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"The path toward smart cities: the approach of a local utility in Italy"

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Abstract

Global urbanization trends and the idea of sustainability represent two major challenges for cities. The concept of Smart City has been developed as a strategy to drive economic growth, improve quality of life of people and enable cities to use technology, information and data to improve infrastructure and services. This research thesis is organized to provide a synopsis of the various elements which compose a smart grid, and it focuses especially on technologies and system configurations that can be used for converting a micro-grid in a "Smart micro-grid".

In the first part I will introduce the concept of Smart Cities, by illustrating how smart cities and smart initiatives have been currently applied and enhanced in the Italian soil through a special promotion platform and a vast range of projects. I will then discuss the role of micro-grids in the context of smart cities. In the first part, I will explain the reasons that led me to adopt a "local analysis approach" applied to a micro-grid like Osimo instead of analyzing a complex network of large size. Through this description, I will introduce the main features of the grid, without underrating the presence of a single connection point with the national grid, the strong penetration of distributed generation and the presence of a district heating network supplied by a cogeneration unit able to operate with "stand alone" mode. After having described the context, I will proceed with an analysis of the criticalities present at the moment and possible improvements to convert the micro-grid in a smart one will be provided. In the same chapter, a broad overview of the current regulatory framework regarding the smart grid will be given and I will focus particularly on the legislation that aims to increase energy efficiency

through the introduction of measurement systems called "smart meters". Once described the context that characterizes the SCs and the MGs, the thesis will concentrate on two of the main improvements planned for a harmonious development of the micro grid examined. The first study concerns the development of a plan for sustainable mobility conducted in cooperation with the local utility Astea which was the industrial partner of the present Ph.D.. It was submitted to local municipalities Osimo and Recanati, both located in Marche Region (Italy), in order to start a project that envisages the installation of several charging stations starting from 2014. The first phase of the operation covers the period 2014-15 – it involves a limited number of electric vehicles and charging stations and it consists in: i) building infrastructures, ii) starting operation of recharge services iii) analyzing data and iv) carrying out a technical-economic validation of results. The second part of the study illustrates the possible technical developments of the CHP-District Heating located in Osimo Town. On the basis of the experience reported by the local utility Astea, some critical aspects in its management and design were put into evidence such as the over-sizing of the gas turbine, the reduction of the marginal profit due to the variation of the pattern condition in the energy sector, low users density along the network and absence of "smart users energy meters". Regarding the abovementioned aspects, some possible modifications of the existing plant configuration will be analysed, in order to improve the system efficiency and manage the variable heat demand during the year in a smart way.

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Acronyms and Abbreviations

AC	Alternating Current
AEEG	Autorità per l'Energia Elettrica e il Gas
CAN	Control Area Network
CF	Capacity Factor
CHP	Combined Heating and Power
COP	Coefficient of Performance
CRS	Congressional Research Service
DC	Direct Current
DER	Distributed Energy Resources
DG	Distributed Generation
DH	District Heating
DHN	District Heating Network
DOE	Department of Energy
EC	European Commission
EIP	European Innovation Partnership
ES	Energy Storage
EU	European Union
EV	Electric Vehicle
GT	Gas Turbine
HP	Heat Pump
HRSG	Heat Recovery Steam Generator
ICDP	Automotive Distribution Research, Insight, Implementation
ICT	Information Communication Technology
IEA	International Energy Agency
IEC	International Electrotechinal Commission
IPM	Integrated Planning and Management
LPG	Liquefied Petroleum Gas
MG	Micro-grid
NPV	Net Positive Value
OPF	Optimal Power Flow
PBP	Pay Back Period
PES	Primary Energy Saving

PHE	Plate Heat Exchanger
PHEV	Plug-in Hybrid Electric Vehicle
PV	Photovoltaic
PWM	Pulse With Modulation
RDG	Renewable Distributed Generation
RSE	Ricerca Sistema Energetico
SC	Smart City
SCADA	Supervisory Control and Data Acquisition
STIG	Steam Injected Gas Turbine
TES	Thermal Energy Storage
UC	User Card
UNRAE	Unione Nazionale Rappresentanti Autoveicoli Esteri
VAT	Value Added Tax

Chapter 1.

1. Introduction

1.1. Background

The concept of Smart City has been introduced as a strategy to drive economic growth, improve quality of life of people and enable cities to use technology, information and data to improve infrastructure and services. The Smart City concept has received increasing attention over the last years and it now appears as a new paradigm of intelligent urban development and sustainable socio-economic growth, whose origin can be traced back to the Smart Growth Movement of the late 1990s [1].This research thesis is organized to provide a synopsis of the various elements which compose a smart grid, and it focuses especially on technologies and system configurations that can be used for converting a micro-grid in a "Smart micro-grid".

In the first part I will introduce the concept of Smart Cities, by illustrating how smart cities and smart initiatives have been currently applied and enhanced in the Italian soil through a special promotion platform and a vast range of projects.

I will then discuss the role of micro-grids in the context of smart cities. In the first part, I will explain the reasons that led me to adopt a "local analysis approach" applied to a micro-grid like Osimo instead of analyzing a complex network of large size. Through this description, I will introduce the main features of the Microgrid, without underrating the presence of a single connection point with the national grid, the strong penetration of distributed generation and the presence of a district heating network supplied by a cogeneration unit able to operate with "stand alone" mode. After having described the context, I will proceed with an analysis of the criticalities present at the moment and possible improvements to convert the micro-grid in a smart one will be provided. In the same chapter, a broad overview of the current regulatory framework regarding the smart grid will be given and I will focus particularly on the legislation that aims to increase energy efficiency through the introduction of measurement systems called "smart meters". Once described the context that characterizes the SCs and the MGs, the thesis will concentrate on two of the main improvements planned for a harmonious development of the micro grid examined. The first study concerns the development of a plan for sustainable mobility conducted in cooperation with the local utility Astea which was the industrial partner of the present Ph.D.. It was submitted to local municipalities Osimo and Recanati, both located in Marche Region (Italy), in order to start a project that envisages the installation of several charging stations starting from 2014. The first phase of the operation covers the period 2014-15 – it involves a limited number of electric vehicles and charging stations and it consists in: i) building infrastructures, ii) starting operation of recharge services iii) analyzing data and iv) carrying out a technical-economic validation of results. The second part of the study illustrates the possible technical developments of the CHP-District Heating located in Osimo Town. On the basis of the experience reported by the local utility Astea, some critical aspects in its management and design were put into evidence such as the over-sizing of the gas turbine of the CHP unit, the reduction of the marginal profit due to the variation of the pattern condition in the energy sector, low users density along the network and absence of "smart users energy meters".

Regarding the abovementioned aspects, some possible modifications of the existing plant configuration will be analysed, in order to improve the system efficiency and manage the variable heat demand during the year in a smart way.

Chapter 2.

2.Smart cities

2.1. Smart Cities application domains

The Smart City (SC) is a complex model influenced by several factors strictly connected to the application domain of the considered area, such as communication network, utilization of ICT technologies, services and utilities, transports and citizens. For this very reason, since SC initiatives have to meet different needs in different countries, it is difficult to provide a common definition of SCs and to indicate precisely current trends at global scale. We encounter a multitude of definitions and solutions but none of them is prevailing or universally acknowledged[2;3;4;5;6]. However, the various solutions agree on the fact that a SC should be able to optimize two different domains:

-Infrastructure domain (e.g. transport infrastructures, energy distribution networks, natural resources);

-Application and Services domain (e.g. human capital, intellectual capital of companies, and organizational capital in public administration bodies).

The emphasis of the first approach is concerning on production and the distribution of energy, transportation and logistics, waste management and pollution control, and it looks at the way ICT can harness information processing in these fields. The second one instead conceive SCs on bottom-up approaches in which cities provide access to data and allow citizens to make their own decisions. Consequently, it underrates the importance of investments in urban living domains related to welfare and social inclusion policies (e.g. the assistance of disabled citizens), culture and education, whereas ICT plays a more limited role in enabling sustainability and handling ‘‘transactions’’. This variety of visions and facets regarding the SC concept is an expression of the multitude of urban living domains to which technology and policy interventions can be applied. This research thesis pays attention especially on technologies and system configurations that can be used for converting a Microgrid in a "Smart Microgrid" by adopting an Infrastructure domain approach. In particular the discussion concerns two of the main improvements planned for an harmonious development of the micro grid examined: the development of a plan for sustainable mobility and the possible technical developments of the CHP-District Heating located in Osimo Town. But before going into the details, it is useful to undertake an overview of the Italian smart cities context.

2.2. Italian smart cities context

In 2016 Italian cities are still far from the level reached by the major European cities, even if the degree of innovation continues to grow [7].Concerning Italian Smart Cities, on the top of the list we can find for the metropolitan cities: Bologna, Milan and Turin. Compared to previous years Roma worsens their position, which ranks ninth in the rankings. Florence and Genoa following Rome, remaining within the top 15places.Also this year the metropolitan cities of the Center-North are positioned on the top of the list, while Naples becomes the first city of the South. The medium-sized cities are still growing. The medium-size cities continue their upward trend: they are in positions of being tucked in the ranking, with more than 23 cities between the 4th and 39th place. Parma surpasses Trento and in 2016 becomes the highest medium-sized city on the ranking (5th place). Parma is followed by Trento, Brescia and Reggio Emilia, the other medium-sized cities in the top 10.The Centre-North is placed on top of the ranking in the segment of medium-sized cities: the first South medium-sized city is Lecce (52nd place).It is increasing the delay of small towns. The 2016 ranking shows a correlation between the scores obtained by adopting an "Infrastructure domain" approach with the scores recorded by applying an "Application and Services" domain approach. It is obvious that those who have invested in creating an intelligent infrastructures are able to offer smart services and best practices to their citizens. In addition, the Cities that define a strategy and a structured vision, to better address your own path to the Smart City, are generally characterized by higher performance and are positioned at the top of the list.

	Position		***Position***
Bologna	1	***Ferrara***	21
Milano	2	***Pisa***	22
Torino	3	***Forli***	23
Mantova	4	***Cremona***	24
Parma	5	***Pavia***	25
Trento	6	***Ravenna***	26
Brescia	7	***Rimini***	27
Reggio Emilia	8	***La Spezia***	28
Roma	9	***Sondrio***	29
Firenze	10	***Vicenza***	30
Modena	11	***Udine***	31
Genova	12	***Napoli***	32
Padova	13	***Cagliari***	33
Bergamo	14	***Varese***	34
Venezia	15	***Siena***	35
Lodi	16	***Prato***	36
Bolzano	17	***Livorno***	37
Verona	18	***Aosta***	38
Piacenza	19	***Treviso***	39
Monza	20	***Bari***	40

Tab.1: Italian SCs Classification

In order to gather together all the different projects spread throughout the Italian territory, in May 2015, ANCI launched "Italian Smart Cities" : a national platform that collects all the different projects and experiences which follow the smart approach [8]. The platform shows "smart city initiatives" and their impacts on people's quality of life and it shows how these initiatives can be reproduced in other contexts and territories.

The following table reports a brief description of smart city projects related to the first three main cities of the previously described list:

CITY	PROJECT	DESCRIPTION
BOLOGNA	BOLOGNA SMART CITY	Developing innovative solutions to improve urban quality of life, put technology at service of people. The challenge of Bologna Smart City responds with a strategic alliance between the world of research, business and public sector who want to combine resources, talents and ideas to make the city more sustainable in order to reduce costs, avoid energy waste, improve diffusely quality of life, ensure social inclusion and participation, promote culture as a means of community growth and economic development. This is the strategic vision of the Bologna Smart City Project. The collaboration between the City Council, University, and Aster (a consortium company for innovation and technology transfer), which culminate in a Memorandum of Understanding, aims to define the priorities, strategies and tools for the development of the Bologna Smart City project, including the construction of opportunities to access external funding(National/European).The design platform also is experimenting with a new model of joint working between different institutions, as well as between public and private. The ambition is to create an environment able to elaborate actions and projects for the territory in which the University of Bologna contributes through

		research skills, ideas and experiences involving all disciplines Municipality, University and Aster have identified seven key areas for developing the first joint actions and collect new subscribers by organizations and companies interested in developing specific actions and "smart partnership": -Cultural Heritage (enhancement and upgrading of the old town and its cultural heritage); -Hyperbole 2020 Cloud & Crowd (re-design of the Civic Network Hyperbole, cloud-based technology and integrated digital identity, to raise the offer of content and Public Administration services, companies and citizens); -Intelligent networks (Smart Grids, Ultra Broadband Fiber to Home (FFTH) and Smart Lighting); -Sustainable mobility (development of a network of mobility - even electric - intelligent); -Safe neighborhoods and sustainable (Restructuring public and private heritage to efficiency and energy production, security monitoring of buildings, waste management, social housing, home automation, co-working, services and new environments for knowledge workers and researchers); -Health and Welfare (e-care, e-health, process optimization and business intelligence); -Education and technical education (development projects in education, promotion of new technical and scientific knowledge).

MILANO	SMART CITY PLAN	"Milan Smart City plan" begins in 2012 with the approval by the City of Milan to a specific delegation appointed to develop smart city initiatives. Then, during the spring of 2013, was activated a participatory process related to the development of strategic policies, through open public and technical meetings with all stakeholders involved in this process of innovation. The main goal of the Administration is to create a supportive environment to make Milan and its metropolitan area a Smart City. With its centers of excellence, its 11 universities and academies, its research centers and its businesses, Milan is building its future metropolis of knowledge and smart and sustainable creativity. There are currently 81 active projects that pay particular attention to living, mobility and government areas.
TURIN		Turin is a city aligned with the European strategy to meet the challenge of "Smart Cities", in terms of development of energy-environmental, economic and social sectors as well as gain more knowledge in terms of interconnection capacity and interactivity. Turin also joined in 2009 to the Covenant of Mayor and approved in 2010 the action Plan for sustainable Energy (TAPE - Turin Action Plan for Energy). As the same time, the City has continued to promote the participation in European and national calls to start research projects, technological development and innovation related to the themes of "Smart City". To better manage the route to the "smart city", the City of Turin association with

		Turin Smart City Foundation have launched, in February 2013 the strategic planning process, through the project "SMILE (Smart Mobility Inclusion Life & Health and Energy) lasted five months and coordinated by Torino Wireless Foundation, that led to the development of the Master plan of Turin Smart City. The SMILE project involves about 350 people of nearly 66 institutions that support public policies and strategic planning. The Master-plan draws the path to the transformation of the city: sustainable mobility, rational use of energy and renewable resources, improving quality of life , improving digital services in order to increase the attractiveness to tourists and investments. The Masterplan SMILE, represents a reference point for future projects of the city, including projects related to European programs (such as Horizon 2020) by maintaining constantly aligned to strategic programming and adapting it to new challenges in metropolitan character.

Tab. 2: Resuming table of main SCs projects

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2.3. Smart Cities: European regulation

European Policy and Regulation concerning on innovative forms of regulations and smart city policies are strictly necessary to enable large scale implementation and roll-out of SCs. Actually, Cities need an appropriate set of framework conditions in the field of policy and regulations in order to be able to smarten up. New governance concepts are developed to coordinate and integrate smart city stakeholders within the change process so to identify strengths, weaknesses, opportunities and threats. This connects with the need of' Integrated Planning and Management' (abb. IPM). IPM involves spatial, temporal and technical coordination of different policy areas and planning resources to achieve defined goals using specified (financial) instruments. To increase the deployment of these solutions, the European Commission has started the European Innovation Partnership on Smart Cities and Communities that will bring together European cities, industry leaders, and representatives of civil society to smarten up Europe's urban areas, in 2012.So far, the European Innovation Partnership (EIP) on Smart Cities and Communities has received some 370 commitments to fund and define smart solutions and regulations in the areas of ICT, energy, and transport. These commitments involve more than 3,000 partners from across Europe and create a huge potential for making our cities more efficient, and create new business opportunities. Its success requires the involvement of all governmental and non-governmental players, private sector, and citizens. It is particularly challenging as it involves managing long-term planning perspectives and short term actions, addressing domains as diverse as transport, energy, ICT and beyond – in both existing (retrofit) and new urban territory. According this dynamic context, the following paragraph of the present research, concerning on general rules and Directives related to SCs and pays attention on regulatory provisions, related to smart metering systems.

2.4. Smart Grids and meters: European Regulation

Smart Meters represent an essential part in the evolution from traditional power grids into smart grids. Wide-ranging policies and rules have both a direct or, in most cases, indirect impact on the smart metering system applied to Electricity, Gas and District Heating and Cooling sector. The most significant are listed below:

- Directive 2009/72/EC [9] of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market of electricity;
- Directive 2009/73/EC [10] of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market of gas;
- Directive 2012/27/EC [11] on energy efficiency and smart meters;

As concerns Directives 2009/72/EC2 (Electricity) and 2009/73/EC3 (Gas), the Member States or National Regulatory Authorities shall strongly recommend an efficient use of electricity and gas, thus including the use of smart metering systems, where appropriate. Both Directives affirm that Member States will ensure the implementation of intelligent metering systems that will assist the active participation of consumers in the energy supply market. Furthermore, the Electricity Directive asks Member States or any competent authority subject to that assessment, to prepare a National plan for the implementation of intelligent metering systems. Whereas the roll-out of smart meters is assessed positively, at least 80 % of consumers will be equipped with intelligent metering systems by 2020. Similarly the Gas Directive states that Member States or any competent authority subject to that assessment, will prepare a National program for the implementation of intelligent metering systems. From a policy-making perspective, it is important to note that the European Regulators' Group for Electricity and Gas released the “Final Guidelines of Good Practice on Regulatory Aspects of Smart Metering for Electricity and Gas”. These documents provide recommendations for Member States regarding smart metering roll-out, cost benefit analysis and data security and integrity. This confirms a certain consistency and convergence with the work effectuated by the European Commission related to smart meters. Concerning billing and metering, in the District Heating sector, the most important legislative act on a European level is Directive 2012/27/EC on end-use energy efficiency and energy services. It covers a vast array of measuring instruments from gas meters and electricity meters, to heat meters. In relation to the measurement of energy consumption, Article 9 of the present Directive, requires Member States to comply with the following obligations:

- Ensure that final customers for electricity, natural gas, district heating, district cooling and domestic hot water are provided with competitively priced meters that accurately reflect their actual energy consumption and that provide information on actual time of use.
- Ensure that such meters are always provided when:

  a) a new connection is made in a new building;

  b) building undergoes major renovations.
- Where Member States implement intelligent metering systems and roll out smart meters for natural gas and/or electricity sector:

  a) The metering systems must provide final customers with information on actual time of use;

  b) Objectives of energy efficiency and benefits for final customers must be fully taken into account when establishing the minimum functionalities of the meters and the obligations imposed on market participants;

  c) The smart meters and data communication must be secure and the privacy of final customers must be in compliance with relevant Union data protection and privacy legislation;
- As regards metering of the use of heating, cooling and domestic hot water:

  a)Buildings supplied from a district heating/cooling network or a central source servicing multiple buildings must be equipped with a central heat or hot water meter installed at the heating exchanger or point of delivery;

  b)Final customers residing in multi-apartment or multi-purpose buildings, whether such buildings are supplied from an external source or a common source within such buildings, individual heat or hot water meters for each apartment or unit in such buildings must be provided by 31 December 2016. However, in buildings where the use of heat meters is not technically feasible or cost-efficient, individual heat cost allocators must instead be installed on each radiator in the individual apartments/units of those buildings. Finally, where this solution is not cost-effective, alternative methods of heat consumption measurement may be considered.

Article 10 of the present Directive in relation to billing and billing information requires Member State to comply with the following main obligations:

- Where final customers have individual meters, gas, heating, cooling, domestic hot water), where technically possible and economically justified, they must be provided with billing information as from 31 December 2014 that is accurate and based on actual consumption.
- Member States may exempt the consumption of natural gas when it is used for cooking purposes only.
- Where there are smart meters, these must enable accurate billing based on actual consumption and the final customers must have the possibility of access to complementary information on their own historical consumption.
- Where smart meters are available or not, Member States must ensure that:

  a) Upon request of the final customer, metering data including complementary information on historical consumption is made available to an energy service provider designated by the final customer.

  b)All final customers are offered the option of electronic billing information and electronic bills;

  c)All final customers must receive their energy bills and billing information free of charge and they can access their consumption data free of charge and in an appropriate way. An exception is provided in the context of heating and cooling in multi-apartment buildings supplied from a district heating or another common heating/cooling source, for cases where the task of measuring, allocation and accounting for actual individual consumption is assigned to a third party such as a service provider or local energy supplier.

Chapter 3.

3. Smart City Approach applied to micro grid

3.1. Micro-grid

By doing reference to the research article of Ye, et al., “Forming a definition for Micro-grids (MGs) has been a difficult and elusive endeavor” [12].However, the Congressional Research Service (CRS) introduce a different definition of a MG: A MG is any small or local electric power system that is independent of the bulk electric power network. For example, it can be a CHP system based on a natural gas combustion engine, or diesel generators, renewable energy, or fuel cells. A MG can be used to serve the electricity needs of data centers, colleges, hospitals, factories, or entire communities (i.e., “village power”) [13]. In another report from the U.S. Department of Energy (DOE) has defined the following definition of MG: A MG is a small energy network that combines Distributed Energy Resources (DER) with local variable loads, which can operate in parallel with the grid or island mode, in order to provide an high level of reliability and resilience to grid disturbances. Another definition of a MG is as follows: A MG is a group of interconnected loads and DER within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A MG can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode. As previously described, opinions differ about the aggregated generation capacity that should be contained within the MG's power system and whether there should be a single point of connection with the main grid or multiple coupling points.” However, the MG needs to have the ability to be isolated from the main grid either by a single or multiple disconnection point. It also has to include real-time, on-site controls to match the MG's generation and storage capacity to power use in real time, as well as have some way to interact with the grid.” According to the sources examined for this thesis, the key features of a MG include:

• operation in both island mode or grid-connected;

• presentation to the MG as a single controlled entity;

• combination of interconnected loads and co-located power generation sources;

• provision of varied levels of power quality and reliability for end-uses.

3.2. Local versus National strategies applied to Micro-grids

The size of a city may represent a relevant factor for the development of Smart City initiatives [14].In the present thesis, I have chosen to adopt a method focused on a local scale, directly applied to a MG. In order to explain the main reasons that lead to this choice, I will provide a brief list of advantages observed from this "restricted" viewpoint:

- The smart city concept entails an economic enhancement competition and competitiveness concern urban plans, as cities are differentiated among them because of their peculiar and local features [15; 16]
- An efficient urban management requires the integration and implementation of the existent urban network and the creation of connected smart grids also in other sectors –thus a local level approach is more effective in making cities smart [17; 18];
- Cities can play an active role in the innovation process deploying a vast array of activities which revolve around citizens’s needs – this process should result in the establishment of a smart city context [19;20;21].
- During the process of transformation into Smart Cities, big cities or metropolis usually face more problems than small towns. That is why small towns may be considered ideal settings for pilot projects [22].

3.3. Micro-grid case study: Osimo Town

In Chapter 3.2, I have presented the benefits observed by adopting a local scale approach. The town selected for the present thesis as a case study is Osimo, a small town located in Central Italy. The management of services such as: electricity, gas, water and District-Heating is entrusted to Astea Spa, an utility company that operates in this field from 1909. The following table provides a brief list of the main features which characterize this territory:

Osimo main features	
Altitude	265 m a.s.l.
Area	106.74 km^2
Inhabitants	34,866

Tab. 3 Osimo main features

The analysis and the study of innovative solutions for the town of Osimo was due to different reasons:

1)High penetration of distributed generation;

2)Energy network designed with a unidirectional approach (energy flows from centralized Power Plant or Primary substation to final users);

3)Presence of a single physical point of interconnection between Osimo electricity network with high National transmission network;

4)Presence of a single network operator related to energy distribution;

5)Presence of a single point of centralized production (Cogeneration Power Plant);

6)Prevision of a plan for sustainable mobility in order to reduce pollution and greenhouse gas emissions.

Starting from these different points, I will illustrate how improvements have been adopted in some of the previously described areas (point 5 and 6). But before going in to the detail some aspects related to Osimo town will be described.

3.3.1 Distributed generation

Over the last years, Osimo, like most Italian cities and towns, underwent a fast growth of Renewable Distributed Generation (RDG).Currently, on the territory of Osimo, about 752 PV power plants are installed with a total amount of 35.9 MWp. The following figure show the trend of the PV capacity installed over the last period.

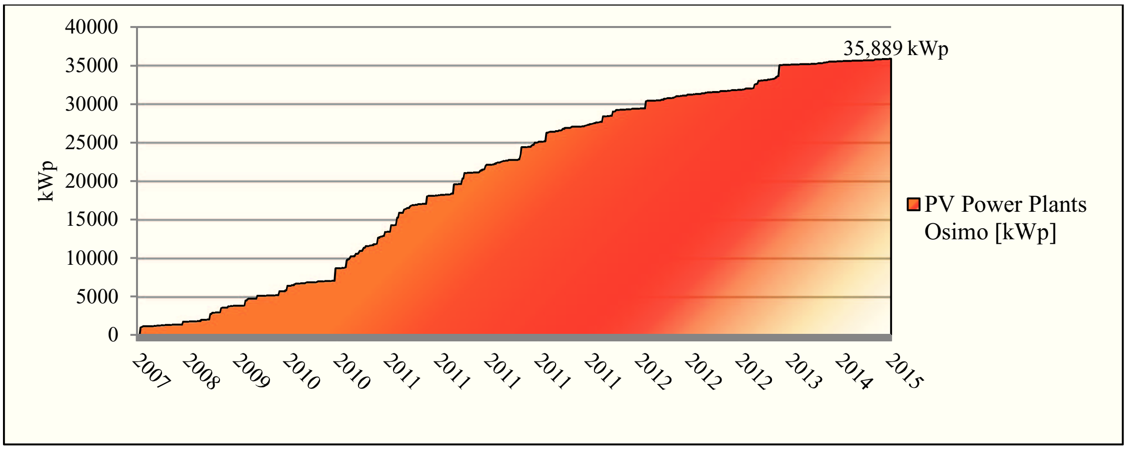


Fig.1 PV Power Plants Trend

The need to connect such a large number of plants has led to considerable investments on infrastructures especially for the realization of new medium-voltage lines and new electric cabins processing medium- low voltage. The next step which is fundamental to improve the power quality of the "micro grid", is represented by the Energy Storage (ES).ES is a viable technology that could be used by the utility, to manage the load curves, especially during peak demand times or otherwise during peak production times derived from distributed power plants. According to Zprime & IEEE [23] the main benefits derived from ES are:

- Providing supplemental power to meet peak demands;
- Improving power reliability;

- Reducing energy costs;

Other minor benefits are:

- Providing backup power during outages/shortages;
- Improving power quality;
- Reducing carbon footprint;
- Reducing Infrastructure costs.

By doing reference on commercial aspect, the ES and renewable energy market has seen battery and other system component costs falling rapidly, allowing ES to become an economical alternative to the traditional power generation methods for certain applications. Furthermore the installation of ES technology is driven by the provision of innovative models that pay attention on:

- The economic benefit related to PV source coupled with battery energy storage performance trough a detailed financial model;
- The life time of battery energy storage through a model that consider the variable nature of battery replacements.

In addition, a similar technology to consider, could be Vehicle to grid (V2G) technology (strictly related to the plan for sustainable mobility described in the following paragraph). V2G is a new and emerging technology that utilizes Electric Vehicles as ES system to power and be powered by the grid. Thanks to bi-directional chargers, utilities grid operators could communicate with plugged-in cars, buying electricity from car owners during peak demands and selling it back when demand is lower.

In relation to the previous benefits, it is obvious that ES technology (coupled with V2G) represent a valid solution to overcome the criticalities related to distributed generation in Osimo town. Nevertheless, if the cost of this technologies does not decrease significantly and if external funding from both private and public sectors are not well defined, utilities will not be able to develop projects which involve the installation, application and optimization of this new and emerging technology.

3.3.2 Grid utility Evolution: from "mono-directional" to "multi-directional flow"

The current utility grid of Osimo town, was designed to accommodate power flows from the central generation source or primary cabin to the transmission system and eventually to the distribution feeders with as little loss as possible. At the distribution level, the system was designed to carry power from the substation toward the load. Renewable distributed generation, particularly solar PV, provides power at the distribution level challenging this classical paradigm.

A large portion of distribution system components, including voltage regulators and protection systems, were not designed to coordinate with bidirectional power flow and bidirectional fault currents from distributed generation. As these resources become more and more commonplace, the nature of the distribution network and its operations are changing so as to handle power flow in both directions. In order to reduce the negative impact due to the wide spread of DG, some corrective measures are going to be adopted:

- Optimal DG locations based on loss minimization: this approach provide the basis for a simple quantifiable rule concerning monotonic dependence of DG locations and the resulting distribution losses. In some cases some DGs may not be technically feasible because their presence leads to a non-convergent power flow solution.

-Optimal DG locations as voltage support: DG units are not subject to centralize dispatch and reactive power generation is in most cases restricted by the Distributor System Operator. Therefore, several changes are required in order to fully profit from the benefits resulting from DG integration, and voltage support emerges as one of the main services to be provided by DG units. This derives from the fact that a significant growth of DG penetration will require new operation philosophies in order to exploit reactive power generation capability of DG units, with the objective of optimizing network operation, minimizing active power losses and maintaining voltage profiles.

Therefore it must be consider the need for voltage support for both optimizing distribution loss and for ensuring feasibility of the power flow. The static interdependence of distribution losses and the voltage profile is influenced by both choosing the location of DGs and by the system-wide on-line voltage dispatch using, for example, an AC Optimal Power Flow (OPF). As more and more distribution systems have SCADA, dispatching voltage on-line could become an inherent part of operating rules in future energy systems.

Chapter 4.

4. Electric mobility in cities: a new smart approach

4.1. Purpose statement

Transportation represents the largest energy consumer worldwide [25] and one of the main causes of urban pollution [26, 27]. For this reason, sustainable mobility in urban areas is a major issue both in national [28-32] and in local energy planning [33], and the debate on its future is still open [34-36]. Over the last few years, several studies concerning the implementation of sustainable mobility have been carried out [37-42] but only few experiments have been done at a local scale [43-46].The estimation of the future market share of electric vehicles is a big issue in electric mobility studies. A wide range of factors such as: national incentives plans, development of new alternative technologies, oil price, are changing transport policy agenda in the European Union (EU) and are 'influencing the reliability of any forecasting' [47].The present thesis illustrates the economic analysis carried out by a local utility in cooperation with Polytechnic University of Marche. It was submitted to local municipalities Osimo and Recanati, both located in Marche Region, Italy in order to start off a project that envisages the installation of several charging stations starting from 2014. The first phase of the operation covered the period 2014-15 it involved a limited number of electric vehicles and charging stations and it consisted in: i) building infrastructures, ii) starting operation of recharge services iii) analyzing data and iv) carrying out a technical-economic validation of results. This analysis intends to be a basic approach, at local scale, to the rapidly evolving market of recharging infrastructures. The trend of Plug-in Hybrid Electric Vehicles (PHEVs) and Electric Vehicles (EVs) are considered in the Italian market scenario for EVs [48] and are adapted for local scale. The project was approved by local municipalities and started at the beginning of 2014 with the installation of three charging stations.

4.2. Recent studies on electric mobility in Italy

In Italy, transport sector accounts for a share of energy consumption of 29.7% [49].The increasing interest in electric mobility in Italy has been confirmed even by reports and studies to which we will refer in the present thesis, with a special attention to the projection of EV figures in the next 15-20 years. A study by Mobility Research Centre [50] showed that the spread of electric vehicles is affected by the following factors: congestion of urban centers, integrated technology in daily life, environmental issues. Reduced pollution, low noise and the modern image created by electric vehicles are three essential elements appreciated by Italians. But referring to consumer survey literature, it is evident that price still represents the main concern for electric vehicle sales. In this sense, support policies including price incentives for EVs over the long- term (to 2020 and beyond) will be extremely important. Figure 1 shows the results obtained by the national survey.

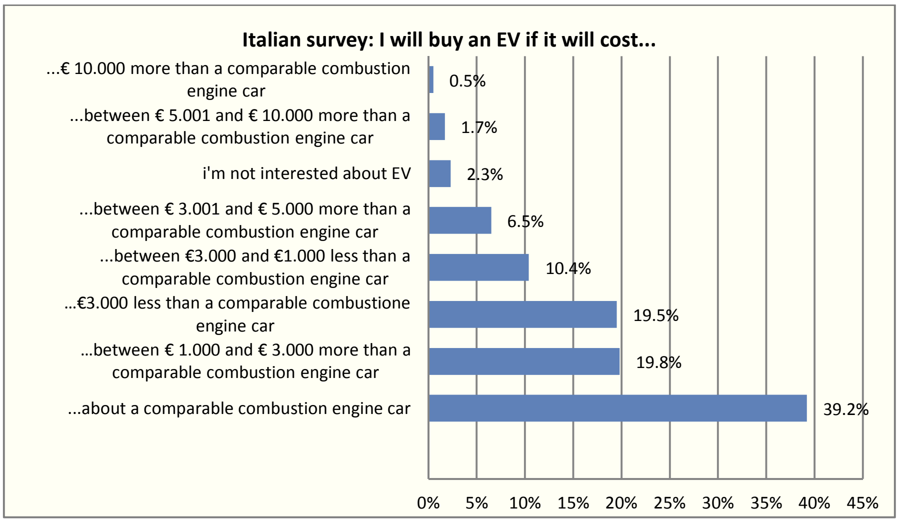


Fig.2Willingness to buy an EV in Italy

UNRAE (Unione Nazionale Rappresentanti Autoveicoli Esteri), the Association of foreign car makers, revealed in its study [51] encouraging results on the electric vehicles over the last four years (Figure 3).

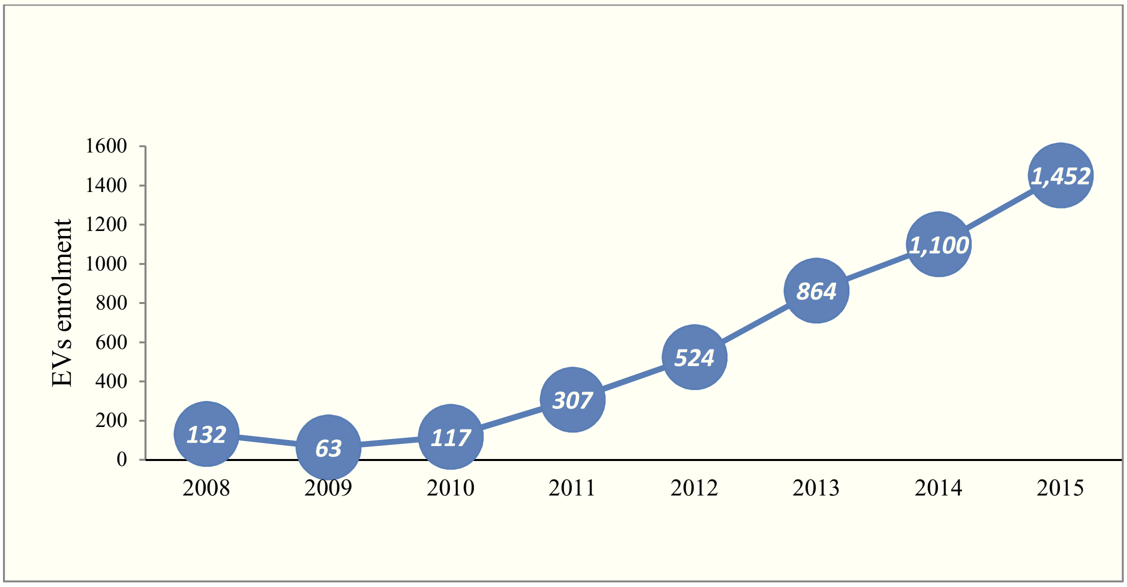


Fig. 3Trend of EVs registration in Italy

At local scale, Perujo et al. [52] studied the introduction of electric vehicles in private fleet in the Province of Milan whilst Euro-mobility, the Italian association of mobility managers, presented a study on sustainable mobility in 50 cities [53].

In order to evaluate correctly the impact of electric vehicles and the resulting estimates, several parameters need to be defined:

- Average distance normally traveled by an Italian driver: a recent study conducted by ICDP (Automotive Distribution Research, Insight, Implementation) estimates that the average annual distance is about 11,000 km per year [54].
- Car fuel consumption: according to RSE study, it is possible to draw a comparing table of the average consumption of five different fuels: diesel, petrol, natural gas, LPG and electricity (Table 3).
- EVs 2020 scenario: RSE study also reports a slow growth of electric vehicles within 2020. It is estimated that Italy will experience a growth from 1% to 3 % of EVs fleet.

Fuel	**Diesel**	**Petrol**	**Natural gas**	**LPG**	**Electricity**
Unit Consumption	l/100 km 6.9	l/100 km 8.6	Nm3/100km 8.64	l/100km 9.72	kWh/100km 17.94
Unit Consumption	MJ/100 km 220.6	MJ/100 km 318.7	MJ/100km 295.5	MJ/100km 233.0	MJ/100km 64.6*1

*1 The value is without considering electric efficiency of the power plant producing the electricity

Tab. 4 Average fuel consumption

- EVs 2030 scenario: TERNA (the main shareholder of the Italian high voltage electricity transmission grid) presents every year forecasts of electricity demand in Italy and recently has carried out an analysis of EVs diffusion by 2030 that is based on the "National Energy Outlook"[55].This study suggests three different "Visions". "Vision 1" envisages a “Slow Progress”. It reflects a slow progress in a system development with unfavorable economic and financial conditions. Vision 1 is also the Vision with the lowest increase of green energy. The level of demand grows with a slow annual rate. The second analyzed scenario ("Vision 2") is the “Mid transition”. It reflects a medium transition in energy system development with favorable economic and financial conditions. Thus, Vision 2 hypothesizes a medium increase of green energy. The level of demand grows with a medium annual rate compared to the first Vision. The third possible scenario is the “Green Revolution” scenario or "Vision 3". It reflects a green transition in the energy system development with more favorable economic and financial conditions. Vision 3 supposes a high increase of green energy. The level of demand grows with a higher annual rate compared to the first and second Vision.

Scenario	**Generation &Load framework**	**EVs range %**
Vision 1 "Slow Progress"	-Electricity demand lowest level -No demand response -No electric plug-in vehicles -Smart grid partially implemented	5%
Vision 2 "MidTransition"	-Electricity demand slightly higher than Vision 1 -Demand response potential is partially used -Electric plug-in vehicles (with flexible charging) -Smart grid partially implemented	15%
Vision 3 "Green Revolution"	-Electricity demand higher than Vision 2 - Demand response potential is fully used - Electric plug-in vehicles (with flexible charging & generation) -Smart grid implemented	30%

Tab. 5 Visions 2030

4.3. Regulatory framework

Wide-ranging policies influence and rule the EV market, from technical to non-technical aspects. As concerns EVs, attention has to be paid to European Directives, Regulations and Resolutions. In particular, we refer to the European Parliament Resolution (P7_TA2010 0150) on Electric Cars [56]. This regulation which refers to the Directive 2009/28/CE [57],was approved by the EU commission and its member states and it helped paving the way for the establishment of a single EV market, which means: a reduction of space, of congestion, of total energy consumptions, of CO2 emissions. Another fundamental Directive is 2009/33/EC on the Promotion of Clean and Energy Efficient Vehicles [58]. This Directive aims at promoting clean and energy–efficient road transport vehicles in the EU by encouraging their sales and consequently their market. The Directive requires public authorities to include the environmental impact of vehicles into procurement decisions. Authorities have to consider the externalities inextricably intertwined with energy consumption, CO2 emissions and other pollutant gases emitted during operational lifetime of vehicles. Electric vehicles are explicitly mentioned in the Directive because their energy consumption must be measured in order to calculate the lifetime energy costs. Italy has issued significant guidelines in its Decree-Law on development (N. 83/2012) [59], subsequently converted into Act in August 7, 2012, n. 134. Chapter IV-bis of the Act entitled "dispositions in order to promote mobility with low-emission vehicles". The Act contains important innovations whose main purpose is to produce progressive and radical change in urban mobility, such as the enhancement of charging station networks for electric-vehicles. In order to promote the installation of recharging stations, this law introduces a set of rules that require (in some cases) the provision of connections for recharging points. Safety requirements for charging systems are outlined by IEC/EN 61851-1 ed. 2.0 [60]. This regulation must be applied to on-board and off-board equipment to charge electric road vehicles at standard AC supply voltages (as IEC 60038) up to 1000V and DC voltages up to 1500V, and to provide electrical power for any additional vehicle (if required) when connected to the supply network. Settings of electrical connectors, plugs, socket-outlets, inlets and cable assemblies for electric vehicles, are defined by IEC 62196-2 [61]. It contains categorizations on plug types, dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories and it is the standard reference adopted by the most common EV-connectors.

4.3.1 Italian regulation

Concerning Italian regulation, a relevant resolution was made by AEEG (Autorità per l'Energia Elettrica e il Gas - Italian Authority for Electric and Gas Energy) in order to support EVs development. This resolution is headlined ARG/elt 242/10 [62] "special provisions for testing recharging stations in public areas". It provides measures (based on European Directives) to develop the public charging of electric vehicles in order to incentivize electric mobility at national scale. Recently, the Italian Ministry of Infrastructures and Transports allocated € 5mln to support the construction of charging stations networks [63] within the framework of the National infrastructural plan for recharge of electric vehicles [64].A relevant step forward in the electric mobility was confirmed by the Decree law n.83/2012converted, with amendments, by law of 7 August 2012, n.134 entitled "dispositions in order to promote mobility with low-emission vehicles ". It contains a financial plan that intends to sustain the purchase of low-emission vehicles and electric cars. At the purchase of a new vehicles with CO2 emission under 50 g/km (years 2013 and 2014), the Italian state grants a subsidy up to 20% of the price of the vehicle or maximum € 5.000. Subventions will be reduced to 15% or max € 3.500 in 2015. An electric vehicle is also exempt from annual circulation tax for five years since the moment of its registration. Thereafter, EVs will benefit from a 75% reduction of the annual circulation fee[65].

4.4. Infrastructure: connection mode and charging systems

Currently, IEC/EN/CEI 61851-1 ed. 2.0 is the main reference adopted to connect electrical devices. Charging mode can be slow (4-8 hours), semi-fast (1-3 hours) or fast (10-50 minutes). The difference depends on the power output by charging point and the "rate of charge" of the vehicle (at the present time, most of the Plug In vehicles allow 16A of maximum current).

The standard modes defined in IEC 61851-1 include:

- Mode 1 (slow charge for 6-8 hours at home): it is possible to recharge the battery of the EVs (eg 3 kW of installed capacity) at home, with a normal socket.
- Mode 2 (slow charge for 6-8 hours at home): it is possible to connect the electric vehicle to the main AC with domestic connectors up to 16A, or industrial up to 16A , 30 mA "automatic cut-out" as protection upstream, control device on the cable (safety system PWM: Pulse With Modulation).Actually, the most common applications refers to nominal power of 3.5 kW (single phase wiring, 230V voltages and currents of 16A).
- Mode 3 (slow charge or semi-fast charge in public-domestic environment): This connection mode is compulsory in public environments. The connection between electric vehicle and AC power supply has its own connectors. The automatic cut-out (as protection upstream) and control device in the station (security system PWM) are necessary to operate according to basic requirements defined by technical regulations. Cars can also be charged in fully equipped public areas, so that it is possible to make up for the time spent parking recharging the vehicle. At the moment, the most common applications refer to nominal power of 3.5 kW (single phase wiring , 220V voltages and currents of 16A) and 22 kW (three-phase wiring , 220V voltages and currents of 32A) .
- Mode 4 (DC fast charging): It is possible to connect the EVs (with external battery charger) to the DC power supply. It refers to "fast charging stations" that permits a

rapid refill of the battery in few minutes. This kind of station requires special connectors and high power supply. A DC charging station is much more complex and voluminous than an AC station, due to the presence of AC/DC converter able to handle current up to 125A (voltage of 400V).

By doing reference on car side connectors, we can find three different kinds of solutions in the car-market today: the solution developed by Yazaky (Japan) [66] (type 1 of IEC 62196-2), the solution developed by Mennekes (Germany) [67] (type 2 according to IEC 62196-2) and the solution developed by CHAdeMO Association [68] (DC charging connector). The first (Yazaky connector) is designed for charging with single-phase AC. The connector has five pins: two AC wires, two signal pins and ground. It is compatible with IEC 61851-1/SAE J1772-2012 [69] for proximity detection and control pilot function. The second (Mennekes/VDE automotive solution),has a single size and is layout for currents from 16A single-phase up to 63A three-phase (3.7 kW to 43.5 kW). The connector has seven pins: three AC wires, two signal pins, neutral and ground. The CHAdeMO connectors have a DC fast-charging connector composed by ten pins: two power DC pins, five analog control pins, two CAN (Control Area Network) digital pins, one free pin. The CHAdeMO technology provides high-voltage charge (up to 500VDC),high current (125 Amps) through JARI Level-3 DC fast charge connector.
With Reference to charging station side connectors, two different types of connection systems are adopted: one developed by Mennekes and the other one developed by 'EV Plug Alliance', an alliance formed by SCAME, Le-Grande and SCHNEIDER. Both connectors can be used in public charging stations even if the latter has a greater degree of protection (IPXXD) and it is aligned with standard requirements for home plugs, thanks to Shutter Protection System demanded by 12 European countries.

4.5. Payment modes

Nowadays, there is not a fixed price to recharge vehicles in public stations. According to some of the largest sellers [70-72], there are mainly four kinds of payment modes:

1-Number of recharges
2-Expiry date
3-Combined mode (number of recharges with expiry date)
4-Free charging

All this modes normally require a contactless User Card (UC) associated to a single user. In the first case, UC can be charged with a limited number of electric recharges. Once all the recharges are done, it is necessary to top it up again.
The second mode imposes an expiry date, which prevents the use of the card after a certain deadline. The third case is a combination between the previous two modes. The last one is the free charging mode, which is usually adopted in the start-up phase.

4.6.Reference data for the perspective analysis

It is necessary to set reasonable boundary conditions to correctly define a valid analysis regarding an investment in EVs charging stations. In particular estimation are needed for parameter such as: car fuels prices, electricity prices. The prices of diesel fuel, gasoline, natural gas and LPG are real prices taken from official data [73]. Electricity price "for public recharging uses" was calculated according the aforementioned resolution (ARG/elt242/2010),as the sum of the following components: transmission fee (66.88 €/MWh); tariff fee (49.96 €/MWh); taxes(12.5 €/MWh), estimated cost of energy and charging service (93.80 €/MWh of which 22 €/MWh is the generation fee).

Year	2015	2020	2030
Electricity (€/kWh)	0.2230	0.2191	0.2325

Natural Gas (€/Nmc)	0.6732	0.6805	0.7245
Lpg (€/l)	0.6130	0.7595	0.8470
Unleaded Petrol (€/l)	1.5340	1.5069	1.6806
Diesel (€/l)	1.4050	1.6167	1.8510

Tab. 6 Energy commodity prices 2015-2030

In the present thesis, we have taken into account the viewpoint of a standard costumer who wants to purchase a car and he has to choose between an EV or a combustion engine car. The main factors which determine the choice are summarized as follows:

- prices of energy commodities: the following table shows the fuel prices considered in this study. 2015 prices are real market prices; 2030 prices taken into account, are projections from IEA "International Energy outlook 2015" [74];

- Electric car vs Traditional car cost: Table 7 compares the average prices of an economy EV with prices of an equivalent car powered by traditional fuels (Natural Gas, LPG, Petrol, Diesel fuel) showing that even with subsidies the electric car is, on average, 4,000-7,000 € more expensive than traditional ones.

TYPE	AVERAGE CAR PRICE [€]	"EV price gap" [€]	SUBSIDIES/INCENTIVES INCENTIVE [33] [€]	SUBSIDIES/INCENTIVES REDUCED CAR COSTS [49] [€]	SUBSIDIES/INCENTIVES PROMOTIONAL CHARGING PRICES IN PUBLIC STATIONS [50] [€]	SUBSIDIES/INCENTIVES REDUCED VAT (5%) [€]	FINAL "EV gap" [€]
ElectricVehicle	**30,000**	**-**	**5,000**	**250**	**250**	**5,100**	**-**
Natural gas	15,000	15,000	-	-	-	-	4,400
LPG	12,500	17,500	-	-	-	-	6,900
Diesel Fuel	13,500	16,500	-	-	-	-	5,900
Petrol	12,500	17,500	-	-	-	-	6,900

Tab. 7 Car costs comparison according to 2013 prices

The column "average car price" was obtained by considering as a benchmark the current market scenario of economy cars. The "incentive" column represents the maximum amount of the Italian government subsidy to purchase Electric vehicles (according Decree law n.83/2012). "Reduced car costs" column considers the minor costs of insurance and free-Road tax applied to EVs for the first five years [73]. "Promotional charging prices in public station" reports the opportunity to get a recharge with a relevant discount in a public recharging center (this benefit is only for the first year) ."Reduced VAT" (5% instead of 22%) introduces a hypothetical (but realistic) assumption, aimed at reducing the final gap between EVs and traditional cars.

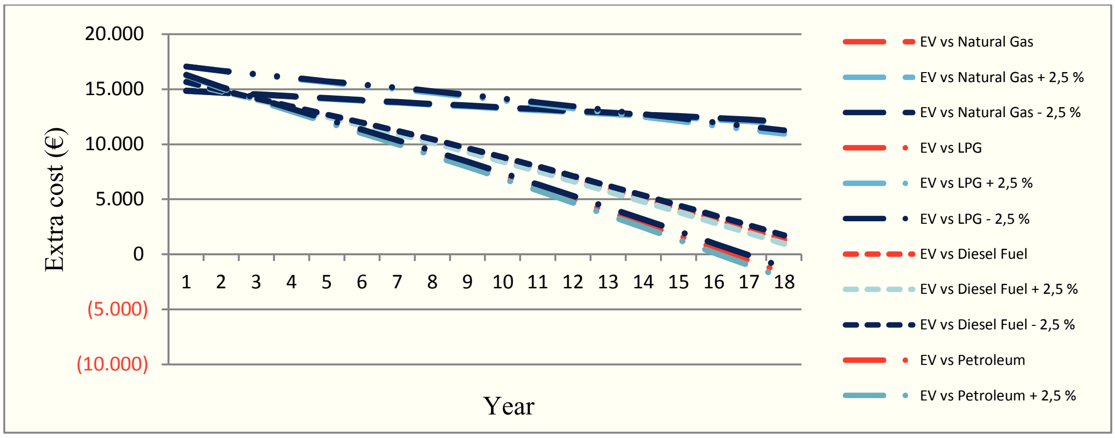


Fig. 4PBP of the extra cost (without subsidies)

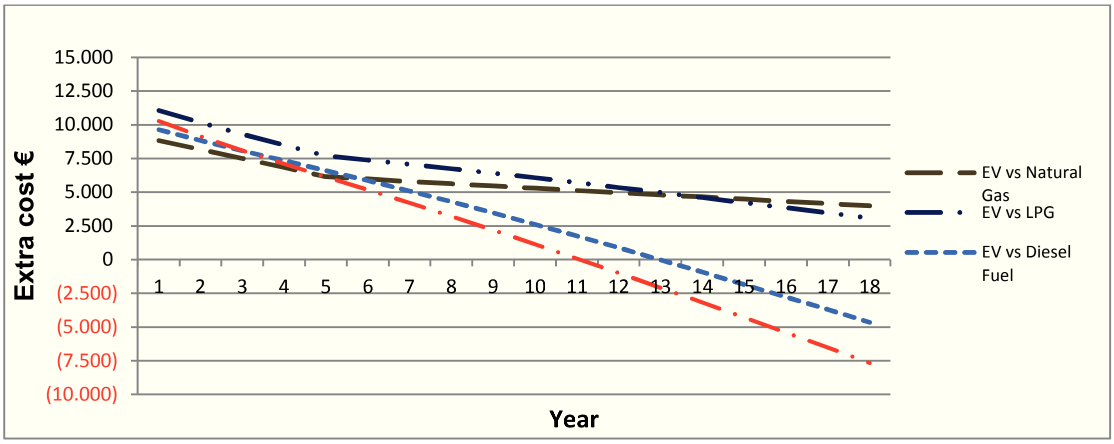


Fig. 5PBP of the EV extra cost (with subsidies)

The results shown in Figures 4 and 5 suggest that financial incentives combined with VAT reduction can reduce significantly the PBP of the EV extra cost which otherwise will be out-of-market.

4.8. Provider's point of view on electric mobility

A significant part of the present study is without any doubt the estimation of the future electric vehicle market penetration. Based on ENTSO-E projections, it was possible to hypothesize nine different scenarios of EVs spreading in the local areas where the Utility group operates. By referring to the abovementioned trend, the number of EVs will reach nearly 2,100 units in 2020 and will increase up to 9,000 units in 2030. As aforementioned, a recent study estimates that standard distance normally traveled by an Italian driver will be about 11,000 km per year. Assuming that average consumption of an EV, is 17.94 kWh/100 km (5.58 km/kWh), considering a power supply of 25.5 kW for each recharging station with a Contemporary Factor (CF) of 40%, it is possible to estimate the number of recharging stations that should be installed.

4.8.1 Number and position of charging stations

The first step of the study was to estimate the number of EVs in 2020 and 2030. This result was obtained by conceiving three different scenarios of EVs penetration. For each electric vehicles market penetration rate, three different CF (named as Capacity Factor) are considered. The CF is the main parameter affecting the economic feasibility of the investment: high value of CF corresponds to an high value of energy sold and reduction of payback time. The second step of the study was the estimation of the number of charging stations. This number resulted from the evaluation of the following essential parameters:

-Standard distance normally traveled by an Italian driver;
-CF: 35% - 50% -75 % are three different yearly percentage of equivalent hours considered for the present analysis (based on individual parking amount of time collected from a statistic survey commissioned by Astea utility). Nevertheless, it remains the rare chance in which simultaneity factor could reach 100%. Despite that, according to Astea Grid Monitoring System, the present grid is able to bear the new electric load contribution. Table 8 summarizes main data from the estimate.
- PBP of a single recharging station: this value represents the length of time necessary to recover the cost of a single recharging station. The calculation of PBP was derived for each CF by considering a total economic margin for power unit of 22 €/MWh and a cost of € 5,544 for a single recharging point.

	% EVs 2020	EVs 2020 N.	% EVs 2030	EVs 2030 N.	C.F.	PBP single Recharging Station	Recharging Stations 2020	Recharging Stations 2025	Recharging Stations 2030
Scenario 1	1%	358	5%	1,792	35%	3.2	9	20	45
Scenario 2	1%	358	5%	1,792	50%	2.3	6	14	32
Scenario 3	1%	358	5%	1,792	75%	1.5	4	9	21
Scenario 4	2%	717	15%	5,377	35%	3.2	18	49	136
Scenario 5	2%	717	15%	5,377	50%	2.3	13	34	95
Scenario 6	2%	717	15%	5,377	75%	1.5	8	23	63
Scenario 7	3%	1,075	30%	10,755	35%	3.2	27	85	271
Scenario 8	3%	1,075	30%	10,755	50%	2.3	19	60	190
Scenario 9	3%	1,075	30%	10,755	75%	1.5	13	40	127

Tab. 8 Data summary

There is not only one method of installing charging stations. In the present study, the estimate has been obtained from theoretical evaluations and the direct experience of experts from different working areas (University, Energy Services Provider's, municipalities involved). This basic approach is necessary to single out the best areas to install a “recharging center”. The essential parameters adopted to decide where to install charging stations are:
-Traffic density flow: this was calculated by utility technicians;

-available parking areas: a list of parking area was compiled, in order to assess the best location to create a recharging center. The selection is based on exchanging parking areas already available in the towns.
-electrical grid: charging station must be installed in locations without criticalities in the grid infrastructure.
The locations of recharging centers chosen at the present time, are shown in figures 6 and 7, thus for seeing plausible scenario (see Scenario 5).

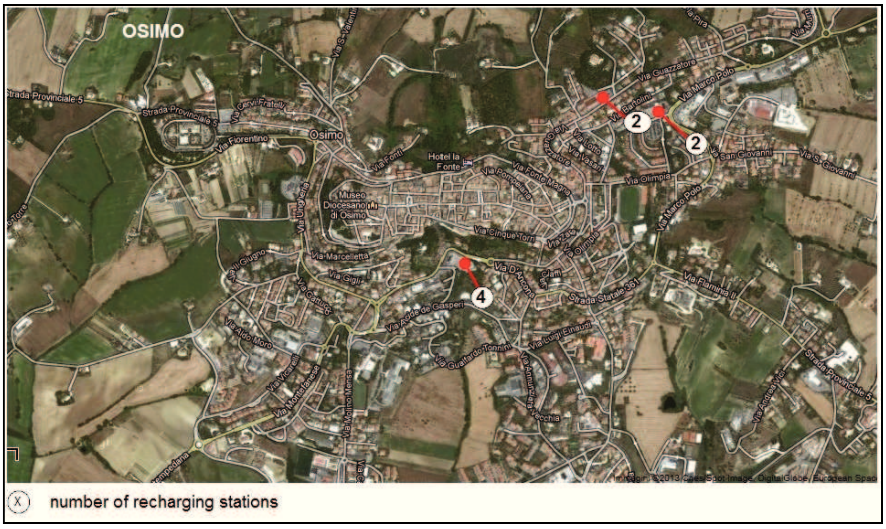


Fig. 6Charging Stations layout in Osimo

Fig. 7Charging Stations layout in Recanati

Nowadays three recharging points are available: two of them were installed in each headquarter of Astea (both in Osimo and Recanati); the third is a charging station installed in a public parking in Recanati. The last charging station consists of a column characterized by both charging station-side connectors described in section 4.2: Mennekes and 'EV Plug Alliance'.

4.8.2 Charging stations investment costs

The basic elements that characterize an investment cost analysis are: economic parameters and energy forecasts. These values are influenced by changes in the general economic conditions. Consequently, accurate long-range forecasts are extremely difficult to make. In order to achieve congruity in the present analysis, a list of economic parameters is provided. This forecast is based on similar data used by Energy Service Companies for energy investment analysis. Data shown in table 9 give detailed information on the recharging points investment parameters.

Equity	40%
Bank Loan	60%
Actual Cash	0%
Depreciation rate of recharging system	10%
Bank interest	5.5%
Financial depreciation rate	5.0%
IRES rate	27.5%
IRAP rate	4.73%
Discount rate	4%
Inflation	2.0%
Electricity cost	5.5%
Electricity distribution cost	3%

Tab. 9 Energy and economic investment parameters

The main investment costs are summarized in Table 10. The evaluation of investment is referred to a MODE III of charge, according charging levels defined by the International Electro technical Commission (IEC) 61851-1. Cost figures compiled inTable 10 have been calculated through a careful market survey even if a margin of uncertainty must be allowed.

Recharging Station Cost + Installation Cost	EUR 5,544
Advertising	EUR 2,200
Various	EUR 234
Cost per power unit	EUR/kWh 320
Economic margin distribution	EUR/MWh 12
Economic margin selling	EUR/MWh 10
Total economic margin per power unit	EUR/MWh 22

Tab. 10 Investment Input data

4.8.3 Pay-Back analysis

Payback analysis is an important financial decision making tool to assess the payback period of an economic investment. The main outcomes are the payback time and the Net Present Value (NPV) that is the amount of money earned over the time period examined . The matematical formulation of the PBP and NPV are:

$$NPV = 0 = \sum_{i=1}^{PBP_t} \frac{R_i}{(1-j)^i} - C \qquad (1)$$

$$NPV = \sum_{i=1}^{n} \frac{R_i}{(1+j)^i} - C \qquad (2)$$

where C is the initial investment, R_i is the cash flow in year i, j is the discount rate, n defines the temporal horizon of the investment. The PBP time is reached when NPV =0. By doing reference to the cash flow R_i , the same can be calculated as:

$$R_i = (W \cdot 8760 \cdot \frac{CF}{100}) \cdot P \quad (3)$$

where W (kW) is the nominal power of charging station, P (€/kWh) is the profit for the utility, and CF (Capacity Factor) is the yearly percentage of equivalent hours that the charging station is supposed to work at nominal power. CF is the main parameter that influences the economic feasibility of the investment. The following table 11 shows the trends of PBP and NPV for each hypothetical scenario in relation to the aforementioned investment input data whilst Tables 12-13 show economic index derived from a variation margin of ± 2.5%.

	% EVs 2020	EVs 2020 N.	% EVs 2030	EVs 2030 N.	CF	Recharging Stations 2020	Recharging Stations 2025	Recharging Stations 2030	PBP 2030	NPV
Scenario 1	1%	358	5%	1,792	35%	9	20	45	8	€ 83,401
Scenario 2	1%	358	5%	1,792	50%	6	14	32	6	€ 227,020
Scenario 3	1%	358	5%	1,792	75%	4	9	21	5	€ 333,771
Scenario 4	2%	717	15%	5,377	35%	18	49	136	9	-€ 22,210
Scenario 5	2%	717	15%	5,377	50%	13	34	95	8	€ 420,647
Scenario 6	2%	717	15%	5,377	75%	8	23	63	6	€ 748,787
Scenario 7	3%	1,075	30%	10,755	35%	27	85	271	10	-€ 351,040
Scenario 8	3%	1,075	30%	10,755	50%	19	60	190	9	€ 541,350
Scenario 9	3%	1,075	30%	10,755	75%	13	40	127	8	€ 1,219,311

Tab. 11 Summary table -base line condition

	% EVs 2020	EVs 2020 N.	% EVs 2030	EVs 2030 N.	CF	Recharging Stations 2020	Recharging Stations 2025	Recharging Stations 2030	PBP 2030	NPV
Scenario 1	1%	358	5%	1,792	35%	9	20	45	8	€ 92,339
Scenario 2	1%	358	5%	1,792	50%	6	14	32	6	€ 236,094
Scenario 3	1%	358	5%	1,792	75%	4	9	21	4	€ 342,925
Scenario 4	2%	717	15%	5,377	35%	18	49	136	9	€ 1,019
Scenario 5	2%	717	15%	5,377	50%	13	34	95	8	€ 443,078
Scenario 6	2%	717	15%	5,377	75%	8	23	63	6	€ 771,382
Scenario 7	3%	1,075	30%	10,755	35%	27	85	271	10	-€ 308,641
Scenario 8	3%	1,075	30%	10,755	50%	19	60	190	9	€ 582,839
Scenario 9	3%	1,075	30%	10,755	75%	13	40	127	7	€ 1,259,993

Tab.12 Summary table -base line condition + 2.5% of economic margin

	% EVs 2020	EVs 2020 N.	% EVs 2030	EVs 2030 N.	C.F.	Rechargin g Stations 2020	Rechargin g Stations 2025	Rechargin g Stations 2030	PBP 2030	NPV
Scenario 1	1%	358	5%	1792	35%	9	20	45	8	€ 74.737
Scenario 2	1%	358	5%	1792	50%	6	14	32	6	€ 218.493
Scenario 3	1%	358	5%	1792	75%	4	9	21	5	€ 325.434
Scenario 4	2%	717	15%	5377	35%	18	49	136	9	-€ 44.776
Scenario 5	2%	717	15%	5377	50%	13	34	95	8	€ 397.942
Scenario 6	2%	717	15%	5377	75%	8	23	63	6	€ 726.465
Scenario 7	3%	1075	30%	10755	35%	27	85	271	10	-€ 391.930
Scenario 8	3%	1075	30%	10755	50%	19	60	190	9	€ 500.763
Scenario 9	3%	1075	30%	10755	75%	13	40	127	8	€ 1.178.355

Tab. 13 Summary table -base line condition - 2.5% of economic margin

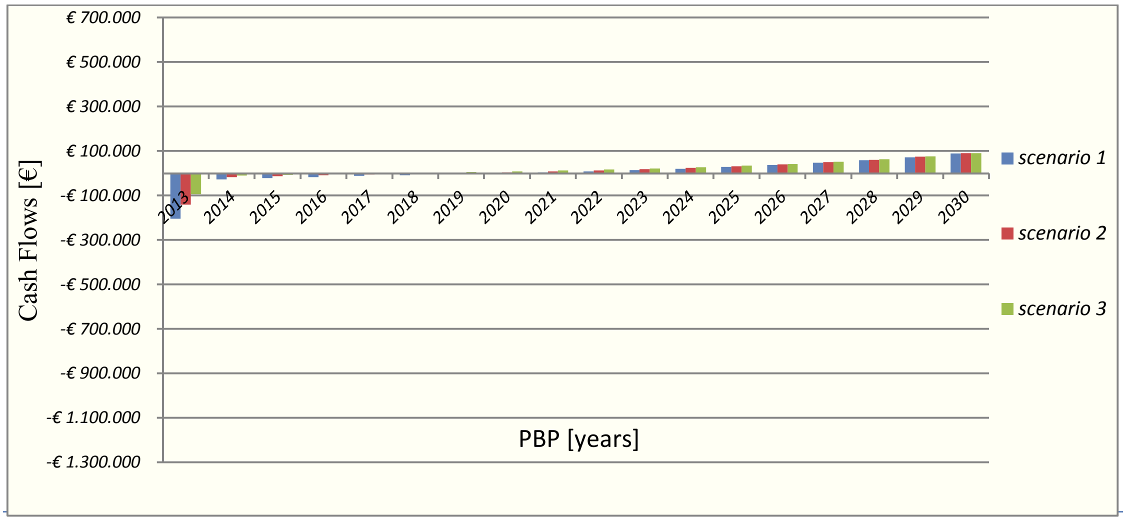


Fig. 8Cash flows Scenario 1-2-3

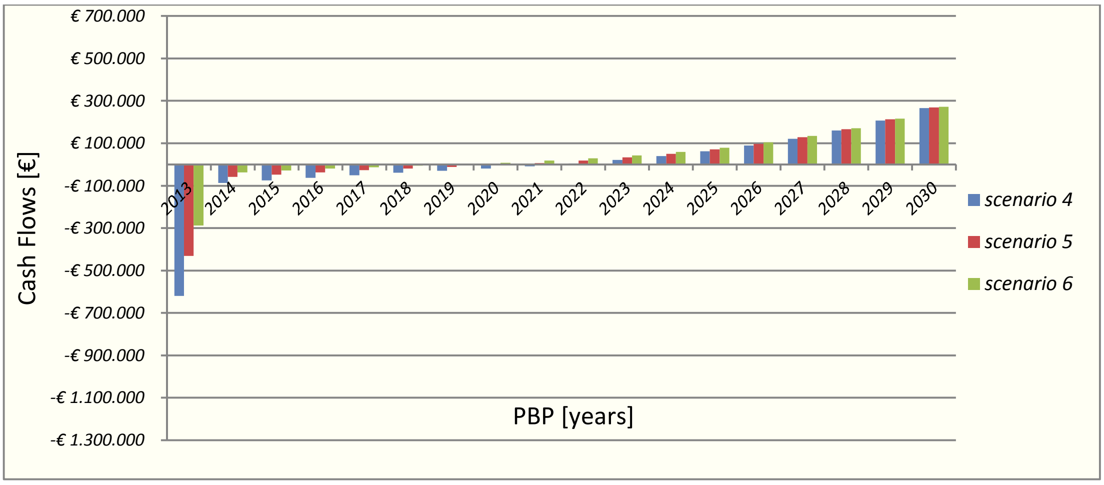


Fig.9Cash flows Scenario 4-5-6

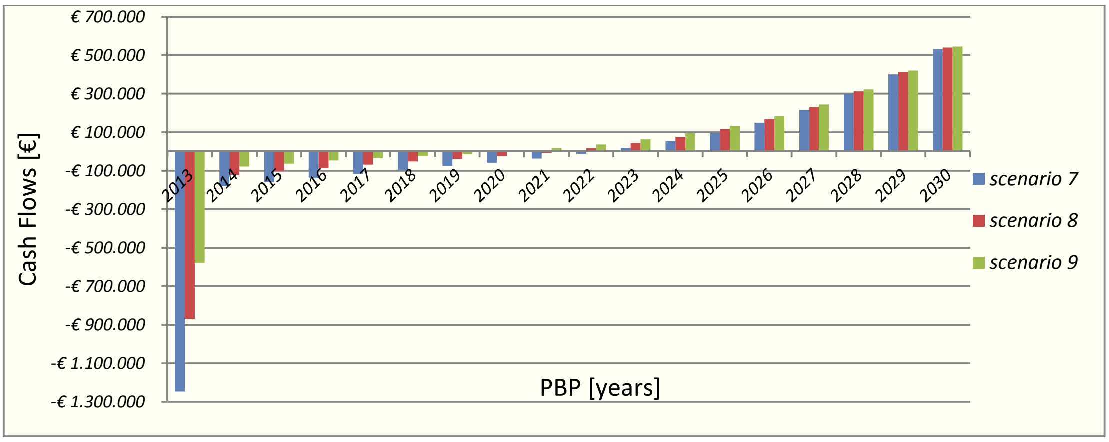


Fig. 10Cash flows Scenario 7-8-9

4.8.4 Preliminary analysis on the impact on the electric grids

In this paragraph, we provide some figures about the burden connected to electric mobility infrastructure on the local electric grid. In particular, Figure 11 shows the increase of energy consumption linked to electric vehicles, while Figure 12 shows installing trend of charging stations and the subsequent increase in electrical power demand.

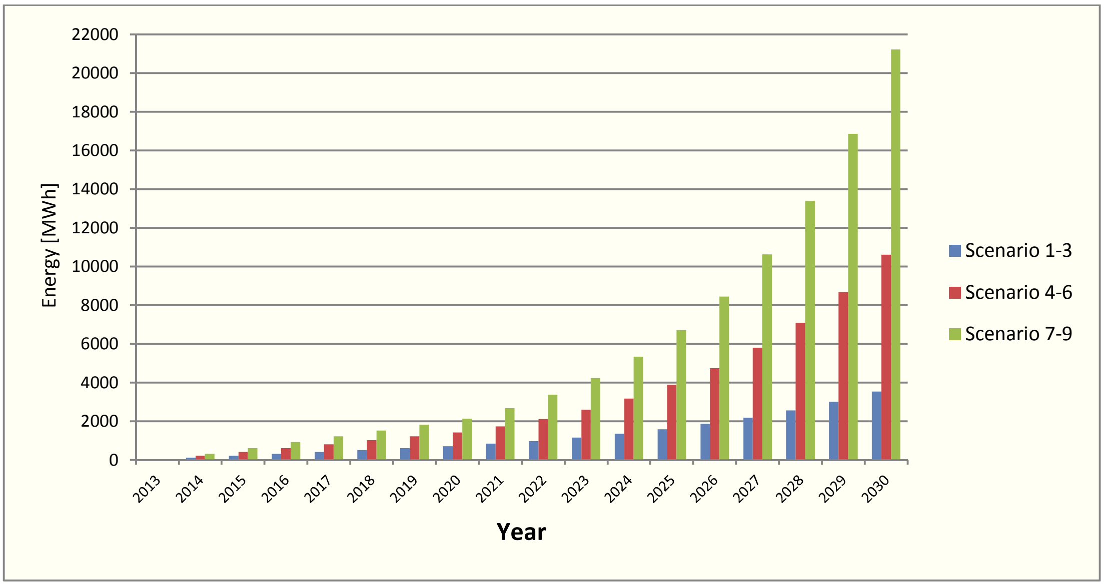


Fig. 11Energy consumption trend between 2013 and 2030 due to EVs

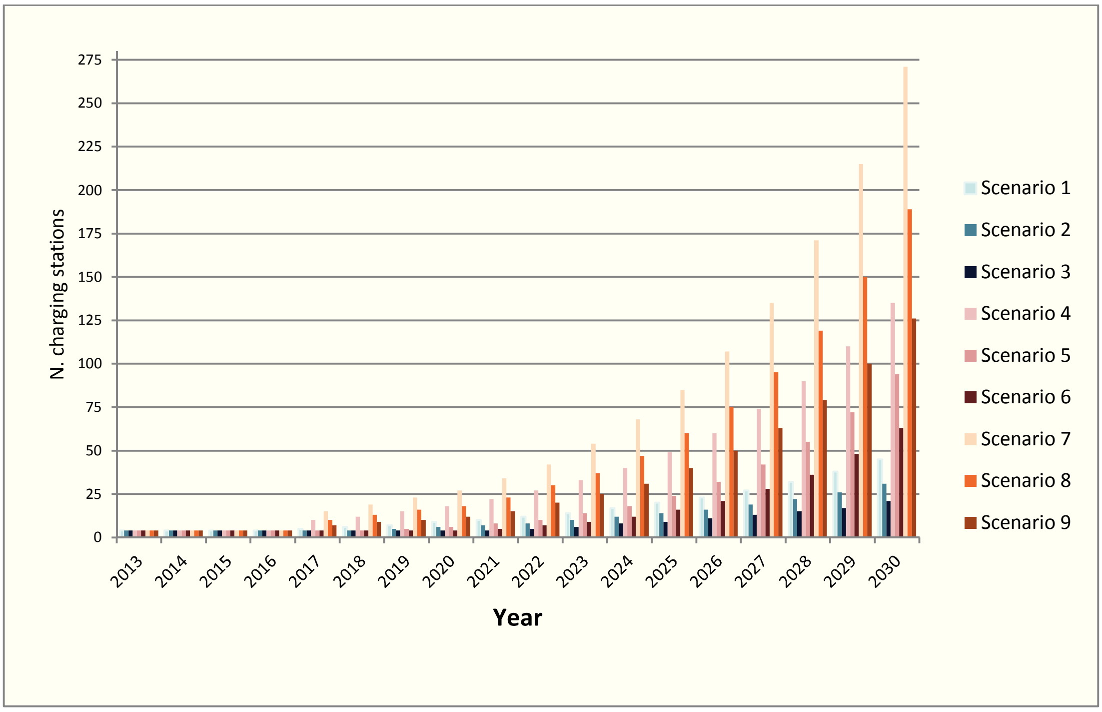


Fig. 12Number of recharging stations

4.9. Comments and further steps

The present study has resulted in the installation of recharging infrastructures for electric vehicles. Indeed, payback period was approximately consistent with other investments in energy infrastructure. Being carried out by a local utility, the project may be ambitious, even because it is subject to external constraints not easily predictable, such as the evolution of electric vehicle market and the cost of commodities (fuel and electricity). Nevertheless, the strength of the project lies in its flexibility ,the opportunity to develop the plan gradually from an infrastructural and an economic point of view. The first step, which has been already achieved, consisted in the installation of three charging points, together with the substitution of two diesel cars (out of 30 vehicles of the entire ASTEA fleet) with two electric ones. This initial infrastructure started its monitoring in 2014 in order to verify, and if needed to revise, the present study. It is important to point out that the methodology presented in this study can be easily adapted to other towns/cities, not only in Italy. Last but not least, we will take in consideration the opportunity of accessing national or European funding programs that are fundamental for the return of the investment. As aforementioned, there are a lot of variables and high costs to consider if someone wants to invest in recharging infrastructures for electric vehicles. Therefore, some incentives would ease the final choice of utilities and municipalities. Furthermore, as it has already occurred in the photovoltaic market, subsidies could have a twofold result— on the one hand, they would work as demonstrative models to which other utilities and municipalities hark back; on the other hand, they could boost the recharging infrastructure market and consequently reduce the capital costs due to economy of scale. Finally, it must be remarked that the installation of recharging infrastructures for electric vehicles has implications for the reputation of the utilities and municipalities involved, which play, in this way, an exemplary role spreading good practices at local scale.

4.10. Conclusions

The present study presents the economic analysis carried out by the local utility (Astea Group) in collaboration with "Università Politecnica delle Marche" and presented to local municipalities involved (Osimo and Recanati, Marche Region, Italy) in order to start an operation that will lead to the installation of several charging station starting from 2014. The first phase of the operation covered the period 2014-15: it involved a limited number of electric vehicles and charging stations and it consisted in building infrastructures, starting operation of recharge services, analyzing data and finally carrying out a technical-economic validation of results. The validity of the project relies in the opportunity of proceeding gradually from both an infrastructural and economic point of view. The study showed beneficial results related to the installation of a recharging infrastructure for electric vehicles since and payback period was more or less aligned with traditional energy investment (4-10 years). The opportunity of accessing funding programs (national or European) will be important to reduce the risk of the investment subject to external constraints not easily predictable (evolution of electric vehicle market and cost of commodities). The presence of subsidies is important both for the spread of demonstrative cases and for the kickoff of economies of scale, which would lead to a reduction of capital cost of recharging infrastructure for electric vehicles In the end, even utilities may obtain advantages from the realization of similar projects since, becoming exemplary models, their images will be positively affected.

Chapter 5.

5.New running strategies of a DH Power Plant in southern Europe

5.1. Research purpose

A District heating scheme (DH) comprises a network of insulated pipes used to deliver heat from generation site directly to end users to satisfy their space heating and domestic hot water demand. Heat networks can be coupled both with centralized generation plants or distributed generation units. A wide range of production technologies (boilers, cogeneration plants, heat pumps....) and energy sources (fossil fuels, renewable energies, waste heat...) can be adopted. Since these systems were first introduced in the US in 1880s, the technologies involved drastically changed and mainly the carrier fluid temperature was reduced from steam (first generation of DH) to low temperature water (30-70°C). The 4th generation district heating, meant to play an important role in the implementation of future sustainable energy systems [75-76]. The European Commission (EC) mentions them as an instrument for achieving the EU2020 objectives [77]: smart heating and cooling grids together with smart electricity grids will be part of the future Smart Cities, where thermal energy, electricity, gas and transport sector will be integrated and optimized. In particular, the EC requires each European Country to carry out an evaluation of the national potential of cogeneration (CHP) and district heating and cooling by December 2015. Indeed, according to the Energy Efficiency Directive, CHP and district heating and cooling (CHP-DH) have significant potential for primary energy saving (PES), which is largely untapped in the Union [78].

Main advantages of DH can be summarized as: reduced costs for end users, reduction of fuel consumption and increased environmental quality, flexibility in choosing heat sources, enhanced community energy management,. On the other hand, the drawbacks are represented by the initial capital investment for building the network as well as the difficulty in finding a right site for generation units placed close to end users [79].

Considering the challenges to be faced in new networks or to adapt the existing ones to the requirements of the latest concept of district heating (4th generation), main issues to be addressed are then: a better valorization of local resources and their more efficient use, renewable integration, transition to low temperature networks as well as to low temperature energy demand by final users, inclusion of thermal storages [80-82]. Moreover it is necessary to develop intelligent systems using smart metering and control solutions for an optimized management of the network and its possible multiple energy sources. All these aspects are part of the technical research priorities [83] for district heating and cooling sector.

In literature, several authors dealt with the economic and operational optimization of district heating systems. Among them, Jie et al. [84] presented a model to assess the best operational strategy of a DH by minimizing the pumping and heat loss costs. Similarly Pirouti et al. [85] showed how to minimize annual total energy consumption and costs for a United Kingdom DH. Dalla Rosa et al. [86], instead, discussed a way for the optimization of the network decreasing the heat loss by reducing the carrier fluid temperature and including renewable energies and waste heat as energy sources. Somcharoenwattana et al. [87] analyzed the operational improvement of DHs in Thailand by means of thermal storage, considering on peak and off peak periods, while Gopalakrishnan and Kosanovic [88] did an economic optimization of an existing combined cycle district heating in Northeast US to provide the best daily operational structure.

Purpose of this thesis is also to analyze possible technical developments of a CHP-district heating located in the Mediterranean area by means of a case study: main criticalities are highlighted and possible solutions for an optimized operation are proposed. Some useful indications for CHP-DH design and operation are drawn through the analysis of the real plant under consideration.

The thesis is organized as follows: after the Introduction, section 2 describes the main features of the CHP-DH system and presents its existing criticalities, highlighted during the operation of the real plant; section 3 discusses the possible solutions proposed to solve the criticalities and results obtained from the evaluations performed; conclusions are reported in section 4.

5.2. Methods

The approach performed in this thesis aims to define technical and operational improvements of a district heating coupled with a combined heat and power (CHP) unit. The CHP-DH-system examined refers to an existing installation located in a mild weather area in central Italy. By doing reference on recorded data from the operation of this sample case, criticalities are considered in order to define possible solutions and assess their feasibility. In particular the introduction of an internal combustion engine, a heat pump or a storage tank in the existing CHP-DH-system are taken into account.

Energy comparison of the existing configuration of the plant with all the different configurations are performed by calculating the key performance indicator, primary energy savings (PES), for each management mode:

$$PES = \left(1 - \frac{1}{\frac{CHPH_\eta}{RefH_\eta} + \frac{CHPE_\eta}{RefE_\eta}}\right) \cdot 100\% \qquad (1)$$

The PES is calculated considering electric efficiency ($CHPE_\eta$) and the thermal efficiency ($CHPH_\eta$) of the CHP unit (based on the recorded values of monthly thermal and electric production), compared with the reference thermal efficiency ($RefH_\eta$) and electric efficiency ($RefE_\eta$) in case of separate production, that are respectively 90% and

53% [93].In particular, the thermal efficiency of the CHP plant is calculated as the ratio of the CHP thermal energy production and the CHP fuel consumption; the electric efficiency as the ratio of the CHP electricity production and the CHP fuel consumption. Whereas the total efficiency of the CHP plant is given by the summation of the thermal energy and electricity production divided by the total fuel consumption.
Moreover the exergetic efficiency (ε_{ex}) of each configuration is evaluated:

$$\varepsilon_{ex} = \frac{Q_{th} \cdot \left(1 - \frac{T_{amb}}{T_{DH}}\right) + L}{LHV_{fuel}} \quad (2)$$

Where Q_{th} is the thermal energy production, supplied to the district heating at T_{DH} (assumed at 80°C, as explained later), and L is the electricity production. LHV_{fuel} is the lower heating value of the fuel used (in this case 9.4 kWh for $m^3$of natural gas). The ambient temperature T_{amb} is assumed equal to 25°C.

Finally the CO_2 emissions are calculated multiplying the primary energy content of the fuel by the factor 202.16 g CO_{eq}/kWh of natural gas obtained from IPCC reference values for natural gas combustion [89]. Regarding the economic evaluation, the net present value is assessed (NPV) by means of:

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0 (3)$$

where C_t represents the net cash inflow during the operation time analysed, C_0 the initial investment, r is the discount rate and t is the number of time periods. Main parameters adopted in the analysis are: electricity price 50 €/MWh, thermal energy price 105 €/MWh, natural gas price 0.33 €/sm^3.

5.2.1 Description of the CHP gas turbine

The Cheng Cycle consists of an Allison 501-KH gas turbine in combination with a heat recovery steam generator (HRSG) that is closely matched to assure high cycle efficiency. Steam from the HRSG is injected into the gas turbine combustion region to increase the power output of the basic engine (figure 13) .

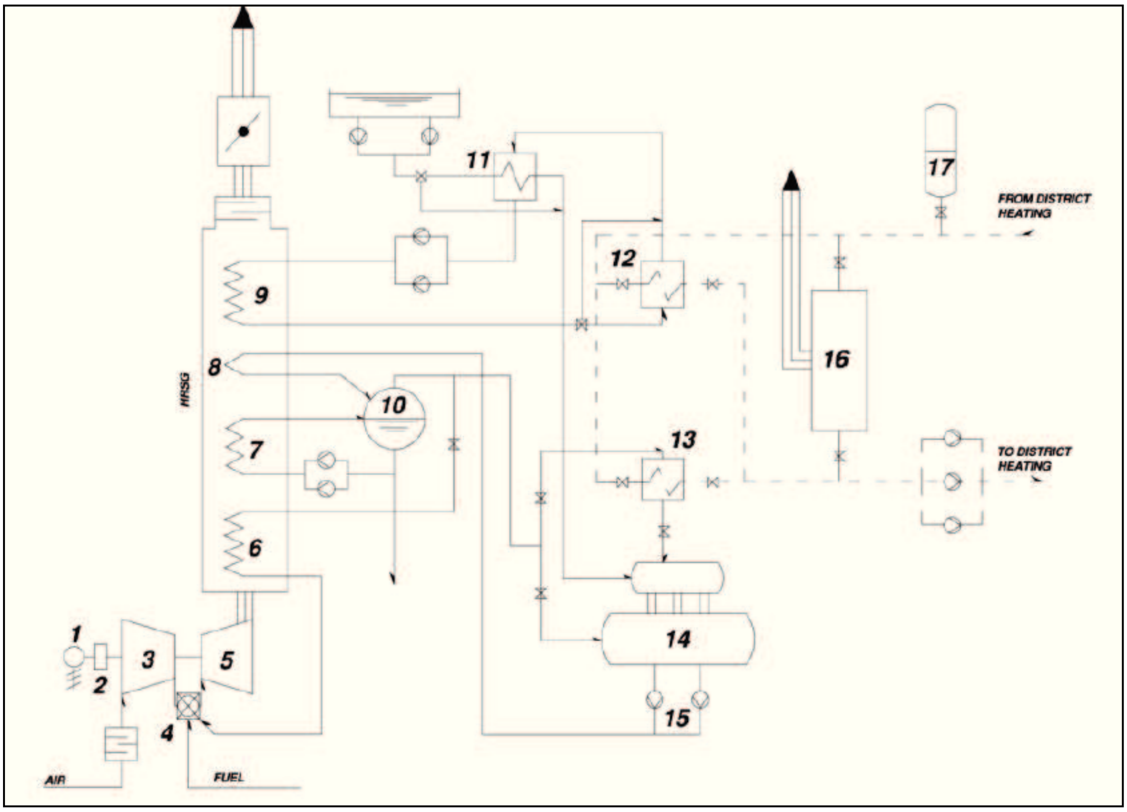


Fig. 13 CHP plant schematic: 1. Alternator; 2. Reduction gear; 3. Compressor; 4. Combustor; 5.Turbine; 6. Superheater; 7. Boiler bank; 8. Economizer; 9. Final recuperator; 10. Steam drum; 11.Demineralised water plate pre-heater; 12. DH plate exchanger; 13. DH condensing exchanger; 14.De-aerator; 15. Boiler feed pumps; 16. Boiler; 17. Expansion tank.

The KH version of the 501 engine incorporates modifications by Allison specifically for operation on the Cheng cycle. The HRSG unit consists of:

- A superheater located immediately downstream of the turbine exhaust diffuser section, to raise the temperature of the injection steam to as high a value as possible before injection. This temperature elevation reduces the amount of additional fuel that needs to be supplied to the gas turbine to raise the temperature of the steam to turbine inlet temperature, and thus enhances the engine heat rate.
- a combustor, located immediately downstream of the superheater, followed by a combustion duct section. This secondary combustion provides for the production of additional steam either for increased power generation or for process, depending upon the desired operating condition.
- a boiler bank designed to improve steam capacity;
- an economizer located upstream of the boiler bank;
- a final recuperator for the pre- heating of feeding water.

The plant is an indoor installation located in a building properly created. The fuel is natural gas, which is supplied by the utility at a pressure of 24 bar. A gas valve regulates the pressure to 17,5 bar required to supply the gas turbine. Engine air is drawn through ducting into a plenum within the gas turbine-generator set enclosure. A self-cleaning filter through which the engine air is drawn is located in this areaway. Cooling air for the generator, gearbox and gas turbine is drawn into the enclosure through a silencer/filter on top of the enclosure, circulated separately through the generator and through the remainder of the enclosure and exhausted through one duct extending through the roof. While the gas turbine generator set and the HRSG were designed to keep the external noise levels to within acceptable values, the plant control room is soundproofed and air conditioned. Interconnecting power and instrumentation wiring from the generator set, the HRSG and auxiliary equipment is run in trays under the operating floor, leaving a relatively free and uncluttered area around the unit. Steam is generated by the HRSG at a drum pressure of 15 bar. This pressure is dictated by the need to provide steam for injection into the gas turbine at a pressure of approximately13,5 bar allowing for pressure drops through the line, flow control valve and the superheater. Existing fired boilers will be used to provide heat during periods when the cogeneration plant is down or during winter time when heat demand exceeds gas turbine heat capacity. Electrical power is generated at 6 KV, the voltage of the main electrical bus, and the generator is tied through a protective breaker directly to the bus. Electrical energy is supplied to serve the needs of the auxiliary equipments installed inside the plant, and excess is exported to the local utility grid. If the power plant electric demand exceeds the output of the cogeneration plant, the shortfall can be imported from the utility grid. In case the utility grid is down, the cogeneration plant can supply the town of Osimo as an isolated grid.

5.2.2Control and instrumentation

The overall automation is composed by two main section:

- The first one covers the control functions for the gas turbine and generator set (named N90 PCU);
- The second one covers the control functions for the Heat Recovery Steam Generator/ the Balance of Plant & Auxiliaries and the District Heating (it is implemented by the ANSALDO ADAMS distributed control system).

These two automation system operate independently with the exception of a certain number of signals exchanged between them by dedicated wired connections.

The N90 PCU automation is used to perform different functions as:

- automatic plant start-up /shut-down sequencing;
- components and plant control and supervision;
- definition of load set-points and thermal/electrical loads partitioning;
- general control strategies;

- general turbine/generator protective signal generation;
- interfacing toward ANSALDO ADAMS automation system;
- interfacing toward the video/keyboard operator interface.

The plant start-up and shut down are accomplished with minimum operator action; all turbine starting sequence, through generator synchronization are pre-programmed in the control logic.

The automation section covered byN90 PCU is mainly devoted to the turbogas/generator set control and supervision; also it is devoted to a limited number of functions as:

- Steam drum pressure;
- Injection steam flow;
- Injection steam block valve position switch (open/close);
- Injection steam line and superheater drain valves position switch (open/close);
- Injection steam flow control valve output;
- Injection steam block valve output;
- Injection steam line and superheater drain valves position output;

The automation section covered by ANSALDO ADAMS refers to HRSG, Balance of Plant, Auxiliaries, District Heating, Electrical Power Distribution and is structured in electric cabinets and in a dedicated control desk allocated near the N90 operator interface unit (in the control room).

The ANSALDO ADAMS operator interface desk is structured in a conventional way using dedicated automatic/manual stations, pushbuttons, indicators and recorders.

5.2.3Operating Condition

From a cogeneration point of view the plant is, despite its simplicity, quite flexible, especially if supplementary firing is performed. Indeed, the electricity/heat ratio can

easily be changed by varying the quantity of steam injected into the turbine. Moreover, the plant includes two conventional boilers (with both 4,3MW of thermal power) that provide thermal energy when demand exceeds the STIG plant capacity [90-92].
A performance chart of the whole plant is shown in Figure 14. Three different operation areas are distinguishable:

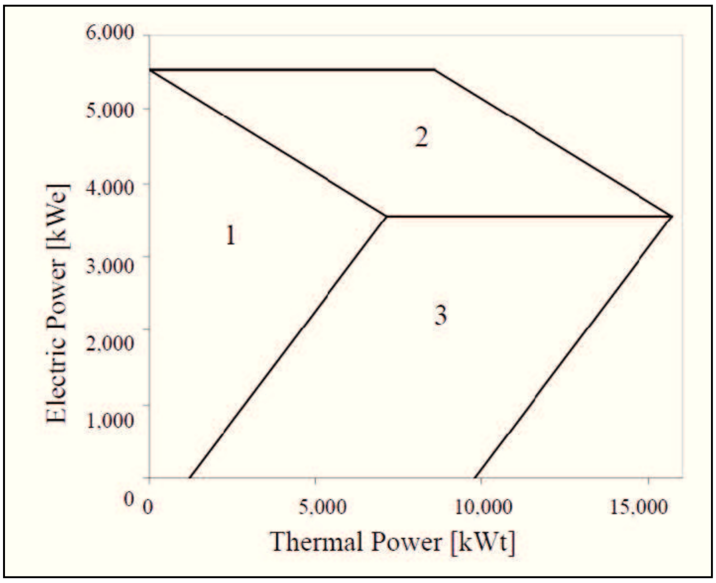
- area 1: only the turbogas is running and the electricity/heat ratio is modified by changing the amount of steam injected. The electric power output reaches a maximum of 5.5 MW_{el} and decreases down to 3.5 MW_{el} when a heating power output of 7.1 MW_{th} is required.
- areas 2: both the gas turbine and the auxiliary boilers are running; a part of the steam produced is injected into the turbine while the rest is used for district heating
- area 3: both the gas turbine and the auxiliary boilers are running, all the steam is used for district heating.
- 

Fig. 14Plant performance chart

Table 14 collects the monthly performance values of the plant. It is possible to see that the thermal load in autumn/winter season is much higher than the thermal power production of the CHP plant, thus the production from the additional boilers is necessary to satisfy totally the thermal demand. This means that, in autumn/winter season, the CHP can operate with the highest total efficiency since the waste thermal power output from the gas turbine can be completely recovered to supply the DH.In fact, during heating season (November-March), gas turbine electric efficiency ranges between 25.9% and 31.6%; all waste heat is usefully recovered in the DH plant as demonstrated by both the thermal efficiency (ranging between 22.0% and 40.8%) and total efficiency of the CHP plant (ranging between 53.6 and 66.7%). Boilers are operated to supply all the thermal energy when the CHP plant is off (7:00 pm to 8:00 am in the working days and during weekends) or to fill the gap between the thermal energy required by the DH load and the thermal energy provided by the gas turbine. Because of the commodities price framework, the gas turbine operates only during electricity tariff peak hours (8:00 am - 7:00 pm every working day) all over the year. On the contrary, in spring/summer season the thermal production of the gas turbine exceeds the thermal load, as a consequence the CHP plant operates with lower total efficiency since, having electric energy production from gas turbine priority on thermal energy output, the latter is partly wasted in the environment.

Month		1	2	3	4	5	6	7	8	9	10	11	12	Total/ Average
DH load	MWht	3,438	3,941	1,966	1,488	940	707	608	544	708	946	1,818	3,408	20,512
CHP electricity production	MWhe	1,066	940	1,205	1,261	1,363	969	689	393	1,146	1,398	1,148	969	12,547
CHP Thermal energy production	MWht	1,521	1479	838	654	391	226	143	79	260	434	797	1384	8,207
CHP fuel consumption	x 1000 m^3	424	386	405	405	411	288	203	116	340	424	386	386	4,171
CHP Electric efficiency	%	26.7	25.9	31.6	33.1	35.3	35.8	36.1	36.1	35.9	35.0	31.6	26.7	32.0

CHP Thermal efficiency	%	38.1	40.8	22.0	17.2	10.1	8.4	7.5	7.2	8.1	10.9	22.0	38.2	20.9
CHP Total efficiency	%	64.8	66.7	53.6	50.3	45.4	44.2	43.6	43.4	44.0	45.9	53.6	64.9	52.9
Boiler Thermal energy production	MWht	1,917	2,462	1,128	834	549	481	464	465	448	511	1,022	2,024	12,305
Boiler fuel consumption	x 1000 m^3	222	286	131	97	64	56	54	54	52	59	119	235	1,428

Tab. 14 Monthly performance values of the CHP plant (reference year: 2013)

5.2.4District heating network

The district heating network (DHN) examined is located in Osimo, in Central Italy. The DHN consists of polyurethane insulated pipes, provided with an external mechanic protection in polyethylene. The users connected to the grid are 1,265:75 public or commercial customers, 1,189 residential buildings (Figure 15).

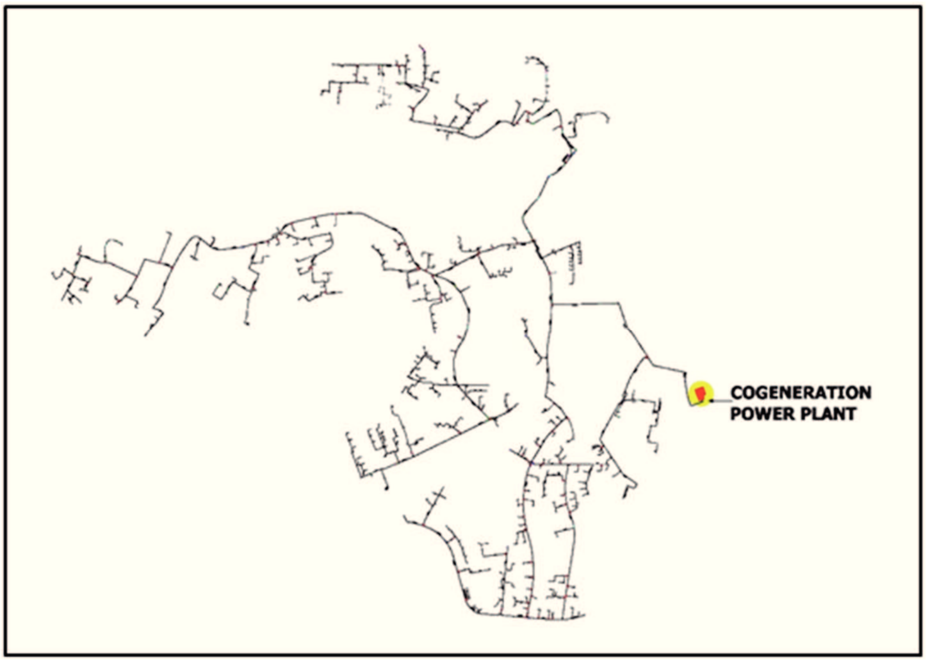


Fig.15District heating network map.

About 53% of the total thermal energy demand comes from the residential buildings, while 47% is used by the public/commercial customers. Figure 16 reports the thermal load duration curve of the district heating plant showing that, on the one hand, the maximum thermal power provided by the gas turbine is not sufficient to cover DH thermal peak loads and, on the other hand, that for almost half of the time, the thermal power load is less than 2 MWth, the minimum value being about 350kWt.

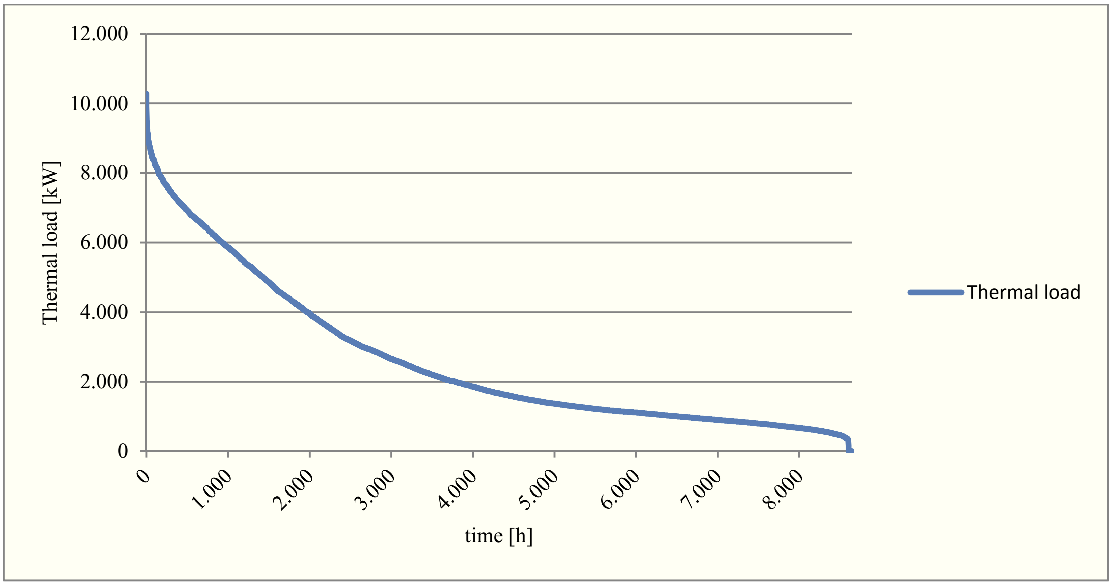


Fig. 16DH thermal load duration curve

In Fig. 17 the typical trend of the daily heat demand in different seasons is shown. It is evident the significant reduction it goes through in summer, but also in spring for the mild weather of the installation site. In particular, Figure 17 confirms that the annual baseload thermal power of the DH plant is in the range between 500-1,000 kWth, mainly used to provide thermal energy for sanitary hot water production in summer. In this case, the efficiency of the CHP-DH is very poor. Indeed, if the CHP plant follows the thermal demand, thus recovering all the waste heat, it will work at very high partial load with detriment of electric efficiency; if the CHP plant works with good electric efficiency, then the wasted heat will be very high.

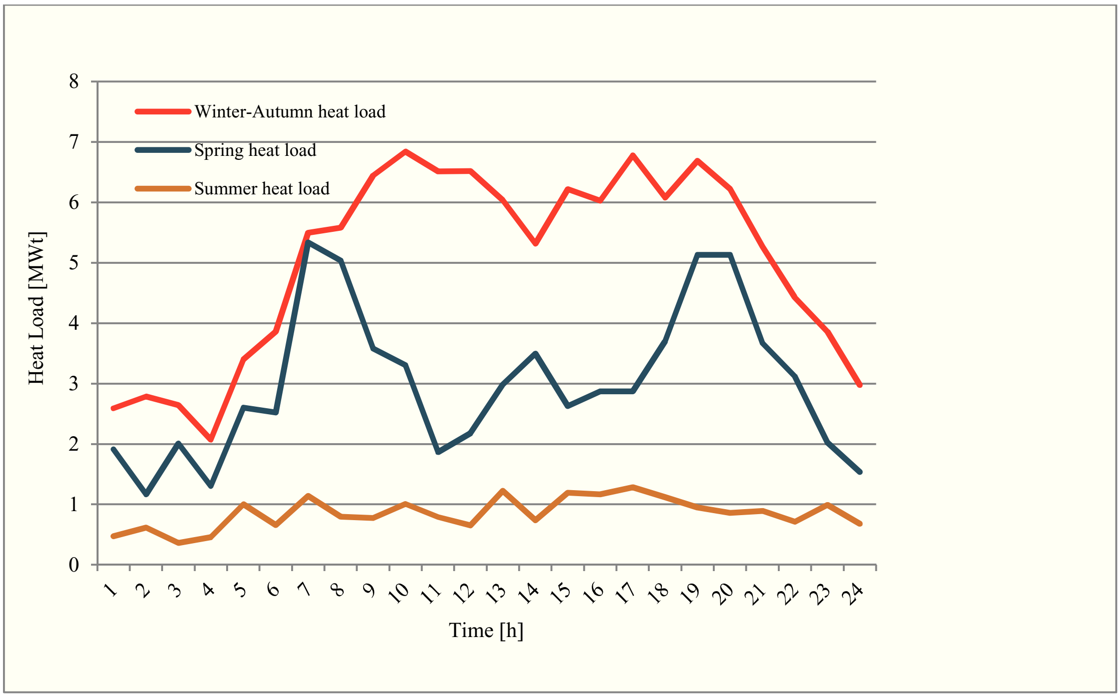


Fig. 17Trend of average daily heat demand with varying the season.

The carrier fluid is pressurised hot water (at 16 bar) and, at present, the supply temperature is below 100°C, but it changed since the plant was firstly operated. In fact at the beginning the inlet water was provided at 105-110°C, then the end users needs were carefully assessed by the plant operator and, starting from 2009, a step-by-step decreasing inlet water temperature was supplied, in order to reduce heat losses along the network, maintaining the customers thermal comfort. In Figure 18 the monthly average temperature of the supply water during the period 2008-2013 is shown. In 2008 the previous management with high supply temperature is still in action, while in 2013 it is evident a temperature reduction, below 100°C in winter and below 80°C in summer, when a further temperature reduction is possible thanks to the warmer ambient and ground temperature.

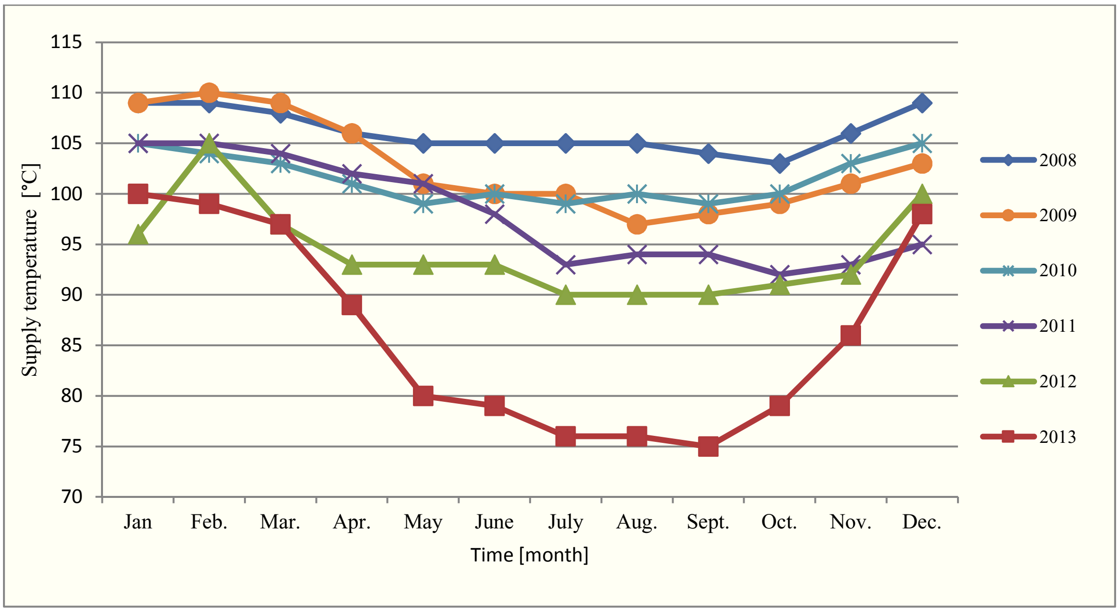


Fig. 18 DHN water supply temperature trend for the period 2008-2013.

In Table 15 the annual heat losses along the network for the different supply water temperature trend are reported, together with the incidence of the heat losses on the total heat produced and with the yearly average temperature (between the inlet and outlet temperature to the DH) weighted on the monthly heat production. From these figures, the benefit produced by the action of reducing the supply temperature is evident.

Year	2008	2009	2010	2011	2012	2013
Heat losses [MWh]	6,975	6,953	6,643	6,255	6,040	5,598
Incidence of heat losses %	34.36	34.25	32.72	30.81	29.75	27.58
Yearly weighted average temperature [°C]	87.3	86.6	83.9	80.6	78.7	76.5

Tab. 15 Network thermal losses during the period 2008-2013.

For completeness, such thermal losses depends on: losses along pipes of the network and for losses in users substations, where plate heat exchangers (PHE) are installed. Regarding the calculation of the annual network heat losses, they are obtained as summation of the monthly network heat losses Qloss,m and are assessed as follows (UNI EN ISO 12241:2009 standard [93]):

$$Q_{loss,m} = t_{net,m} \cdot (\theta_{net,m} - \theta_{ground,m}) \cdot \sum_j \cdot \left(\frac{l_j}{(R_{net,j} + R_{ground,j})} \right) \quad (1)$$

where $t_{net,m}$ is the monthly operation time of the district heating network, $\theta_{net,m}$ is the monthly average supply temperature, $\theta_{ground,m}$ is the average temperature of the ground, l_j is the length of the pipe j, $R_{net,j}$ is the linear thermal resistance of the pipe j, $R_{ground,j}$ is the linear thermal resistance of the ground. The thermal resistance of a buried pipe instead is based also on the UNI EN ISO 12241: 2009 :

$$R_{net,j} = \frac{1}{2\pi} \cdot \sum_{j=1}^{n} \frac{1}{\lambda_j} \ln \cdot \frac{D_{e,j}}{D_{i,j}} \quad (2)$$

where λ_j is the thermal conductivity of the pipe j, $D_{e,j}$ is the external diameter of the pipe j and $D_{i,j}$ is the internal diameter of the pipe j. The thermal resistance of the ground is:

$$R_{ground,j} = \frac{1}{2\pi\lambda_g} \cdot ln \frac{4\, H_{g,j}}{D_{i,j}} \quad (3)$$

where λ_g is the thermal conductivity of the ground, H_g is the distance between the centre of the pipe j with the ground surface and D_i is the internal diameter of the pipe j. As far as the plate heat exchangers are concerned, they were annually accounted for by summation of the monthly contributions, assessed by means of the following equation:

$$Q_{lossPHE,m} = t_{net,m} \cdot \sum_{h=1}^{n} K_h \cdot A_h \cdot (\theta_{PHE,m,h} - \theta_{env,m}) \quad (4)$$

where $t_{net,m}$ is the monthly operation time of the district heating network, K_h is the overall heat transfer coefficient,A_h is the transfer area between PHE and environment,

$\theta_{PHE,m,h}$ is the monthly average temperature of the PHE$_h$and$\theta_{env,m}$ is the monthly average temperature of the environment surrounding the PHE$_h$.

5.2.5 Criticalities of the existing plant and solutions proposed

By doing reference on the 22 years of operation of the considered plant, some critical aspects in its management and design were put into evidence and they are summarized as follows:

- Reduced marginal profit: this is mainly due to the high ratio between the natural gas purchase price (used to fuel the gas turbine and the auxiliary boilers) and the electricity selling price. This dramatic change in prices mostly originates in the increase of the electricity produced by PV power plants, that caused a reduction of the electricity selling price. Thus it is of paramount importance to employ highly efficient cogeneration systems, properly sized on the basis of users thermal and electric demand.
- over-sizing of the gas turbine of the CHP unit: the turbine needs to work at partial load with low energy performance for a long period of time during a year. This is essentially due to the reduced thermal load necessary in spring and summer related to the mild weather in the site of the plant,
- low users density along the network: the considered network presents a wide extension and a few customers along every branch (see Figure 4). This aspect causes an increase in pipes thermal losses.

As regards the latter point is concerned, the strategy of reducing the supply water temperature has already been implemented to partially solve this issue. Regarding the other abovementioned aspects, some possible modifications of the existing plant configuration were analysed, aimed in particular at increasing the system efficiency and managing the variable heat demand during the year in order to make the operation of the plant profitable:

- installation of a new cogeneration gas engine so as to improve the power plant performance in terms of primary energy savings (PES);
- utilization of waste heat from gas turbine by means of a heat pump to increase the energy recovery;
- integration of a thermal energy storage to implement load shifting strategies for the system operation optimization.

5.3. Results and discussions

In the present paragraph the impact on the plant performance of the solutions previously mentioned is analysed. In the first part, the installation of a new cogeneration gas engine is considered (section 5.3.1). Then, as a further step, the utilization of waste heat from gas turbine by means of heat pumps is evaluated (section 5.3.2). Finally, the introduction of a thermal storage to increase the energy efficiency of the cogeneration unit is taken into account (section 5.3.3). In the following figure, the schematics of the different configurations are shown.

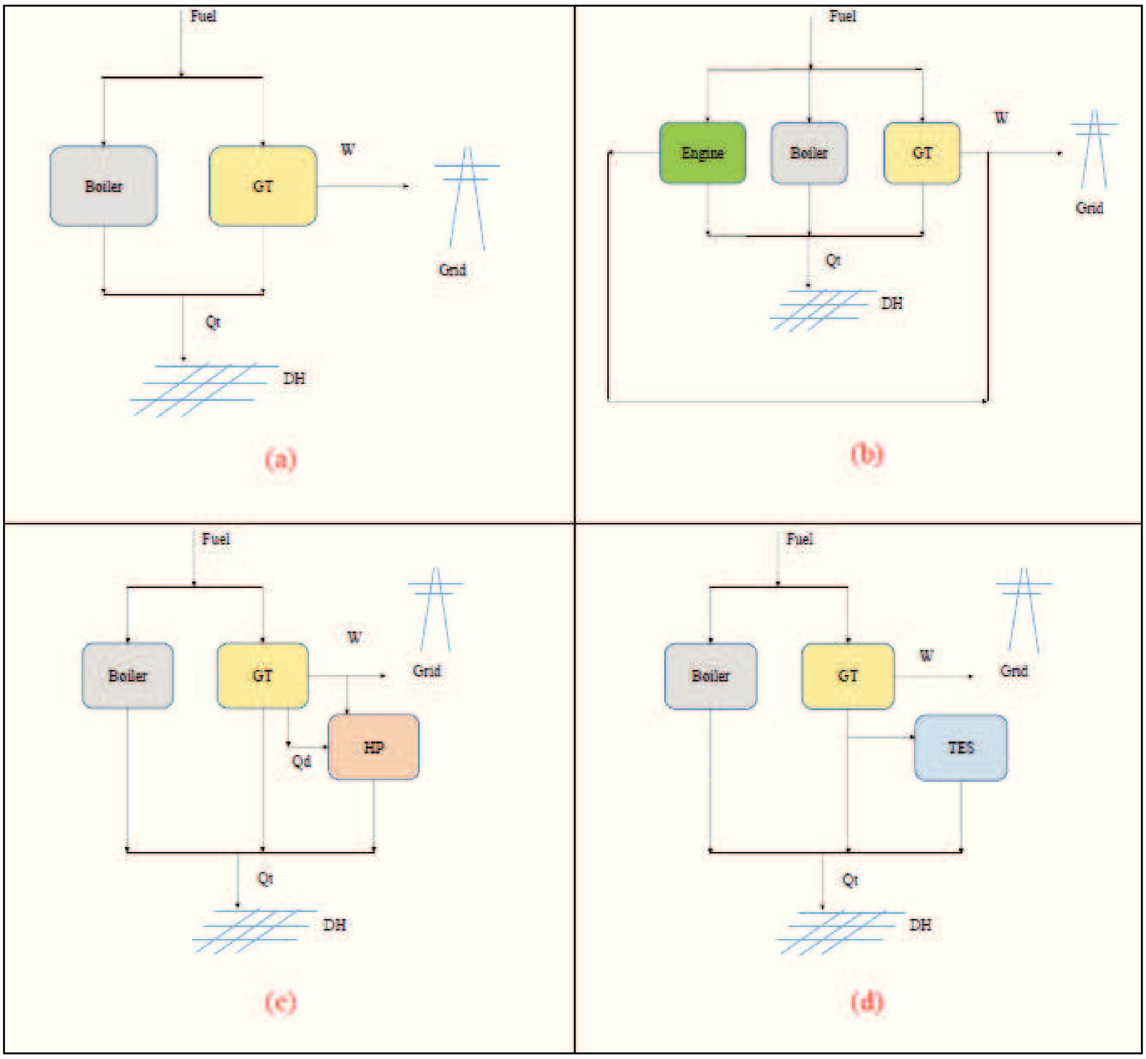


Fig. 19Schematics of the CHP-DH plant configurations:
a) present configuration with only gas turbine (GT) and boilers; b) configuration with the new cogeneration gas engine; c) configuration with the heat pump (HP); d) configuration with thermal energy storage (TES). Qt is the thermal energy provided to the district heating (DH), W is the electricity sold to the grid, Qd is the waste heat recovered by the heat pump.

5.3.1 Introduction of a new cogeneration gas engine

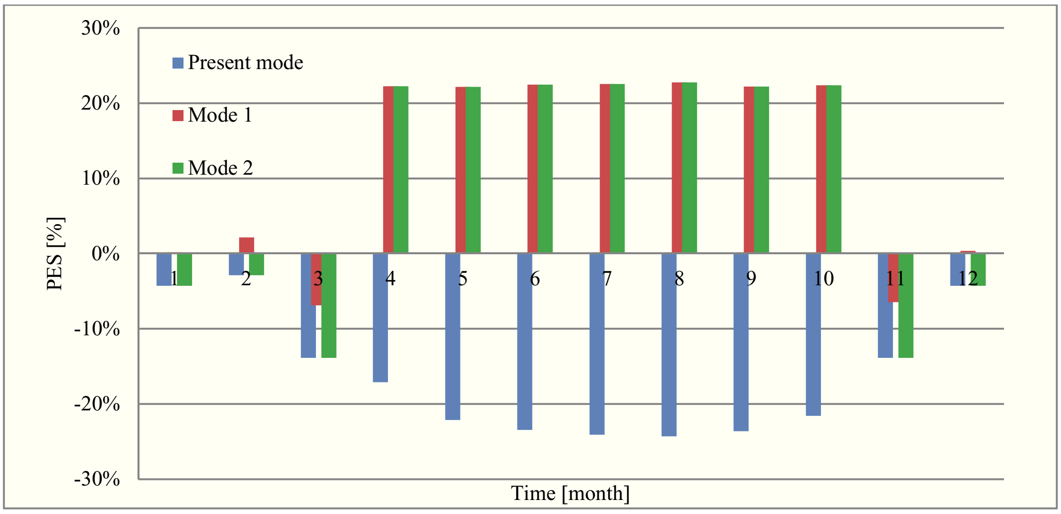
As previously described, the existing plant consists of a gas turbine, which is always on during peak electricity demand (from 08:00 a.m. to 07:00 p.m.) in summer and winter time. The thermal energy demand exceeding the gas turbine capacity is provided by auxiliary gas boilers. Such gas turbine was found to be over-sized for summer operation. Moreover, as it will be shown, its operation is no more competitive in the present market scenario. Thus the replacement of the existing gas turbine could be a valid option for improving the process performance. According to the considerations carried out in section 2.2, the revamping plan consists of a new cogeneration gas engine unit of 600 kWe power, designed to meet the base load heat requirement. Two different management strategies are considered for the new cogeneration engine:

- Mode 1: the gas engine is always on during the day both in summer and winter. Gas boilers are used to satisfy the extra thermal demand during the year, while the gas turbine is on only during winter time to cover the peak demand.
- Mode 2: the gas engine is on during the all day in summer and is switched off during winter. Gas boilers are used to satisfy the extra thermal demand during the year, while the gas turbine is on only during winter time to cover the peak demand.

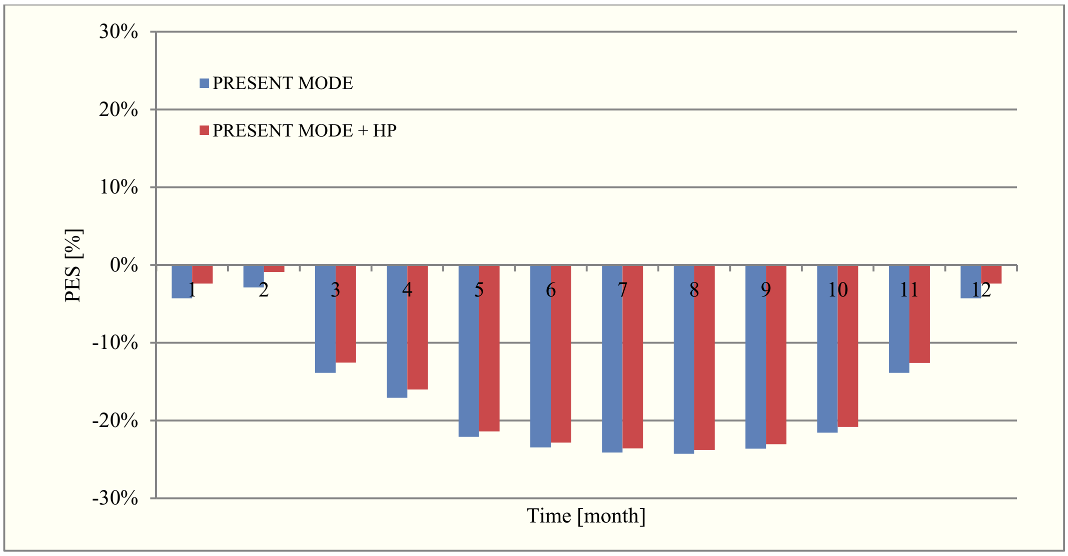
The following figures shows the monthly trend of PES for the existing plant and for the repowering in its two management strategies. First of all it is possible to notice that the existing configuration of the plant is not competitive with the separate production, this is mainly due to the increased reference electric efficiency, higher than the value in use when the plant was formerly built ($RefE_{\eta}$~40%). This highlights once more the need for a renovation of the CHP plant. On the contrary, the introduction of the gas engine as new cogeneration unit produces a reduction of the primary energy consumption, especially in summer time when the heat load is drastically reduced. This result is obtained thanks to a more proper sizing of the generator on the basis of the real thermal base load and also to the higher thermal and electric efficiency achieved. Moreover there is not a huge difference between the two management strategies considered (Mode 1 and Mode 2), even if operation Mode 1 is slightly better in winter season than Mode 2, as also demonstrated by the annual PES reported in Table 16 (reference year: 2012).

	Present mode	CHP Mode 1	CHP Mode 2	HP	TES
Average PES	-14.57%	4.06%	1.20%	-9.99%	-6.71%
Average electric efficiency	31.97%	32.10%	30.46%	33.30%	27.34%
Average thermal efficiency	20.91%	35.94%	36.16%	21.78%	35.04%
Average total efficiency	52.88%	68.03%	66.62%	55.08%	62.38%
Exergetic efficiency	29.91%	31.99%	28.59%	30.85%	28.99%
CO_2 emissions (10^3 t)	10.6	8.0	7.5	10.2	9.1
PBP (years)	-	6	14	4	10
NPV after 20 years (M€)	-	1.019	0.181	1.196	0.443

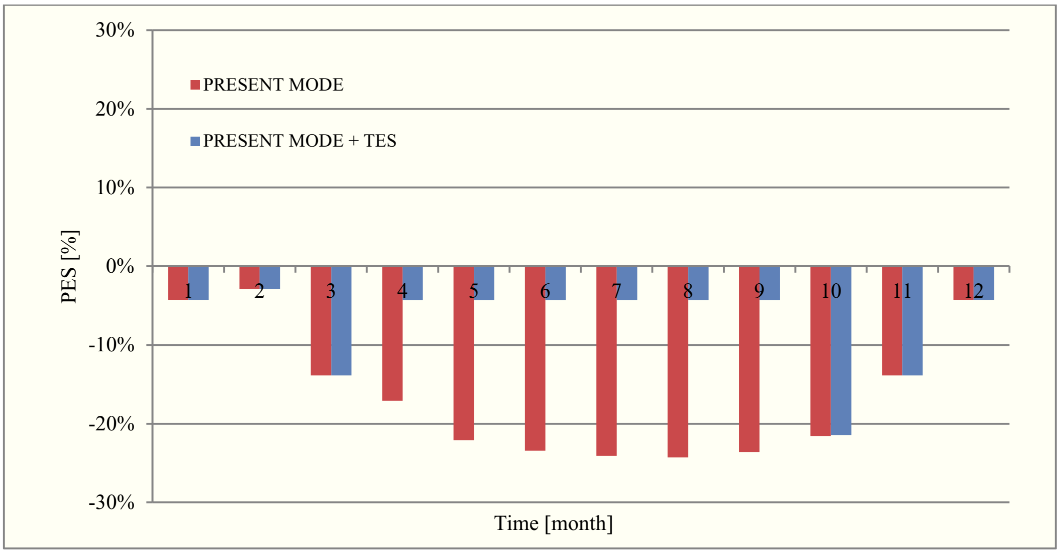
Tab. 16 Performance comparison for the different configuration analysed



(a)



(b)



(c)

Fig. 20Comparison of PES for the present scenario vs. the configurations with (a) CHP gas engine, (b) HP and (c) TES.

In order to complete the analysis for the introduction of the new cogeneration unit, also the economical aspect was taken into account. Figure 21 presents the net present value (NPV) for the investment in the two operative modes.
The main parameters adopted in the analysis are specified in section 5.2. In addition we have considered a maintenance cost of 2 c€/kWh. For Mode 1 and 2 a capital cost for the gas engine of 600,000 € plus an annual maintenance fee of 45,000 € were assumed. The NPV is positive both in Mode 1 and in Mode 2 at the end of the period (20 years), but only in Mode 1 it is possible to recover the investment in a reasonable time (6 years vs. 14 years) thanks to the more efficient management strategy.

5.3.2 Utilization of waste heat from gas turbine by means of heat pumps

In the present part the possibility of using a heat pump (HP) to recover the waste heat from the exhausted gases of the GT coming out from the HRSG, is considered. Similar solutions have already been studied and proposed in other works in order to offer improvements in terms of energy efficiency and permits the utilization of waste heat [95-96]. Actually this solution was first considered when the district heating was supplied with overheated water and not at low temperature, as modified recently. In that case the exhausted gas, with a temperature around 104-110°C, could not be directly used to warm the supply water to the network and the heat pump was necessary to lift up the temperature. At present this condition is no more existing (because the supply temperature to the DHN is in the range 75-80°C), but some benefits from installing the heat pump can still be achieved, especially from the economic point of view, as shown later on.
In Figure 22 a schematic of the working principle of the heat pump is shown: it recovers waste heat from exhausted gases (maximum sensible heat available is 630 kW) by means of an intermediate carrier fluid (R134a) at the evaporator side (working at about 30°C)

and release useful heat to the DHN at the condenser side (working at about 80°C). Considering the high compression ratio necessary for this operative conditions, a two stage heat pump is necessary to achievea good performance that, based on manufacturer data, can allow an average COP of about 3.3. The heat pump is driven by the electricity produced by the CHP system itself.

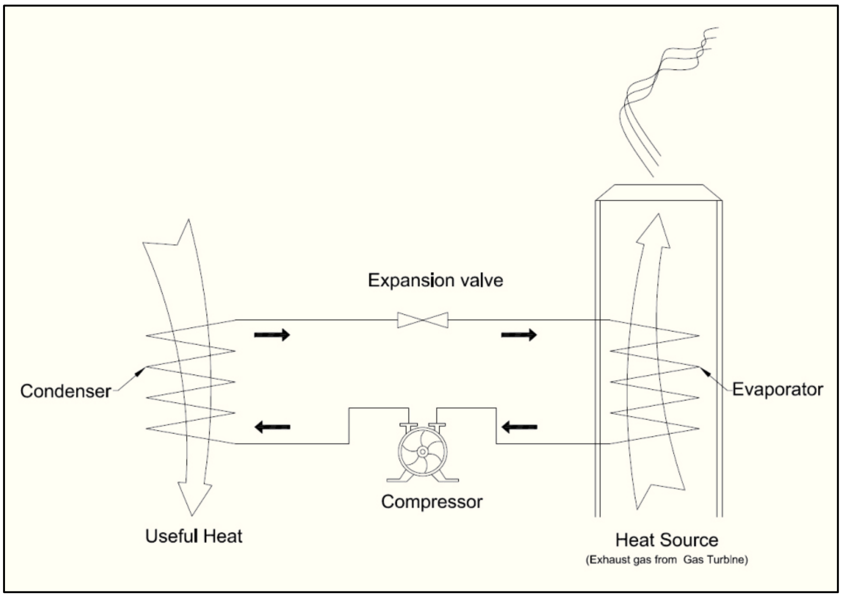


Fig. 211 Schematic of the working principle of the heat pump.

The use of the HP has two favourable consequences both from the energetic and the economic point of view. First of all it makes possible to recover more thermal energy without increasing the fuel consumption (boilers operate for a shorter time), thus an overall increase of the efficiency is achievable and primary energy savings are possible as demonstrated by a PES improvement (see tab.16)

From the economic point of view, instead, the heat pump makes it possible also to increase the profit. Indeed, it allows to transform electricity (otherwise sold in the Italian electric market at an average selling price of 50-60 €/MWh [97]) into heat (sold by the

DH-CHP plant operator at 170 €/MWh) as demonstrated by the NPV analysis performed for this case. It is assumed the GT is always on only during winter and summer. The maintenance cost for the heat pump is 1 €/MWh and the initial investment 350'000€ considering a size of avout 900 kWt. The interest rate is set to be 5% and the useful life of the system is 20 years. The results shown in Figure 21 highlight a payback period of 4 years and after 20 years the investment value is of about 1,196,000 €.

5.3.3 Improvement of the CHP plant by using Thermal Energy Storage

The introduction of a TES may increase the thermal efficiency and the economy of a cogeneration plant through a careful compensation between thermal production and consumption [98]. The main advantage derived from including a TES is related to the insufficient thermal load capacity of the gas turbine that at present asks the boilers to step in to satisfy the peak demand. Such peak-load boilers can be substituted by a TES, charged during low load time.

In this section the design procedure and the economical feasibility study for the introduction of a TES in the system under study are presented.

In order to assess the TES volume, first the duration curve for the thermal power produced by the boilers is drawn and the maximum energy produced at peak power is calculated (it was assessed at 342,531 kWh). A 10% of the maximum energy produced is considered for sizing the TES, in order to respect also the space constraints for its realization. Assuming an operating temperature difference of 30°C, a tank of 1,000 $m^3$is necessary. Such tank can be used to reduce the peak thermal production of boilers in winter and can provide thermal energy for 12/24 h in spring and summer, as shown in Figure 23 and 24.

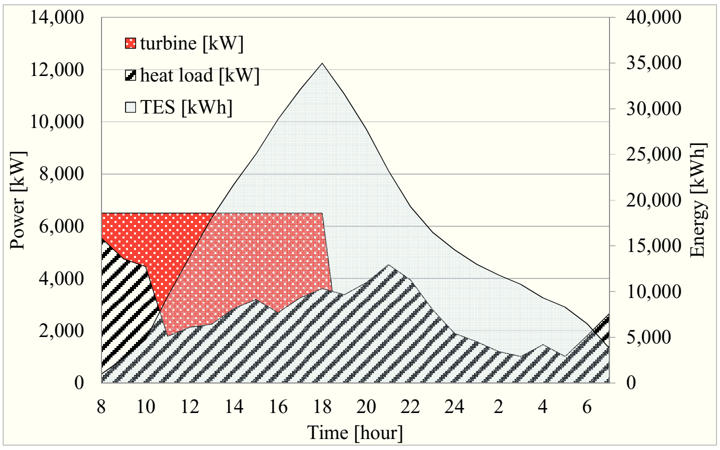


Fig. 222 TES energy management in a typical summer day

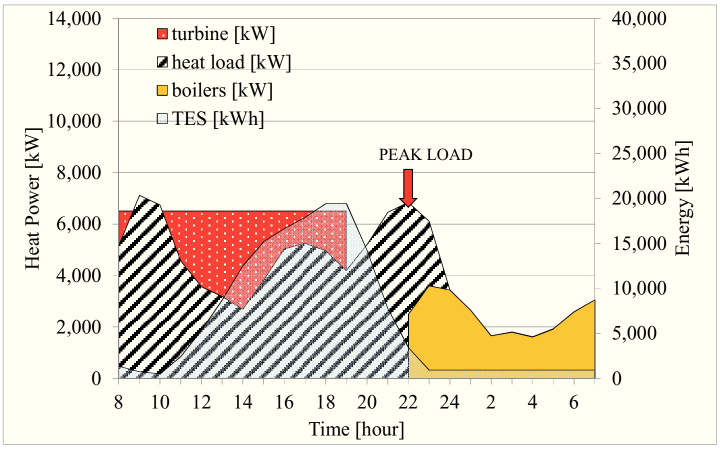


Fig. 233 TES energy management in a typical winter day

Figure 23 reports the energy management operated through the TES during a summer day. The storage allows to store the surplus of thermal energy produced by the turbine to be used when the turbine itself is off (during evening and nights when the price for electricity is lower). Figure 24, instead, shows the use of the thermal energy storage during a typical winter day. Again the turbine produces the heat demand requested and the surplus is stored in the TES. Then the TES energy is supplied to the thermal network in order to reduce thermal peak demand .The best period to use the TES is in spring and

summer, when the thermal demand is low and it is possible to have an extra thermal production to be stored in the tank for later use. Furthermore, thanks to the tank, the turbine can work at full load instead than at partial load, increasing its efficiency. This fact is clearly represented by the PES trend during the year (Figure 20).The possibility of shifting the thermal and electricity production in time could generate also an economic advantage when there is a considerable difference in the tariff structure of the electric energy [99].
Unfortunately for the present situation of the Italian energy market, the difference of the tariffs is very limited and this makes the introduction of the TES not really profitable, as shown by the NPV in Figure 21

5.3.4 Comparison of the solutions analysed

Table 16 reports the summary of the performance for each of the solutions proposed in the present part of this thesis. With respect to the present CHP-DH plant configuration, all the solutions proposed entail an improvement in terms of both total efficiency and primary energy saving. The best solution for profitability and energy performance enhancement is the existing CHP-DH plant coupled with a 600 kW_{el} CHP plant with internal combustion engine managed according to the strategy described as “Mode 1”. This solution achieves the highest PES and average total efficiency with a NPV of about 1 M€ after 20 years. A similar high NPV can be achieved improving the existing CHP-DH plant with a high temperature heat pump. This solution is very attractive in terms of profitability, but it is the worst solution for primary energy saving and total efficiency improvement. In fact, even if it slightly increases the energy performance with respect to the existing CHP-DH plant, it still presents a negative PES, meaning that it has a lower efficiency than the separate production of thermal energy and electricity. The other two solutions, namely TES and 600 kW_{el} CHP plant managed according to the strategy

"Mode 2", are the least interesting due to high payback time and low net present value after 20 years.

5.4. Conclusions

This part of the present thesis analyses possible technical developments of a CHP-district heating located in the Mediterranean area. On the basis of the 22 years of operation of the considered plant, some critical aspects in its management and design were put into evidence; the criticalities are mainly related to the changes occurred in the last years in the energy sector both under the economic and technical point of view. Indeed, the high penetration of renewable energy resulted in a drop of electricity selling price; as a consequence, only the most efficient power plants operate profitably in the market, so that the final result is an increase of the reference electric efficiency for separate production of heat and electricity. The thesis presented and assessed three possible solutions for an optimized operation of the CHP-DH- plant: the installation of a new cogeneration gas engine; the utilization of waste heat from gas turbine by means of heat pumps; the introduction of a thermal storage to increase the energy efficiency of the cogeneration unit. The best solution in terms of both profitability and energy performance enhancement is the existing DH-CHP plant coupled with a 600 kWe CHP plant with internal combustion engine operating all over the year to satisfy the baseload thermal energy demand of the DH plant. The use of a high temperature heat pump is attractive in terms of profitability, but it slightly improves the energy performance of the existing plant whose primary energy saving remained negative (i.e. less efficient than the separate production of both thermal energy and electricity). The use of TES, instead, is the least interesting due to high payback time and low net present value after 20 years.

Chapter 6.

6.Overall Conclusion

The aim of this thesis is to provide a synopsis of the various elements which characterized a smart grid, and it focuses especially on technologies and system configurations that can be used for converting a micro-grid in a "Smart micro-grid" by taking into account the specific features of the context and by developing different and appropriate strategies. In the opening chapters I have introduced the concept of Smart Cities, by illustrating how smart cities and smart initiatives have been currently applied and enhanced in Italy through a special promotion platform and a vast range of projects. I have further defined the role of micro-grids in the context of smart cities. In addition, I have explained the reasons that led me to adopt a "local analysis approach" instead of analyzing a complex network of large size. Once described the context that characterizes the SCs and the MGs, the thesis has been focused on two of the main improvements planned for a harmonious development of the micro grid examined. Within Chapter 4, the study focused on a payback analysis of an investment in charging stations. The final results showed that the capacity factor (CF) is a basic parameter to reduce the PBP and thus the investment risk. CF is strongly influenced by EVs spreading, which in turn depend on the spread of charging station infrastructures. As concerns Chapter 5,this part of the present thesis, has explained the possible technical developments of the CHP-District Heating located in Osimo Town. Three possible solutions are defined for an improved operation of the CHP-DH- plant: the installation of a new cogeneration gas engine; the utilization of waste heat from gas turbine by means of heat pumps; the introduction of a thermal storage to increase the energy efficiency of the cogeneration unit. The best solution in terms of both profitability and energy performance enhancement is the existing CHP-DH plant coupled with a 600 kW_e CHP plant with internal combustion engine operating all over the year to satisfy the baseload thermal energy demand of the DH plant. The use of a high temperature heat pump is attractive in terms of profitability, but it slightly improves the energy performance of the existing plant , whilst the use of TES, instead, is the least interesting option due to high payback time and low net present value after 20 years. The thesis has made a comprehensive effort to provide a clear view of "Small-scale planning models" directly applied to a Microgrid, that may play a fundamental role in converting a micro-grid in a "Smart micro-grid". However, these models need to be part of a broader strategic program (National/European) that prioritizes holistic policies and strategies, integrates infrastructures assets and processes across energy, ICT and Transport, to keep a global leadership in the sustainable development of cities and communities.

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