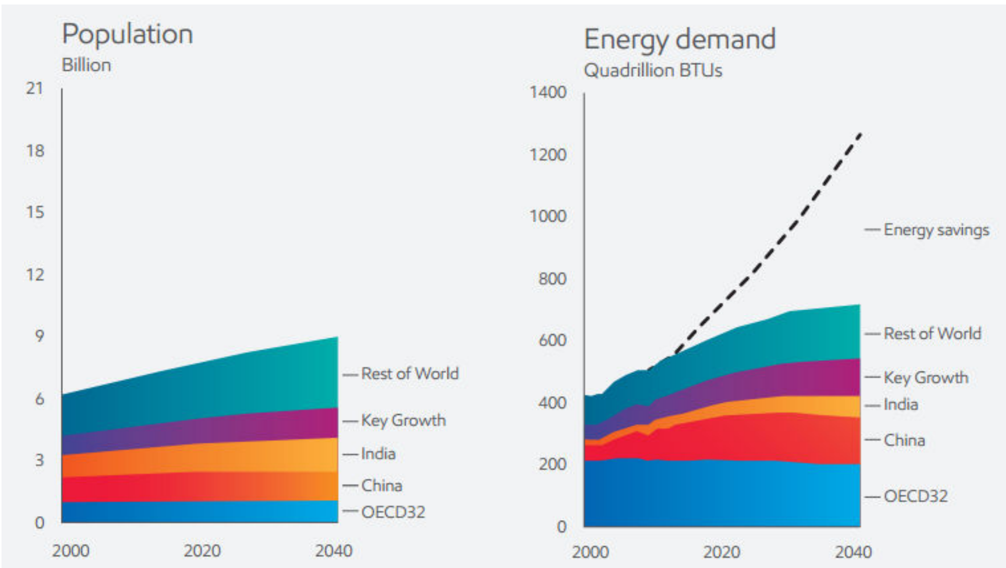

Figure 1: Population Growth and Energy demand (Source: United Nations and [11])

Referring the use of fossil fuels, this is their situation (Fig.2): the use of oil, natural gas and coal will go from 82% in 2010 to 79% in 2025 and 77% in 2040 even though such fuels continue to cover more than a third of global demand. If in 2010 the share of natural gas stood at 22%, in 2025 it will amount to 24% and in 2040 to 27%; the share of coal in 2010 was 26%, in 2040 it will drop to 19 %; the percentage of oil in 2010 was 34, in 2025 and in 2040, 31. The oil will continue, however, to be the main energy source in the world. The increase of methane gas on one side and the decrease of the carbons on the other, are to be considered a positive fact, since combustion gas emits lower quantities of carbon dioxide and other harmful substances and therefore, it is a cleaner alternative to carbon and oils [7-12].

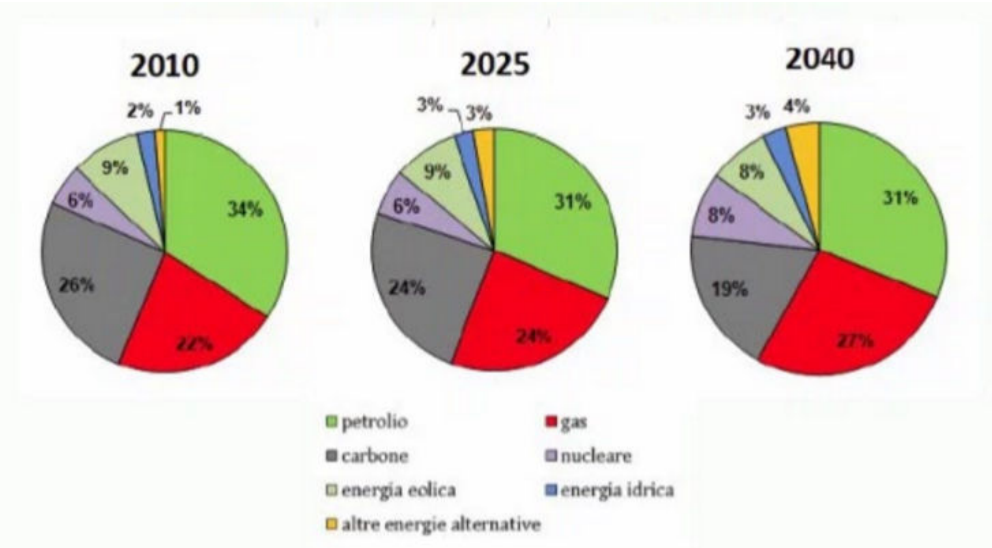

Figure 2: Word energy sector by sources (Source: [12])

Alternative energies (excluding hydropower and biomass energies) will increase substantially, but nevertheless, in 2040 will represent only a modest 4% of the world energy picture.

Looking at the individual economic sectors, the picture that emerges is very different. From 2010 to 2040, the energy demand will increase by 28% in the private and commercial sector, by 35% in industry, and in the transport sector, there will be an increase of 42%. In the latter sector, the oil will continue to play a key role.

In Fig.3, the forecasts of the primary energy trends for the residential/commercial sector, transport and industry between 2000 and 2040 are represented. In the residential/commercial sector, the trend is divided by energy source: it is clear that the bulk of the demand is met by electricity and heat. The trends of primary energy for transportation and industry are characterized by sector of employment.

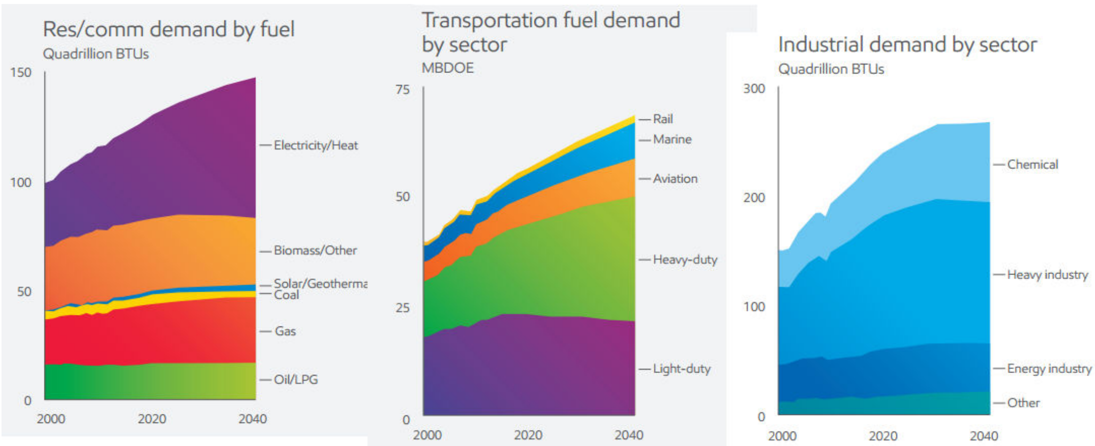

Figure 3: Energy demand for residential/commercial sector, trasportation and industrial sector (Source: [11])

In Fig.4, the forecast of primary energy demand in the residential sector is shown for different countries: it is clear that the countries where the birth rate is very high and economic development is fast, energy demand will be very high, especially in terms of electricity.

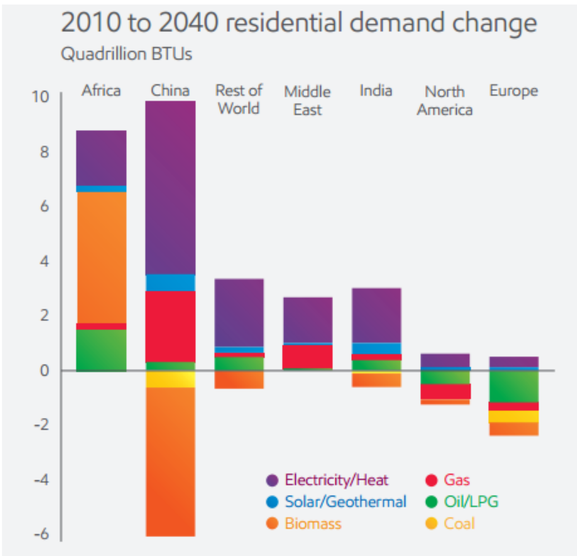

Figure 4: 2010 to 2040 residential demand change (Source: [11])

In the electricity sector (Fig.5), in the coming decades, significant changes in the world will happen. To better understand, a premise is necessary: even today, 1.3 billion people have no electricity. In this sector, higher growth rates are expected: between 2010 and 2040, the 90% at worldwide level, the 163% in non-OECD countries and only 23% in OECD countries. In the energy production, there will be a very high increase of alternative energies. Between 2010 and 2040, the most significant increase will regard wind energy (540%), other alternative energy (188%) and hydropower (80%). Referring to fossil fuels (Fig.5), by 2025 coal will continue to increase slightly and then will decline, while between 2010 and 2040, the gas will increase substantially (78%). The oil, which is used rarely in the electricity production, in the future will become meaningless. In this sector, there is a clear tendency to use clean fuels. Between 2010 and 2040, nuclear energy will increase by 109% [7-12].

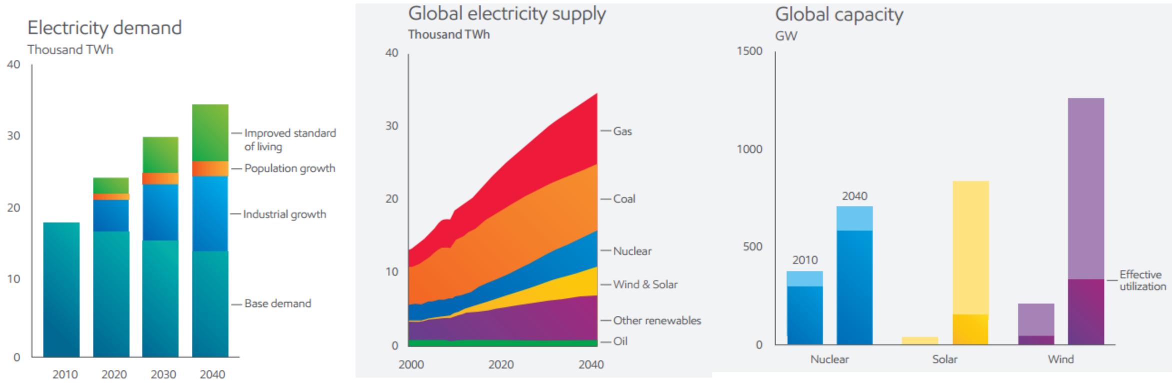

Figure 5: Electricity demand, Global electricity supply per sectors and Global capacity to integrate renewables (Source: [11])

1.3. Renewable sources

Near to fossil fuels, renewables sources should be considered: fortunately, in the last decades they have been used extensively. This happened under the pressure of the continuous scientific researches about the catastrophic consequences of indiscriminate pollution and therefore the awareness of part of the world population to act in the direction of sustainable development [13-22]. In this direction, there have been many international agreements to protect the environment [2-4, 13], which provide a reduction of greenhouse gas emissions in order to contain the 2-degree rise in global temperature by 2040, see Fig.6 [6].

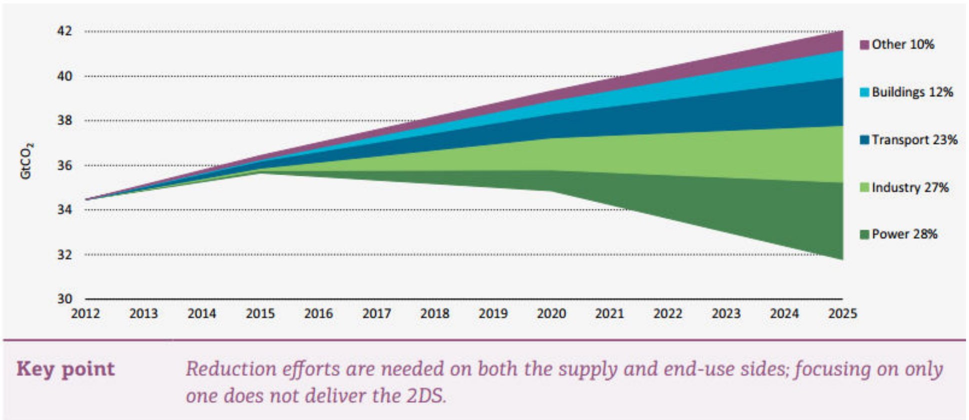

Figure 6: Sector contributions to emission reductions (Source: [6])

The production of energy from renewable sources is therefore the most valuable weapon to achieve the goal. An analysis performed by [5, 22-23], the energy market in Europe since the 70s has been subjected to a radical change regarding the used sources. It is noted that in the last decade, renewables have boomed and contribute significantly (Fig.7).

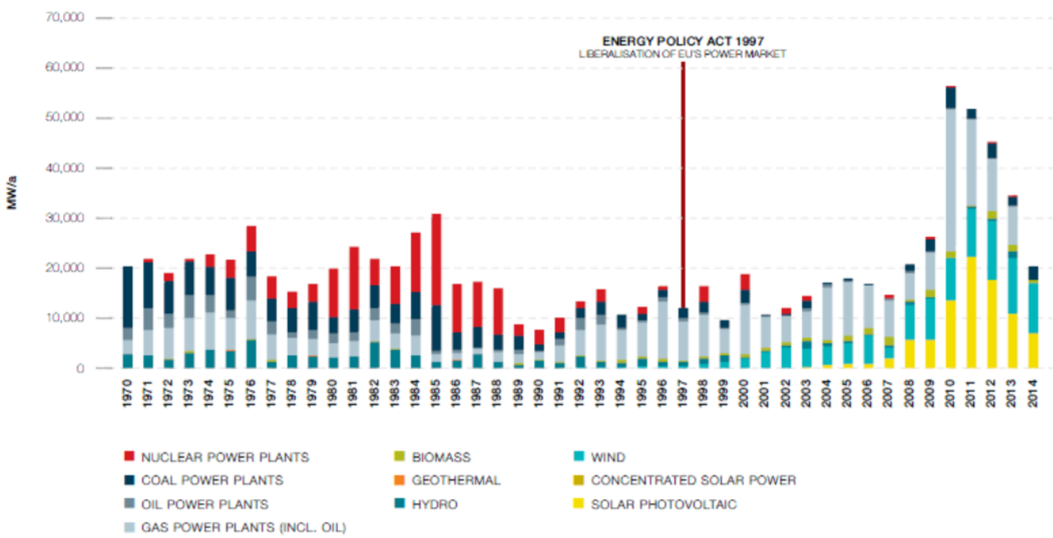

Figure 7: EU annual power plant market: 1970-2014 (Source: Platts, REN21, EWEA, GWEC, EPIA, National Statistics, IEA, Breyer, Greenpeace [5, 22-23])

The Renewable Policy Network for the 21st Century (REN21) has undertaken a global renewable market analysis each year in June since 2004. The publication – "Renewables – Global Status Report" [22] – is among the most comprehensive global and national surveys of the renewable industry sector. According to their latest edition, the global renewable energy market in 2014 was dominated by three power generation technologies: Solar photovoltaics (PV), wind, and hydro. Combined, these technologies added 127 GW of new power generation capacity worldwide.

Other renewable sources contribute as shown in Fig.8: on a total of approximately 19% of contribution by renewable, about the 10% is obtained by modern renewables as hydropower, biofuels, wind or solar or biomass geothermal power and biomass or geothermal solar heat. The other 9% is obtained by traditional biomasses.

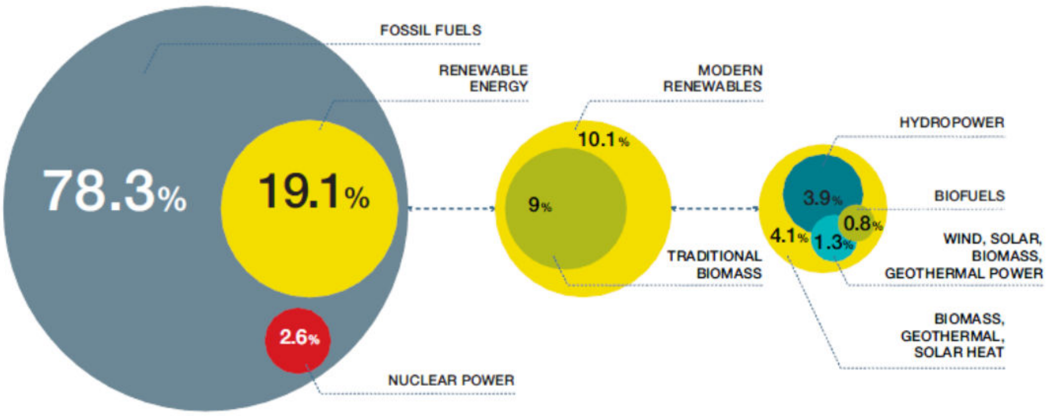

Figure 8: Estimated renewable energy share of global final energy consumption 2013 (Source: [22])

In Fig.9, it is underlined the sharing by renewable sources to product electricity at the end of 2014.

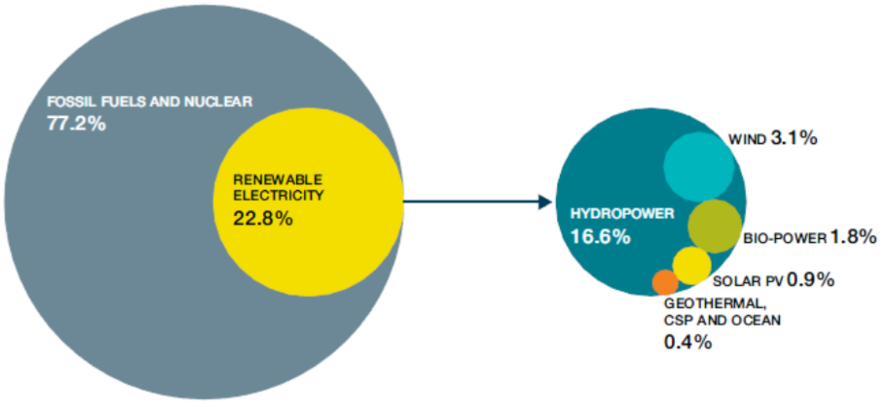

Figure 9: Estimated reweable energy share of global electricity production, end 2014 (Source: [22])

Looking at the distribution by region (Fig.10), in the next decade, renewable sources will be almost stable in countries already heavily industrialized, while a considerable increase will happen in developing countries with strong demographic and economic expansion.

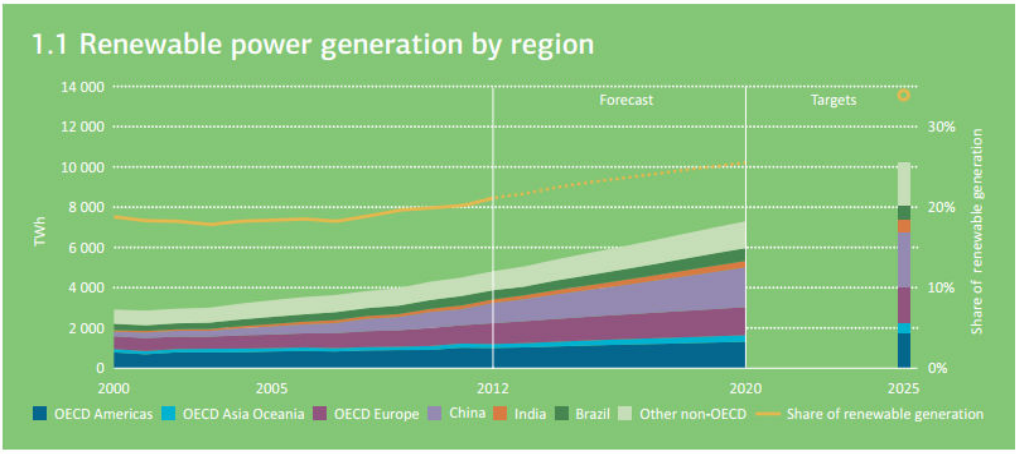

Figure 10: Reweable power generation by region (Source: [6])

1.4. Italian energy configuration

Italy does not fall in the category of countries in which it is expected an increase in the population or a strong economic development. Indeed, following the economic crisis in 2008 that has affected all developed countries, energy demand in Italy has declined: in 2013, the GDP fell by 1.9%, and this reduction is matched by a decline in the 3.0% in primary energy consumption and 3.9% in end-use. Turning to the use of sources, there has been a general decline of fossil fuels, with a greater reduction in percentage of coal (-12.2%), followed by gas (-6.5%) and oil (-5.2%). In contrast, it was confirmed the increase of renewable energy (+15.8%), which covered 15.2% of gross domestic consumption. Again, referring to the production of electricity, the combined effect of the economic crisis and the increased role of renewable energy has heavily penalized the use of fossil fuels (-12%) [24-25].

Table 1 shows the production and use of electricity in the last two years, pointing out that, even in 2013, net production has covered the 87.5% of the national demand with 44.3 TWh of imports, which allowed cover the remaining part of the request.

TABLE I. TERNA ELECTRICITY BALANCE IN 2012-2013 [GWH] (SOURCE: TERNA, [24-25])

	2012	2013(A)	VARIAZIONE %
Produzione lorda	299.276	287.830	-3,8
Servizi ausiliari	11.470	10.450	-8,9
Produzione netta	287.806	277.380	-3,6
Ricevuta da fornitori esteri	45.408	44.331	-2,4
Ceduta a clienti esteri	2.304	2.178	-5,5
Destinata ai pompaggi	2.689	2.389	-11,2
Disponibilità per il consumo	328.220	317.144	-3,4
Perdite	21.000	20.394	-2,9
Consumi al netto delle perdite	307.220	296.750	-3,4
Agricoltura	5.924	5.800	-2,1
Industria	130.801	124.700	-4,7
Terziario	101.038	99.800	-1,2
Domestico	69.457	66.450	-4,3

(A) Dati provvisori.

In a context of significant reduction of total production, the growth of electricity production from renewable sources remains strong (+17% between 2012 and 2013), due to the increase of wind power (+12%), photovoltaic (+19%) and biomass and waste (+12%), but above all for the remarkable contribution, between 2012 and 2013, hydroelectric production (+21%), see Table 2.

TABLE II. GROSS PRODUCTION PER SOURCES 2009-2013 [GWH] (SOURCE: TERNA, AEEGSI)

FONTE	2009	2010	2011	2012	2013(A)
Produzione termoelettrica	219.081	221.808	217.674	205.075	177.540
Solidi	39.745	39.734	44.726	49.141	45.812
Gas naturale	147.270	152.737	144.539	129.058	109.990
Prodotti petroliferi	15.878	9.908	8.474	7.023	6.110
Altri	16.188	19.429	19.935	19.852	15.628
Produzione da fonti rinnovabili	73.561	80.254	84.896	94.201	110.290
Idroelettrico	53.443	54.407	47.757	43.854	53.240
Eolico	6.543	9.126	9.856	13.407	15.000
Fotovoltaico	677	1.906	10.796	18.862	22.400
Geotermico	5.342	5.376	5.654	5.592	5.650
Biomassa e rifiuti	7.557	9.440	10.832	12.487	14.000
PRODUZIONE TOTALE	292.642	302.062	302.570	299.276	287.230

(A) Dati provvisori.

1.5. Integration of Renewables

The production from renewable sources has become important in order to achieve the goals to protect the environment and human life (Fig.11). This has led over the last decades, the free uncontrolled connection to the distribution network of production plants, generally of small size, going to increase what in literature is referred to Distributed Generation (DG) [26].

Indeed, nowadays, the massive presence of DG underlines a number of problems that up to now the electrical system had not had to face.

First, the request for connection of DG is growing and the electricity system that should host it, is old and has limited capacity; also the strengthening of the power system would require substantial investments.

Second, the electrical system has so far been thought for a strictly passive exercise, in which the energy is transmitted from large production plants and arrives to the end user through the network of transmission and distribution network, according to a unidirectional flow. The presence of DG connected to the distribution network allows instead inputting energy from the end user's generator into the electrical system, according to a bi-directional flow.

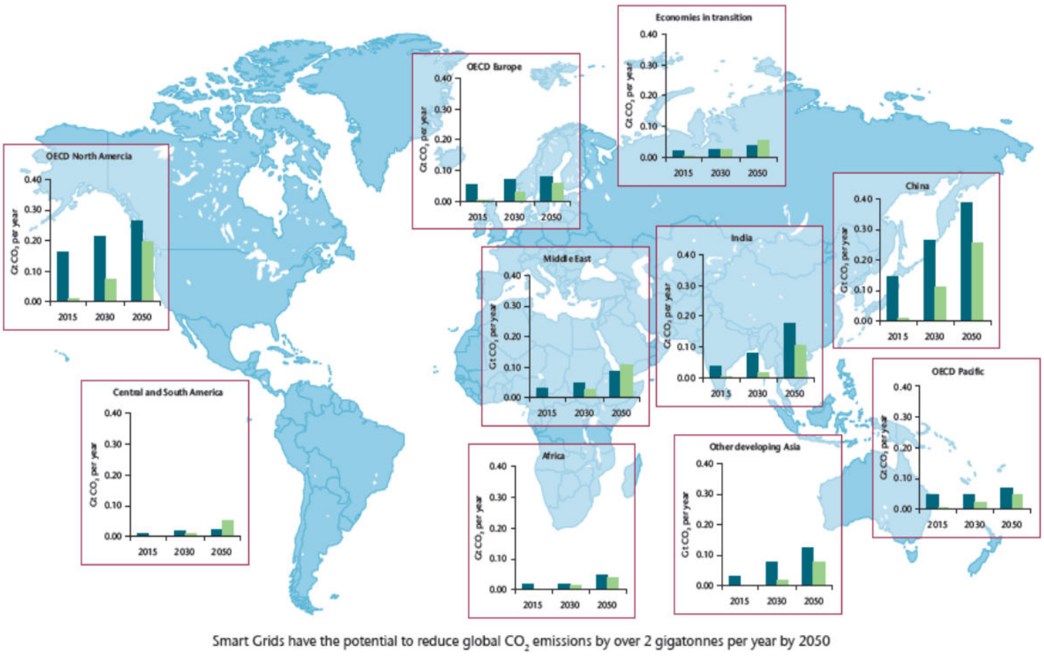

Figure 11: World reduction of CO_2 emissions (Source: [33])

In addition, it must take into account another peculiarity that characterizes some types of renewable sources, that is the non-programmability and intermittent behavior. As penetration of intermittent renewables like wind and solar increases, extra steps must be taken to ensure a reliable flow of electricity to consumers. These steps create additional, often overlooked, costs. For example, additional generating capacity, such as natural gas-fired plants, must be made available to back up wind and solar during the times when the sun is not shining and the wind is not blowing [11].

A massive penetration of DG connected to the MV distribution networks therefore requires the adoption of innovative techniques of network protection against events that may modify its proper operation, as failures or malfunctions of the plants connected to it.

The presence of the DG in size comparable with the local loads may in fact bring to abnormal operation of the protection devices, which may lead to lack of action or untimely tripping [27-29]. Such malfunctions can seriously affect the quality and security of electricity supply to the utilities.

For this reason, the current electricity system is subject to a number of very incisive changes that are leading to be the system autonomous "smarter" in order to resolve any technical problems, to provide auxiliary services to users and network operators, to ensure greater flexibility and security, integrating optimally the systems using renewables. In this way, the whole electrical system is evolving towards new concepts: the network that physically connects the DG becomes *Smart Grid* (SG) [30-35], the user who owns a DG plant will be a *Prosumer* [36-39], the economic platform to prefer to the National Electricity Market will be the *Local Market* [40-43] and new figures will appear as the *Aggregator* [44-47], aimed to manage a cooperation of users (named *Smart Community* [21, 48-52]).

1.6. The Smart Grid

The Smart Grid is the grid of the future. Give an exact definition of it is difficult, because Smart Grid does not means only development of new technologies, but also *optimized* planning and operation of the grids. Indeed, based on sustainable development, supply security and cheapness, Smart Grid includes several concepts referred to new generation forms, new technologies to increase reliability, use of active demand also in collaboration of electricity markets, new energy applications.

Different government organizations have tried to define Smart Grid. Here, the most detailed definition are reported.

The U.S. Department of Energy (DOE) has suggested the definition of smart grid as follows. “An automated, widely distributed energy delivery network, the Smart Grid will be characterized by a two-way flow of electricity and information and will be capable of monitoring everything from power plants to customer preferences to individual appliances. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and enable the near instantaneous balance of supply and demand at the device level” [53].

Canadian Electricity Association has defined smart grid as follows. “The smart grid is a suite of information based applications made possible by increased automation of the electricity grid, as well as the underlying automation itself; this suite of technologies integrates the behaviour and actions of all connected supplies and loads through dispersed communication capabilities to deliver sustainable, economic and secure power supplies” [54].

The Ontario Smart Grid Forum has defined the smart grid as follows. “A smart grid is a modern electric system. It uses communications, sensors, automation and computers to improve the flexibility, security, reliability, efficiency, and safety of the electricity system. It offers consumers increased choice by facilitating opportunities to control their electricity use and respond to electricity price changes by adjusting their consumption. A smart grid includes diverse and dispersed energy resources and accommodates electric vehicle charging. It facilitates connection and integrated operation. In short, it brings all elements of the electricity system production, delivery and consumption closer together to improve overall system operation for the benefit of consumers and the environment” [55].

In Europe, Smart Grid is considered as follows: “A smart grid is an electricity network that can intelligently integrate the actions of all users connected to it—generators, consumers and those that do both—in order to efficiently deliver sustainable, economic and secure electricity supplies. A smart grid employs innovative products and services together with intelligent monitoring, control, communication, and self-healing technologies. Smart grids development must include not only technology, market and commercial considerations, environmental impact, regulatory framework, standardization usage, ICT and migration strategy, but also societal requirements and governmental edicts” [56].

It is worth to underline that in the European definition of Smart Grid, for the first time, “societal requirements and governmental edicts” are mentioned: it means that Smart Grid is not only referred to the world of energy. It means that Smart Grid is a tool to great welfare that begins from energy and arrives to the end-user and the society in its entirely (Fig.12).

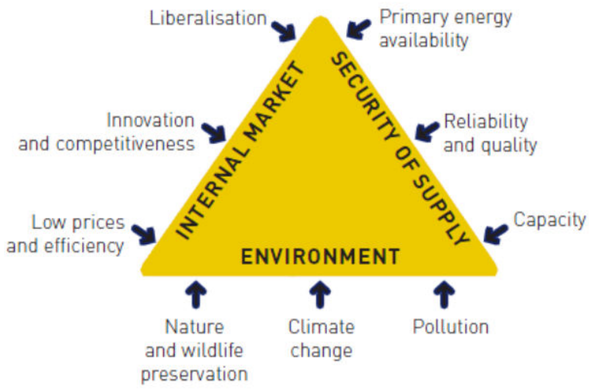

Figure 12: Elements that a Smart Grid tries to integrate (Source: [56])

In general, a smart grid is the combination of a traditional distribution network and a two-way communication network for sensing, monitoring, and dispersion of information on energy consumptions (Figg.13-14).

It must include [30, 34, 53-67]:

(1) improved reliability; (2) ease of repair, particularly remote repair; (3) self healing, automatic repair or removal of potentially faulty equipment from service before it fails, and reconfiguration of the system to reroute supplies of energy to sustain power to all customers [53, 57-58];

(4) increased physical, operational and cyber security and resilience against attack or natural disasters [53, 57-58];

(5) Interactive, appropriate information regarding the status of the system is provided not only to the operators, but also to the customers to allow all key participants in the energy system to play an active role in optimal management of contingencies [58];

(6) increased energy efficiency along with the environmental benefits gained by such efficiency [53, 57];

(7) integration of a greater percentage of renewable energy sources, which can be inherently unpredictable in nature; (8) flexibility: the rapid and safe interconnection of distributed generation and energy storage at any point on the system at any time [53, 57-60];

(9) integration of plug-in electric vehicles;

(10) predictive, that is use of machine learning, weather impact projections, and stochastic analysis to provide predictions of the next most likely events so that appropriate actions are taken to reconfigure the system before next worst events can happen [53, 57-58];

(11) optimization: knowing the status of every major component in real or near real time and having control equipment to provide optional routing paths provides the capability for autonomous optimization of the flow of electricity throughout the system; (12) a reduction in peak demand, [58];

(13) use of information and communications technology to gather and act on information in an automated fashion [57, 52-63];

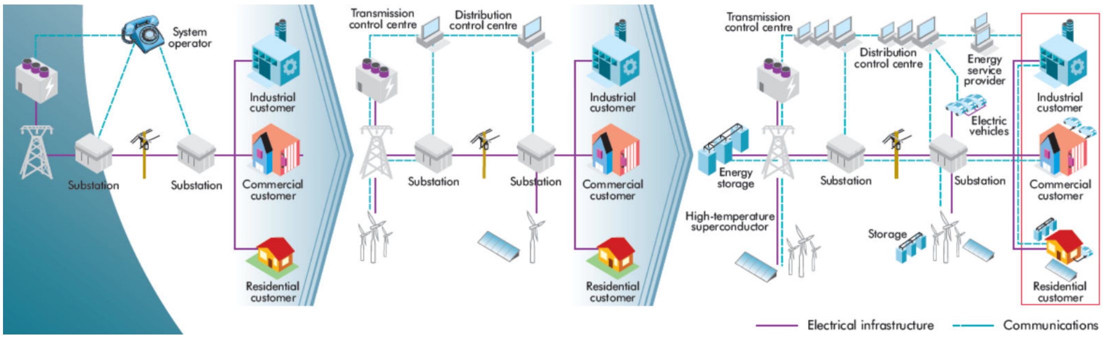

Figure 13: Example of Smart Grid (Source: [33])

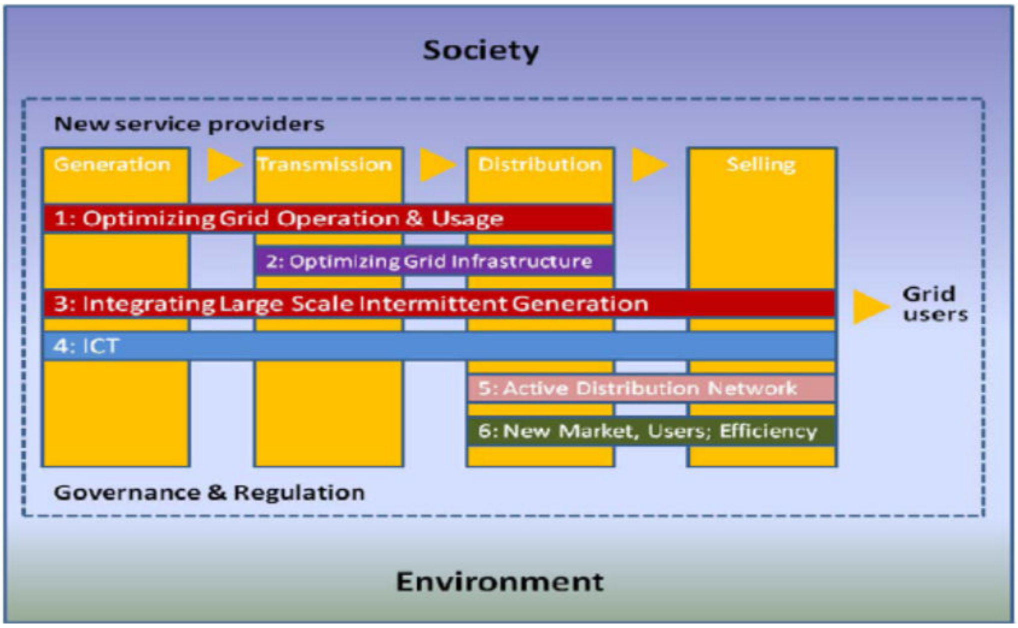

Figure 14: Strategic Document for Europe's Electricity Networks of the Future (European Technology Platform on Smart Grids)

1.6.1. The Smart – MicroGrid

One main feature of the smart grid is the possibility of customer participation in the overall grid energy management. In this way, the customer must have the tools to realize an effective participation. Starting from this need, in a smaller dimension, that is the customer-dimension, it is usually to talk about Smart – MicroGrids, or in general MicroGrid (MG). The MG answers to all the aforementioned requirements, coordinating generation devices, storage systems and electrical/heat loads that are connected to the same low or medium voltage grid, which in turn is connected at the Point of Common Coupling (PCC) to the main distribution grid [69-70].

One specific characteristic of a MG is the possibility to operate either connected to the main grid or islanded from it. This unique feature allows the MG to be disconnected from the main grid when the power quality of the main grid is not satisfactory or when it fails. As a result, the users of the MG will have a higher quality of supply for the loads within it. Furthermore, if the elements in the MG are operated taking into account economic and emission policies, it offers a way of obtaining cheaper and cleaner energy for the users connected to it.

In order to provide energy of the required quality in a secure, economical and clean way the different renewable resources within the MG must be operated in a coordinated and coherent fashion. To that end, a control system for the MG is fundamental. The control system must consider forecasted demand, electricity and fuel prices and the technical constraints on devices to plan and schedule the operating set points and the relationships with the main grid in terms of both market participation and ancillary service provision [71].

In details, the MG includes an LV network, loads (some of them interruptible), both controllable and non-controllable, micro-sources (MS), storage devices, and a hierarchical-type management and control scheme supported by a communication infrastructure used to monitor and control MS and loads. The head of the hierarchical control system is the Micro Grid Central Controller (MGCC). At a second hierarchical control level, load controllers (LC) and micro-source controller (MC) exchange information with the MGCC that manages MG operation by providing set-points to both LC and MC. The amount of data to be exchanged between network controllers is small, since it includes mainly messages containing set-points to LC and MC, information requests sent by the MGCC to LC and MC about active and reactive powers, and voltage levels and messages to control MG switches [72-73].

1.7. The Prosumer

The user who has a Smart MicroGrid is generally known as Prosumer. Indeed, thanks to the possibility to own a small size, generally renewable non-programmable, generation system, as photovoltaic generator, the user changes his behaviour of simple consumer. He now can produce energy, becoming a PROducer and, at the same time, he can consume energy as a conSUMER, that is a *Prosumer*. So, the Prosumer has an active role in the grid operation: indeed, when his own energy production is greater than his consumption, the surplus energy is injected into the grid [34-39, 74].

Many difficulties of nowadays grid management depend on exactly this prosumer's active role: as said before, the impossibility to control non-programmable resources causes several technical disturbances on the entire electrical system and also the increase of the operational costs.

For these reasons, also the prosumer must become "smart": participation of the prosumer into Demand Response (DR) programs and into Demand Side Management (DSM) can gives him a degree of "smartness".

DR is often associated with the short-term changes for the critical hours during a day/year when the demand is high or when the reserve margin is low, whereas Demand Side Management refers to the long-term changes in the electricity consumption achieved through investments in energy efficiency. Demand Side Management is an effort realized by the demand side only to improve energy efficiency. In addition to improving the reliability of the power system, and making short-term impacts on the electricity markets leading to financial benefits for both the utility and the end-users, DR can reduce the system peak load in the long term and therefore postpone the need for building new power plants, leading to considerable environmental impacts [75]. Moreover, DR refers to active participation by end-users in electricity markets, seeing and responding to prices as they change over time [76]. In this way, DR involves end-users to change their normal consumption in electric usage (*their behaviour*) in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized [76-77]. Doing this, DR educates end-users about energy use with time of use (TOU) rates, dynamic rates, and energy use feedback can also produce reductions in end-users' total energy use and cost [78].

So, DR programs in the short period and DSM in the long period, can allow benefits to the whole electricity systems. In general, from an economic-market point of view, DR reduces general costs of energy supply, increases the reserve margin, and mitigates price volatility by means of smart-term responses to electricity market conditions. From an environmental point of view, DR and DMS provide environmental and/or social purposes by decreasing energy usage, defining commitment of not environmentally friendly generation units, leading to energy efficiency augmentation, and/or reduction in greenhouse gas emissions. Network also benefits in DR application by maintaining the system reliability, decreasing demand in a short period of time and reducing extra generation/transmission capacity enhancement [79-81], while the DMS optimizes the power flows in the network, regulates the voltage profiles, acting on reactive flows and tap changers in substation, minimizes the energy losses, reconfigures the network, exploits storage devices and responsive loads in an integrated way [57, 79-82].

1.8. Virtual Power Plant / Energy District

Prosumers participating to DR programs and favourable to DSM applications can really give another degree of smartness to the entire electrical system. It is important to underline that to improve even more the management of the electrical system, every prosumer (or in general user) should not be considered in himself, but all the prosumer of a same area should be considered in an *aggregated* manner.

Why is it necessary to aggregate? Aggregate different kinds of users (consumer, producer and prosumer) can achieve several types of advantages [83]:

- Aggregate various load/generation profiles can reduce the error (that is an imbalance) in the forecasting of the same profiles: a lower error means a lower cost to supply the demand and a higher utility in the sale of energy.
- Aggregate the generation capacity of different users allows to the users to participate in the market sessions: a small single user runs in economic barriers to enter alone in the market.
- Aggregate the users belonging in a limited area can realize other market sessions (as Local Market, explained later), which can allow to users to have more favourable economic condition to buy/sell energy between them.

- Aggregate load and generation profiles and considering the presence of storage systems, can allow to the users of the same area to become provider of ancillary services to the grid.

For these reasons, nowadays it is usually talking about aggregation of user in terms of Virtual Power Plant (VPP) [84-86] or Energy District (ED) [70, 83, 87-90].

The VPP and the ED almost indicate the same thing that is an aggregation of users: the different between the two definitions consists in the context in which VPP and ED are used. Indeed, in literature, VPP is often referred to the technical control, while the ED is frequently related to the management, especially toward the market, of the users' aggregation.

Indeed, from a technical point of view, a VPP, considered as a cluster of dispersed generator units, controllable loads and storages systems, aggregated in order to operate as a unique power plant, is generally classified in term of centralized/decentralized control, hierarchical or not architecture, and so on [91-93]. The communication is bidirectional, so that the VPP cannot only receive information about the current status of each unit, but it can also send the signals to control the objects. The control of VPP can operate according to its targets, which can be, for example, the minimization of the generation costs, minimization of production of greenhouse gasses (GHG) and maximization of the profits. In order to achieve such targets the control of VPP needs to receive information about the status of each unit on the one hand, and on the other hand forecast - especially for renewable units like wind and photovoltaic (PV). Furthermore, the information about the possible bottlenecks in the grid plays a relevant role in the optimization process of the VPP operation, choosing the optimal "modus operandi" [94].

From a management point of view, the Energy District (ED) is a centre of energy consumption and production made of several interconnected prosumers both from the electrical and thermal points of view. The prosumers belonging to the ED are connected with the grid by a unique point of delivery (POD), generally a MV/LV substation, where the exchange with the electrical system takes place in an aggregate form. ED is a coalition of end users that wish to minimize community energy costs.

However, the idea to aggregate residential, commercial and small industrial energy consumers was suggested and promoted by academy [95-96] and government [97] and, rather than conceptual, it is an operational practice in Italy [98].

Such aggregations are mainly nonprofit organizations [99] that provide their members with economic advantages by minimizing energy consumption costs by varying energy usage according to the hourly variations in energy tariffs, with the additional social benefit of decreasing the chances of system overload [100].

1.9. The Aggregator

The management of the aggregation must consider a supervision entity, the “Aggregator”, operating in the name and interest of the whole aggregation. The Aggregator is a no-profit entity, whose task is to collect and coordinate the distributed resources (generation, loads and storage systems), offering energy services to the users’ aggregation, but also to the other participants of the electrical system, through a suitable remuneration [70, 82, 87-90, 101].

In this way, the Aggregator buys the flexibility of the users in terms of load shift/reduction, variation of the injected power into the grid from generators/storage systems, etc. and makes it a negotiable Active Demand (AD) product. Then the Aggregator sells this AD product on the market to the other participants of the electrical systems, that is the Transmission System Operator (TSO) or to the Distribution System Operator (DSO) or the same users [102].

The Aggregator collects, forecasts and manages the distributed energy resources to minimize the energy cost to the flexible users through the AD, and to maximize the input into the grid through the Distributed Generation (DG) and the grid flexibility through the AD.

In details, the Aggregator is able to [103]:

- Collect the flexibility of domestic and small-size commercial users (big-size users, as industrial, generally stipulate particular flexibility conditions in their supply contracts with the distributor) to construct AD products to sell into markets. To do this, Aggregator should perform as a consultant, offering technical and economic solutions to the users to maximize the utility and the flexibility.

- Know the requirements and the opportunities of the AD. Therefore, the Aggregator collects the requirements and the signals from the different participants to the electrical system through the market, to construct the offers that satisfy the participants' needs. The Aggregator knows the geographical position of the consumers and the producers/prosumers and this information is important to match the correct require (e.g. load reduction in a certain section of distribution grid) with the opportune service (e.g. generation increase from renewable sources or discharge storage systems), considering also the technical and economic constraints [45, 104].
- Create utility for all the users of the aggregation and for the subjects out of the aggregation. For example, the users can see paid their flexibility; the DSO can obtain ancillary services to support the grid operation; and so on [105].
- Manage the financial risks linked to the market uncertainties (risks on market prices) and to production/consumption of the prosumers (in terms of quantities to negotiate). In particular, to limit the risk linked to the quantities, the Aggregator should divide the users in groups based on consumption, behaviour, flexibility, identifying clusters of clients. In this way, the Aggregator may foresee the users' reaction to the volume/price signals and may suppose the price-sensitivity [106].

1.10. Local Market

In previous paragraphs, it has been introduced the possibility to create local trades of energy to exchange energy in more favourable economic conditions. Actually, with the spread of small-size DG, two phenomena can be observed: on one hand, the presence of a lot of electrical energy from renewables is sell into national electricity markets at bargain price but this bargain price does not arrive to the end-user who sees his bill unchanged. On the other hand, the number of local producers is increased but they cannot participate to the energy market because the entry barriers to become a supplier are very high [40].

Considering these aspects, in many countries, the idea of a local market rises: in the local market, the energy demand meets directly the energy availability, that is users who need energy, present offers to buy energy, while users who have energy in surplus on their needs, present offers to sell energy. In this way, skipping intermediaries, users may have more economic conditions both in sale and in purchase. Moreover, by an optimized management of local market, also technical problems as grid congestions can be limited [42, 107-108].

Before explain how the idea of local market has been thought (see Section 2), a brief description of Italian Electricity Market and of some consideration about energy costs in Italy are provided.

1.11. The Italian Electricity Market

The Italian Energy Market [109], known also as *Borsa Elettrica*, rises in Italy after the acceptance of Italian low D. Lgs. n. 79/99 (*decreto Bersani*), as part of the transposition of the EU directive on the creation of an internal energy market (96/92/CE). The *Borsa Elettrica* is an essential tool for the creation of a competitive electricity market in Italy and was founded with the purpose of encouraging the rise of transparent equilibrium prices, which allow manufacturers and consumers to buy and sell energy where there is a greater affordability.

From the 1st January 2005, also the participation of active demand programs is starting: all the concerned operators have the opportunity to buy directly from the *Borsa* the energy they need, with the requirement to program on an hourly basis its energy withdrawal profile.

From the 1st November 2008, the *Gestore dei Mercati Energetici* (GME) introduced the Forward Electricity Market (*Mercato a Termine dell'Energia* - MTE) to allow trading of electricity in time horizons longer than those offered by traditional daily markets. In accordance with the Art.17 of Allegato A - AEEG Resolution no. 111/06, GME also manages the Electricity Account Registration Platform *(Piattaforma dei Conti Energia a termine* - PCE), which is the platform through which operators, which have concluded bilateral contracts outside the bidding system, register the commercial bonds and declare its electricity injection and withdrawal profiles, to perform under those contracts.

The main actors involved in the operations of the electrical system, each with a specific role expressly defined by legislation, in addition to the Italian Parliament and the Italian Government, are:

- the Ministry of Economic Development (MSE) , which defines the guidelines for strategic and operational safety and cost-effectiveness of the national electricity system;
- the *Autorità per l'energia elettrica, il gas ed il sistema idrico* (the Italian regulator, AEEGSI), which guarantees the promotion of competition and efficiency in the sector, with functions of regulation and control;
- Terna S.p.A, which manages the national transmission network and the electricity flows through the dispatching, that is balancing the supply and demand of energy, 365 days a year, 24/7;
- The Energy Services Operator (*Gestore dei Servizi Energetici* - GSE) , which withdraws CIP6 energy production and manages their sale on the market,
- The Single Buyer (*Acquirente Unico* - AU), which acts to ensure the electricity supply in Standard-Offer Market (*servizio di maggior tutela*) Customers service and in Safeguard Customers service;
- The Energy Markets Operator (*Gestore dei Mercati Energetici* - GME), which organizes and manages the electricity market, under criteria of neutrality, transparency, objectivity and competition between producers.

The energy trading, aimed to plan of production and consumption units, is held by GME, which organizes and manages the Energy Markets, consisting in:

- the Day-Ahead Market (*Mercato del Giorno Prima – MGP*), venue for the trading of electricity supply offers and demand bids for each hour of the next day. All electricity operators may participate in the MGP. In this market, supply offers may only refer to Injection and demand bids only refer to Withdrawal.
- the Intraday Market (*Mercato Infragiornaliero - MI*), venue for the trading of electricity supply offers and demand bids, in respect of each hour of the next day, which modify the Injection and Withdrawal Schedules resulting from the Day-Ahead Market.
- the Ancillary Service Market (*Mercato dei Servizi di Dispacciamento - MSD*), venue for the trading of supply offers and demand bids in respect of ancillary services. Terna S.p.A. uses this market to acquire resources for relieving intra-zonal congestions, procuring reserve capacity and balancing injections and withdrawals in real time. Participation in the MSD is restricted to units that are authorised to supply ancillary services and to their Dispatching Users. The MSD produces two separate results:
  1) the first result (Ex-Ante MSD) concerns Offers/Bids that Terna S.p.A. has accepted on a scheduled basis for relieving congestions and creating an adequate Reserve margin;
  2) the second result (ex-post MSD or Balancing Market (*Mercato di Bilanciamento – MB*)) concerns Offers/Bids that Terna S.p.A. has accepted in real time for balancing injections and withdrawals (by sending balancing commands).
- the Forward Market, venue where Forward Electricity Contracts with delivery and withdrawal obligation are traded.
- the Account Registration Platform for physical delivery of financial contracts concluded on financial derivatives market (IDEM) organised and managed by Borsa Italiana S.p.A.

Unlike other European energy markets, the market of the GME is therefore not a purely financial market aimed only to the determination of prices and quantities, but it is a real physical market where physical injection and withdrawal programs are defined.

1.11.1. Brief analysis of electricity costs in Italy

The sale by the Borsa Italiana is expected to lead to a lowering of the purchase price of electricity to the end-user. Actually, this does not always happen. Indeed, Italy suffered a differential in average prices of energy products with major European countries and this condition results in higher energy prices than the average (see Fig. 15). The causes of these differences are many and not always clearly identifiable, ranging from tax levels to infrastructure deficit, the composition of the energy mix in unfavorable market mechanisms. For the purpose to reduce prices for end-users, some of these causes may be removed with relative ease, while others have structural origins that would make more difficult, or at least the longest, a hypothetical removal [110].

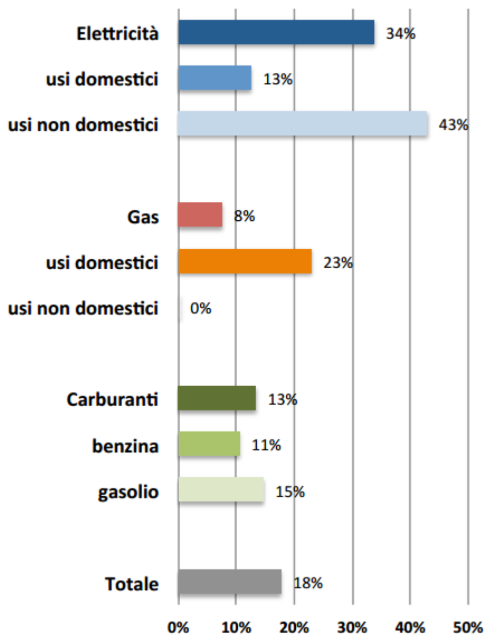

Figure 15: Differential of energy products average price in Italy vs U27 European average price (Source: SUSDEF)

The trend in the wholesale price, namely the Single National Price (*Prezzo Unico Nazionale* - PUN) that is formed in the power exchange in the negotiations of the MGP, in the year 2014 had the curve as shown in Fig.16 while during 2015, as shown in Fig.17.

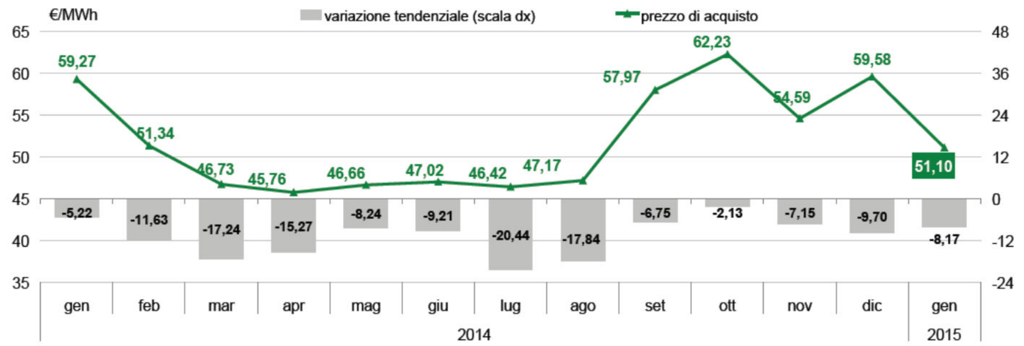

Figure 16: Trend of PUN at MGP, in 2014 (Source: GME)

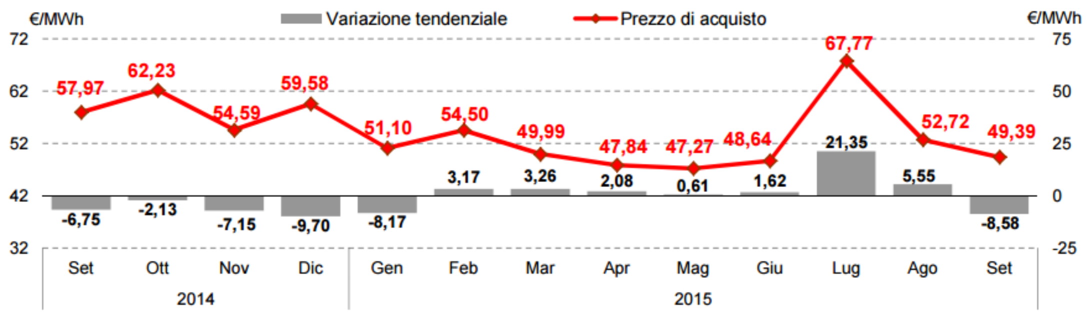

Figure 17: Trend of PUN at MGP, in 2015 (Source: GME)

Looking at Fig.17, apart in July 2015, the PUN is basically decreased during 2015 compared to the trend in 2014, reaching around 50€/MWh in September 2015.

Despite a favorable trend in commodities prices, it is to be noted that the electric final prices continue to suffer significantly from the impact of general network duties. The total annual requirement of general network duties in 2015 reached, indeed, the 15 billion of Euro, doubling the needs of the year 2011, as a result of significant growth in the A3 component to ensure the incentives for renewable sources [111], (see Fig.18).

Gettito consuntivato annuo oneri generali elettrico e ulteriori componenti
(dati in milioni di euro)

	Oneri generali									
	A2	**A3**	**A4**	**A5**	**As**	**Ae**	**UC4**	**MCT**	**UC7 (**)**	**TOT**
2011	255	6.542	345	61	54	-	70	35	110	**7.472**
2012	151	10.281	295	41	18	-	69	33	236	**11.124**
2013	167	12.643	448	43	17	-	66	62	191	**13.638**
2014	323	12.903	435	51	17	799	64	47	114	**14.754**

(**) dal IV trimestre 2011 la componente UC7 ingloba i corrispettivi di cui all'articolo 32, comma 2, del dlgs n. 28/11

Legenda: A2: a copertura degli oneri per il decommisioning nucleare
A3: a copertura degli incentivi alle fonti rinnovabili e assimilate
A4: a copertura delle agevolazioni ferroviarie
A5: a sostegno della ricerca di sistema
As: a copertura degli oneri per il bonus elettrico
Ae: a copertura delle agevolazioni per gli energivori (introdotta dal 1 gennaio 2014)
UC4:a copertura delle compensazioni per le imprese elettriche minori
MCT: a copertura delle compensazioni territoriali agli enti locali che ospitano impianti nucleari
UC7: per la promozione dell0efficienza energetica negli usi finali

Figure 18: General Network Duties, in 2015 (Source: AEEGSI)

Clearly, the end-user price is no more than the set of many items.

With effect from 1st April 2015, for the family type, the final price for the supply of a kWh, can be broken down into the following items [111] (Fig.119):

- 7.38 c€ (39.85% of the total bill, including taxes) for the costs of energy supply;
- 0.89 c€ (4.81%) for the retail marketing;
- 3.32 c€ (17.90%) for network services (transmission, distribution and measurement);
- 4.44 c€ (23.98%) for general network duties;
- 2.49 c€ (13.45%) for taxes including VAT and excise duties.

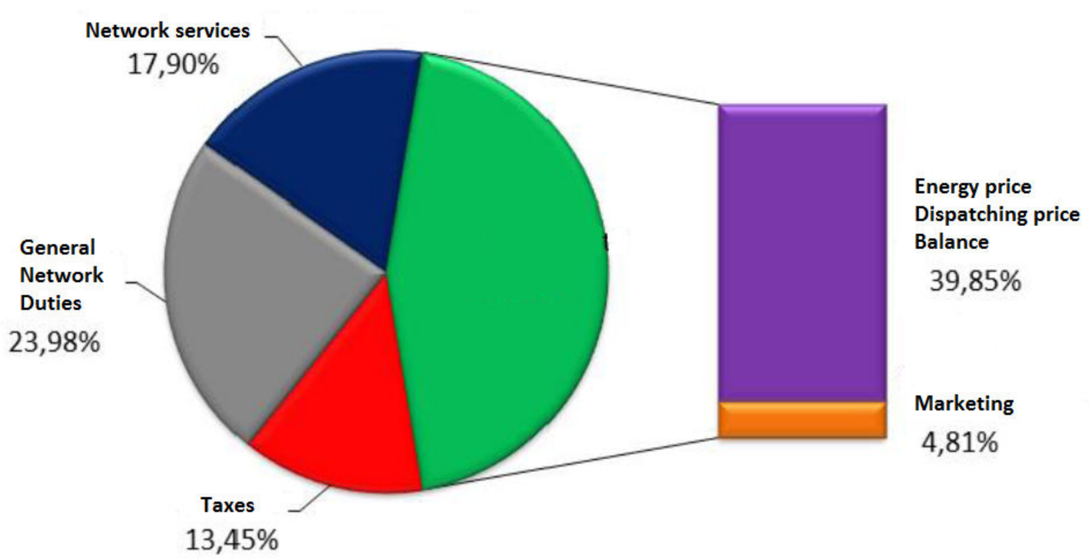

Figure 19: Final price for the supply of a kWh in items

By the implementation of the local electricity market, the goal should be to get an economic benefit on items of Energy price, Dispatching price, Balance and Marketing, that together cover the 44,66% of the final price payed by the end user.

1.12. Smart Community

All the concepts described above can be summarized into a single bigger idea, that includes all the aspects referred to Human life, from technical to social questions: the Smart Community.

The smart community identifies an urban ambient where the requirements of residents, businesses and institutions are satisfied, through the widespread and innovative use of communication, mobility, environment and energy efficiency technologies to improve the quality of citizens' life [48, 112].

The goal to improve the quality of citizens' life is not only related to the satisfaction of their daily needs of energy, food, services or to the digitalization of their routine actions.

A smart community tries to use its resources to meet current needs while ensuring that adequate resources are available for future generations. To do this, a smart community tries to maintain nature's ability to function over time by minimizing waste, preventing pollution, promoting efficiency and developing local resources to revitalize the local economy. Ultimately, a smart community is a living system in which human, natural and economic elements are interdependent and link each other [113-114].

Looking to Fig.20, the concept of Smart Community can be summarized in three main areas where economy, environment, governance, lifestyle, transport can be related each other: Human, Infrastructure, Planning and Management [112, 115-11].

In *Human* environment, some aspects referred to the citizen are evaluated: his health and his education, social programs and public safety. In this direction, the citizen becomes the hub of Smart Community innovation and he plays an active role in it [117-122].

In *Planning and Management* environment, there are sectors such as administration, public security, urban and environment planning. In this contest, governments and municipalities are already using smart technologies in the cities: from municipal wireless network to integrated IT systems, smart credentials, energy management systems, security, smart buildings active from an energy point of view and capable to generate the energy they require and, in some moments, to sell the surplus of energy to national grid. For this reason, one of the biggest challenges that smart communities are going to face is the integration, and the consequential optimal management, of a wide range of users below to different areas and technologies, as smart grid, telematics, public transport and smart ticketing [117-122].

In *Infrastructure* environment, problems referred to transport, energy, water and environment in general are considered. In this direction, programs for the CO2 reduction all around the world have led to the new trend of producing energy locally at the distribution level, by using non-conventional/renewable energy sources like natural gas, biogas, wind energy, solar energy, fuel cells, cogeneration systems

(CHP), micro-turbines and Stirling engine, all hereinafter referred as Distributed Generation (DG) [117-122].

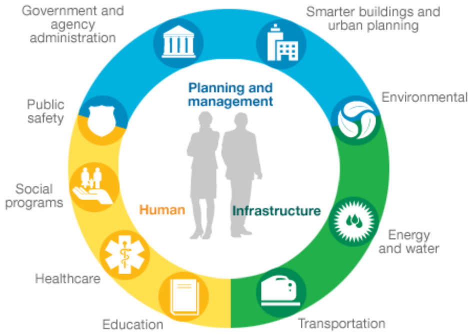

Figure 20: A snapshot of smart community concept [115].

2. Second Section – RES NOVAE Project

Before describe the results referring Local Trading Models, obtained in these three years of Ph.D. School, a brief description of the project thanks to the research in this field has been possible, is presented.

2.1. Project PON RES NOVAE

The ambitious sustainability goals (increasing energy efficiency, reducing greenhouse gases emissions, delivery of new value-added services and overall improvement in quality of life) set by the Municipal Energy Plans and in particular the Sustainable Energy Action Plan (SAEP) [123], require a national context in which the infrastructure, in particular energy systems and ICT infrastructure, are able to provide "awareness" of the state of system and its most critical components, “ability” to evolve and quickly adapt to the changes of external conditions through integrated and interconnected solutions.

In this context, the Project RES NOVAE, acronym of “Reti, Edifici, Strade, Nuovi Obiettivi Virtuosi per l'Ambiente e l'Energia” [124] aims to research, model and experiment on a demonstration the complex and dynamic management of the energy fluxes at the municipal level. Based on the integration of energy technologies and ICT, optimizing in their operations, RES NOVAE tries to reduce energy costs, to limit the problems due to the multi-generation of energy from renewable sources, decreasing the environmental impact and raising the awareness of energy and environmental issue in the community users. In energy field (Renewable energy and smart grid), the project promotes innovation through the development of technological and management solutions that support and strengthen the recovery, the production and the integrated management of the various renewable energy sources and of their distribution systems, taking into account the need to enhance relations between the urban and rural dimensions in energy, environment and climate policies of smart communities. Regarding the scope of energy efficiency (Energy efficiency and low-carbon technologies), the project activities are aimed to improve the energy and environmental performance of urban areas, through the development of integrated technologies and business models, able to reduce energy consumption and to promote the rational use of natural resources.

The project, ending on 31 December 2015, focus on the Italian Regions of Calabria and Apulia and contemplates a final experimental phase in the cities of Cosenza and Bari, where the most important aspects of research will be presented.

The research has the ambitious goal to deepen the many issues related to the transformation, already under way, of the supply and management model of energy resources. The harmonized management, into a single framework that would give greater and more immediate value to citizens and its leaders, first will provide the information and tools necessary to start the slow, but indispensable, cultural evolution toward a more conscious management of energy and environment resources in urban settings.

In this way, two “Urban Control Centres” will be implemented in Bari and Cosenza, respectively, with the goal to provide energy/environmental information to the public administration, to the citizens and to all interested players. The “Urban Control Centres” will help in the planning of city energy needs, thanks to objective and reliable data, in the management of local critical situation and in the cultural evolution of the citizens about the rational use of limited energy resources, taking care of the environment.

The “Urban Control Centres” will be the final and touchable product of different research lines, followed to implement an optimized management of energy resources:

1. Research and develop of new **Smart Grid** applications, linked to the management of the BT distribution network, to integrate the renewable sources, to improve the service quality to the clients and the energy efficiency. Among these applications, those able to provide new value-added services to the end users, to increase awareness about energy consumption, and to encourage the use of the most appropriate storage solutions, will be searched.

2. Research and development of new technical solutions and applications enabling innovative services within the building (**Smart Building**). Monitoring, coordinating and modulating in time the energy needs at the level of individual dwelling, building or building networks, optimizing the management of energy sources and integrating renewable energy sources installations through innovative solutions (heat storage, solar cooling), new services aimed to increasing energy efficiency in buildings will experience.
3. Research and development of new management techniques of urban elements referring to energy and environmental impact (e.g. street lighting, storm water, car port, energetic characterization of public buildings or buildings with public value as monuments). Through the modelling of smart objects, where physical objects are equipped with detection, calculation and communication capabilities and are able to perceive and interact with the environment and with other intelligent objects, the real time monitoring of energy use will be possible. In this way, it will possible to define rational and self-regulating energy uses for public goods in open urban areas (**Smart Street**).

In particular, the Centers in Bari and in Cosenza will be two pilot demonstrators aimed to create efficient and sustainable urban contexts in which the energy distribution systems, buildings networks and production from source renewable energy, ICT infrastructure are able to provide solutions that ensure integration and interconnection, awareness of the state of the system and its most critical components, ability to evolve and adapt quickly to the changing external conditions.

In Bari, the pilot demonstration will manage the BT network in smart grids optical thanks to experimentation of a monitoring and control system of network parameters and the new application developed during the research project. All results will be implemented in the "Urban Command Center", an information network supported by hardware and software systems, creating a modern system of control and management of energy resources available to the Public Administrations.

In Cosenza, the pilot demonstrator, named "Demo Cosenza", aims to make the citizens participating in the daily and simple use of the strategies able to reduce greenhouse gas emissions through energy technology, object of the project research.

The aim is to make available the effects of the research, to transfer the results in tangible and interactive demonstration objects, the use of which is stimulated by digital systems of information and social formation to enable citizens, at the same time, to trigger collaborative processes to improve the usability of the results.

"Demo Cosenza" will include a "Smart Street", that is the principal street which connects the city centre to the inner city, will equip with a Wi-Fi network. In the Smart Street, the sculptures of Bilotti Museum (MAB), will become Virtual Objects, that is interactive objects able to provide information to users who walk in the Smart street even the "Urban Lab CreaCosenza", a space addressed to the needs of communication, education and participation.

The purpose of the proposed demonstrator is to highlight how the various technologies and communication and control systems developed during the research activities are integrated with each other and how these technologies and systems can interact with other projects about the smart and sustainable use of the city.

This will be demonstrated through the implementation, at prototype level, of a Smart User Network (SUN) that, in addition to the elements of Smart Street, will also integrate renewable sources of energy production, storage systems, etc. in order to supply, with high degree of reliability, critical and/or not-critical utilities.

The research developed in the three years of Ph.D. School starts from these points.

2.2. The Smart User Network – SUN [125]

First, an idea of smart MicroGrid has been implemented during the Project RES NOVAE. In Fig.21, the particular configuration of MG called *Smart User Network – SUN* is shown.

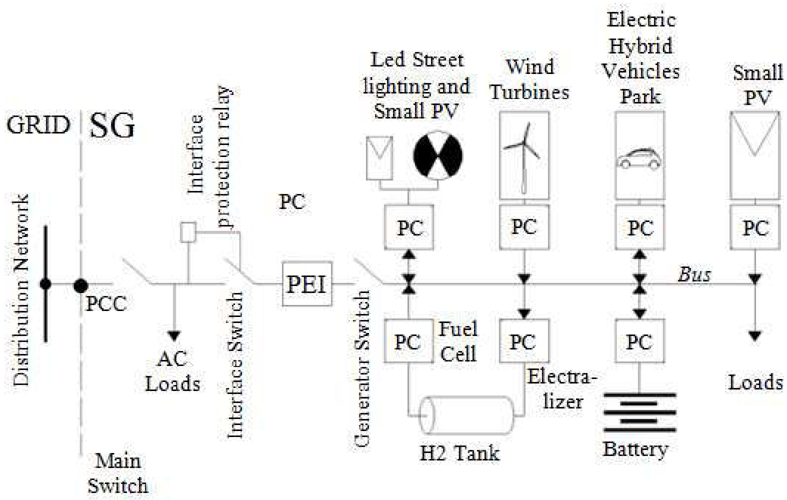

Figure 21: Smart User Network

In the SUN, the MS are connected to a common DC bus through appropriate Power Converters (PC), while the connection to the grid is realized by a Power Electronic Interface (PEI), in order to provide the required flexibility to ensure operation as a single aggregated system and to maintain the specified power quality and energy output. Electrical loads can be in AC or DC thanks to the presence of the common DC bus: depending of AC or DC type, they require an appropriate Converter.

The SUN is separated from the public distribution network using the Main Switch, the opening of which determines the islanding operation of the MG. The PEI controls the bi-directional power flow between distribution network and user network: it works as MGCC, understanding the SUN condition (grid-connected or islanded), knowing the direction of energy flows (absorbing or injecting energy), detecting any critical situation and deciding in that situation what loads must supply or not. The other PC act as LC or MC devices: they are not simple converters, but they are implemented to detect any abnormal condition.

The most important particularity of the SUN is the presence of storage systems. The use of one or more of the aforementioned energy storage systems can effectively compensate for load variations, so making possible to operate transmission, sub-transmission and distribution networks with lighter designs, that is to say, energy storage can be used instead of more complex, expensive and inefficient needed solutions (oversizing of base-load generation units, peaking generation units based on combustion turbines, ...).

Moreover, taking advantage of the new contest of the free market of the electrical energy, in a distribution grid with energy storage systems, electrical energy can be purchased at low rates, can be stored and, then, can be sold, during a peak of the load demand, at a higher rate. Finally, in the illustrated micro Smart Grid configuration, the electric vehicles and the charging stations have a significant potential impact on the energy absorbed from the grid or provided by renewable energy micro-sources or by the storage systems [125].

The SUN represents the point of departure of all the research results: indeed, in the following, the possibility to control and manage opportunely the generation and consumption of a user, passes through the chance to have a network that allows to provide information about generation and consumption, to act on these parameter, to operate quickly on critical events.

2.3. The Prosumer Problem [126]

Near to the possibility to control and manage production and consumption profile of a prosumer, the implementation of a local trading passes through the participation of the prosumer to the DR programs, as said in Section 1. In this direction, a model to illustrate how the participation to DR program, can vary the load profile of a prosumer has been studied.

The prosumer is considered as a residential unit with some appliances. An appliance may be used more than one in the H-hour. Then, let A denote the set of appliances in this unit, which may include a washer/dryer, a refrigerator, a plug-in hybrid vehicle, etc. For each appliance $a \in A$, an energy consumption scheduling vector x_a is defined as follows:

x_a:$[x^1{}_a; \ldots\ldots; x^H{}_a]$

where $H \geq 1$ is the scheduling horizon that indicates the number of hours ahead which are taken into account for decision making in energy consumption scheduling.

For each upcoming hour of the day $h \in H$, $\{1;\ldots\ldots;H\}$, a real-valued scalar $x^h_a \geq 0$ denotes the corresponding one-hour energy consumption that is scheduled for appliance $a \in A$. On the other hand, let E_a denote the total energy needed for the operation of appliance $a \in A$. Clearly, we always have $\alpha_a < \beta_a$.

Given the pre-determined parameters E_a, α_a and β_a, in order to provide the required energy for each appliance $a \in A$ in times within the interval $[\alpha_a; \beta_a]$, it is required that:

$$\sum_{h=\alpha_a}^{\beta_a} x_a^h = E_a \tag{1}$$

Further to the constraint (1), it is expected that $x_a = 0$ for any $h < \alpha_a$ and $h > \beta_a$ as no operation (thus energy consumption)is needed outside the time frame $[\alpha_a; \beta_a]$ for appliance a. All home appliances have certain maximum power levels denoted by γ_a^{max}, for each $a \in A$. Some appliances may also have minimum stand-by power levels γ_a^{min}, for each $a \in A$. Therefore, the following lower and upper bound constraints are required on the choices of the energy scheduling vector x_a for each appliance $a \in A$:

$$\gamma_a^{min} < x_a^h < \gamma_a^{max}, \forall h \in [\alpha_a, \beta_a] \tag{2}$$

Finally, there is usually a limit on the total energy consumption at each residential unit per hour. This limit, denoted by E^{max}, can be set by the utility to impose the following set of constraints on energy scheduling:

$$\sum_{a \in A} x_a^h < E^{max}, \forall h \in H \tag{3}$$

When appliances $a \in A$ of type "off" and "on" (that is appliances with discrete energy consumption levels) exist, for each of these appliances and at each hour $h \in H$, let y^h_a denote an auxiliary binary variable such that $y^h_a = 1$ if appliance a is "on" and $y^h_a = 0$ otherwise.

By definition, the former requires an energy consumption level of $x^h_a = \gamma_a^{min}$ whereas the latter requires an energy consumption level of $x^h_a = \gamma_a^{max}$. Therefore, for each appliance $a \in A$, the relationship between the energy consumption scheduling vector x_a and the auxiliary vector y, $[y^1_a \ldots\ldots\ldots y^H_a]$ can be expressed as follows:

$$x_a^h = y_a^h \gamma_a^{max} + (1 - y_a^h)\gamma_a^{min}, \forall h \in [\alpha_a, \beta_a] \tag{4}$$

Some loads such as PHEV battery charging are interruptible loads. That is, it is possible to charge the battery for one hour, then stop charging for another hour, and then finish charging after that. However, if the load is an uninterruptible load, then, when the corresponding appliance starts the operation, its operation must continue until it finishes. This requires imposing further limitations on the choices of the energy consumption scheduling vectors. For each uninterruptible appliance *a*, let θ_a denote the time duration, in number of hours, that appliance *a* needs to operate at power level γ_a^{max}. Also at each $h\in H$, let z^h_a denote an auxiliary binary variable such that $z^h_a= 1$ if appliance a starts operating at hour *h* and $z^h_a=0$ otherwise. Then, we have:

$$\sum_{h=\alpha_a}^{\beta_a-\theta_a+1} z_a^h = 1, \forall h \in [\alpha_a, \beta_a - \theta_a + 1] \tag{5}$$

$$z_a^h = 0, \forall h \in H \setminus [\alpha_a, \beta_a - \theta_a + 1] \tag{6}$$

$$y_a^h \geq z_a^h, y_a^{h+1} \geq z_a^h, \ldots, y_a^{h+\theta_a-1} \geq z_a^h, \forall h \in [\alpha_a, \beta_a] \tag{7}$$

Also the thermal loads are considered. If any thermostat-controlled appliances are present in the residential unit, an energy consumption scheduling vector x^h_{th} is introduced for this type of appliance for each upcoming hour of the day $h\in H$. Each x^h_{th} is evaluated by the model of thermostat-controlled appliance in function of the T^h_{sch} scheduling temperature and the T^h_{amb} ambient temperature at hour *h* using the function "*Therm*", that recalls the thermal load model implemented in the Matlab Simulink environment [27]. Naturally, a level of flexibility has been considered and then lower (T^h_{min}) and upper (T^h_{max}) scheduling temperature limits have been set at each hour. Then, the following constraint has been introduced:

$$T_{min}^h \leq T_{sch}^h \leq T_{max}^h \tag{8}$$

Moreover, a fixed switching price, δ, of thermal appliance for a change in power consumption is introduced, therefore the variation of thermal energy consumption for the appliance has been valuated as:

$$\Delta x_{th}^h = x_d^h - x_{th}^h \tag{9}$$

with x^h_d the energy consumption for the thermal appliance at hour *h* corresponding to the desired temperature T^h_d valuated by the function "*Therm*".

Therefore, let A_{th} denote the set of thermal appliances of the unit, we can define a feasible scheduling set X_{th} for all possible energy consumption scheduling vectors $x^h{}_{th}$, ($x^h{}_{th}$; $\forall th \in A_{th}$) that denote the vector of energy consumption scheduling variables for all thermal appliances. An energy schedule $x^h{}_{th}$ is valid only if it satisfies the constraints (8). Since the residential unit is also a producer, in the Prosumer problem, the contribution of renewable source plants production must also considered. With this aim, in the objective function $P^h{}_{PV}$, $P^h{}_W$ and $P^h{}_{mCHP}$ quantities have been introduced. These quantities represent the non-programmable (from photovoltaic, wind plants) and programmable (by MCHP) renewable energy production for each upcoming hour of the day $h \in H$ determined by the coalition Coordinator recalling the following specified functions and sent to each prosumer.

Photovoltaic production

$$P_{pv}^h = Photovoltaic(T_{amb}^h, Irr^h, P_{PV}^h)$$

Wind production

$$P_W^h = Wind(\omega, P_W^h)$$

Stirling-mchp production

$$P_{mchp}^h = Stirling\left(T_{sch}^h, T_{amb}^h, x_{th}^h, P_{mCHP}^h\right)$$

Photovoltaic and wind production are valuated using the corresponding models illustrated in [26]. The third one is valuated using the model of a 1 kW pellet stove micro-CHP WhisperGen Stirling system.

At this point, a feasible scheduling set X can be defined for all possible energy consumption scheduling vectors x: (x_a, x_{th}; $\forall$ $a \in A$ and $\forall$ $th \in A_{th}$) that denotes the vector of energy consumption scheduling variables for all appliances. An energy schedule x is only valid if (1)-(8) are satisfied.

Clearly, the proper choice of x would depend on the TOU tariffs c^h communicated by the aggregator.

"Prosumer Problem"

$$minimize_{x\in\chi} \sum_{h=1}^{H} c^h * \left[\sum_{a\in A} x_a^h - \left(P_{pv}^h + P_w^h\right)\right] + \sum_{h=1}^{H}\left[c^h * \left(x_{th}^h - P_{mchp}^h\right) + \delta\Delta x_{th}^h\right] \qquad (10)$$

$x_a^h \geq 0, \qquad x_{th}^h \geq 0 \forall h \in H$

$$\sum_{h=\alpha a}^{\beta a} x_a^h \quad \leq E_a \quad , \forall h \in H$$

$\gamma_a^{min} \leq x_a^h \leq \gamma_a^{max}, \forall h \in [\alpha_a, \beta_a]$

$$\sum_{a\in A} x_a^h \leq E^{max}, \forall h \in H$$

Appliances with Discrete Energy Consumption Levels

$x_a^h = y_a^h \gamma_a^{max} + (1 - y_a^h)\gamma_a^{min}, \forall h \in [\alpha_a, \beta_a]$

$y \quad \triangleq [y_a^1, \dots, y_a^H]$

Uninterruptible Residential Load

$$\sum_{h=\alpha_a}^{\beta_a - \theta_a + 1} z_a^h = 1, \forall h \in [\alpha_a, \beta_a - \theta_a + 1]$$

$z_a^h = 0, \forall h \in H \setminus [\alpha_a, \beta_a - \theta_a + 1]; z_a \triangleq [z_a^1, \dots, z_a^H]$

$y_a^h \geq z_a^h, y_a^{h+1} \geq z_a^h, \dots, y_a^{h+\theta_a - 1} \geq z_a^h, \forall h \in [\alpha_a, \beta_a]$

Thermostat-controlled load

$\Delta x_{th}^h = x_d^h - x_{th}^h$

$X_{th}^h = Therm\left(T_{sch}^h, T_{amb}^h, x_{th}^h\right)$

$X_d^h = Therm\left(T_d^h, T_{amb}^h, x_d^h\right); \ T_{min}^h \leq T_{sch}^h \leq T_{max}^h$

Then, the local controller determines the optimal choice of energy consumption scheduling vector *x* solving (10).

To test the prosumer model, an ED was simulated considering an aggregation of 30 residential consumers, 20 residential prosumers, 10 small industrial consumers and 10 producers. Three different renewable energy plants were also considered: a 3kWp

PV plant, a 3kWp wind turbine and a 1kWp micro-CHP. Prosumers\consumers were distinguished according to their availability to change their habits in a flexible or rigid way. A rigid prosumer\consumer sets their local controller parameters in a narrow range, whereas a flexible one does so in a larger range and with minor constraints.

Considering the appliance settings, the energy profiles for a rigid and a flexible prosumer are determined solving the Prosumer problem are represent in Figg.22-23. It is possible to see that the load picks are leveled, the load demand is decreased and there is a bigger conformity between load profile and generation profile.

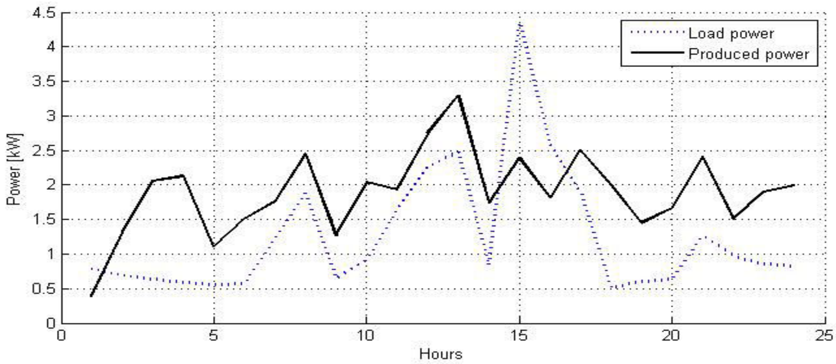

Figure 22: Production and consumption profile for a Rigid Prosumer

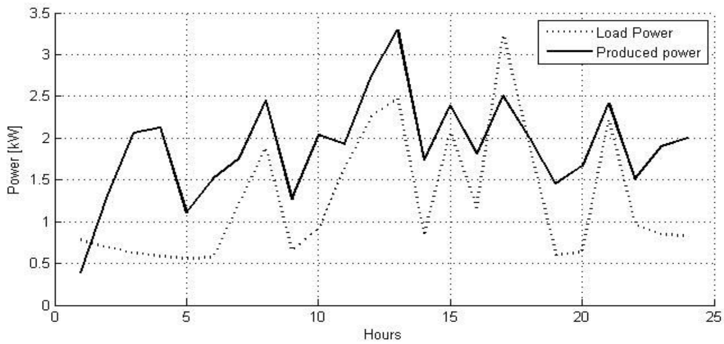

Figure 23: Production and consumption profile for a Flexible Prosumer

The aggregated day-ahead energy profile is obtained by summing the consumption and production energy profiles sent from each ED prosumer to the coalition coordinator. At some hours an energy surplus (positive values) appears, representing an energy reverse flow i.e. energy can be injected into the grid and can be sold on the electricity market. It is worth highlighting that greater energy surplus and subsequently energy reverse flow appears at night time. In Fig.24, the aggregated energy profile with the DR is illustrated in comparison with the profile without DR. It is evident how the prosumer problem approach, as well as maximizing VED utility, is able to reduce the night time reverse energy flow and reduce peak power in daytime hours taking the responsiveness of the prosumers into account.

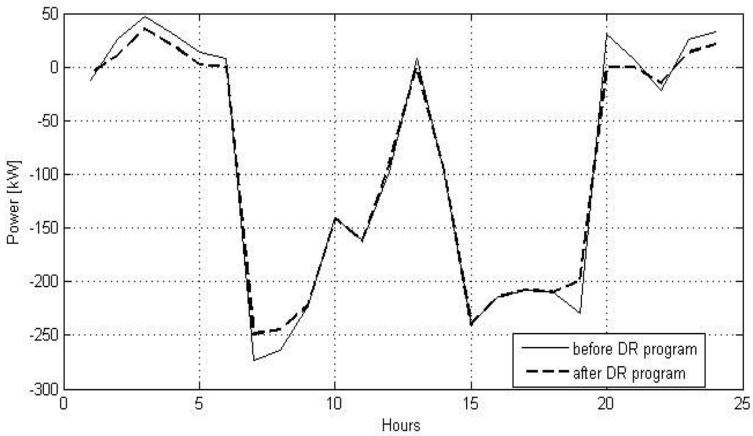

Figure 24: Comparison between the aggregated energy profile without the DR (continuous line) and with the DR (discontinuous line).

3. Third Section – The Proposed Local Energy Management

3.1. Community Energy Provider Management System

The energy sector is a particularly strategic area for realization of smart community concept [50, 91, 127].

The energy sector has as its primary goal the satisfaction of the citizens' needs. This goal, however, must be pursued according to the environmental sustainability, the reduction of pollutants, the recycle and recovery of materials, the rational and efficient consumption of energy and the renewable generation.

The realization of all these aspects is not easy: on one hand, a massive use of electronic and information technologies is required in order to monitor each instant the physical state of the entire electrical system, collecting and exchanging data between the various stakeholders and then managing and checking for any abnormal situations. On the other hand, the participation of all the players who are act into the energy sector, from system operators, market operators, large and small producers to the consumers themselves, is necessary.

To organize and manage such a system, therefore a model of efficient management is required, able to take into account all the aspects of the community itself but also able to consider the signals that come from outside the community.

In Fig.25, the complete model of energy management of a smart community is presented, in which a single entity called supervision Community Energy Provider (CEP) leads the community, acting as Aggregator.

The CEP coordinates all exchanges of energy within the smart community and coordinates the directives/information coming from the outside [70, 91].

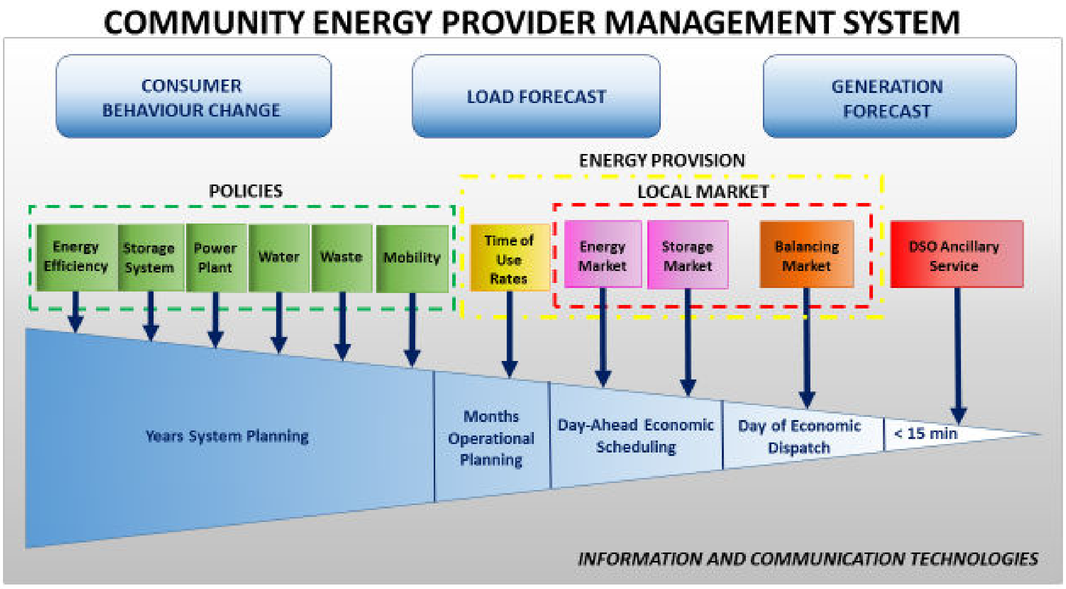

Figure 25: Community Energy Provider Management System

In details, to describe the complete model management in Fig.25, it must emphasize that information and communication technologies are essential and must be put on the basis of every action/control/manage [128-129].

Indeed, these technologies are essential in order to send signals to users about their consumption or their demands; to report and act quickly on any anomalies in the network; to carry out the operations of the different markets throughout the day and to give to the users the market results, to communicate via network operators what happens in the smart community or to receive from them directives, etc. The ITC therefore, results the glue of all activities within the energy management of the smart community.

The isosceles triangle in Fig.25 is the timeline in which the activities take place. As the triangle shrinks, the activities are planned in a shorter time, until they are decided almost in real time.

At the triangle base, the area *Year Planning System* is placed: this is the timeline in which the activities with multi-annual programming are scheduled. At this stage of programming, policies and their application methods are discussed. It should be stressed that the policies can be understood locally, then designed and applied to the smart community, or they can be implemented by national and EU directives and then applied to the needs and possibilities of the smart community.

These policies relate to everything that can be linked to the energy in terms of production, consumption and recovery. Each policy in the energy field is not a single action but it is closely related to the others. In Fig.25 six areas have been identified, in which it is necessary to program the policies: energy efficiency, storage system, power plant, water, waste and mobility.

“Energy efficiency” means the efficient use of energy: this implies the adoption of innovative technologies in plant; the energy efficiency of buildings; the attention to the reduction of any kind of energy waste. In this area, the local governments can do much: firstly, they can be an example by acting on their properties, introducing council guidelines that promote energy efficiency also in private sector.

The policies regarding storage systems have a strong potential: the storage systems are a cross tool for the entire energy sector and their use has technical and economic advantages. The only negative aspect at this moment is the cost of these systems: incentive policies on storage systems are therefore to be hoped to spread the technology.

With regard to the power plant, the policies can be addressed on the management planning of systems, or may provide funding actions and construction of new facilities. Clearly, in this case, renewable energy plants or those that dispose of the agro-food / agro-forestry waste or the organic fraction of municipal waste are to be financed: biomass or biogas plants are typically of this sector and require a strong synergy with the municipal policies on the waste. In fact, regarding the management of waste, a policy like the one that has encouraged the spread of the recycling waste is a valuable aid to the wet fraction collection of waste to ferment and then transform it into biogas. This biogas can then be converted into thermal energy for heating by cogeneration and district heating plants (this lead to the policies on the power plant), or considering policies on mobility, it is possible to encourage the use of biogas or electric vehicles recharged using electricity generated from bio-mass/gas plants.

Finally, the policies of water management must not be underestimate: particularly important in those areas rich in watercourses, the policies that encourage hydropower production can exploit these natural riches without spoiling the landscape and then get a clean and renewable energy source without large investments.

The objective of these policies is therefore to exploit the energy resources present in the territory and to make the smart community participating and interested in energy management in its own territory. Firstly, a goal of CEP is to manage the self-consumption of energy and to sell the excess outside the community.

Shrinking the time horizon, the management considers the phase called Months Operational Planning. This plan marks the beginning of the supply of energy and for this reason, it is a phase therefore more practical than the previous phases. At a monthly level, the activity that takes place, concerns the signing of supply contracts and, in particular, the definition of the tariffs for the energy purchase in the community.

At this stage, CEP acts as an energy provider: it estimates the community energy demand; the energy that could be produced by renewable sources especially from non-programmable ones and the energy that has to be purchased or sold outside the community, in the case of an excess of energy production inside the community. A Time-Of-Use tariff (in the following referred for sake of simplicity with TOU) will be determined in order to assure a gain to the producers and a saving to the consumers in comparison to the gain of purchased or sold energy outside the community.

The local market takes place in order to face the uncertainty of renewable sources and load variability and, in the same time, to implement demand response program thanks to information and communication technologies for responsive consumers. The local market consists of two different time steps: a first phase provides for scheduling of the energy dispatching on the day before the actual in which the energy supply happens, through two sessions of the market. A second phase involves a "repair" market session, in the day in which the energy supply takes place. These three sessions of the market constitute the so-called Local Market, managed entirely by the CEP in the smart community [70, 91].

In the local market, the CEP plays the role of the Power Exchange (PEX) with a "pay as bid" rule: it collects the purchasing offers, upwards compared to market-clearing price (MCP), and selects the most convenient one according to a merit order list. The consumers offering higher price will be selected and their offers accepted. Since there might be several consumers concerned, this results in a market auction.

The market auction is based on the difference between the purchasing and selling electricity price. As shown in [102], the purchasing price of the energy surplus for smart community members in a given hour is higher than MCP, that is the selling price, at the same hour. Since there is a difference between these prices, it can be convenient for a consumer belonging to the smart community to buy the available energy surplus at a price lower than the purchasing price, and for the producer to sell at a higher price than the selling price. The utility of the smart community is increased in the sense that each smart community member can obtain a utility. Definitively from simulation, it is reasonable that the energy price for community members (both for buyers and sellers) is the middle price between the selling and purchasing price. Session is formalized through auctions slots in which each user presents an offer to buy / sell in terms of price and quantity of energy that he is willing to accept.

Also the second market session that takes place the day before the real supply, is carried out via hourly auctions. However, what is auctioned is in this case the free capacity of the storage systems or the possible energy already stored. For this reason, this second session is called Storage Market.

The last phase of negotiations, called Balancing Market is also part of the Local Market. Unlike the previous two, this occurs in the same day in which the supply takes place: it is a phase of adjustment between what was expected and what actually occurs both in production and in consumption. Who participates in this market, will have no economic benefits, indeed, as the action takes place in real time, the cost of implementation of the action will be higher.

Finally, the last phase of this energy management logic is realized in a very restricted time horizon, of less than 15 minutes, and thus provides an immediate adjustment action of the energy flows to and from the national power grid to ensure perfect balance. In this phase, the CEP interfaces with the Distribution System Operator (DSO) and provides or receives ancillary services. These are services that, due to the speed with which they are implemented, have a heavy cost/reward, if they are required/provided outside the smart community [125].

It is worth to underline that in order to avoid technical problems on the entire electrical grid and also to avoid to resort to markets more expensive to level the imbalance between production and consumption of energy, it is essential for energy management of the smart community, to have accurate and timely forecasting profiles of generation and consumption. This availability is somehow obtainable for generation profiles: in fact, the production from traditional fossil fuel is easy to calculate and programmable, while that from renewable energy plants is more difficult because of the variability of the resources. In any case, through the support of efficient systems for forecasting weather, it is still possible to obtain an estimate.

Regarding to the prediction of load profiles, the estimate is much more complicated: this happens not because there are not technologies available today that can monitor or control the consumption, but because the consumption profile is linked to the free will of the user who requires energy. That is why in addition to signs of Load Forecast and Generation Forecast, a sign for Consumer Behaviour Change is present, that is the user's inclination to change his behaviour towards a more "sustainable" one to become a true actor of sustainable development as well as a real smart community citizen.

3.2. Local Trading

The attention has been focused on management models to execute the local trading. Every presented model adds a degree of complexity, that is a set of constraints, to the previous model. For every models, some numerical results are presented.

3.2.1. Local Market (LM) Model [70]

The first Model proposes a simple market platform that allows an effective management of the exchanged power flows among several SUNs and the possibility for all SUNs to provide ancillary services to the electrical system in totality. The SUNs belong to a Virtual Energy District: from an electrical point of view, the SUNs belonging to ED are connected to the public distribution network through a single point of delivery (POD), where the exchanges with the electrical system take place in an aggregated form. The ED management strategy proposed in [50] can be easily extended over a large area, a metropolitan area, where there are several POD, and for each of them a SUN is identified, through which the energy requirements of the community can be reduced, as well as, the congestions on the public distribution network. For this reason, considering several POD, it is more correct talking about a *Virtual* ED (VED).

In VED, physical energy transactions take place either through the public distribution network and through the single Smart Grid infrastructures; the economic transactions require instead the coordination and management of an impartial entity, called Community Energy Provider (CEP).

In practice, the problem of coordination and management that exists between the Power Exchange (PEX) and the Transmission System Operator (TSO) happens in the urban area also. In this dimension, the engaged entities are the CEP and the City Distribution System Operator (CDSO).

It should be noted that, even in the presence of a virtuous behaviour of single SUN - that is the energy is used when it has been produced or purchased when its price is low - an excess of energy can appear in a few hours, for example, when generating plants are oversized respect to the power demands of the consumer. If there is a surplus of energy, the CEP acts as an intermediary between those who want to sell the energy excess and those who want to buy such amount within the VED. Using this energy within the VED might be more a profitable gain then the sale of energy directly to electricity market.

So, the goal of the CEP becomes to prevent the sale of the available energy surplus to the consumers belonging to the VED, through the local market platform that uses market-based instruments for the match between demand and offer of energy (see Fig.26).

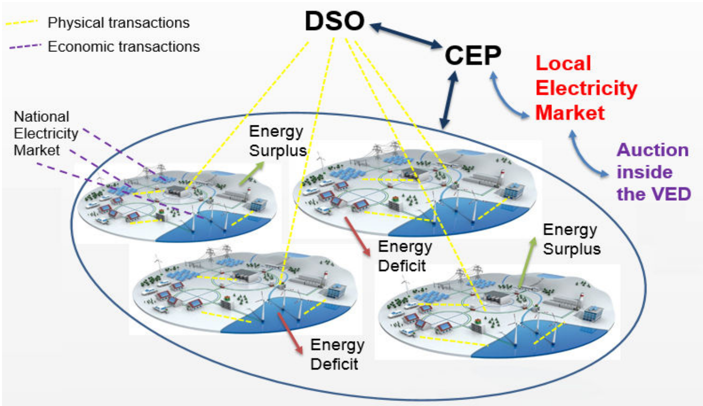

Figure 26: Interaction between DSO, CEP and VED

In Fig.27, the CEP operation mode is described; the CEP receives, through an *interface platform*, information about the selling of the user energy surplus in an hour (in terms of quantity of energy to be sold) from each producer/prosumer and receives from each consumer/prosumer the offers in terms of energy (q^h_i) and price available to buy it ($P^h_{P,i}$). Then the results of the auction will be released by the CEP both to the producers/consumers/prosumers, and to CDSO through appropriate reports via *interface platform*.

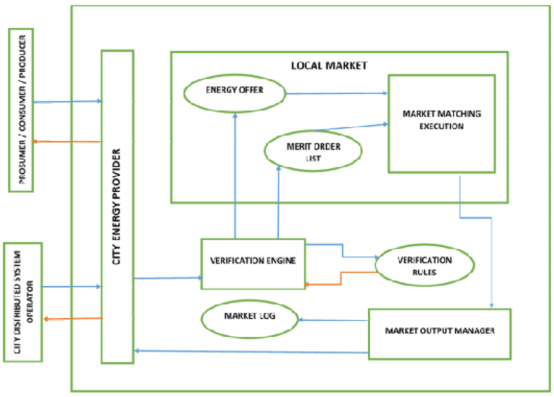

Figure 27: CEP operation

The CEP, then, has the role to manage these offers and to choose ones that maximize the VED utility. To do this task, the technical feasibility of fulfil the requests is verified by *verification engine*, taking into account the technical constrains on the distribution network communicated by the City Distribution System Operator (CDSO). The offers satisfying the verification rules are sorted in *merit order list* and the market auction takes place.

The LM strategy is based on the difference between the purchasing and selling electricity price. As shown in [89], the purchasing price (P^h_P) of the energy surplus for the VED members in a given hour is higher than the market-clearing price (MCP), that is the selling price (P^h_s), at the same hour. Since the P^h_s is less than the P^h_P, it may happen that for a given hour the P^h_s is lower than the P^h_P so it can be convenient for a consumer belonging to the VED to buy the available energy surplus at a price lower than P^h_P, modifying his load profile and for the producer to sell at an higher price than MCP. The gain of the VED is so increased in the sense that each VED member can obtain a gain.

The CEP sends information about the sales of the energy surplus in an hour (in terms of P^h_s and quantity of energy to be sold) and receives from each consumer the offers in terms of quantity and price available to buy this energy surplus re-scheduling its energy consumption. The CEP, then, has the role to manage these offers and to choose ones that maximize the VED gain.

In that way, a LM can take place where the CEP plays the role of the PEX with a "pay as bid" rule: it collects the purchasing offers, upwards compared to MCP, and selects the most convenient one according to a merit order list. The consumers offering higher price will be selected and their offers accepted. Since there might be several consumers concerned, this results in an auction.

It should be noted that, in the process of energy exchange, one of the main problems is that the physical transactions of energy occur through the public distribution network. In this sense, it is necessary to emphasize that the public distribution network may present limits on transport capacity in some parts.

In first simulation, the public distribution network is considered *transparent*, i.e. without taking into account any constraints on the transport capacity.

The LM is implemented by the following optimization model, characterized by a selection criterion such as "price discrimination", on the purchase offers of energy surplus in the VED.

“LM model”

Max U

S.c.

$$U = \sum_{h=1}^{24} U^h \tag{11}$$

$$U^h = R^h_{in\_aggr} - R^h \tag{12}$$

$$R^h_{in\_aggr} = R^h_{auc} + R^h_{res} \tag{13}$$

$$R^h = Q^h_{rev} \cdot P^h_s \tag{14}$$

$$R^h_{auc} = \sum_{i=1}^{n} \left(q^h_i \cdot P^h_{p,i} \right) \tag{15}$$

$$R^h_{res} = Q^h_{res} \cdot P^h_s \tag{16}$$

$$Q^h_{res} = Q^h_{rev} - Q^h_{req} \tag{17}$$

$$Q^h_{req} = \sum_{i=1}^{n} q^h_i \tag{18}$$

$$Q^h_{req} \le Q^h_{rev} \tag{19}$$

$$0 \le q^h_i \le Q^h_{o,i} \tag{20}$$

$$U \ge 0 \tag{21}$$

The optimization model aims to maximize the gain for the VED, that is the gain obtained from the sale of the energy surplus within the VED. This model is subject to the constraints numbered from 11 to 21.

The (11) defines the daily gain (U) as the sum of all gains achieved at each hour of the day in question. The (12) requires that, considering the hour h, the gain in that hour (U^h) is defined as the difference between the time revenue earned from sales of the energy surplus within the VED ($R^h_{in\_aggr}$) and one earned outside of the VED (R^h) on the electricity market. The (13) defines $R^h_{in\_aggr}$: it is equal to the sum of the time revenue from the auction inside the VED (R^h_{auc}) and the time revenue from the remaining sales after the auction (R^h_{res}). The (14) is relative to R^h, defined as the product between the energy surplus available at the hour h (Q^h_{rev}), and P^h_s. The (15) refers to R^h_{auc}: denoted by n the number of the VED members, it is equal to the sum of all products among the time offered purchase price of the i-th consumer ($P^h_{p,i}$) and the accepted energy from the i-th consumer (q^h_i) at the same hour h. The (16) defines the R^h_{res} as the product of the energy injected into the public distribution network (Q^h_{res}) and its P^h_s at the hour h. The (17) indicates the Q^h_{res} as the difference between the Q^h_{rev} and the total energy required by all VED consumers (Q^h_{req}). The (18) determines the Q^h_{req} as the sum of all amount of energy required by the n VED members at the hour h. The (19) requires that Q^h_{req} is less than or equal to the Q^h_{rev}. The (20) indicates that the accepted energy by the i-th consumer is a value greater than or equal to zero, but obviously less than or equal to the energy surplus offered by the i-th consumer $Q^h_{o,i}$. The (21) states that the gain for the VED must be positive. If there is no feasible solution of the optimization problem, this means that there is no gain for the VED.

To validate the LM model, the behaviour of a VED is simulated: it represents an aggregate of 30 residential consumers, 20 residential prosumers, 5 small industrial consumers and 5 producers. It is assumed that each producer has three different renewable energy source plants: a 3kWp photovoltaic system, a 3kW wind turbine and a 1 kW micro-cogeneration system, connected to an own SUN.

The evaluations were performed assuming that the VED is placed in Southern Italy and the simulations were carried out in a typical winter and summer day.

For each producer/prosumer, generation profiles were evaluated, according to [126], as well as plausible loads have been hypothesized according to the characteristics of each consumer, to have a profile for each load. In this way, it was possible to estimate for each hour the occurrence or not of an energy surplus.

The basic values for the evaluation of the results are reported in Tables III and IV.

Table I, referring to a typical winter day, shows, in the first row, the hours of the day; those in bold are the hours when the energy surplus happens. The second row shows the available amount of energy surplus (Q^h_{rev}); the third and fourth rows show the purchase price (P^h_p) and the sale price (P^h_s). Table II reports the same values, but referring to a typical summer day.

TABLE III. Q^H_{REV}, P^H_P AND P^H_S FOR ALL HOURS IN A WINTER DAY

Hour	1	**2**	**3**	**4**	**5**	**6**	7	8	9	10	11	12
Q^h_{rev} [kWh]	0.00	**25.60**	**46.91**	**31.89**	**13.53**	**7.53**	0.00	0.00	0.00	0.00	0.00	0.00
P^h_p [c€/kWh]	6.02	**5.16**	**4.70**	**4.70**	**4.70**	**5.49**	6.39	7.00	7.73	7.68	7.18	6.84
P^h_s [c€/kWh]	5.80	**4.80**	**4.40**	**4.40**	**4.40**	**4.80**	6.00	6.60	7.30	7.20	6.80	6.40
Hour	**13**	14	15	16	17	18	19	**20**	**21**	22	**23**	**24**
Q^h_{rev} [kWh]	**8.12**	0.00	0.00	0.00	0.00	0.00	0.00	**29.93**	**6.40**	0.00	**25.76**	**32.24**
P^h_p [c€/kWh]	**6.26**	6.15	6.42	6.63	6.74	7.06	7.65	**10.13**	**7.21**	7.21	**6.96**	**6.17**
P^h_s [c€/kWh]	**5.70**	5.80	6.00	6.20	6.30	6.60	7.20	**9.20**	**6.80**	6.80	**6.10**	**5.60**

TABLE IV. Q^H_{REV}, P^H_P AND P^H_S FOR ALL HOURS IN A SUMMER DAY

Hour	**1**	2	**3**	**4**	**5**	**6**	7	8	9	10	11	12
Q^h_{rev} [kWh]	**19.05**	0.00	**36.57**	**6.25**	**32.78**	**15.01**	0.00	0.00	0.00	0.00	0.00	0.00
P^h_p [c€/kWh]	**6.02**	5.16	**4.70**	**4.70**	**4.70**	**5.49**	6.39	7.00	7.73	7.68	7.18	6.84
P^h_s [c€/kWh]	**5.80**	4.80	**4.40**	**4.40**	**4.40**	**4.80**	6.00	6.60	7.30	7.20	6.80	6.40
Hour	**13**	14	15	16	17	18	19	20	21	22	23	**24**
Q^h_{rev} [kWh]	**14.26**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**32.24**
P^h_p [c€/kWh]	**6.26**	6.15	6.42	6.63	6.74	7.06	7.65	10.13	8.13	7.21	6.96	**6.17**
P^h_s [c€/kWh]	**5.70**	5.80	6.00	6.20	6.30	6.60	7.20	9.20	7.40	6.80	6.10	**5.60**

In Table V, the results of the LM operation for the winter day are reported. In this table, the third row specifies the energy required by the VED. From the fourth to the seventh row, the amounts of revenues are shown. They are respectively: the sales revenue, the auction revenue, the remaining sales revenue and the collection revenue of the VED. The last row shows the gain of the VED at each hour.

For the winter day in question, the net gain amounts to 0.42€/day. It may seem a non-significant value, but if it is compared with the gain obtained without CEP management, it is easy understood the advantages. In fact, if there is not a CEP, the VED members must buy or sell their energy to the national electricity market at $P^h{}_p$ and $P^h{}_s$, respectively. In this way, there is no auction that can reduce the difference between $P^h{}_p$ and $P^h{}_s$. So The U^h without CEP management becomes a loss equal to -1.2€/day.

Notice how the columns contain null values at the hours when no energy surplus occurs, as shown also in Fig.28: this can be explained by noting that the economic transactions of VED are those of the main electricity market and for that reason, are not considered here.

TABLE V. MARKET PLATFORM OPERATION RESULTS FOR THE WINTER DAY

Hour	1	**2**	**3**	**4**	**5**	**6**	7 -12	**13**	14 -19	**20**	**21**	22	**23**	**24**
Q^h_{rev} [kWh]	0.00	**25.61**	**46.91**	**31.90**	**13.54**	**7.54**	0.00	**8.12**	0.00	**29.93**	**6.41**	0.00	**25.76**	**32.24**
Q^h_{req} [kWh]	0.00	**9.80**	**12.30**	**12.20**	**11.80**	**7.50**	0.00	**8.10**	0.00	**29.90**	**6.40**	0.00	**11.20**	**11.70**
Q^h_{res} [kWh]	0.00	**15.81**	**34.61**	**19.70**	**1.74**	**0.04**	0.00	**0.02**	0.00	**0.03**	**0.00**	0.00	**14.56**	**20.54**
R^h [c€]	0.00	**1.23**	**2.06**	**1.40**	**0.60**	**0.36**	0.00	**0.46**	0.00	**2.75**	**0.47**	0.00	**1.57**	**1.81**
R^h_{auc} [c€]	0.00	**0.49**	**0.56**	**0.56**	**0.54**	**0.39**	0.00	**0.50**	0.00	**2.91**	**0.52**	0.00	**0.73**	**0.68**
R^h_{res} [c€]	0.00	**0.76**	**1.52**	**0.87**	**0.08**	**0.00**	0.00	**0.00**	0.00	**0.00**	**0.00**	0.00	**0.89**	**1.15**
$R^h_{in\_agg}$ [c€]	0.00	**1.25**	**2.08**	**1.42**	**0.61**	**0.40**	0.00	**0.50**	0.00	**2.92**	**0.52**	0.00	**1.62**	**1.83**
U [€]	0.00	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	0.00	**0.04**	0.00	**0.16**	**0.04**	0.00	**0.05**	**0.02**

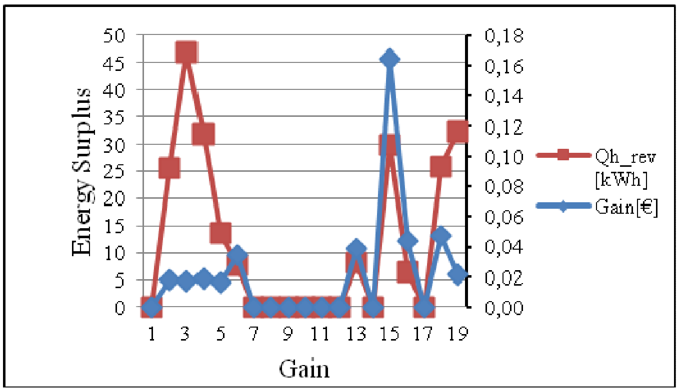

Figure 28: Trend of the proposed market operation for the winter day.

Table VI presents the same results but referred to a summer day.

It must be observed that in summer day the number of hours that are experiencing the surplus energy is less than the winter case: this also implies a less net gain for the VED. Indeed, in this case, it amounts to 0.18€/day, as shown in Fig.29 also.

Like the winter case, the VED Uh for a summer day obtained by the CEP management must be compared with the corresponding value obtained without the CEP management. Without CEP management, the VED has a loss of – 0.63€/day.

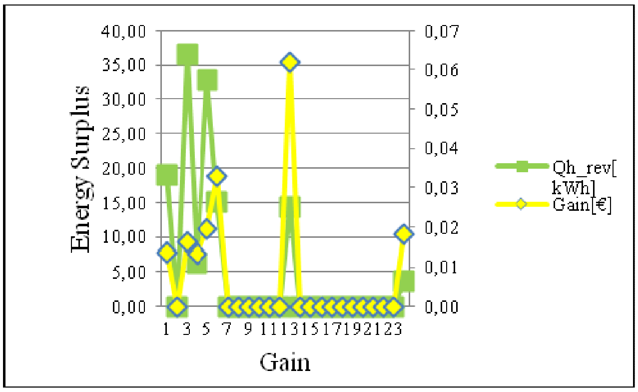

Figure 29: Trend of the proposed market operation for the summer day.

TABLE VI. MARKET PLATFORM OPERATION RESULTS FOR THE SUMMER DAY

Hour	1	2	3	4	5	6	7-12	13	14 -23	24
Qhrev [kWh]	**19.05**	0.00	**36.57**	**6.25**	**32.78**	**15.01**	0.00	**14.26**	0.00	**3.59**
Qhreq [kWh]	**12.70**	0.00	**9.70**	**6.20**	**11.60**	**10.00**	0.00	**14.20**	0.00	**3.50**
Qhres [kWh]	**6.35**	0.00	**26.87**	**0.05**	**21.18**	**5.01**	0.00	**0.06**	0.00	**0.09**
Rh [c€]	**1.10**	0.00	**1.61**	**0.27**	**1.44**	**0.72**	0.00	**0.81**	0.00	**0.20**
Rhauc [c€]	**0.75**	0.00	**0.44**	**0.29**	**0.53**	**0.51**	0.00	**0.87**	0.00	**0.21**
Rhres [c€]	**0.37**	0.00	**1.18**	**0.00**	**0.93**	**0.24**	0.00	**0.00**	0.00	**0.01**
Rhin_agg [c€]	**1.12**	0.00	**1.63**	**0.29**	**1.46**	**0.75**	0.00	**0.87**	0.00	**0.22**
U [€]	**0.01**	0.00	**0.02**	**0.01**	**0.02**	**0.03**	0.00	**0.06**	0.00	**0.02**

It may be noted that the gain obtained through the re-sale of energy surplus by the LMP, is in any case more profitable for the VED, compared to what it can achieve in the electricity market outside the VED: in fact, the LMP allows buyers to buy with a price lower than the corresponding on the electricity market, while producers to sell at a higher price than the corresponding on the electricity market.

Finally, to recreate a true VED, it was supposed to enlarge the VED through a multiply factor equal to 10. Therefore, in this enlarged VED, there are 300 consumers, 200 prosumers, 50 industrial users and 50 producers. In Fig.30, the value of U^h under different situations is depicted for this enlarged VED. In particular, the following U^h value are considered: in a winter case, with and without CEP management and in a summer case, with and without CEP management.

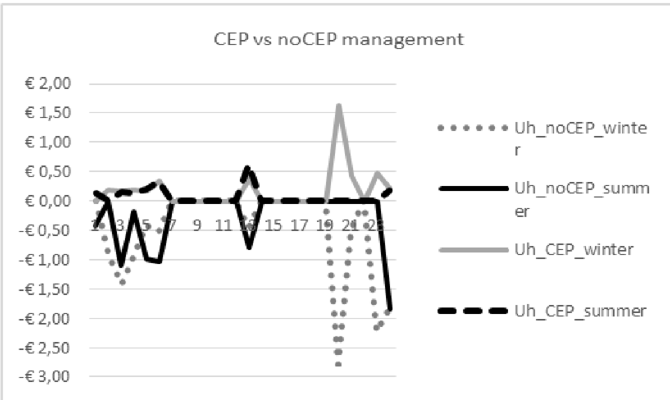

Figure 30: Comparison between the values of Uh obtained with and without CEP management, for an enlarged VED

3.2.2. Constrained Local Market (CLM) Model [91]

In the process of energy exchange, one of the main problems is that the physical transactions of energy occur through the distribution network. In this sense, it is necessary to emphasize that the distribution network presents technical constraints on transport capacity and so affects the market models.

In Fig.31, a distribution network is depicted. Generally, a distribution network presents a radial structure: if different areas of generation/consumption are considered, the energy flows must transit from the transmission network to the farthest area, passing through the intermediate areas. If an area presents a relevant energy production that exceeds its internal demand, an inverse energy flow appears from that area to the transmission network. But, it may happen that in consequence of the generated user energy surplus in area, for example area 2, in order to avoid supply quality reduction, especially in voltage profile, a limit in inverse energy flow on the link between area 2 and the near one has to be settled. Furthermore, this limit on transport capacity avoid the possibility to reverse flow in the transmission grid. Therefore, areas like area 2 become critical areas because, in some cases, production curtailment is the only solution to have a safe distribution network operation.

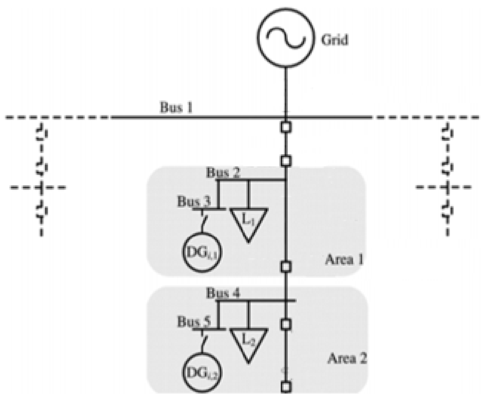

Figure 31: Distribution network example

Then, in order to improve the quality service of network and to ensure its stability, it would be necessary to adopt a *zonal* local market model, that is, different actions have to be taken place depending on the presence or not of the critical areas. If Z is the number of the critical areas and $Q^h_{rev,z}$ is the available *area energy surplus*, i.e. the sum of user energy surplus belonging to such area, in every z area, the following constraint must be considered to avoid congestion problems on the distribution network:

$$\sum_{i=1}^{I(Z)} q^h_{i,z} \geq Q^h_{rev,z} \tag{22}$$

with z=1, 2,…,Z and I(Z) is the number of VED members in z area.

So, the sum of all energy deals accepted in h hour by the i-th user of the z area ($q^h_{i,z}$) must be greater than the *area energy surplus* in the critical area at the same hour ($Q^h_{rev,z}$). Due to this additional constraint, the VED utility (U) will be lower than the achievable VED utility without (22), but the network safety will be stronger. It is worth to underline that if the purchasing offers of the VED members belonging to the critical area does not allow to reduce the energy reverse flow under the admissible limits, (22) cannot be satisfied.

In this case, a residual energy surplus could create problems. This *area residual energy surplus* must be cut by the City DSO.

Therefore, taking into account these new constraints, the LM Model must be changed. It will become the CLM Model, in which the constraints on transport capacity appear.

Max U

S.t.

$$U = \sum_{h=1}^{24} U^h \tag{23}$$

$$U^h = R^h_{VED} - C^h_{VED} \tag{24}$$

$$R^h_{VED} = \sum_{n,z=1}^{N,Z} Rauc^h_{n,z} + \sum_{n,z=1}^{N,Z} Rres^h_{n,z} \tag{25}$$

$$C_{VED}^{h} = Q_{req}^{h} \cdot P_{p}^{h} \tag{26}$$

$$Rauc_{n,z}^{h} = \begin{cases} \left(\sum_{i(n)=1}^{I(n)} q_{i}^{h} \cdot P_{p,i}^{h} + \sum_{i(z)=1}^{I(z)} q_{i}^{h} \cdot P_{p,i}^{h} \right) if\ \forall z \in Z \left(\sum_{i(z)=1}^{I(z)} q_{i}^{h} \leq Q_{\max z} \right) \\ \left(\sum_{i(n)=1}^{I(n)} q_{i}^{h} \cdot P_{p,i}^{h} + \sum_{i(z)=1}^{I(z)} Q_{\max z} \cdot P_{p,i}^{h} \right) if\ \forall z \in Z \left(\sum_{i(z)=1}^{I(z)} q_{i}^{h} > Q_{\max z} \right) \end{cases} \tag{27}$$

$$Rres_{n,z}^{h} = Q_{res}^{h} \cdot P_{s}^{h} \tag{28}$$

$$Q_{req}^{h} = \sum_{i=1}^{I} q_{req,i}^{h} \tag{29}$$

$$Q_{res}^{h} = Qrev_{n,z}^{h} - Q_{req}^{h} \tag{30}$$

$$Qrev_{n,z}^{h} = \begin{cases} \left(\sum_{n=1}^{N} q_{rev,n}^{h} + \sum_{z=1}^{Z} q_{rev,z}^{h} \right) if\ \forall z \in Z \left(q_{rev,z}^{h} \leq Q_{\max z} \right) \\ \left(\sum_{n=1}^{N} q_{rev,n}^{h} + \sum_{z=1}^{Z} Q_{\max z} \right) if\ \forall z \in Z \left(q_{rev,z}^{h} > Q_{\max z} \right) \end{cases} \tag{31}$$

$$Q_{res}^{h} = \begin{cases} \left(a \cdot \left(q_{rev,n}^{h} - \sum_{i(n)}^{I(n)} q_{reqi(n)}^{h} \right) \right) + \left(a \cdot \left(q_{rev,z}^{h} - q_{reqz}^{h} \right) \right) if\ \forall z \in Z \left(\sum_{i(z)=1}^{I(z)} q_{reqz}^{h} \leq Q_{\max z} \right) \\ \left(a \cdot \left(q_{rev,n}^{h} - \sum_{i(n)}^{I(n)} q_{reqi(n)}^{h} \right) \right) + \left(a \cdot \left(q_{rev,z}^{h} - Q_{\max z} \right) \right) if\ \forall z \in Z \left(\sum_{i(z)=1}^{I(z)} q_{reqz}^{h} > Q_{\max z} \right) \end{cases} \tag{32}$$

$$a = binary \tag{33}$$

$$0 \leq q_{i}^{h} \leq Q_{o,i}^{h} \tag{34}$$

$$U \geq 0 \tag{35}$$

The CLM Model is subjected to the constrains (23) to (35).

The (23) and the (24) have the same meaning of the (11) and (12) respectively. It is worth to underline that due to the constraints on the transport capacity, not all the area energy surplus occurring can be transferred to the area where there will be a lack of energy. The maximum transferable energy will be just that imposed by the transport capacity, so if the amount of required energy would be higher, the user must buy it at TOU tariff. For this reason, it is expected that C^{h}_{VED} will be higher than the LMP case.

The (25) indicates the total revenue obtained by the VED in the hour h ($R^h{}_{VED}$). Unlike (13), the $R^h{}_{VED}$ is calculated differently. Because the areas have been differentiated into critical and non-critical, two indexes are introduced: n = 1, ..., N indicates the non-critical areas and z = 1, ..., Z indicates the critical areas. The $R^h{}_{VED}$ will be equal to the sum of all revenues obtained by the market auctions that occur in each area n or z ($Rauc^h{}_{n,z}$), added to the revenues obtained from the sale of the surplus energy rests to the transmission network, in every area n or z ($Rres^h{}_{n,z}$).

The (26) indicates the expression of $C^h{}_{VED}$: it is equal to the total amount of required energy by the VED in the hour h ($Q^h{}_{req}$) multiplied by $P^h{}_p$ at the same hour h.

In (27), the hourly revenue of the auctions ($Rauc^h{}_{n,z}$) is presented as the product of the energy amount offered by the i-th consumer and accepted in the market auction in the hour h and of the purchase price offered by the i-th consumer at the same time h ($P^h{}_{p,i}$). It should be noted that the energy amount offered by the i-th consumer and accepted in the auction at the hour h ($q^h{}_i$) must be always subjected to the constraint of $Q_{max,z}$ for each area z. So if the sum of the amounts of available and accepted energy by the i-th consumers in the hour h is less than $Q_{max,z}$, then that sum will consider, otherwise, $Q_{max,z}$ will consider.

The (28) indicates the hourly revenue obtained from the sale of the residual energy surplus still available ($Rres^h{}_{n,z}$): it is equal to the product between the residual quantity of the energy surplus still available in critical and non-critical areas ($Q^h{}_{res}$) - and so deliverable to the transmission network - and $P^h{}_s$.

If I is the number of all users that require energy in every hour, the (29) defines $Q^h{}_{req,}$, as the sum of all quantities of required energy by each i-th user in the hour h ($q^h{}_{req,i}$).

The (30) shows the $Q^h{}_{res}$ as the difference between the available energy surplus in all areas n and z ($Qrev^h{}_{n,z}$) in the hour h ($Qrev^h{}_{n,z)}$ and $Q^h{}_{req}$.

The (31) shows in detail the calculation of $Qrev^h{}_{n,z}$. This term is equal to the sum of all the *area energy surplus* in the areas n and z, for each critical areas z where the limits on transport capacity $Q_{max,z}$ is not overcame. Otherwise, it is equal to the sum of all the surplus energy in the n areas plus all the maximum transport capacities in z areas.

In (32) Q^h_{res} is equal to the sum of two terms. The first term is the difference between the available energy surplus in the hour h ($q^h_{rev,n}$) and the energy required by all I(n) users at the same time, for each area n. The second term is the difference between the available energy surplus at the hour h ($q^h_{rev,z}$) and the energy required by all I (z) users at the same time, for each area z: this is true every time that the limit on transport capacity is respected. Otherwise, the second term is equal to the difference between the $q^h_{rev,z}$ and the maximum transport capacity for each area z. It should be underlined that every term is multiplied by a binary factor *a* as shown in (33). The factor *a* takes into account the connection to the distribution network: *a* is equal to one if the area n or z is directly connected to the transmission network, and it means that possible residual energy surplus can be injected into the grid. *a* is equal to zero if the area n or z is not direct connected to the transmission network, and it means that possible residual energy surplus must be cut. The constraints (34) and (35) have the same meaning of constraints (20) and (21).

To validate the CLM Model, the behavior of the same VED of LM simulations has been considered. The simulations are carried out referring to a typical winter day.

The input data for the simulation are reported in Table VII.

TABLE VII. Q^{H}_{REV}, P^{H}_{P} AND P^{H}_{S} IN A WINTER DAY

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Q^{h}rev [kWh]	21.83	57.37	76.83	60.40	41.25	35.75	44.54	58.80	41.06	59.65	51.64	72.78
Q^{h}req [kWh]	29.69	31.76	29.92	28.50	27.71	28.22	44.54	58.80	41.06	59.65	51.64	72.78
Q^{h}res [kWh]	0.00	25.60	46.91	31.89	13.53	7.53	0.00	0.00	0.00	0.00	0.00	0.00
P^{h}p [c€/kWh]	6.02	5.16	4.70	4.70	4.70	5.49	6.39	7.00	7.73	7.68	7.18	6.84
P^{h}s [c€/kWh]	5.80	4.80	4.40	4.40	4.40	4.80	6.00	6.60	7.30	7.20	6.80	6.40
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Q^{h}rev [kWh]	69.29	67.04	18.62	34.89	60.39	41.87	44.96	60.39	62.00	39.39	62.45	67.85
Q^{h}req [kWh]	61.17	67.04	35.02	36.08	61.56	41.87	44.96	30.45	55.60	39.39	36.69	35.60
Q^{h}rev [kWh]	8.12	0.00	0.00	0.00	0.00	0.00	0.00	29.93	6.40	0.00	25.76	32.24
P^{h}p [c€/kWh]	6.26	6.15	6.42	6.63	6.74	7.06	7.65	10.13	7.21	7.21	8.13	6.96
P^{h}s [c€/kWh]	5.70	5.80	6.00	6.20	6.30	6.60	7.20	9.20	6.80	6.80	7.40	6.10

As previously mentioned in [70], Table VII shows, in the first row, the hours of the day: those in bold are the hours when the energy surplus happens in VED. The second row shows the amount of energy surplus (Q^{h}_{rev}); the third and fourth rows show the purchase price (P^{h}_{p}) and the sale price (P^{h}_{s}). At the hours in which no energy surplus happens, P^{h}_{p} and P^{h}_{s} are the TOU tariff and MCP respectively; instead when energy surplus occurs, the two prices are the minimum and maximum values that are obtained by market auction into the VED.

The effectiveness of the proposal models will be compared with the results of a simulation where no CEP management is considered. If in a VED there is no CEP who manages the energy exchanges on the local electricity market, it means that all amount of produced energy will be sold on the national electricity market and all amount of required energy will be bought at TOU tariff. The equations from (36) to (39) describe the situation with no CEP management:

$$U_{noCEP} = \sum_{h=1}^{24} U^h_{noCEP} \tag{36}$$

$$U^h_{noCEP} = R^h_{noCEP} - C^h_{noCEP} \tag{37}$$

$$R^h_{noCEP} = Q^h_{rev} \cdot P^h_s \tag{38}$$

$$C^h_{noCEP} = Q^h_{req} \cdot P^h_p \tag{39}$$

The (36) describes the utility for the VED without CEP manage ($U_{\_noCEP}$) as the sum of all hourly utilities obtained in the VED without CEP management ($U^h_{\_noCEP}$). The (37) shows that the $U^h_{\_noCEP}$ is equal to the difference between the hourly revenue obtained if all amount of produced energy is sold on the national electricity market ($R^h_{\_noCEP}$) and hourly cost needed to buy the required energy from the national electricity market ($C^h_{\_noCEP}$). In (38), $R^h_{\_noCEP}$ is equal to the product of the Q^h_{rev} and the P^h_s, while in (39) $C^h_{\_noCEP}$ is equal to the product of the Q^h_{req} and the P^h_p.

The first simulation uses the LM model to manage the energy surplus into the VED previously described that is no critical areas exist. This simulation not considers the distinction of the areas of the VED because the LM model not includes technical constraints on transport.

In Fig.32, the trends of $C^h_{\_VED}$, $R^h_{\_VED}$, $R^h_{\_res}$, $R^h_{\_auc}$ and U^h for LM model ($U^h_{\_LM}$) are shown.

If there is no constraints on distribution network, the $C^h_{\_VED}$ derives only from the situation in which there is an energy demand higher than the available energy surplus. In the case taking in account, this situation happens only in two hours, for a daily cost equal to 1.59€/day. Referring to the $R^h_{\_VED}$, notice that $R^h_{\_auc}$ is the biggest part of it: in fact, the sum of all $R^h_{\_auc}$ is equal to 69.53€/day, while the sum of all $R^h_{\_res}$ amounts to 12.72€/day, for a total sum of all $R^h_{\_VED}$ equal to 82.25€/day. The VED utility $U_{\_LM}$, using the LM model, amounts to 80.67€/day.

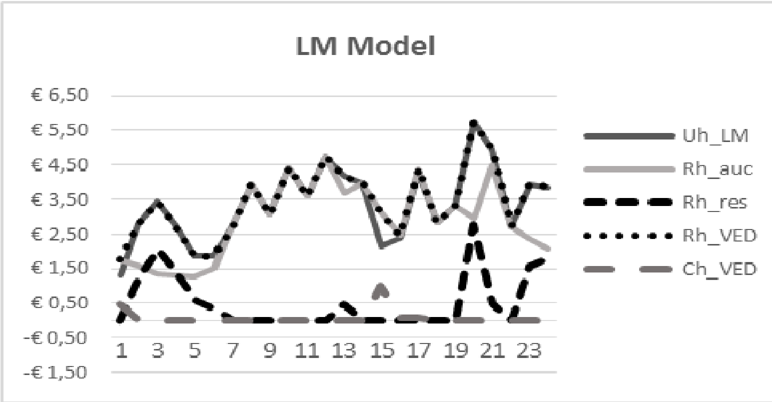

Figure 32: Results of LM Model applied on the VED

If no CEP management and no local market are applied, the VED would buy the necessary energy from the Italian electricity market and sell all the energy surplus to the same market. In Fig.33, the U^h_{LM} and the U^h_{noCEP} are compared: it is worth to underline that the U^h_{noCEP} is very lower that the utility obtained by the CEP management with LM model. The sum of all U^h_{noCEP} is equal to 6.20€/day, producing a different with the U^h_{LM}, named Delta U, equal to 74.47€/day.

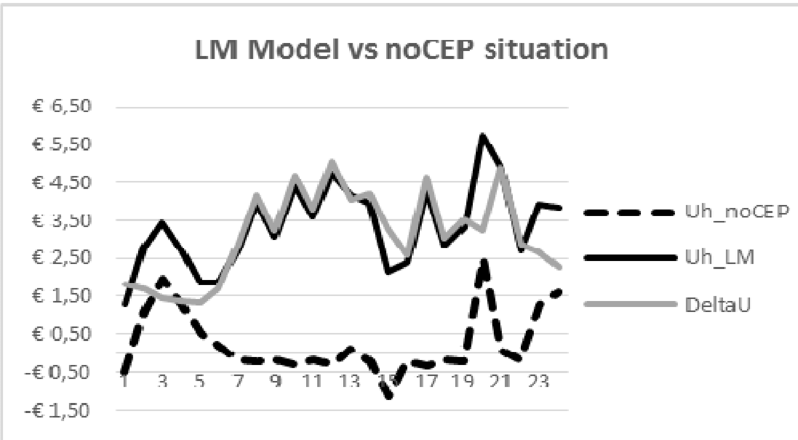

Figure 33: Comparison of the result of LM Model versus no CEP management

Applying CLM Model, the VED is divided into a critical area, referred to as area A, as an example seen Fig.28, and a noncritical area, referred to as area B. It was assumed that all producers are allocated in area A while consumers and prosumers belong to the area B. A maximum transport capacity (Q^h_{max}) of 10kWh towards area A in reverse flow has been assigned. It was supposed that only the area B is directly connected to the transmission network.

In Fig.34, the results of the simulations with the model CLM are illustrated, in terms of $C^h_{\_VED}$, $R^h_{\_VED}$, $R^h_{\_res}$, $R^h_{\_auc}$, U^h for CLM model ($U^h_{\_CLM}$) and $L^h_{\_cutA}$, that is the economic loss due to the cut of production.

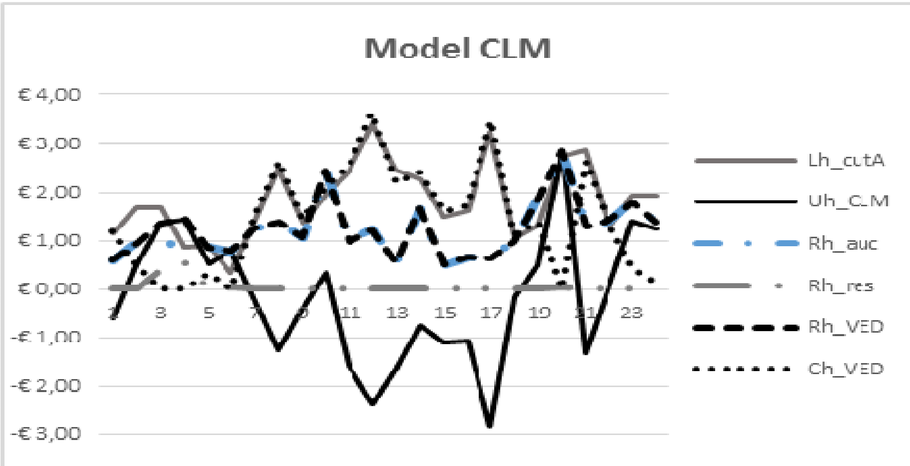

Figure 34: Results of CLM Model applied on the VED

Due to the transport capacity limits, it is reasonable to expect that the term $C^h_{\_VED}$ is bigger than the equivalent in LM model, shown in Fig.34, because not all the production into the VED can be moved freely and thus can satisfy all energy requests. In fact, in CLM model, the sum of all $C^h_{\_VED}$ is equal to 34.22€/day.

Regarding the $R^h_{\_VED}$, also in CLM model, $R^h_{\_auc}$ is the biggest part of it: in fact, the sum of all $R^h_{\_auc}$ is equal to 28.79€/day, while the sum of all $R^h_{\_res}$ amounts to 0.98€/day, for a total sum of all $R^h_{\_VED}$ equal to 29.77€/day. Notice how the presence of the constraints on distributed network reduces heavily the revenues in the VED and increases the cost to buy the required energy.

In addition, due to the combined effect of the transport capacity limit and of the absence of a direct connection of certain area of the VED to the transmission network, the VED production can be cut in order to avoid congestion on distribution network. This is what happens in the area A for the undertaken hypothesis: so it is necessary to cut production in A. To take in account this possibility, $L^h{}_{\_cutA}$ is calculated as the product between the cut production and the selling price of the national electricity market. Fig.34 shows the trend of $L^h{}_{\_cutA}$: it is higher than the trend of $R^h{}_{\_VED}$. This loss amounts to 43.75€/day. Due to the hypothesis, perhaps too restrictive, it means that in A the most of the production is cut because it cannot be transported in B, and cannot be sold in DAEM that is injected into the transmission network. For these reasons, the VED utility $U_{\_CLM}$, using the CLM model, is negative and equal to – 4.46€/day.

In Fig.35, the $U^h{}_{\_CLM}$ and the $U^h{}_{\_noCEP}$ are compared: it should be noticed that only in a few hours, the trend of $U^h{}_{\_CLM}$ is higher than the trend of $U^h{}_{\_noCEP}$, but the different is very small. In some other hours, instead the trend of $U^h{}_{\_CLM}$ is deep negative and the different with $U^h{}_{\_noCEP}$ is significant (i.e. at 5 pm, the different is equal to 2.50€). The different Delta U equal to -10.65€/day.

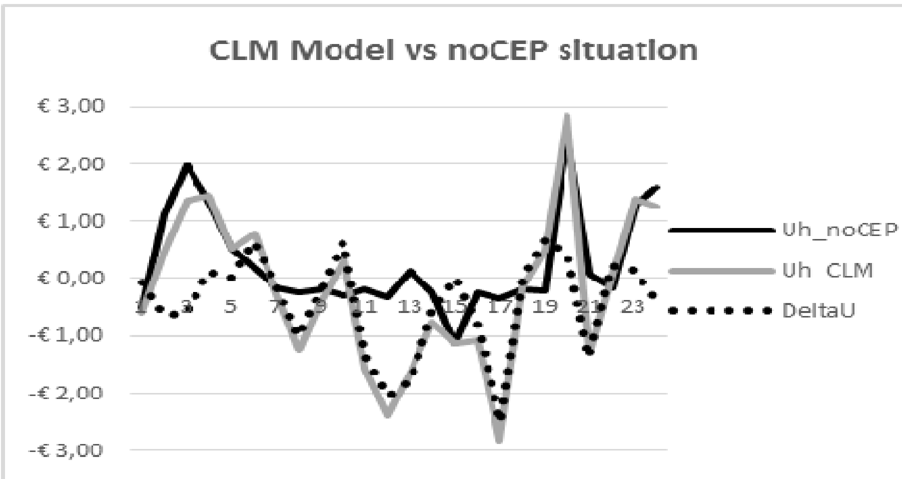

Figure 35: Comparison of the result of CLM Model versus no CEP management

In Fig.36, there is the comparison between the results obtained by the two proposed model and the situation without CEP management. Without any constraints, so applying the LM model, the VED can obtain the maximum utility. If no CEP and local market are considered, the utility of the VED is limited. Instead, taking into account the constraints on transport capacity that is applying the CLM model, the utility of the VED is deeply penalized and it corresponds in a proper loss. Notice how in CLM model, due to the necessity of cut the production to guarantee the safety of distribution system operations, the economic loss generated by these constraints is almost similar to the trend of $U^h{}_{\_noCEP}$.

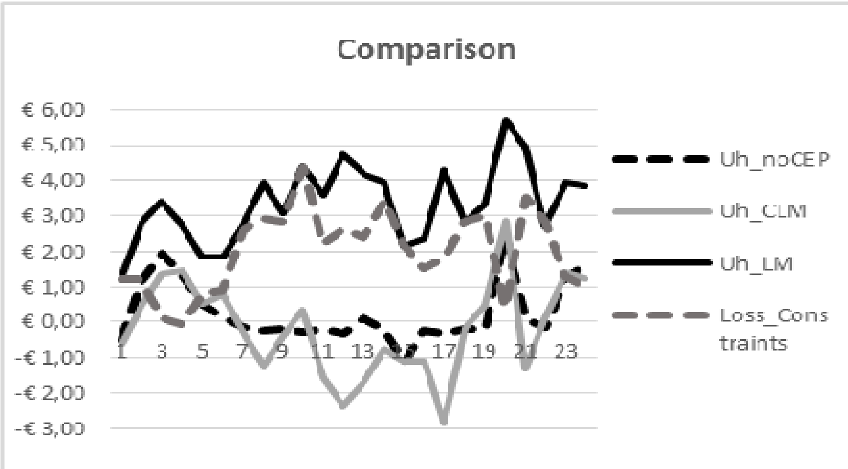

Figure 36: Comparison of the results of LM Model, CLM model and no CEP management situation

In Tables VIII and IX, all the simulation results are reported.

TABLE VIII. MARKET AUCTION RESULTS BY USING LMP MODEL

Hour	1	2	3	4	5	6	7	8	9	10	11	12
R^hauc [€]	1.76	1.57	1.35	1.30	1.26	1.50	2.73	3.94	3.06	4.41	3.59	4.74
R^hres [€]	0.00	1.23	2.06	1.40	0.60	0.36	0.00	0.00	0.00	0.00	0.00	0.00
R^hVED [€]	1.76	2.80	3.42	2.71	1.85	1.86	2.73	3.94	3.06	4.41	3.59	4.74
C^hVED[€]	0.46	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
U^hVED [€]	1.30	2.80	3.42	2.71	1.85	1.86	2.73	3.94	3.06	4.41	3.59	4.74
Hour	13	14	15	16	17	18	19	20	21	22	23	24
R^hauc [€]	0.12	-0.23	-1.13	-0.23	-0.34	-0.19	-0.20	2.47	0.07	-0.16	1.26	1.60
R^hres [€]	3.69	3.97	3.13	2.45	4.37	2.83	3.32	2.96	4.47	2.72	2.36	2.05
R^hVED [€]	0.46	0.00	0.00	0.00	0.00	0.00	0.00	2.75	0.47	0.00	1.57	1.81
C^hVED[€]	4.15	3.97	3.13	2.45	4.37	2.83	3.32	5.72	4.94	2.72	3.93	3.85
U^hVED [€]	0.00	0.00	0.98	0.07	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TABLE IX. MARKET AUCTION RESULTS BY USING CLM MODEL

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Q^{h}rev_A [kWh]	29.70	44.92	48.26	29.52	30.36	16.99	33.72	47.52	28.60	37.15	45.67	63.00
Qmax [kWh]	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Q^{h}_cutA[kWh]	19.70	34.92	38.26	19.52	20.36	6.99	23.72	37.52	18.60	27.15	35.67	53.00
Q^{h}rev_B [kWh]	-7.86	12.45	28.58	30.88	10.90	18.77	10.83	11.28	12.46	22.50	5.97	9.78
Q^{h}deficit_B [kWh]	19.70	9.31	0.00	0.00	6.82	0.00	23.72	37.52	18.60	27.15	35.67	53.00
Q^{h}res_B [kWh]	0.00	0.00	8.65	12.37	0.00	0.55	0.00	0.00	0.00	0.00	0.00	0.00
R^{h}auc [€]	0.58	0.95	0.97	0.89	0.85	0.76	1.24	1.38	1.06	2.42	0.98	1.24
R^{h}res [€]	0.00	0.00	0.38	0.54	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00
R^{h}VED [€]	0.58	0.95	1.35	1.43	0.85	0.79	1.24	1.38	1.06	2.42	0.98	1.24
C^{h}VED[€]	1.19	0.48	0.00	0.00	0.32	0.00	1.52	2.63	1.44	2.09	2.56	3.63
L^{h}cutA [€]	1.14	1.68	1.68	0.86	0.90	0.34	1.42	2.48	1.36	1.95	2.43	3.39
U^{h}VED [€]	-0.60	0.47	1.35	1.43	0.53	0.79	-0.27	-1.25	-0.38	0.34	-1.58	-2.39
Hour	13	14	15	16	17	18	19	20	21	22	23	24
Q^{h}rev_A [kWh]	52.97	48.99	35.03	36.08	61.57	26.11	27.90	39.66	48.62	28.55	41.59	44.29
Qmax [kWh]	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Q^{h}_cutA [kWh]	42.97	38.99	25.03	26.08	51.57	16.11	17.90	29.66	38.62	18.55	31.59	34.29
Q^{h}rev_B [kWh]	16.33	18.05	-16.40	-1.18	-1.17	15.77	17.07	20.73	13.39	10.84	20.87	23.56
Q^{h}req$_{\text{–to network}}$ [kWh]	34.84	38.99	25.03	26.08	51.57	16.11	17.90	0.00	32.21	18.55	5.82	2.05
Q^{h}res_B [kWh]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.00	0.00	0.00	0.00
R^{h}auc [€]	0.53	1.65	0.49	0.65	0.63	0.97	1.87	2.81	1.30	1.41	1.79	1.38
R^{h}res [€]	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
R^{h}VED [€]	0.53	1.65	0.49	0.65	0.63	0.97	1.87	2.84	1.30	1.41	1.79	1.38
C^{h}VED[€]	2.45	2.26	1.50	1.62	3.25	1.06	1.29	2.73	2.86	1.26	1.93	1.92
L^{h}cutA [€]	2.18	2.40	1.61	1.73	3.48	1.14	1.37	0.00	2.62	1.34	0.41	0.13
U^{h}VED [€]	-1.65	-0.75	-1.12	-1.08	-2.84	-0.17	0.50	2.84	-1.32	0.07	1.38	1.25

3.2.3. Constrained Local Market Model with Storage [88]

Starting from the abovementioned problem referring to critical areas, when a not saleable surplus of energy appears, the only solution is the curtailment of production, with the consequence of an economic loss. In this case, a storage system in the critical area may help to reduce the power curtailment and so the economic loss. The VED users who have storage systems offer a certain storage capacity available to store the energy that cannot be sold because of the limits on transport capacity of some parts of distribution network or because there is a lack of energy demand. In respect of the constraints of transport capacity, this amount of stored energy is then available in the next hour for potential buyers even in the adjacent area or injected into the network.

The storage system management, on an hourly basis, implements the logic to discharge the storage system as soon as possible. The storage system may be discharged also because not all the local production can satisfy the energy demand:

the storage system then intervenes with the amount of available accumulated energy, respecting the constraint on the transmission capacity of the line between the areas. Even if the energy demand is lower than the production but there is an amount of transport capacity still available, the storage system gives the energy contained up to saturate the limit of transportation. In this case, the energy passes from the storage system to a non-critical area, without being consumed, and will be sold to the DAEM, making available a new storage capacity.

Therefore, starting from CLM model, a new model has been developed in which the presence of a storage system according with CEP management strategy is considered. This model is named CLM with Storage (CLMS) and is described in the following:

Max U

S.t.

$$U = \sum_{h=1}^{24} U^h \tag{40}$$

$$U^h = R^h_{VED} - C^h_{VED} \tag{41}$$

$$R^h_{VED} = Rauc^h + Rres^h \tag{42}$$

$$C^h_{VED} = Q^h_{req\_net} \cdot P^h_p \tag{43}$$

$$R^h_{auc} = \sum_{n=1}^{N} Rauc^h_n + \sum_{z=1}^{Z} Rauc^h_z \tag{44}$$

$$R^h_{res} = \sum_{n=1}^{N} Rres^h_n \tag{45}$$

$$Q^h_{req\_net} = \begin{cases} Q^h_{req\_n,z} - Q^h_{prod\_n,z} & if \ Q^h_{req\_n,z} > Q^h_{prod\_n,z} \\ 0 \ \ if \ Q^h_{req\_n,z} < Q^h_{prod\_n,z} \end{cases} \tag{46}$$

$$R^h_{auc,z} = \sum_{i(z)=1}^{I(Z)} q^h_{auc\_z,i(z)} \cdot P^h_{p,i(z)} \tag{47}$$

$$Q^{h}_{auc,z} = \sum_{i(z)=1}^{I(Z)} q^{h}_{auc\_z,i(z)} \tag{48}$$

$$Q^{h}_{auc,z} = \begin{cases} Q^{h}_{prod,z} + Q^{h-1}_{storage} \ \ if \ \ Q^{h}_{req,z} > Q^{h}_{prod,z} \\ Q^{h}_{req,z} \ \ if \ \ Q^{h}_{req,z} < Q^{h}_{prod,z} \end{cases} \tag{49}$$

$$R^{h}_{auc,n} = \sum_{i(n)=1}^{I(N)} q^{h}_{auc\_n,i(n)} \cdot P^{h}_{p,i(n)} \tag{50}$$

$$Q^{h}_{auc,n} = \sum_{i(n)=1}^{I(N)} q^{h}_{auc\_n,i(n)} \tag{51}$$

$$Q^{h}_{auc,n} = \begin{cases} Q^{h}_{prod,n} + Q^{h}_{trans\_z-n} \ \ if \ \ Q^{h}_{req,n} > Q^{h}_{prod,n} \\ Q^{h}_{req,n} \ \ if \ \ Q^{h}_{req,n} < Q^{h}_{prod,n} \end{cases} \tag{52}$$

$$R^{h}_{res,n} = Overbalance^{h} \cdot P^{h}_{s} \tag{53}$$

$$Q^{h}_{storage} = \begin{cases} \eta_{storage} \cdot \left(Q^{h}_{prod,z} - Q^{h}_{req,z} - Q_{\max} \right) \\ if \ \ Q^{h}_{prod,z} - Q^{h}_{req,z} > Q_{\max} \ and \ \sum_{i=1}^{h-1} Q^{i}_{storage} < Q_{storageMax} \\ 0 \ \ if \ \ Q^{h}_{prod,z} - Q^{h}_{req,z} < Q_{\max} \ and \ \sum_{i=1}^{h-1} Q^{i}_{storage} > Q_{storageMax} \end{cases} \tag{54}$$

$$Q^{h}_{trans,z-n} = \begin{cases} Q^{h}_{prod,z} - Q^{h}_{req,z} - Q^{h-1}_{storage} \\ if \ \ Q^{h}_{prod,z} - Q^{h}_{req,z} - Q^{h-1}_{storage} < Q_{\max} \\ Q_{\max} \ \ if \ \ Q^{h}_{prod,z} - Q^{h}_{req,z} - Q^{h-1}_{storage} > Q_{\max} \end{cases} \tag{55}$$

$$Overbalance^{h} = \begin{cases} Q^{h}_{prod,n} - Q^{h}_{auc,n} + Q^{h}_{trans,z-n} \\ if \ \ Q^{h}_{prod,n} > Q^{h}_{auc,n} \ and \ Q^{h}_{req,n} < Q^{h}_{prod,n} \\ 0 \ \ if \ \ Q^{h}_{prod,n} < Q^{h}_{auc,n} \ and \ Q^{h}_{req,n} > Q^{h}_{prod,n} \end{cases} \tag{56}$$

$$Q^{h}_{cut} = Q^{h}_{prod,z} - Q^{h}_{req,z} - Q^{h}_{trans,z-n} - Q^{h}_{storage} \tag{57}$$

$$L^{h}_{cut} = Q^{h}_{cut} \cdot P^{h}_{s} \tag{58}$$

The CLMS Model aims to maximize the VED utility in the time, that is, the utility obtained from the sale of the produced energy within the VED. The CLMS Model is subjected to the constraints (40) to (58). The (40) defines the daily VED utility (U) as the sum of all hourly utilities achieved in the 24 hours of the day into account. The (41) requires that the utility at the hour h (U^h) is defined as the difference between the revenue earned from sales within the VED at the hour h (R^h_{VED}) and the cost relating to the purchase of the energy deficit at the hour h (C^h_{VED}). The (42) describes R^h_{VED}, as the sum of the revenue from the market auction inside the VED at the hour h (R^h_{auc}) and the revenue from the remaining sales after the market auction at the hour h (R^h_{res}). The (43) is relative to C^h_{VED}, defined as the product between the energy deficit required to the distribution network at the hour h ($Q^h_{req\_net}$), and the relative purchasing price (P^h_p). The (44) shows the R^h_{auc} as the sum of all revenues obtained by the market auctions that occur in each area n ($R^h_{auc,n}$) and the sum of all revenues obtained by the market auctions that occur in each area z at the hour h ($R^h_{auc,z}$). The (45) indicates that the R^h_{res} is equal to the sum of all revenues from the remaining sales after the market auction that happen in every n area at the hour h ($R^h_{res,n}$). Notice that this type of sale happens only in n area because the authors suppose that only n areas have a direct connection to the transmission network. The (46) defines $Q^h_{req\_net}$ as the difference between the energy required by the users of all n and z areas of the VED at the hour h ($Q^h_{req,n,z}$) and the energy produced by the producers/prosumers of all n and z areas of the VED at the hour h ($Q^h_{prod,n,z}$) if the consumption is greater than the production. Otherwise, $Q^h_{req\_net}$ is null. The (47) describes the $R^h_{auc,z}$. i(z) is the single user belonging to the z area and I(z) are all users belonging to the z area. So $R^h_{auc,z}$ is equal to the sum of all products between the amount of energy that every i(z)-th user is available to buy from the auction at the hour h ($q^h_{auc\_z,i(z)}$) and the purchasing price he is available to spend for that amount of energy at the same hour h ($P^h_{p,i(z)}$). The (48) is relative to the amount of energy that compressively is sold in the auction at the hour h ($Q^h_{auc,z,}$). It is defined as the sum of all $q^h_{auc\_z,i(z)}$, and in (49), it is specified what are the energy flows that are offered in the auction. So, $Q^h_{auc,z}$ is equal to the sum of all energy produced in the z area at the hour h ($Q^h_{prod,z}$) and the stored energy at the hour h-1 ($Q^{h-1}_{storage}$), if the energy required by the users of the z area at the hour h ($Q^h_{req,z}$) is greater than $Q^h_{prod,z}$. While, if the consumption in the z area at the hour h, that is $Q^h_{req,z}$, is lower than the production in the same area and at the same hour, that is $Q^h_{prod,z}$, the $Q^h_{auc,z}$ is just equal to the $Q^h_{req,z}$. The (50) and (51) have the same meaning of (47) and (48), but they are referred to an n area. The (52) indicates what are the energy flows that create $Q^h_{auc,n}$. $Q^h_{auc,n}$ is equal to the sum of all energy produced in the n area at the hour h ($Q^h_{prod,n}$) and the energy transmitted from a z area to a n area connected each other, at the hour h ($Q^h_{trans\_z\text{-}n}$), if the energy required by the users of the n area at the hour h ($Q^h_{req,n}$) is greater than $Q^h_{prod,n}$. While, if the consumption in the n area at the hour h, that is $Q^h_{req,n}$, is lower than the production in the same area and at the same hour, that is $Q^h_{prod,n}$, the $Q^h_{auc,n}$ is just equal to the $Q^h_{req,n}$. The (53) shows the $R^h_{res,n}$ as the product between the amount of energy still available after the satisfaction of energy demand and after the full charge of storage systems, at the hour h ($Overbalance^h$), and the sale price at the same hour (P^h_s). The (54) defines the energy that is stored at the hour h ($Q^h_{storage}$) as the product between the storage system efficiency ($\eta_{storage}$) and an algebraic sum of different terms. This sum is equal to $Q^h_{prod,z}$, minus $Q^h_{req,z}$, minus Q_{max}, that is the limit on transport capacity. This is true until the difference between the $Q^h_{prod,z}$ and $Q^h_{req,z}$ is greater than Q_{max}, and until there is still available storage capacity. If these two conditions are not satisfied, $Q^h_{storage}$ is null. The (55) describes the $Q^h_{trans\_z\text{-}n}$. It is equal to the difference between $Q^h_{prod,z}$ and the sum of $Q^h_{req,z}$. and $Q^h_{storage}$, if this value respects the limit on transport capacity of distribution network (Q_{max}); otherwise, it is just equal to Q_{max}. The (56) identifies $Overbalance^h$. This term is equal to the algebraic sum of $Q^h_{prod,n}$, minus $Q^h_{auc,n}$, plus $Q^h_{trans\_z\text{-}n}$, if the produced energy in n areas at the hour h is greater than the energy sold on auctions in the same areas and in the same hour and if the required energy in n area at the hour h is lower than the produced energy in the same areas at the same hour. The (57) shows the energy that must be cut to avoid congestion problems on distribution network at the hour h (Q^h_{cut}): it is equal to the difference between $Q^h_{prod,z}$ and $Q^h_{req,z}$, $Q^h_{trans\_z\text{-}n}$ and $Q^h_{storage}$. In (58) the loss of revenue due to the cut of produced energy in the hour h (L^h_{cut}) is presented as the product between Q^h_{cut} and the P^h_s.

To validate the proposed CLMS model, the behaviour of a VED constituted by two areas (A and B) is considered. The area A is direct connected to the transmission network and 30 residential consumers, 20 residential prosumers and 5 small industrial consumers belong to it. Area B is connected to area A and 5 producers belong to it. This configuration of area A and area B stresses the possibility that overloads and congestions can appear on distribution network.

A first group of simulations is carried out observing how the energy flows in the VED are modified if the storage system has a fixed value of capacity (50kWh) and the limit on transport capacity changes. The limit on transport capacity can vary depending on the following values: 10kWh, 20kWh, 30kWh, 40kWh, 50kWh, 60kWh and no constraint situation. In Fig.37, the results of the simulation with 50kWh – storage system and 10kWh – transport capacity are shown. In the diagram the trends of U^h, C^h_{VED}, R^h_{auc}, R^h_{res}, L^h_{cut} are depicted. During the central hours of the day, when the energy production is high, the energy curtailment is relevant due to the strict constraint on transport capacity. Therefore, the U^h assumes negative value as the VED must purchase energy from the national electricity market to satisfy the load. In fact, the trend of C^h_{VED} (in diagram indicated as $C^h_{\_CLMS10}$) is quite similar to the trend of L^h_{cut} (in diagram indicated as $L^h_{\_CLMS10}$). In total, the daily utility U for the VED amounts to 1.04€/day, while the daily revenue from the auctions R_{auc} is equal to 34.29€/day and the daily cost C for energy is 34.22€/day. The daily revenue from the remaining sales after the auctions R_{res} is very irrelevant and equal to 0.98€/day. This value is due to the critical condition of area B (severe limit on transport capacity and no direct connection to the transmission network), and due to the fact that in A the most of energy production is used to satisfy the consumption. Notice that the loss of revenue due to the curtailment of production L^h_{cut} is high and equal to a daily value of 40.75€/day.

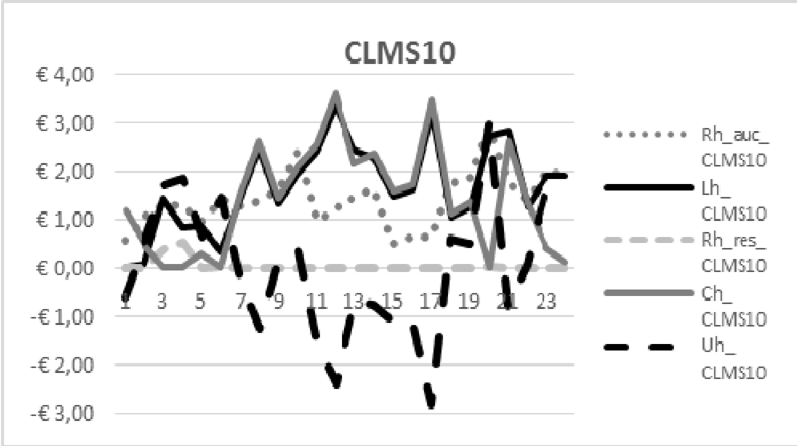

Figure 37: Results of CLMS Model with 10kWh transport capacity and 50kWh storage system capacity.

Before to observe how these values change with the variation of limit on transport capacity, it is worth to underline the positive effect due to the introduction of storage system and the proposal management strategy. To demonstrate this positive effect, the simulation results of CLMS Model with 10kWh transport capacity and 50kWh storage system must be compared with the simulation results of CLM Model with 10kWh transport capacity and no storage system [89], reported in Table X.

TABLE X. RESULTS OF CLM MODEL

CML Model [€/day]	
R^h_{auc}	28.79
L^h_{cut}	43.75
R^h_{res}	0.98
C^h_{VED}	34.22
U^h	-4.46

The presence of the storage system allows obtaining an increase of utility of about 330% respect to the utility obtained without the storage system. This increase of utility is due especially to an increase of revenue from the auction (28.79€/day in

CLM Model vs 34.29€/day in CLMS Model) and a decrease of the loss for energy curtailment (40.75€/day in CLM Model vs 43.75€/day in CLMS Model).

Moreover, the CLMS Model is used to perform sensitivity analysis in order to determine the optimal transport capacity and storage system size. Indeed as increasing transport capacity and storage size is expensive to determine the minimum value that allows to maximize VED utility maybe an important topic for CEP. In Fig.35, the daily values of simulation results of CLMS Model are reported in function of different values of transport capacity. In details, there are the daily values of U, C, R_{auc}, R_{res} and L_{cut} (respectively in the diagram named as $U_{\_day}$, $C_{\_day}$, R_{auc_day}, R_{res_day} and L_{cut_day}). Notice how the transport capacity of 40kWh is a critical value. In fact, for the assumptions taking in account in terms of generation and consumption profiles, in correspondence of this limit on transport capacity, every trend shows a knee. For $U_{\_day}$, R_{auc_day} and R_{res_day}, before the value corresponding to 40kWh transport capacity (see Fig.38), every trend presents a rapid increase; after that value, the variation of the trends is more moderate than before. Similar, $C_{\_day}$ and L_{cut_day} present a rapid decrease before the value of 40kWh transport capacity; after, both the trends tend to zero.

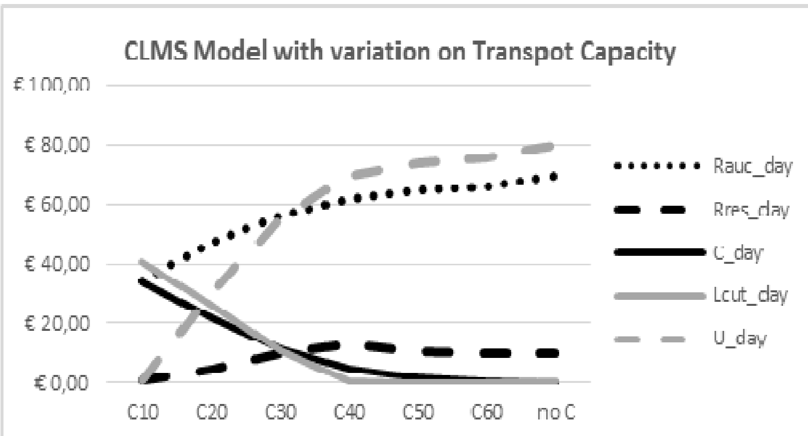

Figure 38. Results of CLMS Model with different values of transport capacity and 50kWh storage system capacity.

The variation of the daily losses L was studied for three values of transport capacity in function of different sizes of storage system and the results reported in Fig.39. In the strictest case, that is a 10kWh transport capacity, even with a large increase of storage capacity, the L does not tend to zero. Furthermore, it would not justifiable the expensive cost to purchase a very capable storage system against a limited reduction of L. In a 40kWh transport capacity case, even with a storage system smaller than 50kWh, the value of L tends to zero. In an intermediate case, like 25kWh transport capacity, L assumes intermediate values and also in this case, it is necessary compare the cost of storage system with the revenue from the reduction of curtailment.

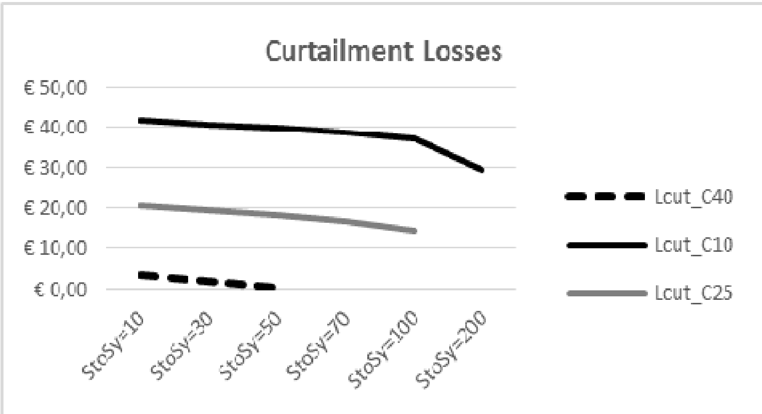

Figure 39: Variation of curtailment losses in function of different values of transport capacity and different values of storage system capacity.

3.2.4. Storage Local Market (StLM) Model [90]

In order to improve the quality of service and to ensure stability and a utility to the users of the VED, it would be necessary to adopt a zonal local market model, that is, different actions have to be taken place depending on the presence or not of the critical areas, as before explained [130].

To obtain more profitable investments in renewable sources plats, micro-storage systems at user level are currently installing [61, 131-134]. The users with storage systems could offer a storage capacity available to store the energy that cannot be sold (i.e. an energy surplus) because of the limits on transport capacity of some areas of distribution network or because there is a lack of energy demand (i.e. an energy deficit). Respecting the constraints of transport capacity, this amount of stored energy could be available in the next hour for potential buyers even in the adjacent area or injected into the network.

In the paper, an extension of the previous local energy market in order to include the availability of user storage is proposed. In particular, a local market session of storage availability takes place after the energy market, where energy that cannot be sold to the national market due to distribution network congestions is sold to the storage owners through an auction (Fig.40).

The benefits of such methodology are clear: no centralized user storage system must be used; the user storage system will be fully utilized increasing the profitability of end user investments in storage system.

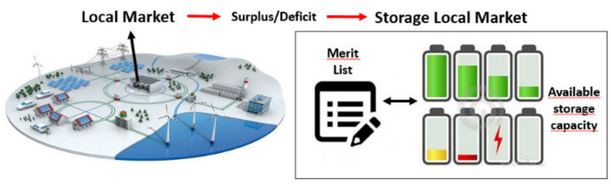

Figure 40. Interaction between Local Market and Storage Local Market

In this direction, the idea is to realize a second auction into the CLMS model just presented in [88]. Now a Storage Local Market (StLM) will be introduced, that is every hour eventual energy surplus or deficit continue to be absorbed or supplied by the VED itself. This idea rises from the desire to lie on, possible least, the energy management of VED on the transmission network: this means that in a VED, the produced energy should be consumed locally, the possible energy surplus should not be exchanged in the national grid, and the possible energy deficit should be buy firstly in the VED. To achieve this goal, the use of storage systems is necessary. In this way, the VED would be able to sustain itself, resorting to the national market only in few cases. In addition, an energy management helped by storage systems allows obtaining to the VED users more profitable economic conditions.

In practice, every hour, near to the auctions in which the basic energy needs are satisfied, other auctions will take place where users, owners of storage systems, provide their storage capacity or the energy already stored (see Fig.41).

Specifically, in an hour in which an energy surplus happens, the users with storage systems participate in the secondary auction, declaring how much energy they are able to store and which price they are willing to pay for store this energy. In an hour in which an energy deficit happens within the VED, the users with storage systems have the priority to participate in the auction for the purchase of energy deficit, then they submit offers to sell energy in terms quantity and selling price.

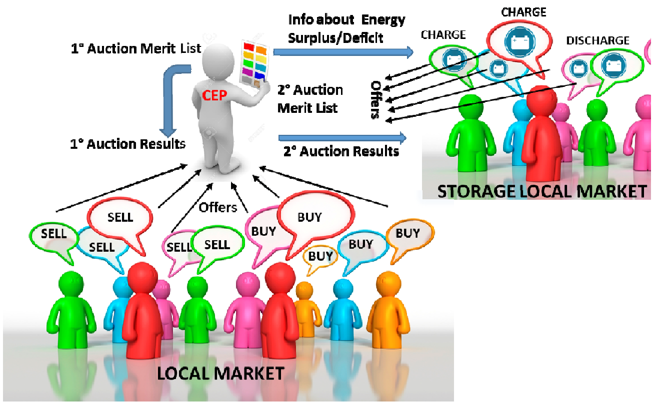

Figure 41: Steps of LMP and StLM

The CEP manages all the purchase and sale offers, orders them in a list of merit according to the offered prices and selects those that provide the greatest positive effect (i.e. a greater utility for those who sell or a greater saving for those who purchase).

The effect of the secondary auction is positive both for the users with and without storage systems. For the first, the advantage is to buy the energy they need at prices much more advantageous than those that would result in the national market (in particular in the intraday market, where the highest prices can be reached due to the immediate regulation to bridge the energy deficit demand). For the latter, the advantage are the assurance of buying energy at a favourable price and the priority to be chosen in the sale of energy when an energy deficit happens. Also for the users with storage systems, a utility for the offered service is always recognized. Indeed, the price ranges, in which the purchase and sale offers take place for the users with storage systems, do not intersect themselves. This means that in a purchasing auction, the users with storage systems present offers at prices ranging between zero and the zonal price P_p^h established at the national market.

Regarding this aspect, a clarification is required: currently, in Italy, the energy produced from distributed generation and injected into distribution network is remunerated at the zonal price, but it is increasingly strong the incentive to promote self-consumption and therefore the incentive to not remunerate the injection of energy into distribution network. This is the reason why the limit on purchase price are zero and P_p^h.

Instead, for the sale auctions, the users with storage systems present offers with prices that vary between P_p^h and the common selling price P_s^h (the rate applied to the consumer). Therefore, the lower is the purchase price agreed and the greater is the selling price accepted, the greater is the utility to the user with storage systems.

The mathematical model that describes the StLM operations is the following:

$$\min C_{storage} - U_{storage} \tag{59}$$

$$C_{storage} = \sum_{h=1}^{24} \sum_{i=1}^{I} P_{acp,i}^{h} \cdot S_{acp,i}^{h} \tag{60}$$

$$U_{storage} = \sum_{h=1}^{24} \sum_{i=1}^{I} P_{acp,i}^{h} \cdot S_{acp,i}^{h} \tag{61}$$

$$P_{acp,i}^{h} = \begin{cases} 0 < P_{acp,i}^{h} < P_p^h \ if\ E_{VED}^h > 0 \\ P_p^h < P_{acp,i}^{h} < P_s^h \ if\ E_{VED}^h < 0 \end{cases} \tag{62}$$

$$\sum_{i=1}^{I} S_{acp}^{h} \le E_{VED}^{h}, \forall h \tag{63}$$

$$0 < S_{acp,i}^{h} < S_{res,i}^{h} \tag{64}$$

$$S^{h}_{res,i} = S^{h-i}_{res,i} - S^{h}_{acp,i} \tag{65}$$

$$S^{h-1}_{res,i,h=1} - S_{max,i} \tag{66}$$

$$E^{h}_{VED} = Prod^{h}_{VED} - Cons^{h}_{VED} \tag{67}$$

StLM model is a minimization problem ((59)), with eight constraints (from (60) to (67)).

In (59) the function to minimize is the difference between the cost needed to store energy ($C_{storage}$) and the utility obtained from the sale of stored energy ($U_{storage}$). In (60), $C_{storage}$ is explained. It is equal to the sum, for every hour h of the day and for every user i (i=1, …, I) who owns a storage system, of the product between the accepted price ($P_{acp,i}^{h}$) and the accepted amount of energy ($S_{acp,i}^{h}$). In this case, $P_{acp,i}^{h}$ is a purchase price while $S_{acp,i}^{h}$ is energy to store. Similar, in (61), $U_{storage}$ is equal to the sum, for every hour h of the day and for every user i (i=1, …, I) who owns a storage system, of the product between the $P_{acp,i}^{h}$ and the $S_{acp,i}^{h}$, where $P_{acp,i}^{h}$ is a sell price while $S_{acp,i}^{h}$ is stored energy ready to be sell. In (62), the $P_{acp,i}^{h}$ is shown. It can vary between zero and the national market purchase price (P_{p}^{h}), if the energy of the VED in h hour (E_{VED}^{h}) is positive (it means that there is an energy surplus in the VED to store). Otherwise, $P_{acp,i}^{h}$ can vary between P_{p}^{h} and the national market selling price (P_{s}^{h}), if the E_{VED}^{h} is negative (that is an energy deficit in the VED to cover). The (63) said that in every h hour, the total amount of accepted energy in the auction must be at most equal to the E_{VED}^{h}. The (64) explains the bounds of the $S_{acp,i}^{h}$: it can vary between zero and the residual capacity of storage for every i user and for every h hour ($S_{res,i}^{h}$). The $S_{res,i}^{h}$ is shown in (65): it is equal to the difference between the residual storage capacity at h-1 hour ($S_{res,i}^{h-1}$) and the $S_{acp,i}^{h}$. If the first hour is considered (h=1), the $S_{res,i}^{h-1}$ is equal to the maximum value of storage capacity ($S_{max,i}$), as in (66). In (67), E_{VED}^{h} is equal to the difference between the VED energy production ($Prod_{VED}^{h}$) and the VED energy consumption at h hour ($Cons_{VED}^{h}$). In this way, E_{VED}^{h} can be positive (an energy surplus) or negative (an energy deficit).

To test the effectiveness of the proposed StLM model, some simulations are carried out. A VED composed of producers, consumers and prosumers is considered: it is supposed that the VED is placed in Southern Italy to take as input data a typical production profile and a typical load profile [89]. In addition, the market prices are considered in function of the zone where the VED is placed [109, 135]. In Fig.42, the input data are shown.

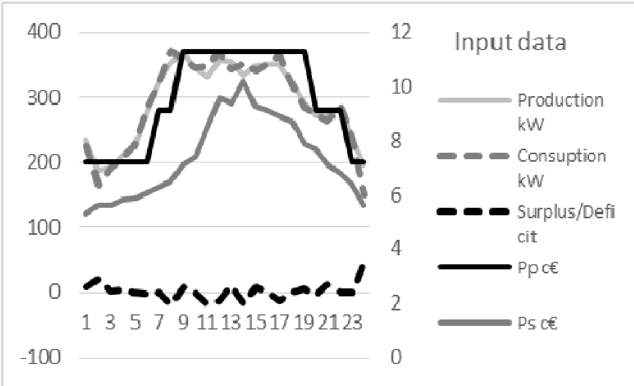

Figure 42: Input data

It is supposed that in the VED taking into account, the number of users who have a storage system is 8 and the maximum value of their storage capacity is reported in Table XI.

TABLE XI. MAXIMUM VALUE OF STORAGE CAPACITY

	kWh
Smax(1)	10
Smax(2)	5
Smax(3)	5
Smax(4)	15
Smax(5)	5
Smax(6)	10
Smax(7)	15
Smax(8)	20

To better understand the auction operations in StLM, in Table XII the auction results are depicted for h=1: the first and second columns show who offers and how capacity is offered; the offers are reorganised in a merit list in function of the offered purchase price, that is in the third column. The fourth column shows what offer is completely, partially or not accepted; the fifth and the sixth columns show the effective amounts of storage capacity; the last seventh and eighth columns present the residual storage capacity.

TABLE XII. AUCTION RESULTS FOR H=1

h=1	E_{VED}	9,6					
Offers	kW	c€			kW		kW
S(2)	5	4,2	Accepted	$S_{acp}(1)$	0	$S_{res}(1)$	10
S(3)	5	3,5	Part. Accepted	$S_{acp}(2)$	5	$S_{res}(2)$	0
S(5)	5	3,2	NA	$S_{acp}(3)$	4,6	$S_{res}(3)$	0,4
S(1)	10	2,9	NA	$S_{acp}(4)$	0	$S_{res}(4)$	15
S(7)	15	2,5	NA	$S_{acp}(5)$	0	$S_{res}(5)$	5
S(8)	20	2,1	NA	$S_{acp}(6)$	0	$S_{res}(6)$	10
S(4)	15	1,7	NA	$S_{acp}(7)$	0	$S_{res}(7)$	15
S(6)	10	1,5	NA	$S_{acp}(8)$	0	$S_{res}(8)$	20

In Fig.43, the comparison between the auction results obtained with the StLM model and the results obtained without StLM model is shown. Without StLM model, the trend is calculated considering that the energy surplus is injected into the distribution network with Ps equal to zero; while the energy deficit is bought from the distribution network at a Pp. This is the worst condition because the purchase price is the highest while there is no remuneration for the energy surplus.

The results trend with STLM model shows instead some positive picks due to the purchase of energy surplus at a price different to zero, while the negative picks are due to the sale of stored energy when an energy deficit happens.

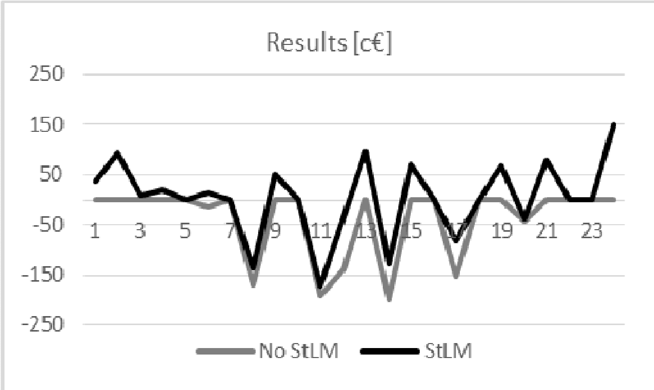

Figure 43: Comparison between No StLM result and StLM results

Considering all 24h, if there is no auctions due to StLM, the CEP would be forced to buy the required energy outside VED spending 903.33c€, while the national market recognises no remuneration to the users who inject their energy surplus into it. With the StLM, the total cost for the CEP to manage the energy surplus/deficit is 321.05c€, divided as follow: 101.83c€ is the total cost for the hourly auctions while 219.22c€ is the cost to buy from national market the energy deficit that is not covered by the stored energy. Obviously, the total cost 101.83c€ is the result of the black trend shown in Fig.40.

In Table XIII, the economic results for every user with storage capacity are shown: notice that negative values mean an effective utility for the users who have stored energy and then re-sell energy during an energy deficit, while positive values mean the cost supported by the user who want to store the energy surplus. At the end of 24 h, it may seem that only the user 6 and 8 have realized a utility. This is true partially because it is worth to underline that the other users, who have support only costs at the end of 24 hours, have their storage systems full of energy ready to be sold in case of energy deficit or self-consumed.

TABLE XIII. UTILITY FOR EVERY USER WITH STORAGE

	c€
S(1)	3,2
S(2)	0,82
S(3)	13,42
S(4)	63,21
S(5)	10,58
S(6)	-63,81
S(7)	21,74
S(8)	-6,62

3.3. The Storage system in a VED management: the case of Stormwater Detention Tank (SDT) [82,136]

The importance of the storage systems has been discussed in previous paragraphs, in terms of solution to mitigate the non-programmability of some renewable sources and in terms of session of local market. In both two cases, it has been supposed that the VED users own a storage system.

Nowadays, storage systems have not the same spread of renewable generation systems as PV, because the costs to install storage systems as batteries are still high. In this sense, to recover energy or to produce energy, also the stormwater detention tanks that often are constructed in city environment to prevent the risk of flooding, can be opportunely consider as storage system, in particular as a distributed storage system. Obviously, to be regarded as storage systems, the SDT must need:

- a mini - hydroelectric group [137-138], using water as an energy carrier, in the hours when the SDT is not required to avoid the risk of flooding;
- an optimized management strategy that chose when and how energy produce/absorb, taking into account economic signals, as market prices.

This solution is well adapt in a Smart Community context, where a more efficient energy management is required of all the devices and all the operators who take part in the complicated national electricity system, from production to distribution and consumption, through all stages of the electricity market.

In this way, a SDT that works as energy storage systems contributes to resolve some common current problems on distribution networks, such as [139-142]:

– facilitate interconnection among different micro-sources from renewables (solar, wind, fuel-cells, etc.) and may make them more reliable and efficient;

– operate the micro-sources properly, efficiently and permanently at the full power, with the surplus of generated energy available to charge the energy storage systems;

– compensate load variations.

3.3.1. Management of SDT

A schematic of the SDT system is reported in Fig.44b. It consists of: (1) a SDT located upstream the watershed of interest, (2) an artificial wet pond located downstream, and (3) a pipeline linking the two tanks equipped with a pumping system/turbine, as shown in Fig.44a. A pre-treatment unit, in which the combined sewage (wastewater and stormwater) from the drainage network is subject to a process of screening and sedimentation, precedes the SDT.

The operating principle is the following one. During rain events, the SDT stores a portion of the urban runoff volume coming from the watershed of interest in the city.

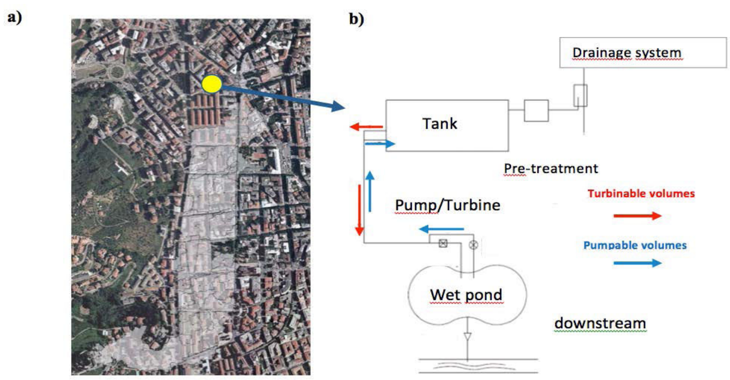

Figure 44: a) SDT site; b) SDT scheme

The management model of a SDT as an energy storage system receives as input signals the purchase and sale prices from the national electricity market: according to these data and to the water level contained in it, it decides when and how much energy generate, or when and how much water pump upstream, minimizing the cost of both operations. Of course, it is worth to underline immediately that the tank is built to its main function, that is limit the risk of flooding, so the operation as storage system starts only after the management model has received the weather forecasts and therefore the water level contained in the tank.

The management model is an optimization problem that minimizes the cost of the operation of the SDT as energy storage system. It is shown as follows:

$$\min \mathrm{Fval} = \sum_{h=1}^{24}(C^h - R^h) \tag{68}$$

with

$$R^h = r^h \cdot P_g^h = r^h \cdot a \cdot Q_g^h \tag{69}$$

$$C^h = c^h \cdot P_p^h = c^h \cdot b \cdot Q_p^h \tag{70}$$

s.t.

$$Q^{h-1} + Q_{rain}^h + Q_p^h - Q_g^h \leq Q_{tank} \tag{71}$$

$$0 \leq Q_p^h \leq Q_{p\_max} \tag{72}$$

$$0 \leq Q_g^h \leq Q_{g\_max} \tag{73}$$

$$Q_p^h \cdot Q_g^h = 0 \tag{74}$$

In (68), the function to minimize is Fval: it is equal to the sum, for each hour h of the day taking into account, of the difference between the hourly costs (Ch) and the hourly gains (Rh). Notice that the gains are represented with negative values because the optimization problem researches the minimum of the costs, so a negative result of Fval has to consider as a utility.

In (69) and (70), R^h and C^h are shown in details: in (2), Rh is equal to the product between the hourly sale electricity price (r^h), established through national electricity market, and the electric power that the turbine is able to generate in the hour h (P_g^h). P_g^h is equal to the product between r^h, a coefficient *a* that takes into account all the turbine parameters (also the efficiency) and the hourly flow rate processed by the turbine (Qg^h). Similarly, (70), C^h is equal to the product between hourly purchase electricity price (c^h), established through national electricity market, and the electric power that the pump is able to absorb in the hour h (P_p^h). P_p^h is equal to the product between c^h, a coefficient b that takes into account all the pump parameters (also the efficiency) and the hourly flow rate absorbed by the pump (Q_p^h).

From (71) to (74) the optimization problem constraints are presented. The (71) is an inequality constraint that limits the maximum quantity of water containable into the SDT (Q_{tank}). The (71) indicates that the quantity of water contained in the tank is equal to the sum of: the quantity of water contained at the hour h-1 (Q^{h-1}), the quantity of the stormwater fallen in the hour h (Q_{rain}^h), the quantity of the pumped water at hour h (Q_p^h), minus the quantity of water needed to electric generation by the turbine at the hour h (Q_g^h).

The (72) and (73) constraints present the lower bounds and the upper bounds of Q_p^h and Q_g^h, respectively. For both the constrains, the lower bound is zero; for Q_p^h, the upper bound is equal to the maximum flow rate that the pump can absorb (Q_{p_max}), while for Q_g^h, the upper bound is equal to the maximum flow rate that the turbine can operate (Q_{g_max}).

The (74) is a constraint of exclusion: it imposes the condition such that in the same hour h, the whole SDT system operates to push the water upstream or to generate energy.

To test the effectiveness the proposed management model, some simulations are carried out, taking into account a 2500m^3 SDT. The tank was equipped with a mini-hydro group composed of a 45kW - Calpeda NM4 150/400 pump with a flow rate of 268m^3/h and a hydraulic head of 40.7m; and an 18kWe – Calpeda NM4 125/315 turbine with a flow rate of 240m^3/h and a hydraulic head of 28m [143].

The simulation are carried out for three typical days: a day with poor rainfall (06/01/2012), a day with rich rainfall (14/04/2012) and a sunny day (21/06/2012). For those days, the values of purchase and sale prices are obtained through the national electricity market. Purchase prices correspond to the values of the rate by hour applied by a typical distribution operator to a non-domestic user with committed capacity exceeding 16.5kW [135]; sales prices are the zonal prices of the national electricity market [109] obtained for the days taking into account.

A first case of simulations has considered only the operation of the tank with the level of rainfall: the management model, as a function of price signals, has not returned the convenience in pumping water upstream, for which the trend of Qp is always zero for all three days. This is due to the purchase and sale prices of energy that are very close to each other and so the model does not find economically advantageous to pump water first and then send it in a turbine to generate energy to sell. In addition, in the calculation of the pumping and generation power, the machine efficiencies have been taken into account: due to the same given value, of course, the management model will find only convenience if there is a substantial discrepancy between the purchase and sale prices.

In Fig.45 the trend of Q_g for the days under examination is shown: on days when the rainfalls occur (6th January and 14th April), a quantity of stormwater is available in the tank, so it is possible to generate energy. In the sunny day (21st June), there is no available stormwater so Q_g is zero on all 24 hours and there is no electricity generation. For these reasons, the value of Fval in 6th January is equal to -7.51€, in 14th April is equal to -19.69€, while in 21st June is zero.

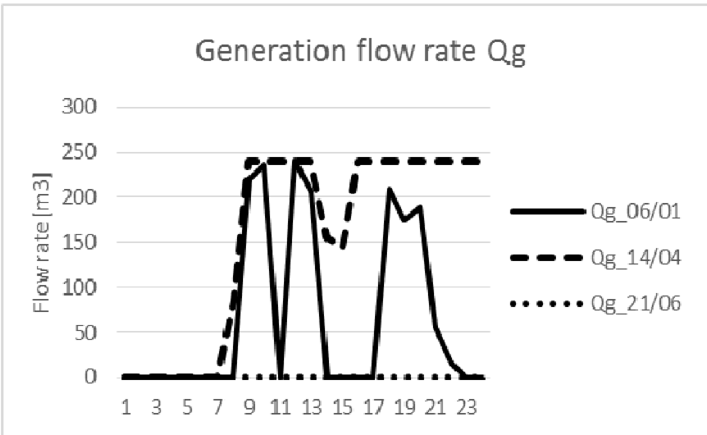

Figure 45: Hourly generation flow rates for the days taking into account

A second case of simulations is considered by imposing a discount on the purchase price of energy, so on pumping action.

This choice is justified considering what happens more and more often in the distribution network. Indeed, with the massive penetration of distributed generation, especially from renewable sources, it often happens that the distribution networks are subject to congestion caused by the huge reverse flows of energy into the network. When that happens, serious problems on security of the network may appear and the network operator (Terna, in the Italian case), requires to the producers of distributed generation to cut their production. The production cut is obviously an action to prevent for the economic loss that involves, but especially for the energy loss which can be recovered in no way. To prevent the cut of the production, the SDT should work as energy storage system, pumping water upstream when there is a large amount of energy not required by the consumers, and then returning it in the form of energy when the selling price is favourable.

Therefore, the idea of applying a discount to the energy purchase price is equivalent to have an available excess energy that can reset or reduce the pumping cost. In Fig.46, the values of Fval is shown as a function of the variation of the discount applied to the energy purchase price for the three days considered. For all three days, the tank operating as an energy storage system is able to guarantee a utility. The values of the discount applied ranging from 100% to 70% on the purchase price: more than this value, the management model considers no longer cost-effective the pumping and does not execute it.

Observing Fig.46, it is worth to underline that as in the simulations without discount, the lower utility is obtained in the case of sunny day. In case with discount that reduces the purchase price, the action of pumping water from the pond to the tank is feasible and the later energy generation recovers economically the action. The day with poor rainfalls, (6th January) allows a not bad utility, while in the day with heavy rainfall the utility is much more significant.

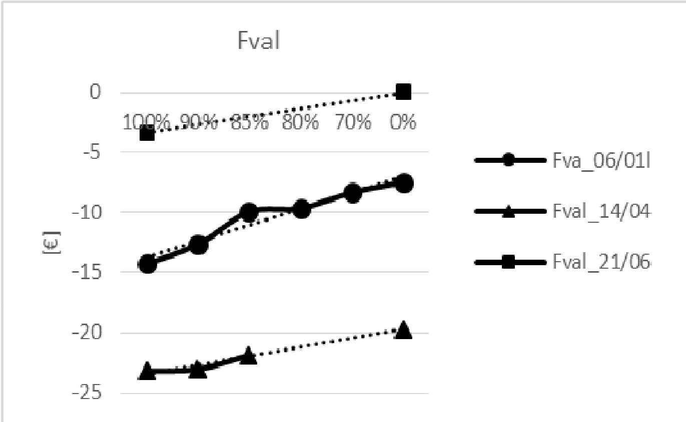

Figure 46: The trend of Fval for the days taking into account, as a function of the discount on the purchase price.

Now, the results of the case with 100% discount on the purchase price are discussed. This situation is equivalent to the case in which there is an excess of energy that can cover all the necessary energy to pump water from the pond to the tank. In Fig.47, the trends of the quantity of pumped water from downstream to upstream for the three days are depicted. In contrast to the common believe, it can be observed how the pumping not happens only in the night hours where the energy price is lower, but also it occurs during the hours of demand peak and then when the highest energy prices are reached.

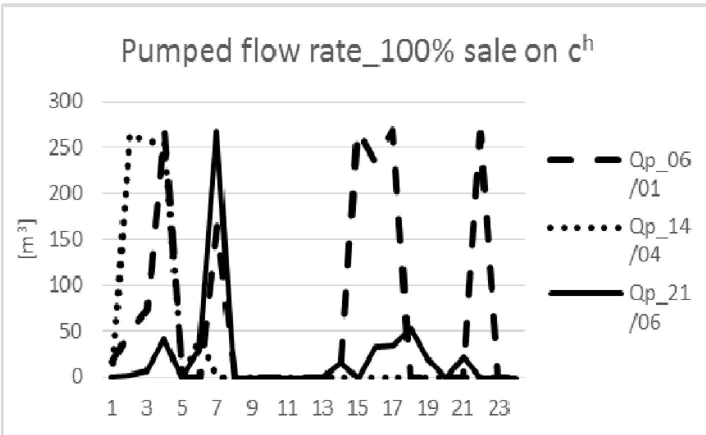

Figure 47: The trend of Qp for the days taking into account.

In Fig.48, the trends of the quantity of the water sent into the turbine for electricity generation for the three days considered are shown. It is clear that the water contained in the tank, that is the stored energy, can provide valuable assistance to meet the electricity demand during peak hours, without prejudice the security of the operation of the tank to limit the risk of urban flooding.

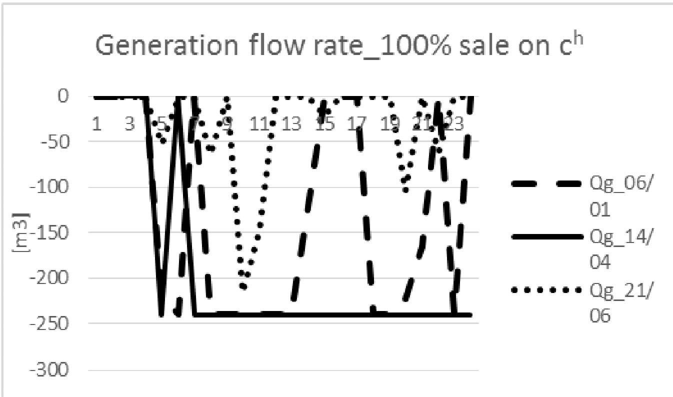

Figure 48: The trend of Qg for the days taking into account.

The Fig.49 shows the trends of the quantity of water moved in the tank (Q) for the three days under examination, when the tank works to accumulate water. If the tank is not used to accumulate water, the trend of Q depend only on the rainfalls and on the action of power generation when requested by the users. In this case, the energy excess that may appear within a few hours of the day, not injectable into the network, however, would be cut off.

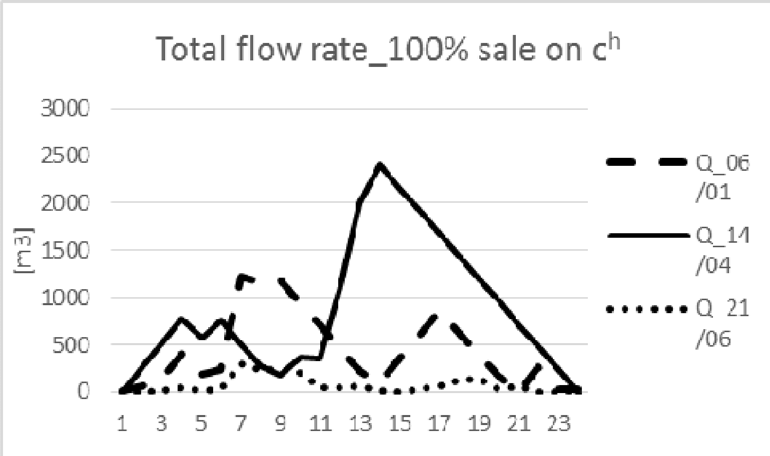

Figure 49: The trend of Q for the days taking into account.

In Table XIV, the values of Fval are indicated, with and without the 100% discount on energy purchase price.

TABLE XIV. **FVAL[€]**

Day / Discount on P^hp	16/01	14/04	21/06
0%	-7.51	-19.69	0
100%	-14.29	-23.19	-3.40

The last analysis gives an annual estimate of how much is the utility if the tank works as an energy storage system. The results are shown in Table XV, having assumed that for the area chosen as location of the tank, on average in the year, the 10% of the days are very rainy like the 14/04/2012, the 25% of days are modest rainy like the 06/01/2012 and the remaining 65% of days are sunny like the 21/06/2012.

TABLE XV. **ANNUAL FVAL[€]**

Discount on P^hp	Fval
100%	-2957.98
90%	-1997
85%	-1705.74
80%	-882.23
70%	-760.96

3.3.2. SDT in a DR program [82]

Obtained a management strategy for a SDT working as distributed storage system, the last analysis considers the possibility to manage the SDT as a prosumer, participating in DR programs and in local market operations of a VED.

Included in the VED, the SDT system works according to the weather forecasts and to the VED local market signals, constrained to shot-time regulation decided by the DR program. Subjected to the DR program, this distributed storage system can be seen as a really VED end-used, in particular a kind of prosumer that answers to the prosumer problem in [87] in which the storage constraints are considered.

The prosumer problem in presence of storage availability becomes in a concise form:

$$minimize_{x \in X} \sum_{h=1}^{H} c^h * \left[\sum_{a \in A} x_a^h - P_{tot}^h \right] \tag{75}$$

$$x_a^h \geq 0, \forall h \in H \tag{76}$$

$$\sum_{a=1}^{A} x_a^h \leq E^{Max}, \forall h \in H \tag{77}$$

$$P_{tot}^h = \sum_{i=1}^{I} P_{Prog}^h + \sum_{k=1}^{K} P_{not\_Prog}^h, \forall h \in H \tag{78}$$

$$P_{prog}^h = P_{mCHP}^h = Stirling(T_{sch}^h, T_{amb}^h, x_{th}^h, P_{mCHP}) \tag{79}$$

$$P_{not\_Prog}^h = P_{PV}^h + P_W^h + P_{SDT}^h \tag{80}$$

$$P_{PV}^h = Photovoltaic(T_{amb}^h, Irr^h, P_{PV}) \tag{81}$$

$$P_W^h = Wind(\omega, P_W) \tag{82}$$

$$P_{SDT}^h = \begin{cases} e \cdot Q^h \; if \; Q^h = Q_g^h \\ f \cdot Q^h \; if \; Q^h = Q_p^h \end{cases} \tag{83}$$

s.t.

$$Q^{h-1} + Q_{rain}^h + Q_p^h - Q_g^h \leq Q_{tank} \tag{83a}$$

$$0 \leq Q_p^h \leq Q_{p\_max} \tag{83b}$$

$$0 \leq Q_g^h \leq Q_{g\_max} \tag{83c}$$

$$Q_P^h \cdot Q_G^h = 0 \tag{83d}$$

The prosumer problem wants to minimize the energy supply costs: in (75) the costs are represented as the product of the hourly cost c^h and the difference between the total consumption and the total production. The total consumption is the sum of all hourly energy demands x for each electric and thermal appliance a. It is worth to underline that in this term x, it is also considered the consumption of energy when the STD works to pump water upstairs. Of course, all the hourly energy demands must be positive to be considered really consumption, as shown in (76). The (77) indicates that the sum of all energy demands for each appliance does not exceed the limit on total energy consumption at each residential unit per hour, E^{max}. The (78) shows the P_{tot}^h, that is the total production per hour for each prosumer. The total production is the sum of the production from programmable and non-programmable sources. In particular, a micro-CHP system can be considered as a programmable source and it depends on different parameters, shown in (79), like the T^h_{sch} scheduling temperature; the T^h_{amb} ambient temperature at hour h; the x^h_{th} energy consumption scheduling vector for this type of appliance for each upcoming hour of the day $h \in H$ and the P_{mCHP} maximum power capacity by the engine.

The common renewable sources, as wind and solar, are non-programmable. The SDT can be considered as a non-programmable source because its operation depends on the weather forecasts: more accurate are the forecasts, the lower is the degree of non-programmability of SDT. The sum of all these resources is represented in (80).

In particular, the P_{PV}^h photovoltaic generation depends on the value of ambient temperature at hour h, T^h_{amb}; the value of I_{rr}^h irradiation at hour h; and the value of P_{PV} maximum power of the PV system, (81). Instead, the P_W^h depends on the parameters of wind, as the ω speed of wind, and the P_W maximum power of wind system, (82).

The constraints from (83) to (83d) represent the conditions about the storage system. It is worth to underline that the constraints are wrote for a storage system as SDT but can be applied to a generic storage system. Indeed, the (83) indicates the power of storage system: this power can be a supply power or an absorption power. In case of SDT, the generation power is calculated as the product between the hourly flow rate of generation Q_g^h and a coefficient *e* that considers all the parameters (included the efficiency) of the turbine in the hydroelectric group. While, the absorption power is a pumping power, calculated as the product between the hourly flow rate of pumping Q_p^h and a coefficient *f* that considers all the parameters (included the efficiency) of the pump in the hydroelectric group. Note that the efficiency when it works as generation mode is higher than it works as pump. For storage systems different to the SDT, Q^h can represent a generic energy vector to supply or absorb. The constraints from (83a) to (83d) indicate the technical limits on the operation of storage system. In case of SDT, the (83a) says that all the incoming and out coming contributes must not exceed the capacity of the tank, considering also the contribute from weather forecast Q^h_{rain}. This term particularizes the constraint for a SDT: without this term, the constraint (83a) is applicable to a generic storage system. The (83b) and (83c) show the technical limits of the energy vector in supply / generation and absorption / pumping operations for a generic / SDT storage system. Then, the (83d) indicates the supply / generation and absorption / pumping operations cannot be made in the same hour.

Applied the prosumer problem to all end-users of the VED, also considering the SDT, the information about the hourly needs can be passed now to the CEP.

In this way, the CEP can realize the energy management through a management model similar to those in [88], starting from the coordinator problem in [87]. This management model becomes a really "aggregator problem", which considers the end-users' needs, included the operations of SDT, and the (local and national) market's needs (that is the grid constraints).

Near to the information about energy needs of the VED, the CEP knows also the structure of the VED in terms of possible violations of limits on voltage profile (this means talking about transport capacity on the lines); type of users; the amount of produced energy in terms of selling offers to the local market; the amount of consumed energy in terms of purchasing offers to the local market. With all these data, the CEP calculates the difference between production and consumption in an hour, named *user energy surplus*, and the sum of the user energy surplus belonging to the VED, named *energy surplus,* see Fig.50.

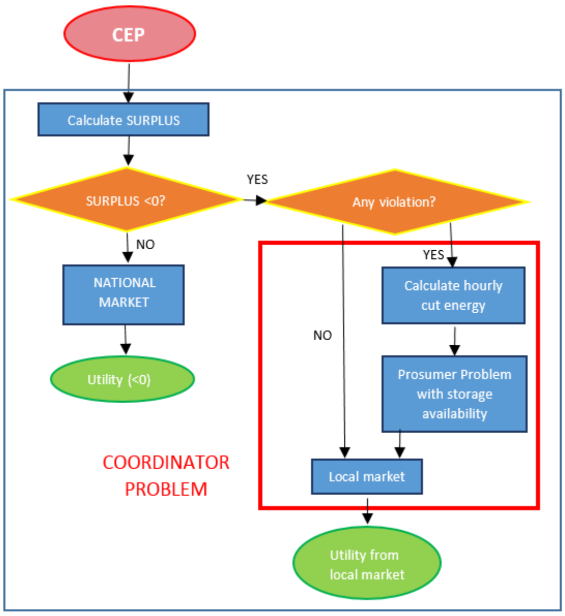

Figure 50: CEP management system

To test the effectiveness the proposed management model, some simulations have been carried out.

The considered VED is composed of 150 residential consumers, 100 residential prosumers, 25 industrial users and 25 producers. The production and the consumption profiles are based on real profiles, as in [87]. The VED is constituted by two areas A and B. The area A is direct connected to the public transmission network and the residential consumers, the residential prosumers and the industrial consumers belong to it. Area B is connected to area A and the producers belong to it. This configuration of area A and area B stresses the possibility that overloads and violations in term of voltage profile can appear on the connection network between the two areas (Fig.51).

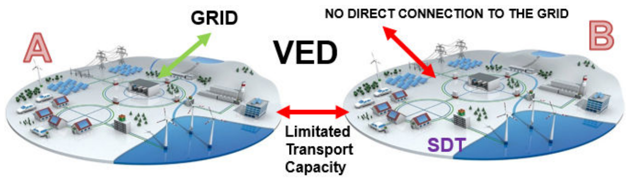

Figure 51: VED structure

In the VED, in area B, a 2500 m^3 SDT is taking into account. The tank was equipped in the same way of [143].

Three groups of simulations are carried out, taking into account a poor rainy day, a rich rainy day and a sunny day, like 06/01/2012, 14/04/2012 and 21/06/2012. The rainfall levels data are taken from [144]. As price values, the purchase price corresponds to the economic condition for customers of enhanced protection offered by a typical Italian market operator [134], while the selling price derives from Italian Electricity Market [109].

For the poor rainy day, the economic results of the first group of simulations are shown in Fig.52.

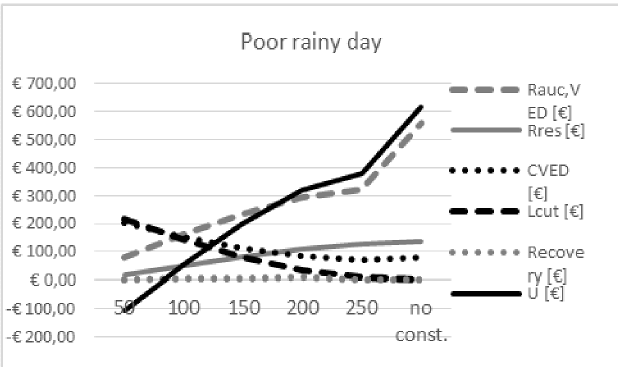

Figure 52: Results for a poor rainy day

In Fig.52, the daily values of $R_{auc,VED}$, R_{res}, C_{VED}, L_{cut}, Recovery and U are considered. These parameters are defined in [90], but their meanings are reported to simplify the discussion of the result: a.U is the daily utility defined as the difference between the revenue earned from sales within the VED ($R_{auc,VED}$) and the cost relating to the purchase of the energy deficit (C_{VED}); b. R_{res} is the revenue from the remaining sales after the market auction; c. L_{cut} is the loss of revenue due to the cut of produced energy; d. Recovery is the revenue obtained through the quantity of energy saved by storage system, re-sold at the selling price of national market.

These parameters are calculated taking into account different values of transport capacity between area A and area B. In particular, the considered values are 50kW, 100kW, 150kW, 200kW, 250kW and unlimited transport capacity (no constraint). It can be noted that, obviously, with the increase of the transport capacity also $R_{auc,VED}$, R_{res} and U grow. Indeed, more energy can be used to satisfy demand, sold to the local market, generated by SDT system and then sold to the local market or to the grid. Furthermore, the increasing of transport capacity involves the decrease of C_{VED} and L_{cut}: the satisfy of the demand allows to purchase less energy from the grid, while, considering also the presence of the SDT system, the mandatory curtailment of production can be limited.

Notice that at 250kW transport capacity, L_{cut} is equal to zero: for this reason, the authors have not considered other values of transport capacity. The daily Recovery seems to be not encouraging to adopt the SDT system because its trend is much lower than $R_{auc,VED}$, R_{res} and U trends. But, in Fig.53, the hourly trend of L^{h}_{cut}, $Recovery^{h}$ and the amounts of energy cut before and after the operation of the SDT system, it can be noted that in some hours of the day (not in the main hours of the day), the SDT system can recover over the 50% of energy that should be cut.

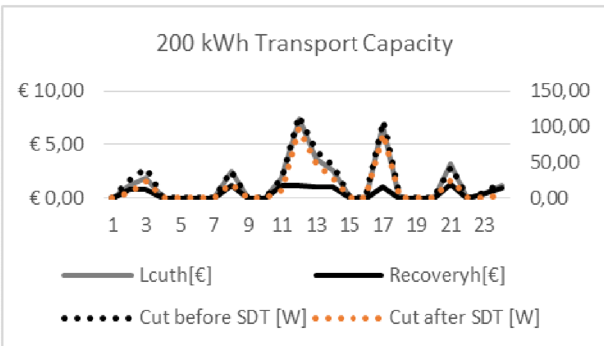

Figure 53: L^{h}cut, $Recovery^{h}$ and the cut energy

Fig.54 shows the amount of energy recovered by pumping water through the SDT system ($Q^{h}_{SDT,p}$) for the considered different transport capacity. It is worth to underline some aspects. First, without transport capacity constraints, the model does not find any economic convenience in the operation of pumping water. This is due to the possibility to transform the entire energy surplus produced in the VED in sale of energy to national grid.

With an energy surplus and with strong limits on transport capacity, obviously, the operation of pumping water happens only in the hours when the energy purchase price and the energy demand are low. This happens because the strong limits on transport capacity do not allow to transfer the surplus energy from an area to another freely. Increasing the transport capacity, the SDT system begins to pump water thanks to the energy surplus in the VED, also in the main hours of the day.

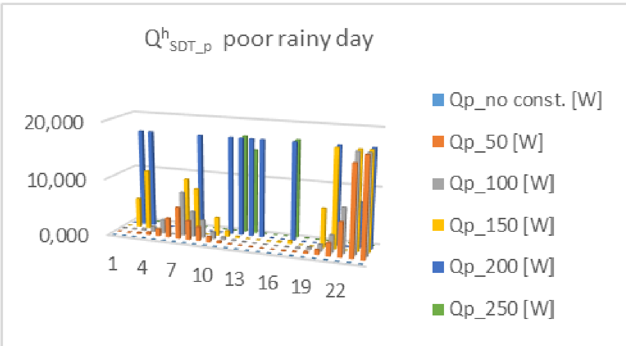

Figure 54. Recovered energy by the SDT system for a poor rainy day

The second group of simulations is carried out considering a rich rainy day. In this case, the numerical results show that the copious rainfalls limit strongly the possibility to use the SDT system into the energy VED management. In effect, the possibility to use the SDT system as storage system to avoid the curtailments of surplus energy or to generate energy when it is required, decreases because the SDT must explain its main function, that is to avoid the risk of flooding in an urban environment. Consequentially, the SDT system does not execute the operation of pumping water upstream because the tank is just full. Furthermore, the SDT system does not generate energy due to the limits on transport capacity. The effect of this situation is that numerical results of $R_{auc,VED}$, R_{res}, C_{VED}, U in a rich rainy day are almost similar to the same values in a poor rainy day. The considerable discrepancy for the rich rainy day consists in the Recovery value. In Fig.55, this parameter is shown. Notice how the Recovery trend is null until the transport capacity assumes a high value (200 and 250kWh); after, Recovery returns to zero because the high values of transport capacity allows to transport the entire energy production to the users or to the grid, so there is anything to recover.

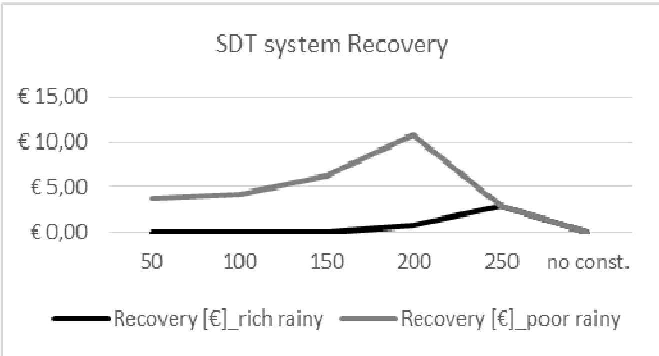

Figure 55: Recovery for a poor and a rich rainy day

Finally, the last group of simulations is carried out considering a sunny day. Numerical results show that in absence of rainfalls, if there is no constraints on transport capacity, the SDT system does not contribute to the local market. Therefore, the utility for the VED is the same obtained in a VED without transport capacity constraints and without storage system.

Considering a limit on transport capacity, the SDT system can recover more energy than the energy recovered in the other two days. Indeed, in Fig.56, the daily Recovery trends for the three days taking into account are depicted. Notice how, in case of a sunny day, the recovery obtained is more considerable especially with severe limits on transport capacity. This is due to the possibility to store more energy because the tank is completely empty. After the value of 200kWh transport capacity, as for the poor rainy day, the Recovery trend tends to zero because, with the increase of transport capacity, the possibility to cut production, and in consequence the necessity to recover energy, decreases.

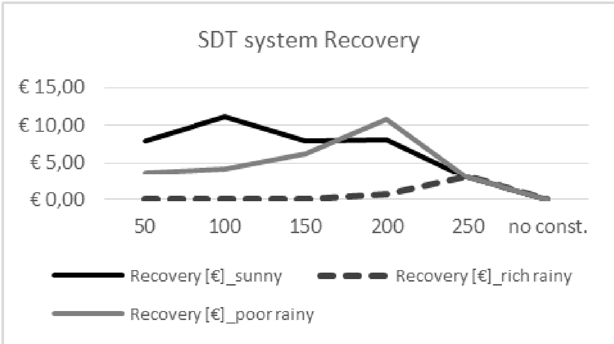

Figure 56. Comparison in Recovery

Table XVI reports the values of the entire benefit that the VED can obtain. The benefit considered is the sum of U and Recovery for the three days taking into account, according to the variation of transport capacity.

TABLE XVI. UTILITY + RECOVERY [€]

U+Recovery	50	100	150	200	250	no const.
Sunny	- 98,37	66,91	208,27	321,23	353,25	603,40
Rich rainy	-106,25	55,76	200,33	317,39	381,13	637,44
Poor rainy	-102,55	59,97	206,98	331,61	381,43	618,01

Some considerations can be discussed. Looking at the values, the poor rainy day seems to be the one whose weather conditions take greater advances of the SDT in the VED, with not strongly transport capacity constraints (from 150 onwards the higher values of benefit appear): this happens because with large transport capacity the SDT contributes to the local market with its own generation.

However, when the transport capacity is very limited, the best benefit takes place in the sunny day because the SDT, not performing its main function, works as a real storage system, and thus allows a greater recovery of energy otherwise lost.

Instead, the rich rainy day presents limited benefit: on the one hand, due to the limited transport capacity, the turbine of the SDT system cannot generate large quantities and then cannot empty the tank. On the other hand, the capacity of the tank is limited yet due to the rainfalls and thus the pump of the SDT system cannot pump large quantitative of water. The only positive aspect is found just when there are no constraints on transport capacity: in this way, the SDT system can offer a bulk contribution with its energy generation.

3.4. Smart Community Management [145]

Al the concepts about smart community and local trading have been finally tested on a proposal of smart community composed of 29 Municipalities of the hinterland of Cosenza, Italy. The municipalities, predominantly hilly and mountainous, with different size and population, compose the Universitas Casalium - UNICAS.

It is good to clear firstly that the simulations have been carried out on data of energy consumption related to buildings/ facilities/ resources owned by the local administrations.

For every Municipality, from the documents called SEAP – Sustainable Energy Action Plan, presented to participate to the European Project "Covenant of Mayors" [123], the consumption and production data have been extracted. The data refer to 2012-2013, but they can be used also today because from 2013 until now no relevant variations happened in terms of real estate and vehicle fleet for every Municipalities.

In particular, the data related to electricity consumption for public lighting, electricity consumption for municipal buildings/facilities (schools, sports halls, pumping stations, etc.), heat consumption of municipal buildings (in terms by volume of natural gas/LPG used) and consumption of fuel (diesel/petrol) for the mobility of the municipal vehicles are analysed. All values are standardized in terms of consumed MWh, in order to be able to make appropriate comparisons. In Fig.57, consumption data are reported: among all the Municipalities, the Municipality of San Giovanni in Fiore stands out because it presents an amount of consumed thermal energy bigger than the other thermal consumptions. This happens due to its characteristics that are the biggest extension and population among the considered Municipalities and its altitude about 1000 m a.s.l.

For the municipalities signed with a star (Carolei, Cerisano, Cellara, Dipignano, Mendicino, San Pietro in Guarano, Scigliano and Serra Pedace) the amount of energy depicted in blue represents the energy consumption for public lighting and electricity consumption for buildings/municipal facilities. Other Municipalities signed with a circle (Belsito, Carolei, Cerisano, Cellara, Dipignano, Malito, Mangone, Rogliano and Scigliano) have not any amount of energy consumption for mobility and this lack is due to the impossibility to find data about fuel consumption or because the Municipality has not a fleet of vehicles.

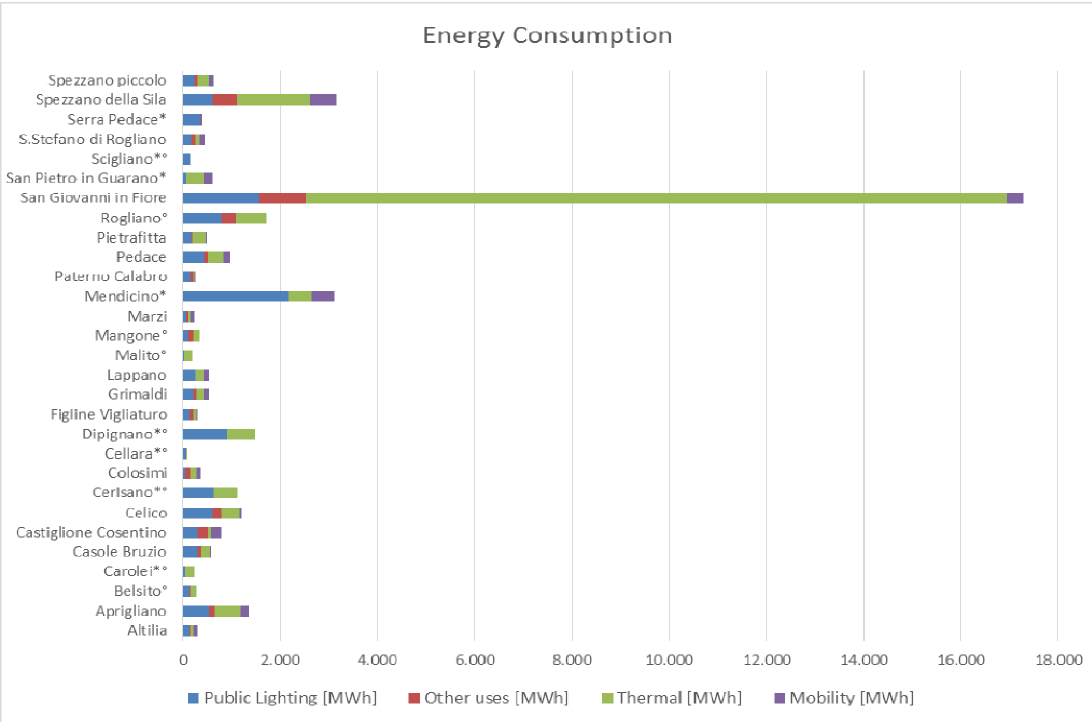

Figure 57: Energy consumption for all the Municipalities

For all kinds of consumption, the cost of the supply is estimated, having previously found the monthly average prices for the energy purchase. The average prices for the energy purchase are found in the agreement with Consip. Consip is a public joint stock company held by the Italian Ministry of Economy and Finance (MEF). The company carries out activities in consulting, assistance, and support in procuring goods and services for Public Administrations (PAs). Consip ensures a more efficient and transparent use of public resources by providing Public Administrations with tools and skills to better manage their own procurement of goods and services, also promoting the competitive participation of enterprises in the public system [146]. In the case study, Consip prices for public lighting, Consip prices for the supply of electricity, fuel prices for heating, prices of automotive fuels are considered [146].

The community therefore requires a total of 39,279.46MWh/year to meet its energy needs and spends a total of 2,238,041.11€/year for the supply. In Table XVII, the details of consumption and spending for the community are shown.

TABLE XVII. DETAILS OF ENERGY CONSUMPTION AND TOTAL COSTS

	MWh	**€**
Public Lighting	11.407,45	815.554,45
Other Uses	3.118,34	390.699,84
Thermal	21.814,06	563.189,30
Transport	2.939,61	468.597,52
TOT	**39.279,46**	**2.238.041,11**

A first analysis is developed considering the actual electrical power generation present in Unicas. In the concerned municipalities, in the years before 2013, the spread of PV systems has been consistent. So even some administrations have well thought out to provide PV systems on the roofs of some public buildings. Taking into account a value of 1400kWh of production per each installed kWp, that is a typical value for the latitude of the community, in Table XVIII (first and second row), for each municipality with PV systems, the value of the installed kWp and the value of annual expected production are shown. The total of annual production is 358.12MWh/year.

TABLE XVIII. MUNICIPAL PV

	Aprigliano	Casole Bruzio	Castiglione Cosentino	Cellara	Mendicino	Paterno Calabro	San Pietro in Guarano	Scigliano	Serra Pedace
Installed PV kWp	28	20	36.8	50	15	36	19	26	25
PV annual Production MWh	39,2	28,0	51,52	70,0	21,0	50,4	26,6	36,4	35,0

The produced energy by the municipal facilities, in their competence areas, is much less than the required energy by the entire community. Considering only the all energy demand (for public lighting, other uses, the thermal consumption and transportation - TOT) in the territories where PV systems are installed, in Table XIX (first line), it is observed, that, apart from the Municipalities of Cellara and Scigliano, in all other cases, the PV generation does not cover even the 10% of municipal energy needs. In the other lines, the percentages of energy that the PV generation is able to cover are shown. In particular in the second line, the share of PV generation on the consumption for public lighting and other electrical uses (PLO) are reported, while in the third line, the share of PV generation on the consumption demand for energy for public lighting, other electrical uses, half of required energy for heating and half of the required energy for transport (PLOT).

The reason to consider the half of required energy for heating and the half of the required energy for transport is connected to the perspective of a multi-annual programming. Indeed, it is admissible to think that in a multi-annual programming, a part of the required energy for heating can be both generated and consumed in an electrical form (e.g. produced by PV systems and consumed by heat pumps). Similar situation can happen for the required energy for transport: this may be used in an electrical form through the replacement of the municipal fleet with fully electric or hybrid vehicles.

Even in these cases, however, the percentages covered by the PV generation remain low, except for the two areas above mentioned.

TABLE XIX. MUNICIPAL PV PRODUCTION ON MUNICIPAL ENERGY NEEDS (%)

	Aprigliano	Casole Bruzio	Castiglione Cosentino	Cellara	Mendicino	Paterno Calabro	San Pietro in Guarano	Scigliano	Serra Pedace
% on TOT	2.88	4.82	6.5	32.83	1.61	7.96	2.29	24.27	8.78
% on PLO	5.94	7.23	10.24	35.00	2.34	9.55	4.48	24.27	10.00
% on PLOTT	3.88	5.78	7.96	33.88	1.91	8.68	3.03	26.27	9.34

From an economic point of view, the Table XX shows the costs for public lighting and other electrical uses (second column), the revenues from selling whole PV production at national grid (third column), and the savings if PV production was exchanged to cover public lighting and other electrical needs (fourth column).

A clarification on the PV production in Italy is necessary. Currently, each municipality with PV systems produces and exchanges the amount of produced energy with the national grid, obtaining two remunerations. The first is an incentive for the use of PV technology (according to the Italian Energy Services Operator - GSE); the second derives from the exchange of the same produced energy with the national electricity market. Referring to the revenue from the exchanges, the exchanged energy is remunerated at the zonal price established by the market. This price is much lower than the purchase price of energy for public authorities (in Calabria, zonal price amounts to 53.64€/MWh, different from the purchase price by Consip Agreement, amounting to 83.39€/MWh).

Leaving out the revenue due to the incentive, for each common is definitely cheaper to exchanged energy rather than sell it: in fact, considering a price equal to the average between the zonal price and Consip price, the savings from self-consumption is about 50% greater than the revenue from the sale (Table XX).

TABLE XX. ECONOMIC COMPARISON ON PLO ENERGY NEEDS

Municipality	**PLO Costs [€]**	**Gain from sells to national market [€]**	**Savings on PLO [€]**
Aprigliano	€ 55.074,68	€ 1.824,11	€ 3.269,05
Casole Bruzio	€ 32.306,90	€ 1.302,93	€ 2.335,04
Castiglione Cosentino	€ 41.963,78	€ 2.397,40	€ 4.296,47
Cellara	€ 16.678,83	€ 3.257,33	€ 5.837,59
Mendicino	€ 180.000,00	€ 2.345,28	€ 4.203,07

Paterno Calabro	€ 18.329,20	€ 977,20	€ 1.751,28
San Pietro in Guarano	€ 49.462,75	€ 1.237,79	€ 2.218,28
Scigliano	€ 12.509,13	€ 1.693,81	€ 3.035,55
Serra Pedace	€ 29.187,96	€ 1.628,67	€ 2.918,80

A different situation would get if all PV generation produced in the municipality were considered, including those produced by private facilities. Indeed, this is the idea that comes closest to an outlined community, in which the forces of the private users are made available to all, providing a recognition for the offered service. In such a situation, the management by CEP and the realization of the local market may find concretization, with all the benefits mentioned in the previous paragraph.

It is worth to underline that the idea of considering all (private and public) PV production rises from the aim to not resort to new plant investments but to use totally the existing PV plants and to consume their produced energy through heat pumps.

Considering the entire PV generation, production data change much: in Fig.58, the annual PV production data [147] are shown for each municipality. Taking into account private production, it is firstly worst to underline that all municipalities have PV generation: except of the municipalities of Celico, Figline Vegliaturo, Mangone, Mendicino and San Giovanni in Fiore, all other have an average production of 250MWh/ year. Mentioned municipalities instead generate a production beyond 1000MWh/year, with Mangone that even exceeds 4000 MWh/year. These values are in fact due to the presence of large PV systems not just to satisfy the energy needs, but also to earn money thanks to the incentive, as a priority, and to the sale of energy, before.

In the entire community, the total PV production amounts to 17484.45MWh/year: this value represents the 115.04% of the electricity needs for PLO, and the 63.41% of the energy needs for PLOTT. These values well explain that there can be great benefits for both private users and the government if the energy produced is managed, exchanged, contracted and then consumed locally. In fact, if this production were sold at a local market such as that provided in the management model of the CEP [72-91], the economic benefit for the community would be greater.

In the local market, as the energy trading takes place through the mechanism of the auction, the energy selling price varies between a minimum equal to the zonal price and a maximum equal to Consip price. This implies that in the local market, in the worst situation, the revenue from the sale would be equal to the current one on the national market.

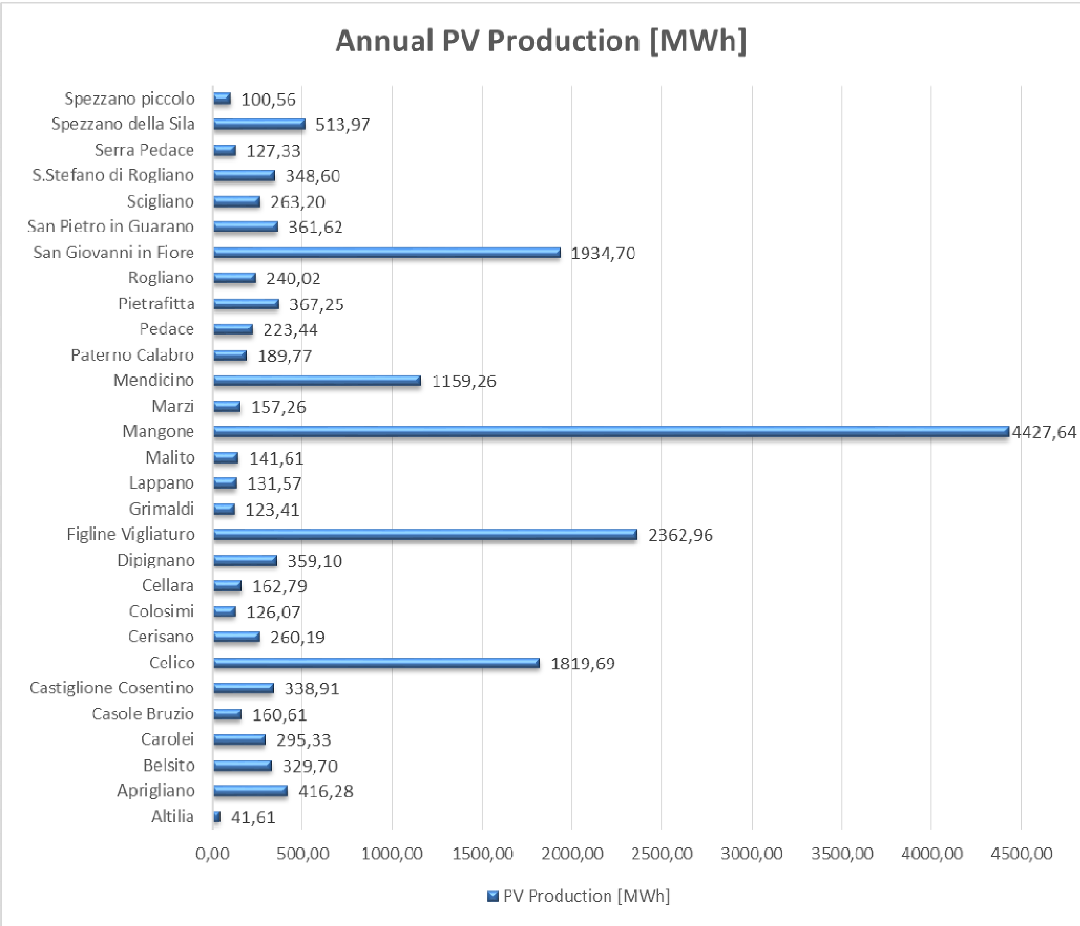

Figure 58: Annual PV production for all the Municipalities

In this regard, several comparisons are performed. Firstly, the authors have thought to curtail the production of the entire community in order to take into account the portion that private users use as self-consumption and the losses: this cut amounts to 30%. In these conditions the total PV production amounts to 12239.11MWh/year representing the 80.52% of the electricity needs for PLO, and the 44.38% of the energy needs for PLOTT. In Table XXI, the details for each municipality and the surplus of available energy are shown.

TABLE XXI. **RESULTS**

Municipality	% Total PV on PLO	% Total PV on PLOTT	Surplus on PLO [MWh]	Surplus on PLOTT [MWh]
Altilia	18,18%	12,75%	0,00	0,00
Aprigliano	44,12%	28,85%	0,00	0,00
Belsito	144,66%	102,78%	71,25	6,25
Carolei	413,46%	141,31%	156,73	60,43
Casole Bruzio	29,02%	23,22%	0,00	0,00
Castiglione Cosentino	47,15%	36,63%	0,00	0,00
Celico	160,13%	126,38%	478,30	265,89
Cerisano	27,99%	20,39%	0,00	0,00
Colosimi	58,44%	34,63%	0,00	0,00
Cellara	56,98%	55,16%	0,00	0,00
Dipignano	27,45%	20,82%	0,00	0,00
Figline Vigliaturo	763,54%	638,26%	1437,44	1394,92
Grimaldi	31,04%	21,18%	0,00	0,00
Lappano	34,49%	23,24%	0,00	0,00
Malito	295,84%	85,22%	65,62	0,00
Mangone	1406,51%	1118,17%	2878,99	2822,17
Marzi	95,32%	61,71%	0,00	0,00
Mendicino	37,60%	30,72%	0,00	0,00
Paterno Calabro	60,44%	54,93%	0,00	0,00
Pedace	29,96%	20,93%	0,00	0,00
Pietrafitta	136,57%	75,23%	68,83	0,00
Rogliano	15,55%	11,99%	0,00	0,00
San Giovanni in Fiore	53,74%	13,67%	0,00	0,00
San Pietro in Guarano	42,68%	28,87%	0,00	0,00
Scigliano	122,83%	122,83%	34,24	34,24
S. Stefano di Rogliano	96,30%	69,57%	0,00	0,00
Serra Pedace	25,47%	23,79%	0,00	0,00
Spezzano della Sila	32,75%	16,89%	0,00	0,00
Spezzano Piccolo	23,50%	15,07%	0,00	0,00
Total	**80,53%**	**44,38%**	**5191,40**	**4583,89**

If the PV generation (cut of 30%) was first used locally, each municipality may see decrease its energy bill: on consumption for PLO, the total savings for the community would reach 46.37% (€ 587,738.22) of the current spending while on consumption for PLOTT, the total savings for the community would be 35.80% (€ 638,400.63). The Fig.59 shows the trends of consumption costs for PLO and PLOTT without considering the PV generation and considering the PV generation.

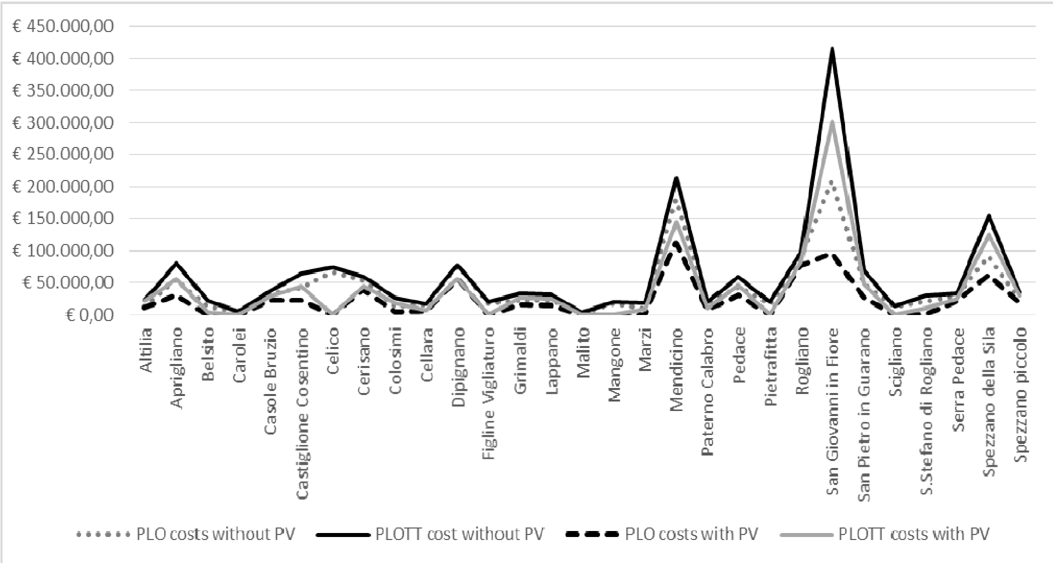

Figure 59: PLO and PLOTT costs

From Fig.59, obviously, the trends of consumption costs for PLO and PLOTT without considering the PV generation are those higher and above all, those that never touch zero, unlike what could happen in some municipalities in which the energetic parity and therefore the resetting of costs could reach.

It is interesting to note the gain difference obtainable in the sales of energy surplus if this were injected in the network and then sold to the national market, or if it was negotiated in the community through the local market (Table XXII). If managed by the CEP, the sale of the surplus is more profitable than the direct sale through the national market and this is due to the economically most advantageous conditions in local market.

TABLE XXII. GAIN VALUES

Municipality	Gain from the sale to national market – surplus on PLO	Gain from the sale to national market – surplus on PLOTT	Surplus on PLO managed by CEP	Surplus on PLOTT managed by CEP
Belsito	€ 3.315,45	€ 290,79	€ 4.628,34	€ 405,94
Carolei	€ 7.293,22	€ 2.812,06	€ 10.181,25	€ 3.925,60
Celico	€ 22.256,75	€ 12.372,59	€ 31.070,17	€ 17.272,00
Figline Vigliaturo	€ 66.888,87	€ 64.910,27	€ 93.376,09	€ 90.613,99
Malito	€ 3.053,52	€ 0,00	€ 4.262,68	€ 0,00
Mangone	€ 133.969,00	€ 131.324,81	€ 187.019,19	€ 183.327,93
Pietrafitta	€ 3.202,96	€ 0,00	€ 4.471,30	€ 0,00
Scigliano	€ 1.593,30	€ 1.593,30	€ 2.224,23	€ 2.224,23
	€ 241.573,07	**€ 213.303,82**	**€ 337.233,24**	**€ 297.769,69**

So, overall, if the private and public resources were managed locally and in communion, the advantage achieved by the community would be the sum of the savings through the use of PV generation and local revenue if the surplus were managed by CEP in local markets. Numerically, this is to say that for consumption for PLO, it should save the 72.98%, while for consumption for PLOTT the 52.50%. These values are significant, especially for small communities where the searching of additional funding is a daily problem. Indeed, the saved money could be used for other services to improve the lives of the community itself (for example, refinance the replacing of traditional municipal vehicles with electric ones, bike-sharing systems for the population, installation of new PV systems on municipal buildings still not covered, ...).

Another scenario, in which investments in power generation are taken into account, has been considered. In particular, a 200kW biomass plant and a 150kW biogas plant will be realized and their production will be available to all users. The choice of biomass and biogas arises from the possibility of recovering the raw material directly on site. Indeed, the biomass system requires the supply of a biomass quantity of about 5,000-6,000 ton/year for its operation. These quantities are widely available on the involved territory. The index of biomass production (average annual increase per unit area of natural and artificial forestry) is usually set to 6 tons per hectare and per year, therefore the amount of biomass potentially obtainable in the involved area amounts to about 49,000ton/year, considering that the total available public surface corresponds to 8,200hectares. No mentioned biomass can be technically exploited because an appropriate rotation of the territory surface have to be ensured in order to avoid the resource depletion in the involved territory. Therefore, the hypothesis to employ the 25% of the available biomass in the year has been adopted. Consequently, the actual amount of biomass potentially producible by wooded areas amounts to about 12,000ton/year. The thermal energy can be used to feed appropriate wood chips driers in order to produce dry woodchips that could be used as energy carrier, both inside and outside the involved local context. Specifically, the production of about 5,000 ton/year of dry biomass, by bringing the moisture content from an initial value of about 45% to a final value of 10%.

For the biogas, in the involved territory, the waste collection can guarantee an amount of 450ton/year: with this amount, a quantity of 170-180 cu.m./ton of biogas (bio-methane) can be produced to supply a 150kW biogas plant.

In a situation of steady state operation, it is assumed that the plants can work for 6,000hours/year. Therefore, it is reasonable to expect a production of 1200MWh/year from the biomass plant and 900MWh/year from the biogas plant.

Adding these contributions to the simulations discussed above, the situation obtained shows that considering only the public PV generation and the contribution of biomass/biogas plants, a percentage of 16.17% on consumption for PLO and a percentage of 8.91% on consumption for PLOTT are reached. Otherwise, considering all the public and private systems of PV generation and the contribution of biomass/biogas plant, the energy costs is equal to zero on consumption for PLO, obtaining also a surplus of 28.86%, while a percentage of coverage of 71.20% on consumption PLOTT is reached.

These results demonstrate that the incentives can compensate in good part the investment.

4. Conclusion

The present Ph.D. thesis fits the current world and national energy situation and explains how the energy sector is evolving towards new scenarios. Indeed, the necessity to improve energy sector in terms of better integration of renewables, increase of clear energy production, rational use of energy, optimization of management, innovation in monitoring and control technologies, is underlined.

In this sense, the thesis highlights the possibility to aggregate several different users in Virtual Energy District and demonstrates how the aggregation creates benefits not only to the users, but also to the electrical system. Obviously, a Virtual Energy District needs to be managed through an opportune strategy. For this scope, the thesis shows a strategy that manages the Virtual Energy District in a coordinated way by a supervision entity called City Energy Provider. The City Energy Provider coordinates all exchanges of energy within the Virtual Energy District and coordinates the directives/information coming from the outside. In particular, it organizes local trading sessions to optimize the rational use of energy and to integrate very well the renewable resources and eventually, the storage availability present in the Virtual Energy District. In this way, the users belonging to the Virtual Energy District can buy/sell energy in more favorable economic conditions than the conditions on national electricity market, the possibility of congestions on the grid decreases and the cut of renewable energy is limited.

The strategy is explained by different mathematical models, which take into account load and generation profiles of the users, DR program, prices from national electricity market, storage capacity and technical constraints on the grid. Numerical results on real cases demonstrate the possibility to obtain savings in terms of use of energy and money.

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