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USING BLOCKCHAIN TECHNOLOGIES TO PROMOTE SUSTAINABILITY AND EFFICIENCY IN THE ELECTRICITY SECTOR

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Anno Accademico 2019/2020

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Introduction

Humanity has undergone numerous changes over the years. One of the biggest has certainly been the worldwide spread of electricity. Since Benjamin Franklin's early studies in the 700s and the subsequent discoveries of such prominent figures as Alessandro Volta with the difference in potential and Michael Faraday with the electromotive force, many years of research, huge economic investments and numerous failures would pass before we get to the point of receiving electricity even in households as we see it today. The turning point was in 1883 when the scientist Nikola Tesla built the first prototype of induction motor working thanks to a particular type of electric at current, in which the electrons changed polarity according to recurring alternances.

It was precisely from here that the idea of the alternating current that supplies our homes today; at the time it was in strong contrast with the current distributed in continuous mode of which General Electric had a monopoly, not allowing its distribution over long distances due to the production of excessive heat and the consequent dissipation of energy.

The rich entrepreneur George Westinghouse, had confidence in the idea from Tesla. Sensing the potential of the discovery, he founded Westinghouse Electric and together with his competitor General Electric he broke out the so-called "Current War".

Although with some modifications, the model of electricity distribution that is used today is exactly what Westinghouse Electric came up with. From those years of the late 1800s to the present day more than a century has passed.

Perhaps despite being convinced of the revolutionary scope of his idea, Nikola Tesla had hardly imagined the enormous change it brought about in the evolution of society and in people's lifestyles.

In fact, the spread of electricity and the enormous increase in its consumption since the mid-twentieth century are closely related to many phenomena such as the increase in population and global welfare, the discovery of revolutionary technological innovations in any field, from medicine to electronics and many others because without such a wide spread of electricity today nothing would be the same. However, as in all revolutions, there are of course also numerous negative consequences that can no longer be ignored over the years.

One of the most important is at an environmental level. Data confirms that the electricity sector today is the greatest emissions producer of greenhouse gases which, as now proven by numerous studies, are those waste products harmful to the planet and widely recognized as the cause of significant environmental and climate impacts, including the increase in average global temperature and the intensification of catastrophic natural events. Global warming caused by human action is now estimated to be around 1°C, with a growth trend of +0.2°C per decade. For this reason, the electricity sector for some years now is entering a new era of changes and an increasingly important drives towards the production of electricity from renewable sources in order to meet the recent issues of environmental sustainability.

However, the transition towards green energy is less simple than it may seem and puts a strain on the solidity and efficiency of the current system because it brings out new problems and new dynamics that could upset all the fixed points of the actors within it. Nevertheless, all this means that the sector has numerous potentials and wide margins of evolution that the most innovative and careful companies will be able to exploit to ride the wave of progress.

The key aspects to keep an eye on are the new technologies that could act as a support for change in the sector. The 2000s have seen the spread of many technological innovations that have radically changed society but one of those innovations today arousing much curiosity is the Blockchain. While it is associated by most people with crypto-currency and especially Bitcoin the reality is that it is also a very valuable tool within countless sectors, primarily in finance but increasingly also in government, logistics and utilities.

As will be analyzed below, its unique characteristics could prove to be very useful for the electricity sector but all this change must absolutely be accompanied by receptivity from all actors in the chain, from the energy producer to the end user. Therefore, the objective of this thesis is to demonstrate how Blockchain technologies are able to promote sustainability and efficiency in the electricity sector.

To do this, it will be first described in detail each link in the chain of a complex sector such as the electricity, and then it will be analyzed it discovering the many problems within it, ranging from the management of the spread of renewable energy, grid congestion to a lack of transparency to the end user. To demonstrate this last point, a sample of people will be questioned in order to give direct feedback of what are the feelings and preferences of consumers.

Finally, it will be explained in depth what is believed to be the solution to the problems identified: the Blockchain technologies also going through Smart contracts. In conclusion, it will be analyzed in detail the concrete applications of these technologies in the electricity sector, the steps with which they may be able to promote renewable energy by increasing global efficiency and some cases of real application in the society.

Chapter 1. THE ELECTRICITY SUPPLY CHAIN AND THE LIBERATION PROCESS IN ITALY

1.1 Electricity Supply Chain

The Electricity Supply Chain is the set of all the stages that makes up the electricity production cycle up to the final consumption.

From a pure technological point of view, the chain consists of four different phases:

- Generation.
- Transmission.
- Distribution.
- Metering.

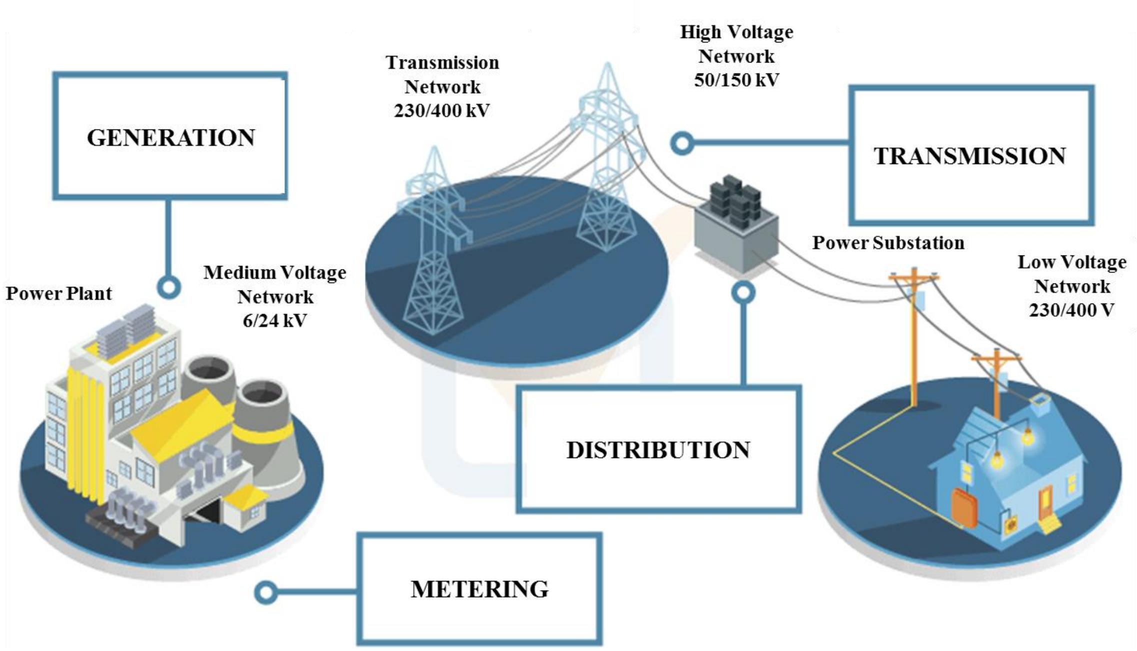

Fig.1 Electricity Supply Chain - Technical Structure (Source Luce.Gas.it)

The Electricity Supply Chain, however, includes not only the technological aspects but also those of the market as follows:

- Wholesale Market.
- Retail Market.

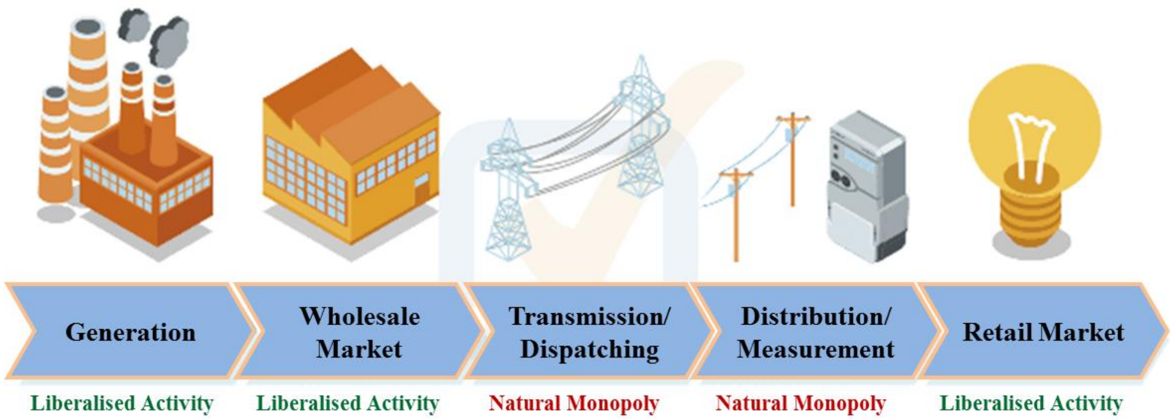

Fig.2 Electricity Supply Chain - Commercial Structure (Source Luce.Gas.it)

When we talk about electricity, we have to consider the term Social Good. Actually, Social Good is a comprehensive term that includes liberal and rightful distribution and environmental sustainability and it applies to services and products that promote the improvement and well-being of individuals, communities and societies.

Consequently, there is a need to balance profit with social well-being together with the quality of service. For this reason, there is an independent authority that checks that operators have a profit and national safety of asset management.

With the advent of smart grid technologies, the energy storage and management systems started to revolutionize the patterns of electricity usage and energy conservation at the consumption premises. Under the sustainable smart grid model, the new technologies try to break down these historical axioms through the use of batteries and energy management systems, improving the efficiency, economics, reliability, and energy conservation for distribution systems.

1.1.1 Generation

Generation takes place always by conversion of a primary source of energy (e.g., wind, natural gas, fossil fuels, etc...). Furthermore, there are multiple production systems which differ by primary source and production mechanism (thermoelectric, geothermal, and hydroelectric). However, the amount of energy produced cannot be unlimited due to the fact that electricity cannot be stored cost-effectively on a large scale and at any given moment its production must reach the consumption otherwise any imbalances would cause a blackout on the national electricity grid. For this reason, production and consumption units are always connected to each other, differently from the gas that has stocking systems, even though the network operator also maintains some generating reserves with which to ensure that the network can remain as stable possible. In Italy, TERNA is responsible for the aforementioned balancing.

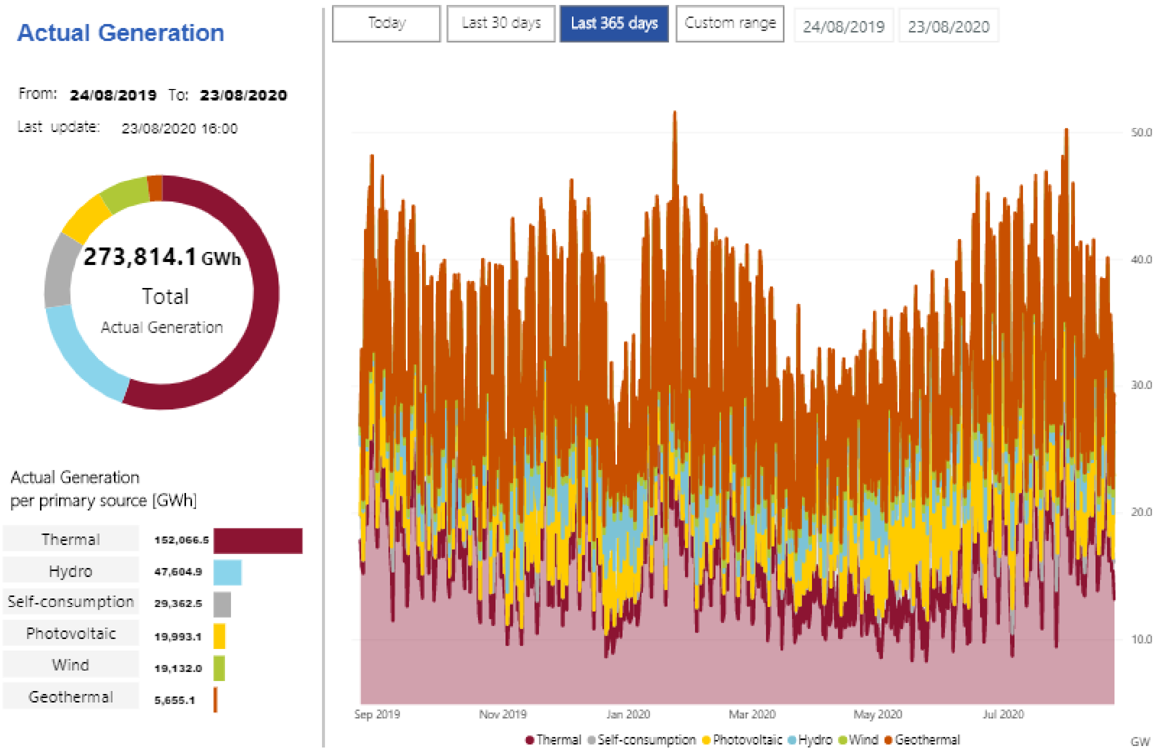

Fig.3 Italy's net hourly total national production, divided by primary source, including self-consumption (Source TERNA)

As a matter of fact, electricity demand is characterized by high variability both on a daily scale and on a medium-term scale and we see an inelastic consumer demand for electricity compared to the price. Consumers are insensitive to price signals especially if we consider that the price in the bill currently does not reflect the price on the market and retail rates are unrelated to hourly market prices.

Domestic production is also often combined by import and the last Annual Report of the Authority (2019) indicated that the domestic needs have been partially satisfied from the import. Generally, Italy purchases energy mainly from neighboring countries (Switzerland and France) just for a mere matter of convenience.

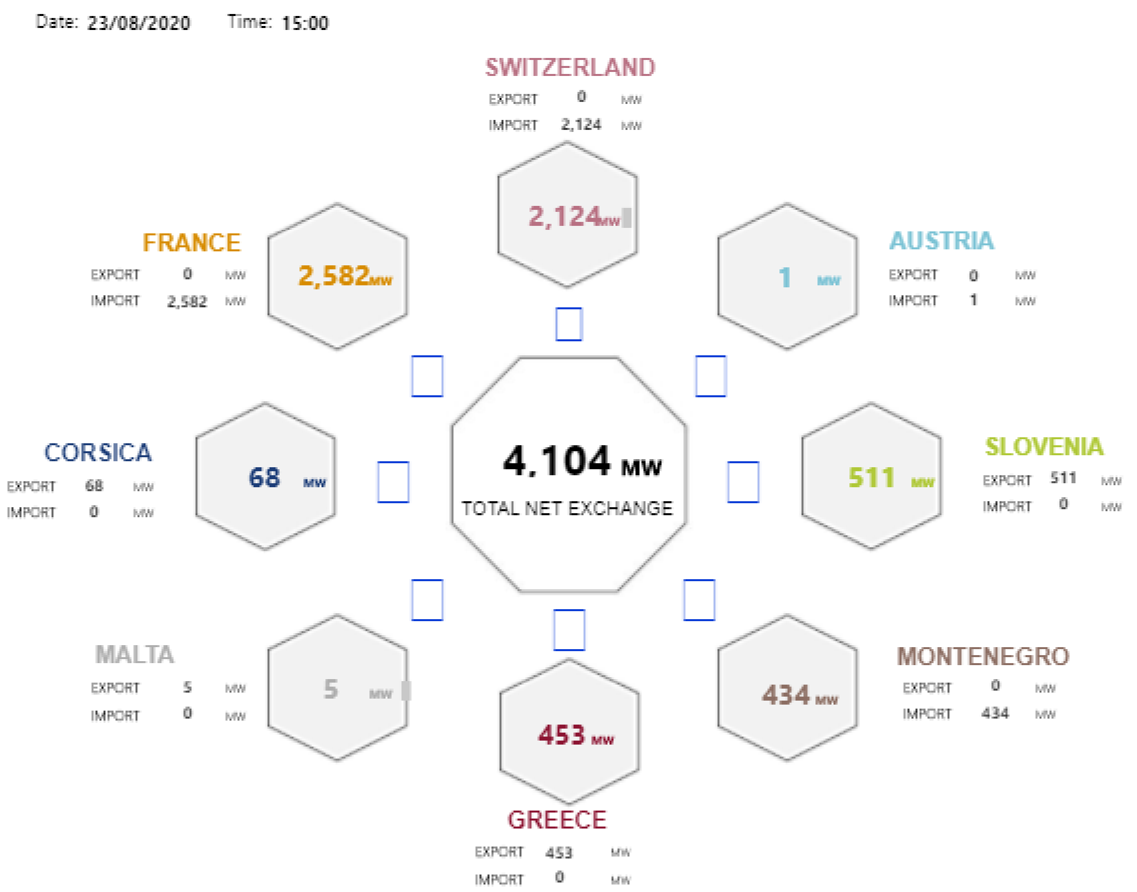

Fig.4 Scheduled Foreign exchange (Source TERNA)

In fact, since energy is imported for the most part from nuclear sources, due to the particular technical characteristics of these plants, the energy produced when the demand is lower than the offer, it is often cheaper to import instead of produce. However, the most significant thing, from an economic perspective, is how different kind of resources and, therefore of production facilities, used for the generation of energy, have an impact on costs and on the market composition. Generally, the objective is to satisfy the demand and at the same time to minimize production costs.

Only traditional technologies can produce energy at a competitive cost to the market while others must be encouraged due to high investment and management costs; in particular, coal plants have the lowest total cost but have opposite problems. This is the reason why energy from renewable and assimilated sources is the first to be used to encourage its production. The remaining part of demand is satisfied from resources based on the generating cost. The regulation of peak demand is achieved with hydroelectric pumping and turbo gas.

In line with the above statement, we can identify three different types of plants as follows:

– Base load: characterized by very high fixed costs and also low variables costs. These types of plants present high production efficiency and are used to satisfy the basic demand which remains essentially constant during the year:

  - Renewable energy sources.
  - CIP6[1].
  - Coal.
  - Imports.

– Midmerit: an intermediate category of plants, between Baseload and Peakload. Midmerit plants have variable costs greater than Baseload but lower than Peakload and the opposite for fixed costs. Usually, they are used to cover the demand between peak and basic power.

  - Combined Cycle Gas Turbines (CCGT).

– Peak load: they have the lowest fixed costs which, in case of short-term use, may offset high variable costs linked to low performance levels. This type of plant is exploited for covering the required power during peak hours.

  - Hydroelectric pumping.
  - Turbo gas.

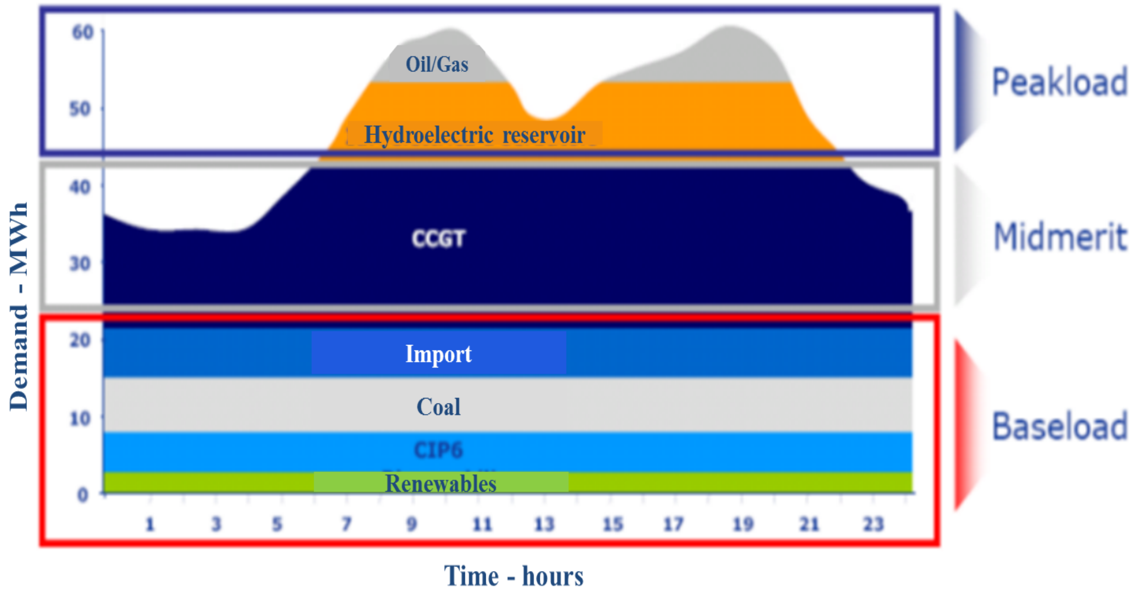

Fig.5 Demand coverage by type of plant (Source G. Trupia)

[1] Resolution no. 6 adopted in 1992 by Interministerial Committee on Prices (CIP - Comitato Interministeriale Prezzi). The resolution promotes the construction of plants for generation of electricity from renewable and/or other eligible sources as per Law no.9/91.

In the context of Italy, the power park consists mostly of combined cycle plants (CCGT), followed by coal and gas turbines and finally by all renewable plants: hydroelectric, photovoltaic, wind and geothermal.

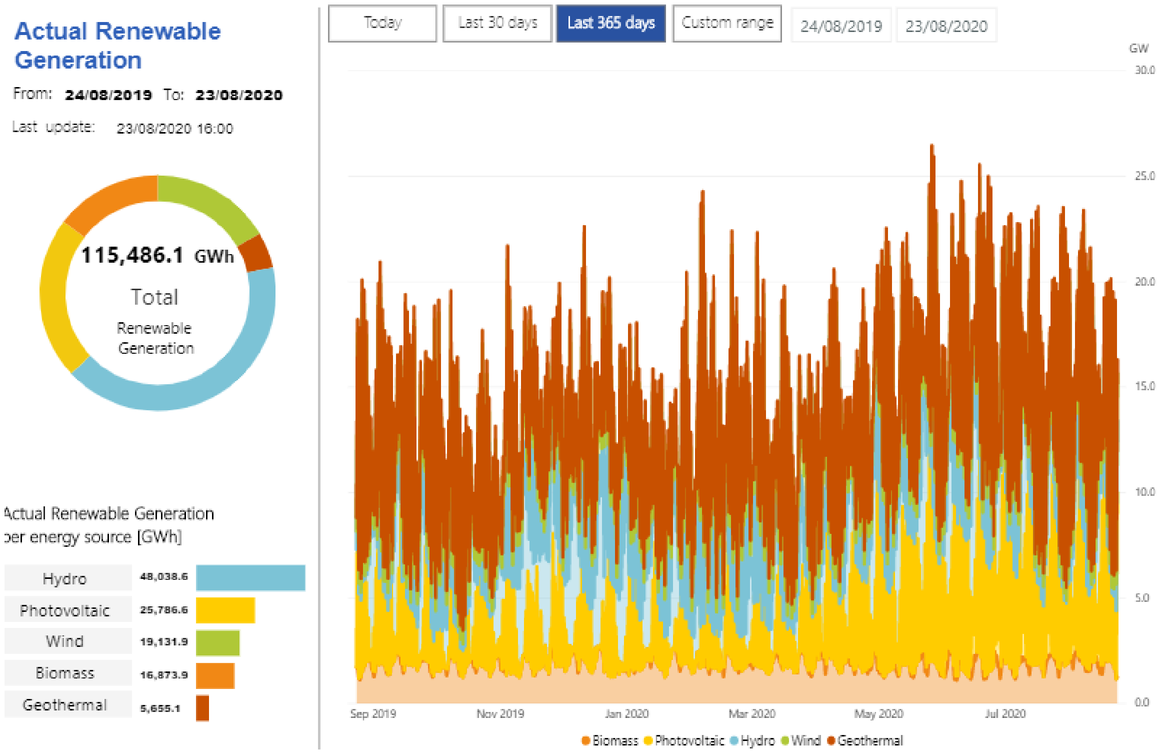

Fig.6 Production from renewable energy sources: water, geothermal, biomass, wind and solar power (Source TERNA)

According to what stated above, due to high fixed costs and the need to remain operational for a high number of hours, Baseload plants can compete only for basic demand as well as Peakload plants can contend only peak demand in order to avoid an intensive use. Due to the considerable initial investment needed, the sector is characterized by the presence of high costs which represent an important deterrent to the entry of new operators in this business. In addition, the investment itself represents an implied risk due to the fact that it may be inefficient if the entry of the new competitor is such as to lead to a lower equilibrium price and the consequent expected rent erosion.

Hence, we can define the Generation phase a Natural Oligopoly, that is to say a market composed of a limited number of activities which produce a homogeneous product and which satisfy a market demand resulting from a multiplicity of consumers where the entry of potential new competitors is hampered by the presence of "natural" entry barriers.

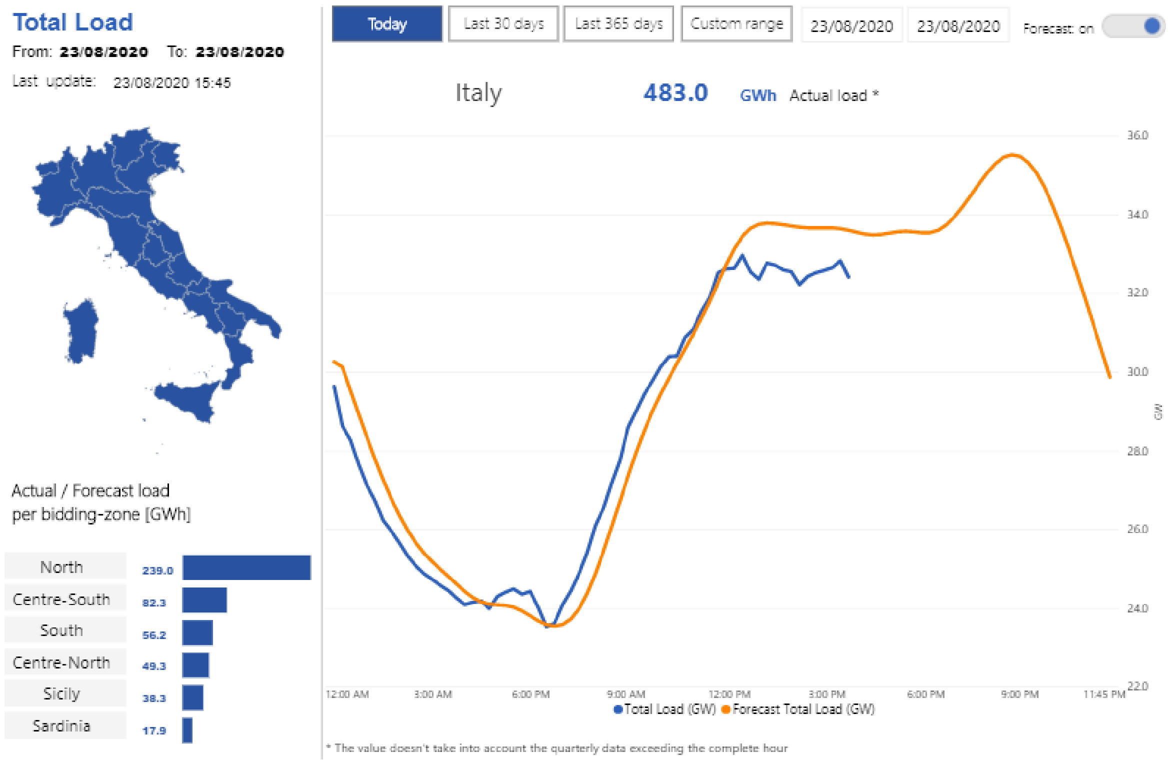

Fig.7 Trend of the Italian electricity system's total demand (Source TERNA)

1.1.2 Wholesale Market

The Wholesale Market is the National market in which producers, the Single Buyer and the Wholesalers/Sellers that supply energy for their consumers (industry, individual citizens, etc...) interface.

The Wholesale of electricity take place through two ways as follows:

- Bilateral OTC (Over The Counter) contracts that are private bargaining between two operators. The price is defined by negotiation between the two counterparties, secret and different from contract to contract. It's a parallel market and for the above-mentioned characteristics, there is a high counterparty risk. Then, these contracts must be communicated to the stock exchange as they must enter the construction curve of supply and demand because as a result there will be those who will produce and consume electricity and will pass through the national network.
- Buying and selling in central markets (Electricity Market). There is a single, transparent and public price for all transactions (market clearing). There are lower transaction costs, limited to the expense for registration and participation in the market. This is the reason why the counterparty risk is inexistent.

However, this phase will be widely described in the next chapter where the composition and the mechanisms of the Italian Electricity Market will be explicated.

1.1.3 Transmission and Dispatching

As far as the Transmission is concerned, the electricity produced is conveyed to the distribution network to which consumers then connect. The Transmission phase is an example of Natural Monopoly. The cost structure that characterizes the management of the network is based on very high fixed costs and relatively low variable costs and allows minimizing costs in the industry with the presence of a single entity. In such a context, there was a need to assign the network management to an independent entity (TERNA S.p.A.) with the purpose of ensuring access to the network under the same conditions between the various competitors (Marzano Law no. 239/04). For this reason, the real-time management of extra-high-voltage energy flows on the Italian's electricity grid, also called dispatching, occurs through the National Transmission Grid (RTN) which is handled by TERNA throughout the TERNA National Control Centre; the aim is to safeguard safety and efficiency.

The National Transmission Grid of electricity consists of:

- AAT (Very High Voltage) transformers that draw power from power plants.
- AAT and AT (High Voltage) lines that transport energy. They can be aerial, underground or submarine.
- Interconnection lines for foreign exchange of electricity.
- Transformation stations for the transfer of energy to distribution companies supplying electricity to end-users.
- TERNA National Control Centre, which monitors the operation of the electrical system ensuring safety and continuity as follows:
    - monitoring of electricity flows;
    - arrangements for managing the coordinated operation of all the elements of the system;
    - programming of grid unavailability;
    - forecasting the Italian electricity requirement and comparing it consistently with production programs resulting from the free energy market.

The National Transmission Grid registers a consistency of over 66,000 km of lines (corresponding to about 73,000 km of electrical circuits) and about 870 electrical stations.

It is characterized by five voltage levels: 380 kV, 220 kV, 150 kV, 132 kV and 60 kV.

Generally, the 380 kV and 220 kV networks (Very High Voltage, AAT) represent the backbone of the Italian transmission grid and serve to safely transport large amounts of electricity over long distances and to avoid dispersion. The voltage levels of 150 kV, 132 kV and 60 kV are, instead, reserved to the sub-transmission networks (High Voltage, AT) and make the distribution of electricity widespread over the territory.

Electricity is transmitted in high and very high voltage in order to avoid excessive dispersion.

RTN is managed by:

- TERNA: 98.5%
- Producers: 0,5%
- Municipal Companies: 1%

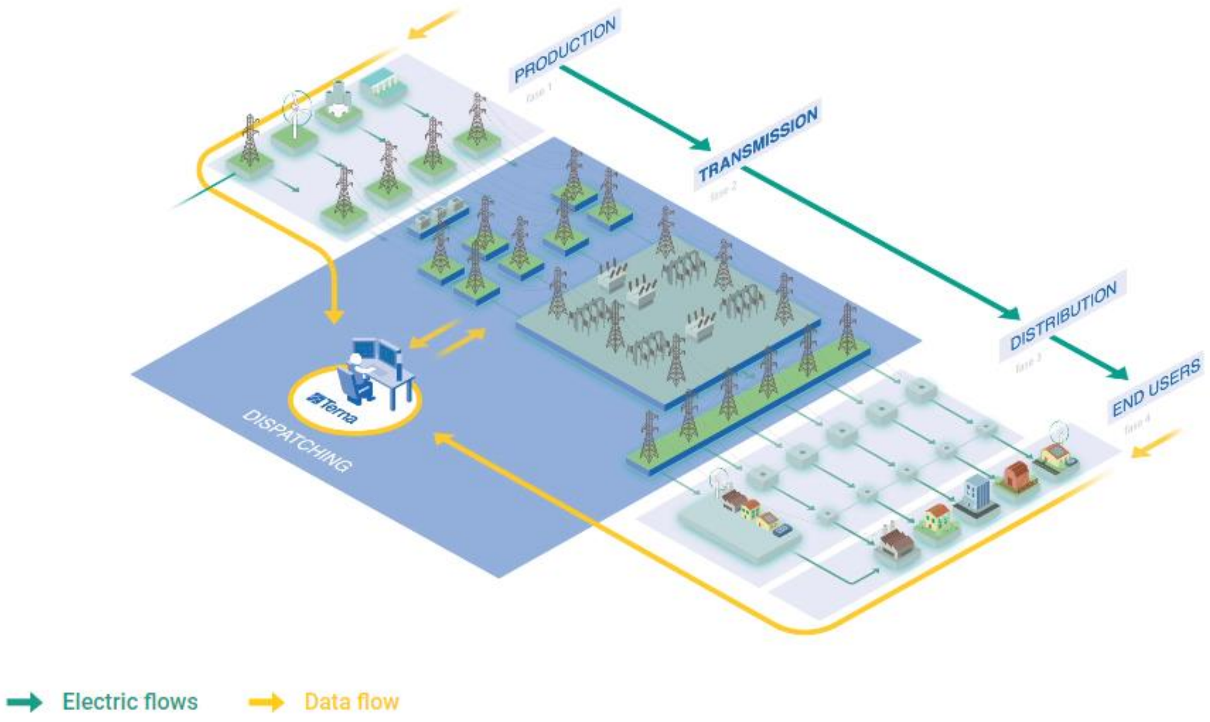

Fig.8 How the Electricity System works (Source TERNA)

1.1.4 Distribution and Measurement

The distribution is the physical transport of energy by means of medium/low voltage networks, from the primary substation (delivery point of the transmission network) to the meters located at the consumption points. A complex network infrastructure allows the

transport of electricity to the end user, through the primary substations (which transform high voltage electricity into medium voltage electricity), the secondary substations (from medium voltage to low voltage) and the transformers.
The distribution companies, operating under concessions, operate local, low-voltage electricity grids and maintain them. It is a monopolistic activity at the municipality level.
In addition to the distribution lines, the distribution network includes voltage transformers, safety systems and measurement systems.
The distributor is responsible for the following activities:

- Transport on own networks.
- Installation and maintenance of electricity network.
- Services to the final consumer (e.g. power increase, metrology).
- Management of relations with sales companies (concession mandate).
- Management of measures.

Network management:

- E-distribution: 91,24%
- Aretis: 2,32%
- Unareti: 0,96%
- Inrete: 0,81%
- Ireti: 0,58%
- Others: 4%

The concessions related to the management of the distribution networks will expire in 2030 and will have to be reactivated by thirty-year concessions.
The energy consumed measurement activity is managed by the distribution company and includes:

- Installation and maintenance of meters.
- The periodic measurement of the energy consumed.

There are various types of meters:

- The totalizer meter: it is the oldest and now represents a small percentage of the installed meters.
- The electronic meter 1G: it corresponds to almost all of the installed meters and is able to record and maintain in active and reactive memory the energy consumed or produced with quartorial granularity, hourly or in the bands defined by the

Authority (F1, F2, F3). It can also transmit the data independently to the server of the distribution company and to the consumer who requests it.

- The 2G digital meter (smart metering systems 2.0): the technical specifications were approved in March 2016 by the Authority for Energy and it will allow having an instant telematics reading and consequently to better managing the bidirectional power flows of the future smart grid.

If the energy measurement of a meter is more detailed and granular, the consumer will be better able to change its consumption according to the hourly energy price. Therefore, a technological evolution such as smart metering 2.0 system will give more consumption awareness to end users who will be less subject to uncertainty. They will have more control over the consumed energy and the price.

1.1.5 Retail Market

The last stage of the supply chain is to sell to the final consumer. Within this stage, there are the sales companies that purchase electricity (mainly from the electricity market but sometimes also directly from the producers) and the final consumers who purchase and consume the electricity. The final consumers, following the liberalization process, may be divided as follows:

- Customers of greater protection (the so-called "*maggior tutela*") or those who remained within the protected market. In this market, the price of raw materials is established quarterly by the Authority on the basis of the evolution of prices on the markets.
- Free market customers and customers of the safeguard service. It was created as a result of the market liberalization and is characterized by the presence of many private energy companies. The latter, being subject to the market competition, may determine prices and offers for final customers in full autonomy and based on their own commercial strategies.
- The safeguard service includes all non-domestic customers who, having no credentials to access the protected market, are steadily or temporarily without a free market electricity contract. In addition, all morose users are included to this category.

As a result of the freeing-up of markets, three supply schemes for final consumers can be distinguished:

Energy supply	Producers/ Wholesalers	Producers/Wholesalers	Single Buyer (AU)
Supplier	**Free Market:** Any sales company. The Authority is pushing in this direction.	**Safeguard:** Local public tender winning sales company.	**Greater Protection Service:** Sales companies indicated by the distribution companies for distributors with more than 100,000 customers.
Delivery price	Directly contracted between customer and supplier	Free and defined in Local public tender (Difference compared to the PUN) Managed with national auctions.	Regulated and defined by ARERA (ex AEEGSI)
Utilities Admitted	All utilities	Utilities in MT or AT, or in any case with the requirements of Medium or Large Enterprises. It includes all the subjects obliged to be on the free market but that have not chosen a supplier (for choice or because they are considered defaulted and no society of sale wants to take them).	BT Utilities, domestic or with Small Business Requirements
Customer share	31,4%	0,2%	68,4%

1.1.5.1 Retail Market Evolution

The Italian "Annual Law for the market and competition" (Law 4 August 2017, no.124), established, from 1 July 2019, the end of the price protection provided by the Authority for the electricity sectors (for domestic consumers and small businesses connected in low voltage) identifying for this purpose a path for the benefit of small end consumers. This deadline was postponed to 1 July 2020 following the approval of the conversion Law of the Law Decree no.91/2018 - Law no.108 of 21 September 2018.

The Law Decree no.162/2019 has provided for a further postponement of the end of the price protection to 1 January 2022 and in case of the conversion into Law by Parliament, from that date, the Authority will cease to define and update every 3 months the economic conditions for the supply of electricity for the small consumers protection.

Already today, small end consumers (families and small businesses) have the right to switch to the "free market", where the customer decides which seller and which type of contract to choose, selecting the offer deemed most suitable for their own needs.

After the protection services are no longer available, the supply of electricity continuity will be guaranteed to small consumers who do not have a seller in the free market so that the customer does not suffer any interruption during the necessary period needed to find a seller on the free market. The Authority will guarantee the publication and dissemination of information regarding the market full opening and the methods of carrying out the services.

In order to grant a smooth transition and improve the consumers understanding and participation in the free market, some important obligations have been introduced for electricity sellers, for the Ministry of Economic Development and for the Authority, including:

- The preparation of "standard" offers for end consumers (PLACET offers): Law no. 124/2017 establishes for all sellers the obligation to offer families and small businesses at least one "standard" supply proposal at a fixed price (in which the price of energy is kept fixed for a certain period of time) and at least a variable price proposal (where the price changes automatically based on changes in a reference index).
- Activation of the Offer Portal: created by the Integrated Information System (SII) operator for the collection and publication in open data mode of all the offers on the electricity retail market. The Offer Portal intends to make it easier for families and small businesses to compare the electricity offers that best suits their needs.
- The List of Electricity Sellers establishment: all electricity sellers, in order to carry out their business, must necessarily be registered in the List of Electricity Sellers, which will be established by Decree (Ministry of Economic Development), as required by Law no.124/2017.
- The preparation of guidelines to promote commercial offers in favor of purchasing groups: Law no.124/2017 provides, in view of the future removal of price protection services (1 July 2020), a series of interventions to support the further development of the competitiveness of the Retail market and the active participation of end consumers by providing, in particular, that for the purpose of

reducing the cost of the electricity bills, the Authority prepares guidelines to promote commercial offers of electricity in favor of purchasing groups, with particular reference to comparability, transparency and the advertising of offers, as well as the creation of IT platforms aimed at facilitating the aggregation of small consumers.

- The retail markets monitoring: the Minister of Economic Development has achieved the required objectives (Law no.124/2017) and has defined any further measures necessary to ensure the termination of the transitional price regulation and the conscious entry into the market of end consumers, according to mechanisms that ensure competition and the plurality of suppliers and offers on the free market.

1.2 The Italian Electricity Market

The electricity sector in Italy was nationalized in 1962 when ENEL (*Ente Nazionale per l'energia ELettrica*) emerged as a state-controlled entity with a monopoly on generation, transmission and local distribution of electric energy in Italy.

The nationalization followed a common propensity in Europe after the Second World War and ENEL incorporated all the previous private companies operating in Italy.

Rural electrification was the first focus of ENEL and it had to immediately face a rapid growth of electricity demand during subsequent decade, largely met with fossil-fuel powered plants. The international oil crisis (1970s) led ENEL to rethink its energy strategy, focusing on nuclear research as well as research on different forms of energy (i.e. wind power). More investments were devoted to nuclear energy until the Chernobyl disaster (1987) which led to terminate further construction of nuclear power stations following a popular referendum.

In 1991, ENEL was obliged by Law to partially liberalize electricity production and in 1992, it became a joint stock company with Italian Treasury as its main shareholder. Subsequently, in 1995, the Government established an independent energy regulator, the Authority for Electricity and Gas[2] (*Autorità per l'energia elettrica e il gas* - AEEG), tasking it with controlling functions on access conditions for parties operating services in compliance with the principles of competition, transparency and equal basis. This was considered a necessary requirement before changing the ownership of ENEL and,

[2] Italian Law no.481/95: "Norme per la concorrenza e la regolazione dei servizi di pubblica utilità. Istituzione delle Autorità di regolazione dei servizi di pubblica utilità".

therefore, a strong signal of the government's willingness to privatize the electricity industry. At that stage, the need to restructure the industry and create competition at least in the generation phase was generally agreed even thought there was not a political consensus on the privatization. In 1999, the Legislative Decree no.79 of 16 March 1999, marked the liberation of the electricity sector from government control through gradual steps and opened up the energy market for other actors to compete. This Decree implemented the European 96/92/EC Directive in the Italian legislation. The European Directive laid down only the general conditions that should be in place to assure the creation of a single Internal European Market (IEM) in Europe, but avoided from designing a concrete market. Given this freedom, most European countries chose to leave market organization to the dynamics of private initiative keeping centralized components to a minimum.

The post-liberalization structure was designed to increase competition, encourage the entry of new operators and reduce the end-user price (early 2000s) and it was based on the adoption of different regulations for Generation (free and managed by private companies) and Transmission (natural monopolistic activity at national level) and Distribution (natural monopolistic activity at municipality level).

In case of natural monopolies, it was decided to grant concession for the operation of certain infrastructures to a single operator because of their unique nature and the economic advantage of not building parallel infrastructures.

1.3 Institutional entities in the Electricity Market

The Decree no.79 of 16 March 1999 focused on separation of ownership the National Transmission Grid from management of the grid itself. Nowadays, along with the Parliament and the Government, there are various institutions whose involvement is essential for the electricity market functioning as follows:

- The Ministry of Economic Development (*Ministero dello Sviluppo Economico* - MSE): it defines strategic and operational guidelines in terms of safety and cost effectiveness of the National Electricity System.
- The Electricity, Gas and Water System Regulator (*Autorità per l'energia elettrica, il gas ed il sistema idrico* - AEEGSI): it guarantees the promotion of competition and efficiency in the sector, with regulation and control functions of the National Energy System. This happen through the determination of tariff prices and general

rules of the electricity market, the quality control of the activities and services provided by operators and, finally, the supervision of acquiescence with its rules.

- TERNA (owned by the *Cassa depositi e prestiti*): it was founded by ENEL in 1999, following the liberalization of the electricity sector with ENEL as the main shareholder. The TERNA group is the owner of the Italian National Transmission Grid for high and extra high voltage electricity and is the largest independent electricity Transmission System Operator (TSO) in Europe. Its role is to ensuring the country's electricity supply and enabling the Italian electricity system to function. TERNA conducts grid planning, development and maintenance activities to optimize high voltage electricity transmission (Transmission Operator). It also ensures that electricity supply and demand are balanced 24 hours a day throughout Italy, a real management of energy flows through the grid, also known as "dispatching" (System Operator). TERNA operates as a monopoly according to the rules defined by the Italian Regulatory Authority for Energy, Networks and Environment (ARERA) and in implementation of the guidelines of the Italian Ministry of Economic Development. About 90% of TERNA activities are conducted on the regulated market.
- Energy Services Manager (*Gestore dei Servizi Energetici* - GSE): the National Transmission Network Manager (*Gestore della Rete di Trasmissione Nazionale* - GRTN), in 2005, changed its name to GSE when the business was taken over by TERNA. GSE promotes the development of renewable sources in Italy through various actions including the provision of incentives provided by national legislation to generating plants. Instead, GRTN was responsible for the management of the National Transmission Network, in addition to the electricity transmission and dispatching. GSE operates by following the strategic lines defined by the Ministry of Economic Development and is the group leader of the following three companies:

    - Manager of Energy Markets (*Gestore Mercati Energetici* - GME): born in 2004, it is the Market Operator and the counterparty for trading which organizes and manages the Italian Electricity Market. It ensures competitiveness between producers and economically manages an adequate supply of power. It deals not only with the Electricity Market but also with the Gas and Fuel Market.

- Single Buyer (*Acquirente Unico* - AU): it was created with the aim of ensuring the supply of electricity to small consumers in the Protected Market, at a single national tariff. The AU buys electricity at the most favorable conditions on the market and then sells it to the distribution companies for the supply of consumers remaining in the Market of Greater Protection.

- RSE (Energy System Research): it develops research activities in the electro-energy sector, with particular reference to national strategic projects of general public interest and it is funded by the System Research Fund.

1.4 Italian Electricity Market management

As mentioned above, the Italian Electricity Market arises from Legislative Decree no.79 of 16 March 1999 and responds to two specific requirements:

- Promoting competition in electricity generation, sale and purchase, under criteria of neutrality, transparency and objectivity, through the creation of a marketplace.
- Ensuring the economic management of an adequate availability of ancillary services.

The Electricity Market is a telematics marketplace for the negotiation of electricity in the Wholesale Market and is managed by the Manager of Energy Markets (GME). It is not a mandatory market because, since bilateral contracts exist, operators can also conclude sales transactions outside the platform.

The high degree of complexity requires a single coordinator known as Dispatcher or System Operator (TERNA) which is equipped with a power control on all the system production facilities. The Dispatcher ensures that the production always equals the consumption and frequency and voltage do not divert from the acceptable levels. In order to do so, the Dispatcher performs the two core activities as follows:

- Ancillary services: every day, the Dispatcher prepares the schedules that each generation plant will have to follow on the next day, in order to meet the expected demand at minimum cost. These programs must also provide for the availability of an adequate reserve margin to be used to face unforeseen events (increases in demand, losses of production units or transmission lines).

– Balancing: the dispatcher guarantees the balance between injections and withdrawals of the entire system at all times and intervenes only when the operating margin reserves are below the security standards (reintegration). The dispatcher then sends order to tertiary reserve units with the intention of starting, increasing or reducing the power output.

The energy required on the national grid to meet net internal consumption (total load) is equal to the sum of net electricity produced and electricity imported from abroad, from which energy absorbed by pumping and energy exported are subtracted.

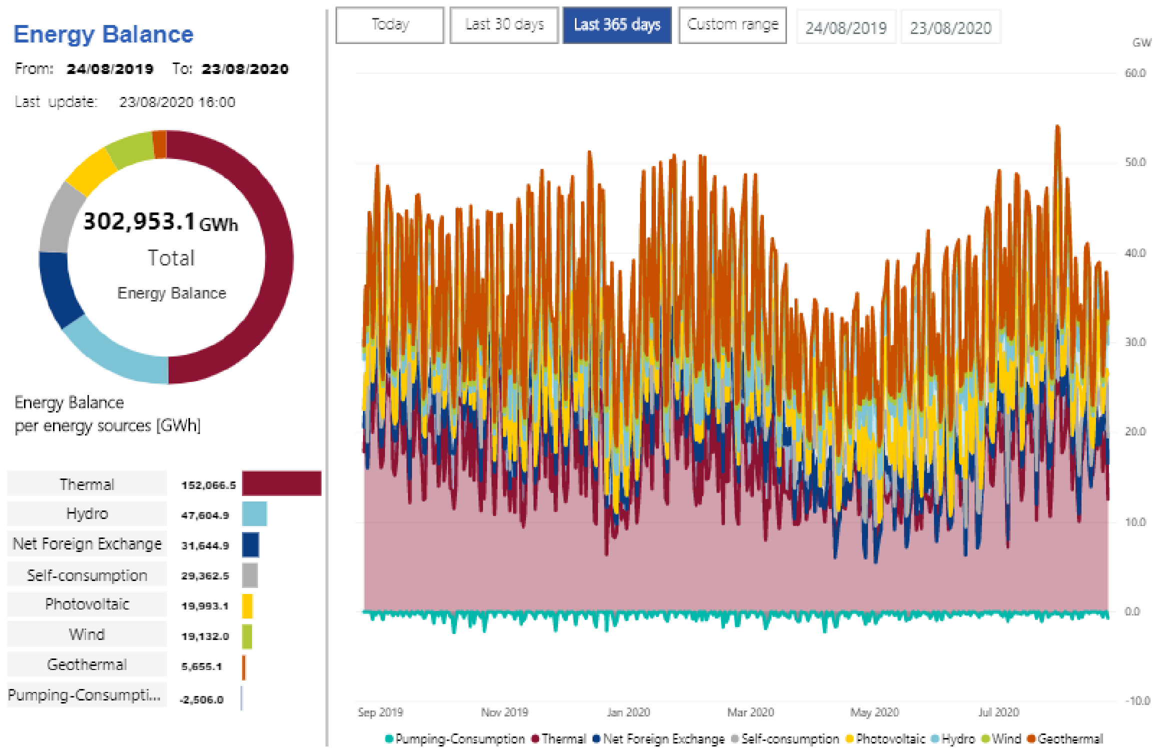

Fig.9 Italian electricity system’s balance (Source TERNA)

1.5 Italian Electricity Market working mechanisms

The electricity price is crucial to satisfy the actors of the market and can be determined based on the following criteria:

– Merit Order: it is a criteria used for ranking Offers/Bids and, for each applicable period, it works as follows:

- Supply offers are ranked by non-decreasing price order.
- Demand bids are ranked by non-increasing price order.

If supply offers and demand bids have the same price, reference is made to the priority criteria set forth in the combined provisions of the Integrated Text of the Electricity Market Rules and of the Dispatching Rules for the Electricity Market.

– System Marginal Price (SMP)**:** it is a uniform price and for each relevant interval, the accepted offers are valued at the equilibrium price of the system, equal to the value of the last accepted offer (marginal offer). Each sale operator obtains revenues equal to the price of the marginal offer multiplied by the total volume of energy sold on the market. With such system an operator, in a competitive market, is encouraged to offer at its own variable cost because the valorization of the accepted volumes will be made on the basis of the marginal price of the system (the most expensive last accepted offer).

The infra-marginal production units will receive remuneration higher than their variable costs that will allow them to cover their fixed costs. The concomitant advantage is the incentive given to innovation and the efficiency of the production. The difference between the offer price and the marginal price recompenses the efficiency of the plants.

– Pay-As-Bid (PAB): it is a mechanism usually selected to face rising prices in markets and it was necessary to switch from Uniform-Price auctions to Pay-As-Bid auctions. In a Pay-As-Bid auction prices paid to winning suppliers are based on their actual bids, rather than the highest price of the supplier. On the other hand, price paid to the consumers is the average price of the winning offers.

Pay as bid (PAB) is a discriminatory price. For each relevant range, accepted bids are valued at the price offered for each of them. The revenue for each sale operator will then be given by the sum of the product quantity-price for each individual offer. With such system an operator, in a competitive market, is induced to submit bids where he bets on the maximum price of the last accepted offer. With the PAB, the offers of the operators are no longer necessarily adhering to their marginal costs. In fact, in this case each operator obtains revenues equal to the price offered for each quantity accepted and, if the offers strictly reflect the marginal costs, it would not be possible to cover the fixed costs sustained for the realization of the generation plant.

The System Marginal Price is the more widespread method of fixing the electricity price in Europe and compared to the Pay-As-Bid has the following advantages:

- Greater transparency and lower risk of exercising market power.
- Coverage of fixed costs of implants through infra-marginal annuity.
- Increased likelihood that the system minimizes the overall cost.
- Increased market access possibilities for new entrants.

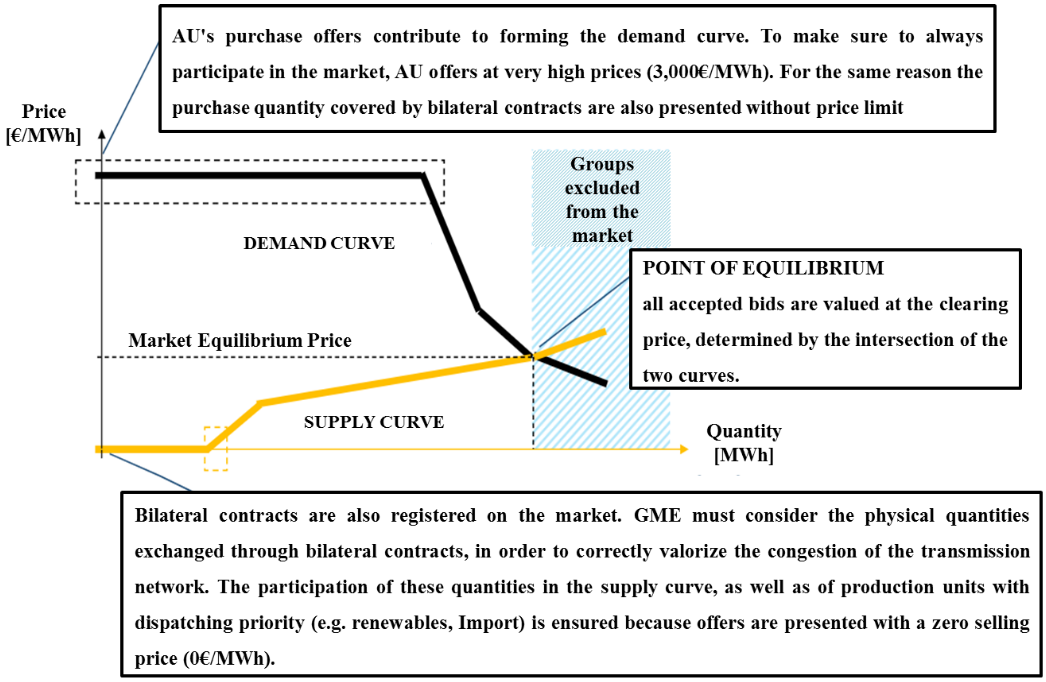

Fig.10 Market equilibrium price formation

1.5.1 Market zones

The Italian electricity network is partitioned in grid sections called "zones". A zone is a portion of the National Transmission Grid with specific transit limits of energy with the corresponding neighboring areas. These transit limits of energy are defined through a calculation model that is based on the balance between electricity generation and consumption.

The identifying process of the zones, representing the Relevant Grid, takes into account the Development Plan of the National Transmission Grid prepared by TERNA.

Zones of the Relevant Grid could correspond with:

- Physical area.
- Virtual area (an area without a physical correspondence).

- Pole of limited production (a virtual area with production limited for security restrictions).

The GME uses a simplified representation of the network to test and remove congestions created by injections and withdrawals that are determined either by the market or by bilateral contracts. The representation highlights the most relevant transit limitations between national areas, foreign areas and poles of limited production.

The National Transmission Grid is connected to foreign countries through twenty-two power lines as follows:

- Four to France.
- Twelve to Switzerland.
- One to Austria.
- Two to Slovenia.

Moreover, there are also some cables connections with Greece, twice with Corsica through Sardinia and a national cable connection links Sardinia with the Italian peninsula. The zones are structured to facilitate the management of energy transits alongside the peninsula and the structure designed by TERNA is as follows:

- Six geographic areas:
    - North (Val D'Aosta, Piemonte, Liguria, Lombardia, Trentino, Veneto, Friuli Venezia Giulia, Emilia Romagna).
    - North-Centre (Toscana, Umbria, Marche).
    - South-Centre (Lazio, Abruzzo, Campania).
    - South (Molise, Puglia, Basilicata, Calabria).
    - Sicily.
    - Sardinia.
- Eight foreign virtual areas: France, Switzerland, Austria, Slovenia, Borzen Slovenian Power (BSP) South Pool, Corsica, Corsica AC, Greece).
- Four national virtual areas, represented by poles of limited production: Rossano, Foggia, Brindisi, Priolo. These areas consist only of production units. Interconnection capacity is less than the installed power of the units.

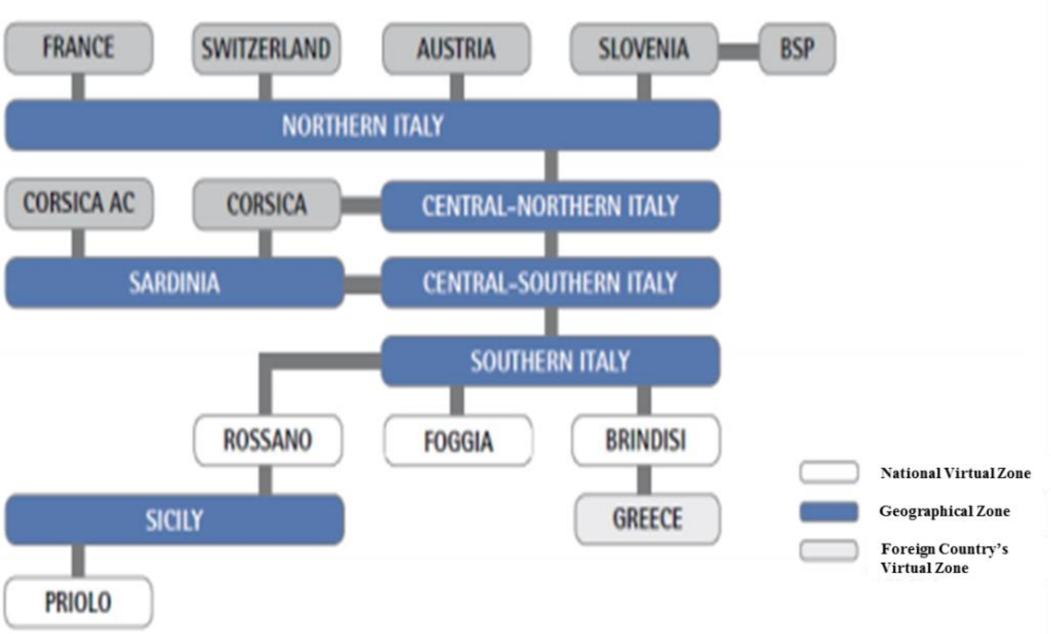

Fig.11 Virtual and geographical zones of the Italian transmission (Source GME)

Each geographical or virtual area includes a set of Offer Points, also called dispatching point that is to say point inside the grid in respect of which supply offers and demand bids are submitted and Injection and Withdrawal Schedules are defined.

Offer Points can be:

- Injection points (Supply Points for Injection).
- Withdrawal points (Supply Points for Withdrawal).
- Mixed points (Mixed Supply Points, both injection and withdrawal).

As far as the Injection and Withdrawal Schedules are concerned, they may be defined as follows:

- The injection schedules consist in the energy amount injected in the day, at the hour and from the offer point pre-set which corresponds with the single production units (i.e. transformation plants from any primary source). TERNA controls directly the production units in order to guarantee the system balance.
- The withdrawal schedules consist in the volume of energy to be withdrawn from the grid on the day, at the hour and at the offer point to which the schedule refers. The offer points may correspond both to individual points of withdrawal and to sets of withdrawal points.

Fig.12 Virtual and geographical zones of the Italian transmission (Source GME)

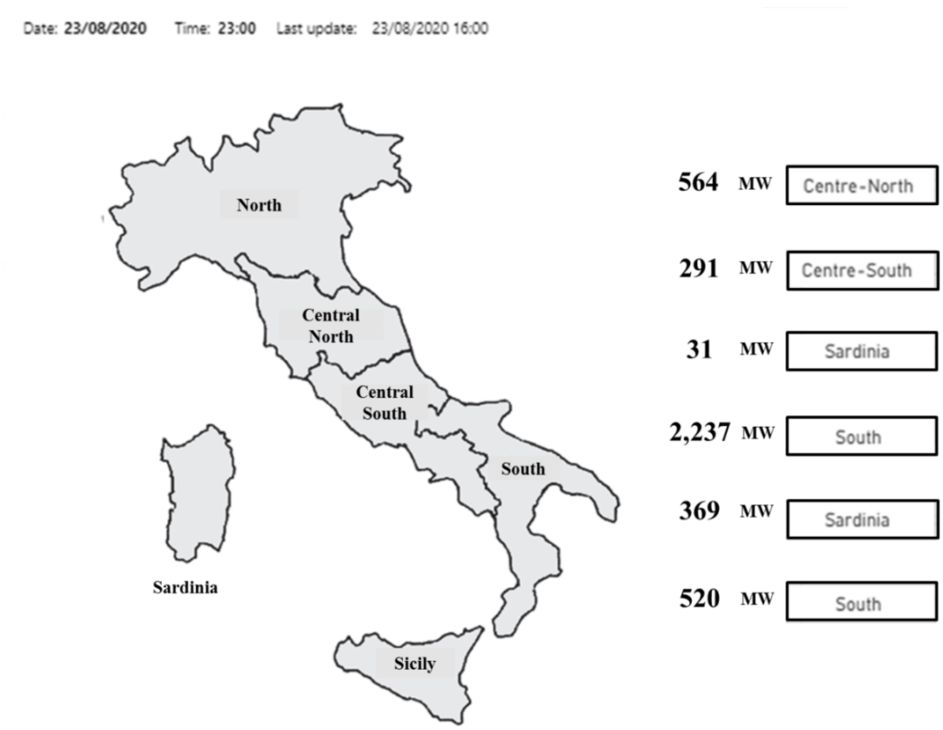

Fig.13 Scheduled trade between Italian market zones (Source TERNA)

Each offer point has its own user. This latter is an agent that has signed a contract with TERNA for the dispatching service (both the injection and withdrawals schedules and the balancing orders). Deviations from the schedules involve the payment of deviation charges, in the form of penalties applied to offer points

1.6 Italian Electricity Market structure

The Italian electricity market is managed by TERNA and GME and its structure is:

- Spot Electricity Market (*Mercato Elettrico a Pronti*-MPE) where producers, wholesalers and eligible final consumers may sell/purchase daily energy orders.
- Forward Electricity market (*Mercato Elettrico a Termine*-MTE) where participants may sell/purchase future electricity supplies.
- Delivery of Electricity Derivates (*Consegna Derivati Energia* - CDE) where financial electricity derivatives contracts are executed.

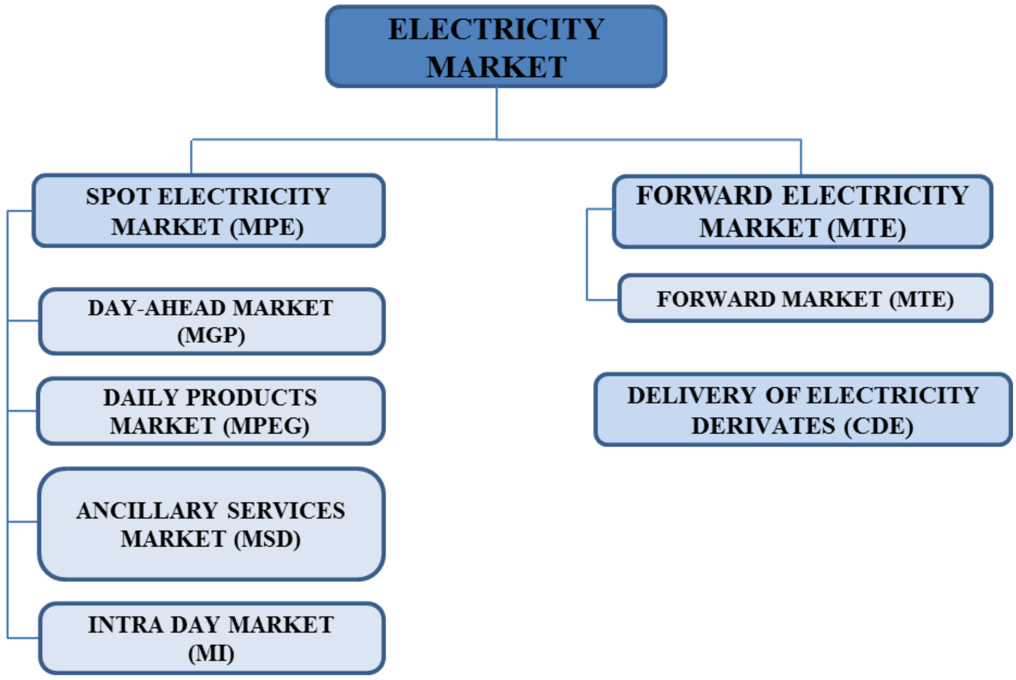

Fig.14 Italian Electricity Market (Source GME)

1.6.1 The Italian Spot Electricity Market (MPE)

The MPE is divided into:

- Day-Ahead Market (*Mercato del Giorno Prima* - MGP): it is an auction market which hosts most of the electricity sale and purchase transactions; hourly energy blocks are traded for the next day and participants submit bids/asks where it is specified the quantity and the minimum and maximum price at which they are willing to sell or purchase. The results are made known the day before the delivery day. Once submitted, the supply offers are assessed and accepted only after the market closure, according to a model based on economic merit and at the same time respect for the limits of transit between zones. The accepted demand bids pertaining to consuming units belonging to Italian zones are valued at the National Single Price (PUN) which is equal to the average of the geographical zones prices, weighted for the quantities purchased in these zones. In this process, GME acts as a central counterparty.

- Daily Products Market (*Mercato dei Prodotti Giornalieri* - MPEG): it is the venue for the trading of daily products with the obligation of energy delivery. The MPEG is a continuous trading market and automatically admit all Participants in the electricity market. It permits trading daily products with "unit price differential" and "full unit price" and for both of them the negotiable delivery profiles are "Baseload" (listed for all calendar days) and "Peak Load" (listed from Monday to Friday). GME acts as a general counterparty.
- Intra-Day Market (*Mercato Infragiornaliero*-MI): it allows Market Participants to modify the schedules defined in the MGP by submitting additional supply offers or demand bids. The MI takes place in multiple sessions and supply offers and demand bids are selected under the same MGP criterion, except for the accepted demand bids which are valued at the zonal price. GME acts as a central counterparty.
- Ancillary Services Market (*Mercato del Servizio di Dispacciamento*-MSD): it is the venue where TERNA procures the resources for the balance of the power system and to solve the inter-zonal congestions, creation of energy reserve, real-time balancing. The MSD is a mandatory market where the auction mechanism remunerates the offered price. It is cleared through a pay as bid algorithm and TERNA is the central counterparty which accepts bids/offers from market participants related to different reserve and balancing services. The MSD is divided into:
    - Ex-ante MSD: it consists of different sub-stages, where TERNA trades energy and balancing services in order to release congestions and to create reserve margins (secondary and tertiary reserve);

- Balancing Market (*Mercato di Bilanciamento* - MB): it consists of different sub-sessions, where TERNA trades real-time balancing services to restore secondary/tertiary reserve and to maintain the balance of the grid.

1.6.2 Forward Electricity market (MTE)

The Forward Electricity Market is the "virtual" seat in which the purchase and sale of forward energy contracts take place and where all operators admitted to the Electric Market may take part. In this market are negotiable two different types of contracts: the Baseload (can be negotiated every day at any time) and the Peakload (can be negotiated only on working days between 9 am and 7 pm in the evening). These types of contracts are negotiable with monthly, quarterly and yearly delivery periods. Operators shall participate by submitting proposals indicating type and period of delivery contracts, number of contracts and price at which they are willing to buy/sell. The offers are then ordered based on the price and according to the same criterion used in the System Marginal Price. In case of the same price the time priority for placing bids is valid. GME acts as a central counterparty.

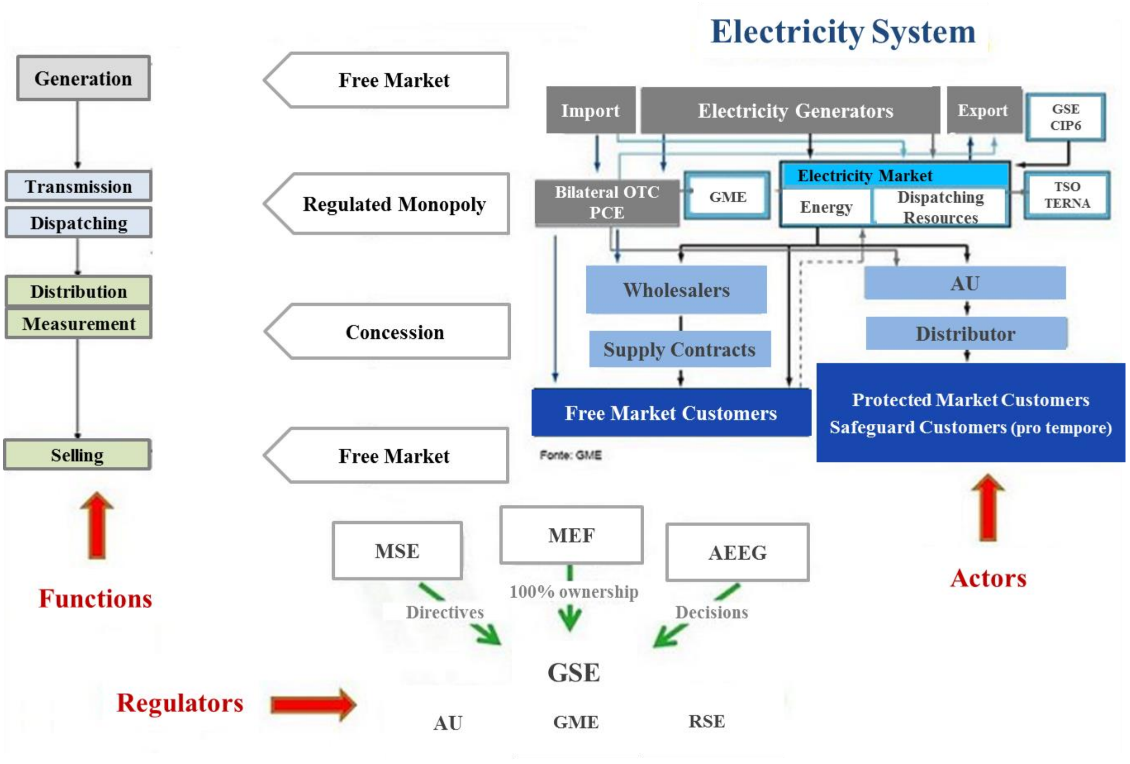

Fig.15 Italian Electricity Market and System (Source GME)

Chapter 2. SUSTAINABILITY AND EFFICIENCY ISSUES IN THE ELECTRICITY SECTOR

2.1 Global sustainability situation

To make an exhaustive analysis of the sector's issues it is crucial to understand its environmental impact during the last and the next years. The sustainability theme has always been relevant for our world but in the recent years it is becoming more and more actual thanks to a bigger interest by medias, because the population is starting to see the consequences on daily lives with high level of pollution, climate change and more natural disasters and thanks to agreements and global goals fixed by international organizations in order to promote sustainable development. An example is the global indicator framework for Sustainable Development Goals (SDG) that was developed by the Inter-Agency and Expert Group on SDG Indicators (IAEG-SDGs) and agreed upon at the 48th session of the United Nations Statistical Commission held in March 2017 and later adopted by the General Assembly on 6 July 2017 as targets of the 2030 Agenda for Sustainable Development. This framework includes 231 unique indicators that are used to monitor the progression of 17 fixed goals. The 13th says "Take urgent action to combat climate change and its impacts". One of the most discussed themes concerning this goal is related to the greenhouse emissions in the atmosphere, considered by scientists the main cause of global warming. The Kyoto Protocol says that those gases are the Carbon Dioxide (CO_2), the Methane (CH_4), the Nitrous Oxide (N_2O), Hydrofluorocarbons (Hfcs), the Sulphur Hexafluoride (SF_6) and Perfluorocarbons (Pfcs).

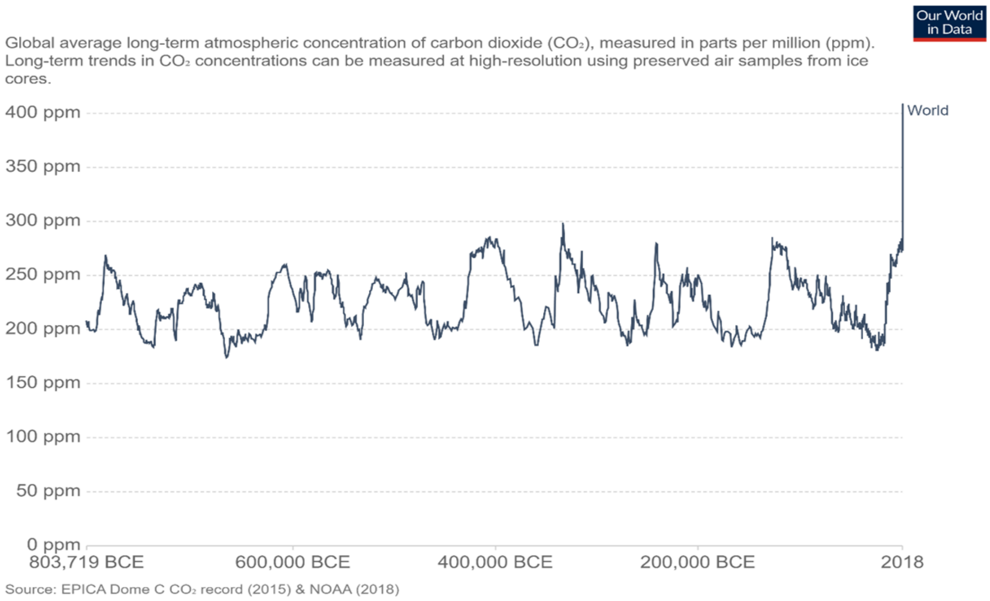

Fig.16 Atmospheric CO_2 concentration (Source Our World in data)

After a short look to data exposed in the Fig.16, the increase of the CO_2 concentration in the atmosphere is too high to only come from natural causes. And this is also confirmed by a drastic increase of the CO_2 emissions by world region over the years. However, focusing only on Europe and Italy it is possible to see a small decrease that will be analysed later.

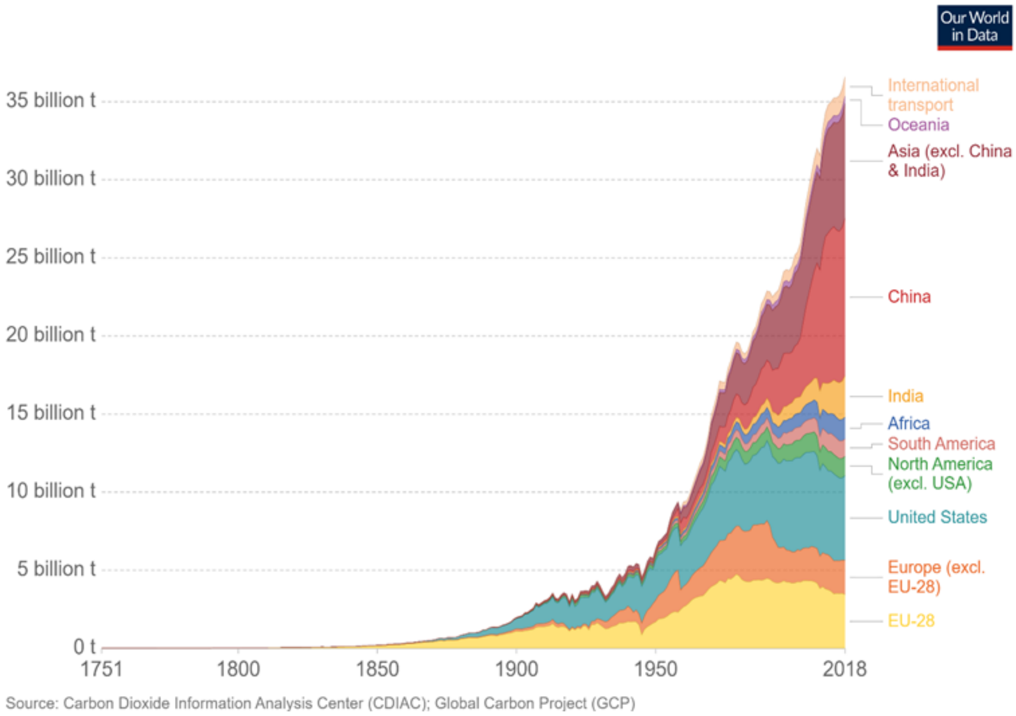

Fig.17 Annual total CO2 emission, by world region (Source Our World in data)

In fact, human activities have impact on different levels: by the consumption of natural resources (mining and water resources), as a modification of the ecosystem (through cementation or deforestation) and as the release into the environment of waste products or in other terms, the emissions of various types of wastes like greenhouse gas.

The consequences of Humans actions on environment have historically been increasing in proportion with scientific progress, economic and demographic growth. Those impacts are monitored by two indicators that are more focused on the consequences of CO2 emissions:

– The *Earth Overshoot Day* (calculated by the international research organization Global Footprint Network): it marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year. The formula is the following:
  "(Earth's Biocapacity/Humanity's Ecological Footprint) x 365 = Earth Overshoot Day".

The *Earth Overshoot Day* this year lands on August 22, this means that in this day the population have consumed four months earlier the whole annual regeneration capacity of the Earth. In Fig.18, it is shown the progression during past years. In 2020 it is highlighted a decrease due to the adjustments made after the Covid-19 pandemic, but the trend is still a worrying increase.

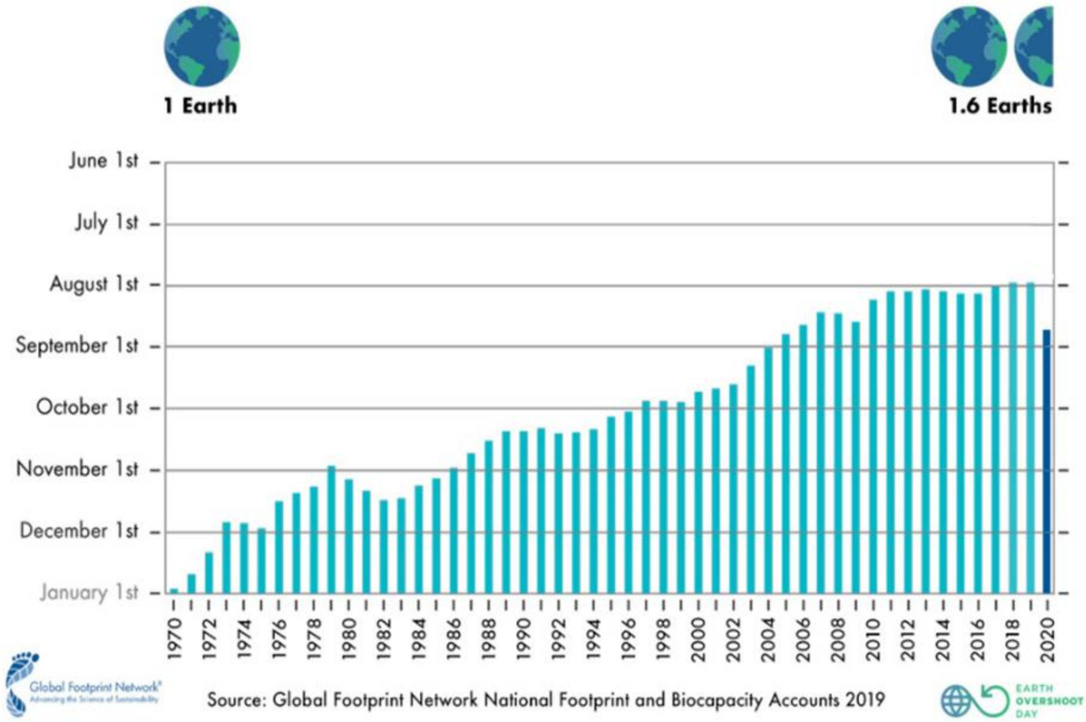

Fig.18 Earth Overshoot day 1970-2020

The figure 19 shows the weight of CO_2 emission in the computation of the *Global Footprint* indicator.

– The *Carbon Footprint*: it is an indicator that expresses the CO_2 equivalent of the total greenhouse gas emissions associated directly or indirectly with a product, organization or service.

To measure those CO_2 equivalent it is required the identification and quantification of the consumption of raw materials and energy in the selected phases of the life cycle of the product or the process.

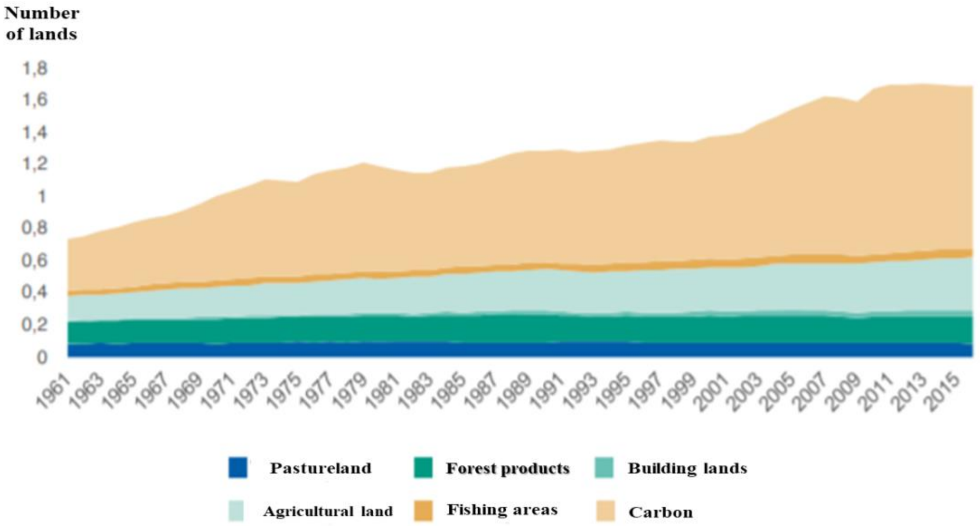

Fig.19 Weight of CO_2 in the computation of the *Global Footprint* indicator
(Source Global Footprint Network)

2.2 Electricity sector impact in sustainability theme

The reason why these sustainability problems are related to the energetic sector is because as those indicators show the emission of carbon dioxide and in general greenhouse gas represents the biggest threat for the planet and the process of electricity creation is one of the main cause of those emissions.

Indeed, the main source of energy production, as it is showed in Fig.20, remains linked to fossil fuels (gas, coal and oil represents more than 85%) therefore the typical waste product of the combustion processes that are necessary for the operation of the electricity plants is mainly CO_2 and in consequence the environmental impact of the energetic sector is very high in particular from the point of view of greenhouse emissions in the atmosphere.

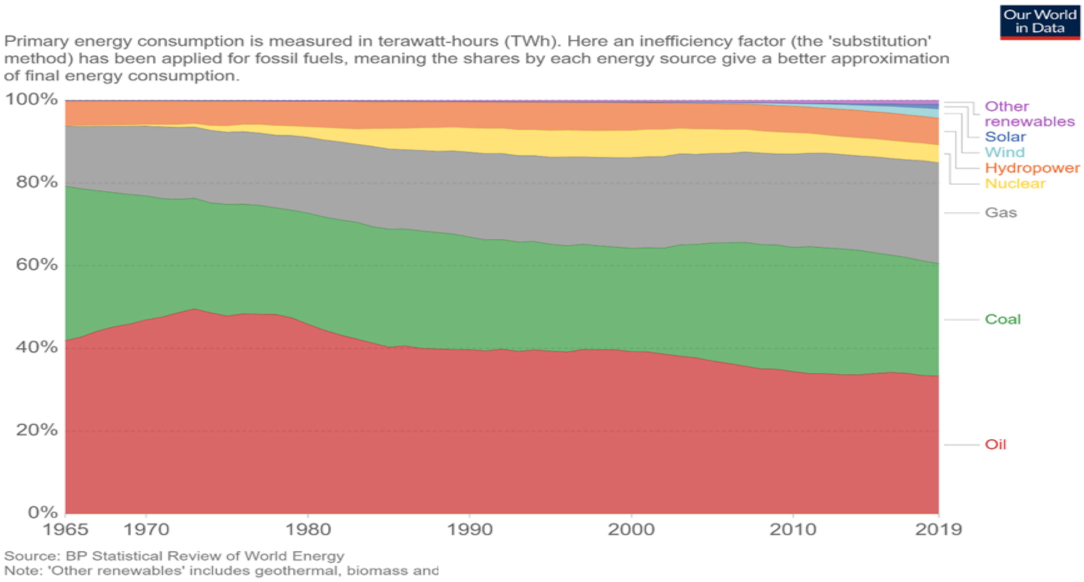

Fig.20 Energy Consumption by source (Source Our World in data)

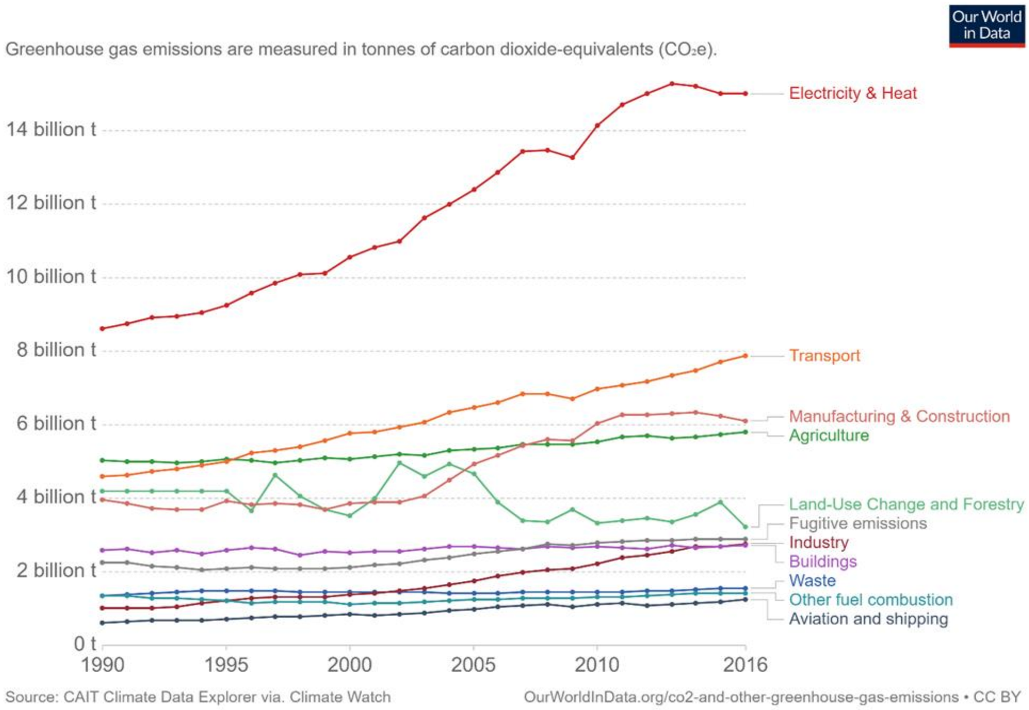

Fig.21 Greenhouse gas emission by sector, World (Source Our World in data)

Moreover, as mentioned before, the global energy production follows the huge increase of primary energy consumed. Indeed, in the last century, and in particular since the second half of the twentieth century, world consumption of primary energy has grown exponentially: about 248% between 1950 and 2019 as it is shown in Fig.22.

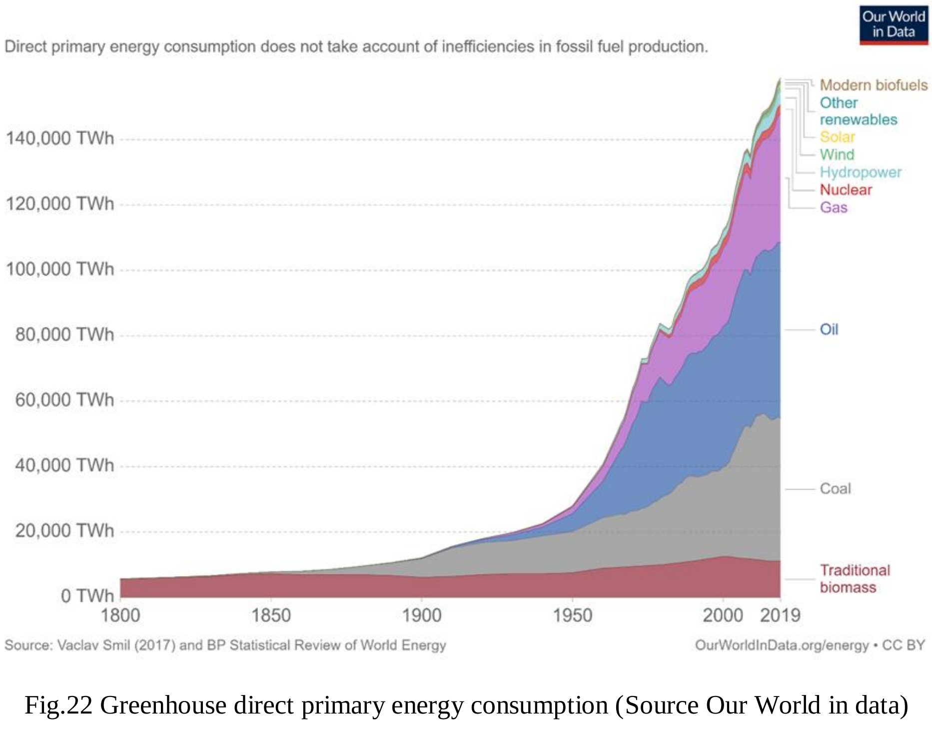

Fig.22 Greenhouse direct primary energy consumption (Source Our World in data)

This means that the increase in emissions at this rate has no hope of being thwarted. The only solution is the recent decarbonisation programs and large investments in renewable energy which, as it has been exposed in Figure 17, it has led to a slight reduction in CO_2 emissions in Italy, Europe and United States. The Figure 23 shows the variation in renewable investment from 2004 to 2015 in the world. It was intuitive to imagine that, below China and Asia which are respectively the first and the third for investment but also the first for CO2 emissions, there are Europe and America that are for instance starting to see the benefits of their actions in particular thanks to the impressive growth in investments in 2011.

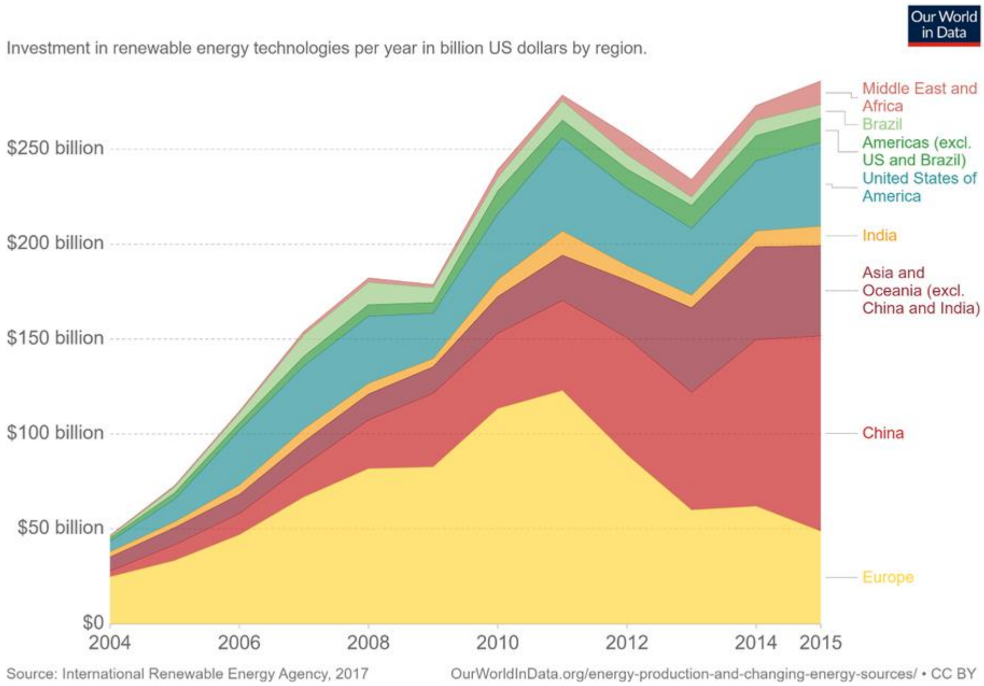

Fig.23 Renewable Energy Investment (Source Our World in data)

However, these efforts and this very limited decrease are not enough to support the increase in consumption and production. Greenhouse gas emissions and global temperatures do not appear to be halting and the global share of primary energy supplied that comes from renewable resources appears to be decreasing, when the primary objective is to considerably increase it until it becomes in the future the majority one (Fig.24).

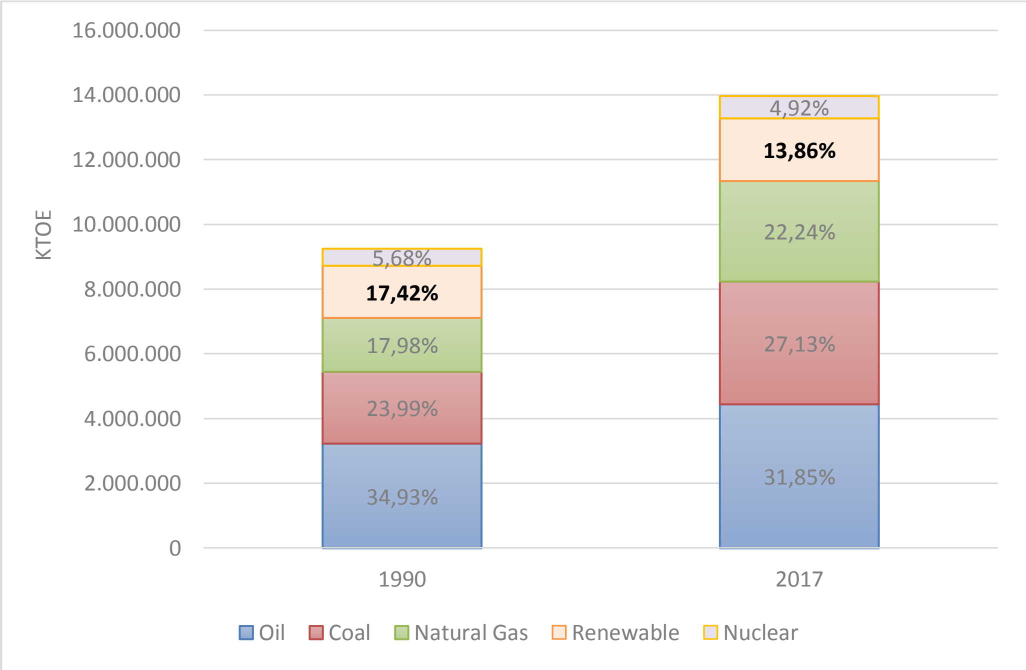

Fig.24 Global share of primary energy by source (Source World energy outlook 2019)

According to the chart below it is possible to understand which is the actual quote of renewable sources in the different energetic sectors.

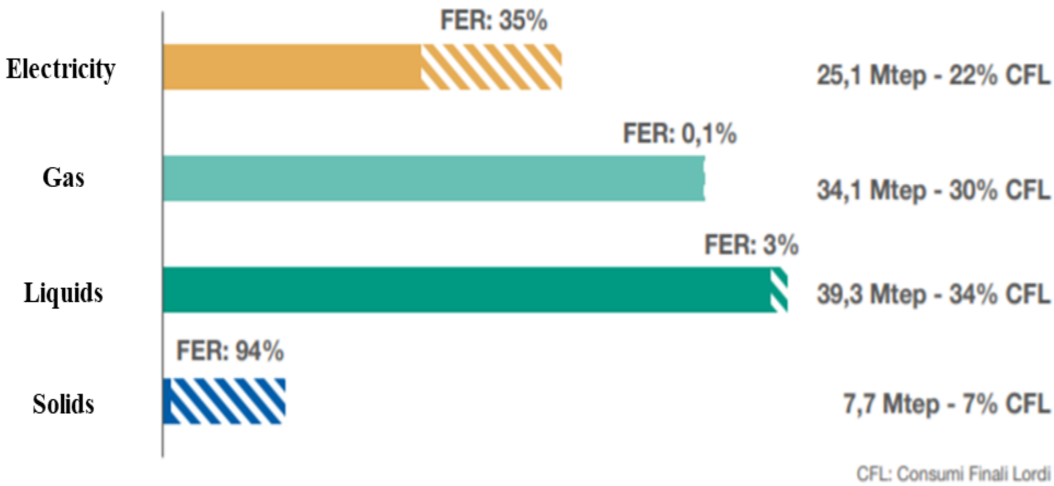

Fig.25 Distribution of final energy consumption by energy carrier and differentiation between conventional and renewable energy sources (Source Eurostat – Elaboration: TERNA)

The Gas and Oil one cover 64% of the total energy consumption and today the production mainly comes from fossil fuels (oil derivatives for the transport sector, natural gas for residential heating and industrial consumption).

Only the 3% in liquids and 0.1% of gas, comes from renewable sources and is mainly associated with biodiesel.

Solid fuels sector represents only 7% of global energy consumption and have a high proportion of Renewable Energy Sources (RES): about 95% that mainly comes from biomass.

The electricity sector cover about 22% of global consumption and counts approximately 35% of energy from renewable sources, mainly coming from energy production through hydroelectric, solar and wind power plants (the chart below show the evolution of the renewable energy produced by source in Italy). It is a sector where there are several possibilities to innovate and to increase the quote of RES.

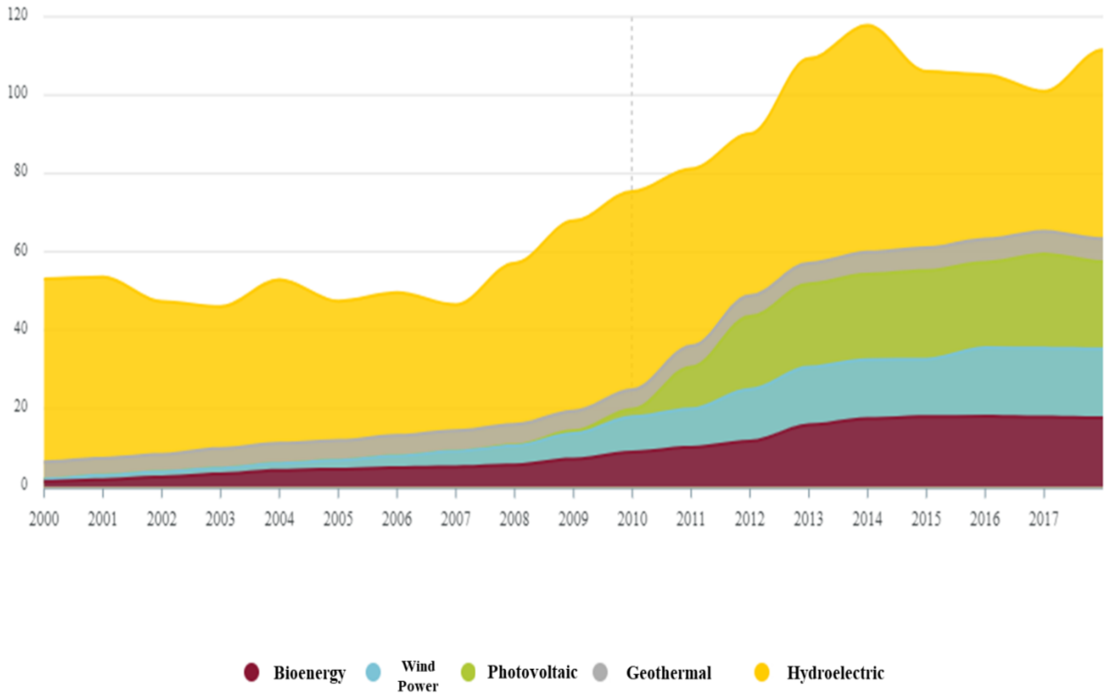

Fig.26 Evolution of renewable energy produced by source in Italy (Source TERNA)

2.3 Renewable energy

Therefore, it seems clear that the current situation is very problematic and that there is a need for an acceleration of the implementation of international and national solutions.

The right way seems to focus more on the electricity sector through the electrification of the consumption, a key tool to reach the goals set by the United Nations and that could enable the transition to a decarbonised system.

A greater penetration of the electric energy consumption in the residential, industrial and mobility sectors, together with the increase in the share of renewables in the energy production mix are crucial tools to change the energy paradigm and improve the quality of life. In this way the weight of gas and oil sector would decrease leaving space for an increase of the electric one.

This change must come from the national point of view and in Figure 27 it is possible to see the evolution over the years of the resources uses in the Italian electric sector and a comforting increase in the renewable percentage.

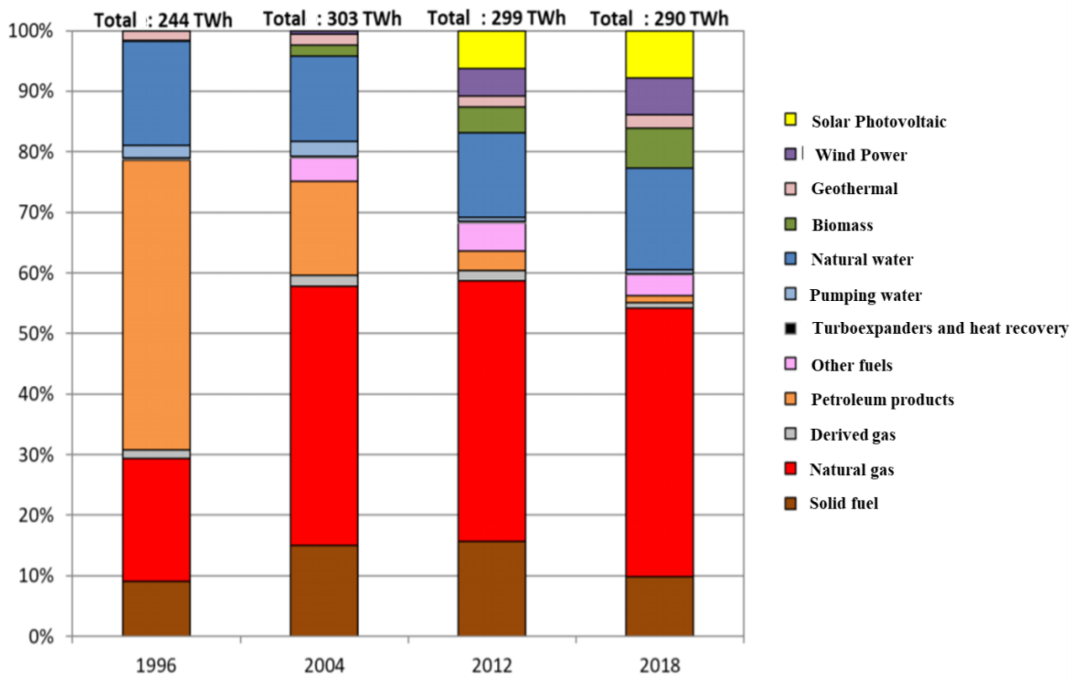

Fig.27 Variation of the production mix in Italy (Source ARERA)

However, there are some problems that slow down this energy transition and they may relate to several matters as incentives, higher costs of renewable energy production, infrastructure changes need, increase in the difficulty of manage a greener grid, the nature itself of the sources and many others.

One of the main characteristic that distinguishes renewable electric plants from traditional ones and that could lead to bigger problems is that by their nature, they are characterized by non-programmable production profiles. It means that the production depends on the presence or absence of the resource which by its nature is intermittent, such as the sun or the wind.

This implies that the electricity produced by these plants does not follow the logic energy demand, but only dynamics related to the single energy sources. The main example is the photovoltaic production that is high in the middle of the day and null at night.

Moreover, concerning the specific geographic Italian case, the growth of RES plants occurred unevenly on the territory and it was only based on the presence of the source and often not consistent with the location of consumption places.

In fact, the construction of RES plants takes place according to logic that prefers the positioning in areas that offer the best conditions of production, availability of resources and simplicity of the authorization path. In few words they did not and they are not taking into account the potential of the energy consumption network.

According to the map, it is possible to see how the wind energy production plants developed for more than 80% in the south of Italy and in the two islands, taking advantage of the characteristic wind power of this part of the peninsula and on the contrary, the photovoltaic energy plants are more distributed and still are more concentrated in the North of Italy with about 44% of the national photovoltaic power.

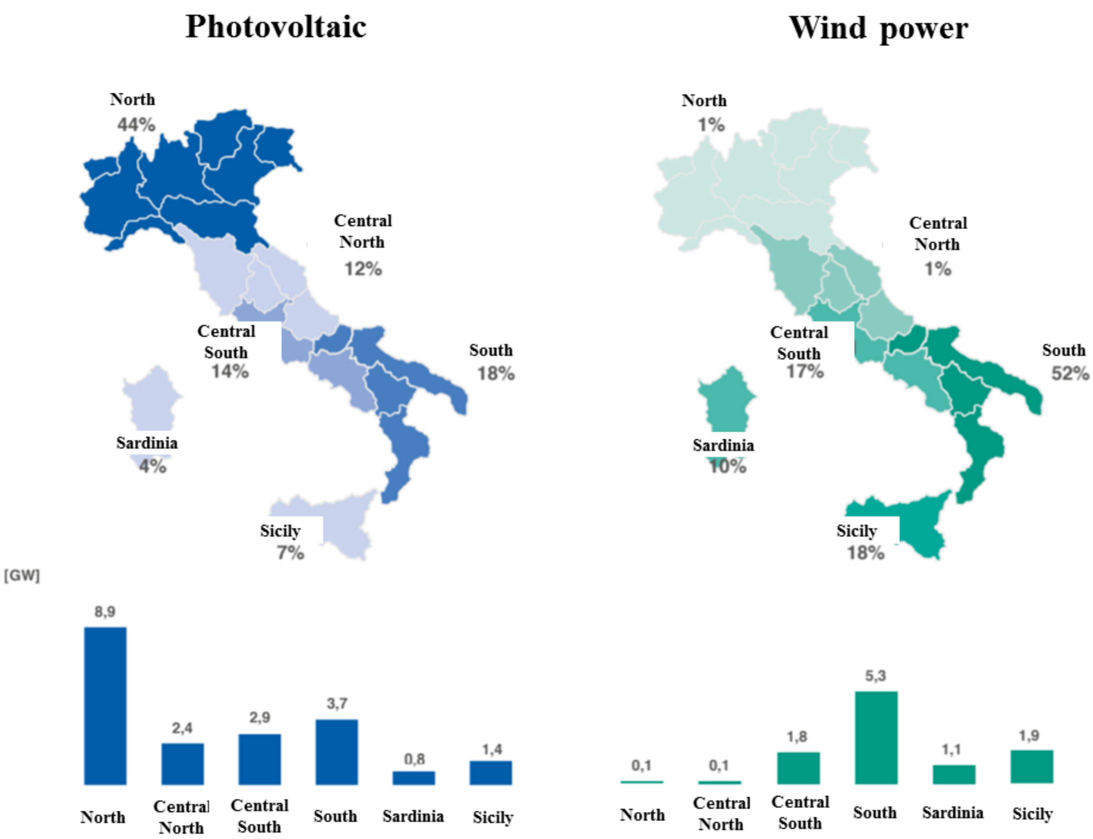

Fig.28 Photovoltaic and Wind power (Source TERNA)

Then the location of Italian plants is also related to technological attributes.

In fact, the development of wind and photovoltaic plants has taken place heterogeneously also in relation to the voltage levels of connection. The wind energy plants are installed for 90% only on the high-voltage grid and photovoltaic energy plants have been built for about 95% on the distribution networks (Medium and Low Voltage): 822.000 plants of the 837.000 total located in the distributed generation come from the solar technology.

All these issues concerning renewable energy production plants lead to several consequences: whereas, as it has already been said, unlike fossil fuels and water sources, "new" renewable sources cannot be used where necessary or where electricity must be available to cover the load, the problem that arises is that electricity is not cumulable but, at the most, through storage systems, it can be converted into other forms of energy from which it is possible to produce electricity again (such as pumping, electrochemical batteries or power to gas systems). However, this process is characterized by high costs and energy conversion losses.

This led to a change in the last years flows of electricity in Italy on the National Transmission Network. In fact, the abundance of new renewable sources especially in the south where the electricity demand is lower causes an inversion of the flow on the transmission network: electricity no longer flows from north to south as in the past but from south to north and from islands to north.

This change in the electricity flow has also taken place on the distribution level. In fact, the spread of the distributed generation (realized for the purpose of using renewable sources, even distant from the places of production), increases the possibility that the electricity produced is not only self-consumed on site or locally. Therefore, the electricity fed into the low or medium voltage electricity networks must be transported elsewhere, raising it of voltage and involving the phenomenon called flow inversion: the electricity that historically flowed on the distribution networks from high voltage to medium and low voltage, can now rise in voltage to be transported and consumed elsewhere.

All these matters have increased the network congestion in the transmission and distribution grid and may require major infrastructure interventions.

Moreover, another impact of the increasing incidence of non-programmable sources and the simultaneous decrease of programmable ones is that as a result, reserve margins are reduced (the power available during the hours when it is necessary to satisfy the electricity consumption in the absence of other production plants), making the system not appropriate to cover the load, as well as the resources for the so-called ancillary services (services that require plants capable of modifying their production as necessary to ensure the correct grid frequency values and the correct voltage profile, as well as to cover the load at any time) which can be a problem for the safe operation of the electrical system.

Finally, plants powered by renewable sources and equipped with inverters mentioned earlier, are characterized by low inertia: this means that, in a system characterized by their presence after a disruptive event on the networks, the frequency decreases more and more quickly than in the case of a system with high inertia or with high presence of traditional plants (due to the rotating masses of the turbines that distinguish the thermoelectric plants of high size), requiring new and timely restoration.

Therefore, all these characteristics of renewable plants evolution, which lead to the just mentioned problems, highlight the need for some improvements necessary to promote sustainable development and at the same time the efficiency of the sector.

In fact, infrastructure developments are required: the strengthening of electrical connections and new developments to transport energy from the place of production to the one of need.

In addition, the most important point is that there is a need for greater coordination in the field of electrical dispatching: the absolute importance of the coordinated operation of production units and consumption units is now clear. Today more than ever, there must be a safe, transparent and real-time control and communication of information regarding the balance between demand and energy supply, thus ensuring the safety of the new electricity system.

Currently in Italy, in order to promote the development of renewable energy production, there are some special market mechanisms and regulatory incentives. In fact, electricity produced from renewable sources can access the market in several ways like through direct access (through the power exchange or direct transfer to traders), through indirect access (by dedicated withdrawal regime) or through on-site exchange (for plants up to 500 kW).

Regarding the dedicated withdrawal, it can be applied to plants with a power of less than 10 MVA (whatever the source) and to plants powered by non-programmable renewable sources of any size, with the exception of plants that benefit of feed-in tariff incentives (which already include the value of electricity) and plants that benefit of particular incentives (from inter-ministerial decrees no.5 and 6 July 2012, 23 June 2016 and 4 July 2019).

The dedicated withdrawal does not include incentives but benefits from some simplifications and advantages. The GSE plays the role of sole commercial intermediary between producers and the electricity system, with transparent and uniform rules throughout the country. In this way, producers turn to it to stipulate the convention that regulates the commercial withdrawal of energy, replacing any other contractual fulfillment without submitting to the procedures for access to the exchange and transport of the energy injected. In addition, unlike the free market, the price of electricity withdrawal is not subject to negotiation between the parties, is defined by the Authority and is equal to the hourly zonal price that is formed on Day-Ahead Market (MGP). The electricity withdrawn by the GSE is then placed on the market without any additional cost to the community.

In addition, for some types of renewable plants (nominal electrical power up to 1 MW) limited to the first 1.5 GWh energy released on an annual basis (2 GWh in the sole case of plants fed by biogas from anaerobic fermenters, solid biomass and liquid biomass) there are also minimum guaranteed prices that represent the minimum guaranteed remuneration whatever the trend of the electricity market. This is in order to protect and secure the survival of small plants that use marginal renewable resources that could not be used otherwise.

However, as illustrated in the figure below, the evolution of electricity withdrawn by the GSE as part of the dedicated withdrawal is decreasing especially in recent years due to the voluntary exit of many plants.

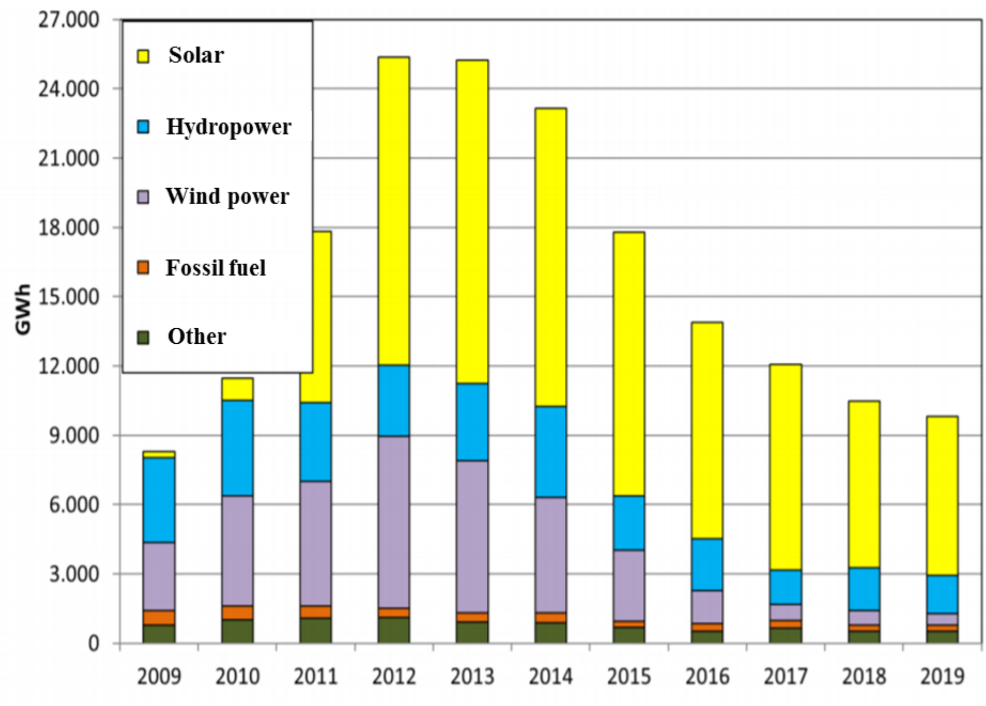

Fig.29 Amount of electricity withdrawn as part of the dedicated energy withdrawal (Source ARERA)

With regard to the on-site exchange, it can be applied to plants powered by renewable sources and cogeneration ones with high efficiency power up to 200 kW, as well as to plants powered by renewable sources up to 500 kW if they entered into operation in 2015.
The on-site exchange is a regulatory instrument that allows to economically compensate the batches of electricity fed into the grid at a certain hour with those corresponding to the energy taken from the grid in a different hour.
Finally, in Italy there are also many different incentive mechanisms to encourage the production of electricity from renewable sources. Specifically, there are economic price instruments: the feed in tariff (all-inclusive incentive tariffs) and the feed in premium.
There are also some obligations and taxes such as the obligation to install plants powered by renewable sources provided by Legislative Decree no.28/11 in the case of construction of new buildings or major interventions and tools such as tax deductions, non-refundable grants awarded locally and various kinds of exemptions.
However, although this is the right path to push for a radical change, what would really be necessary for the integration of these technologies in the market would be their real economic convenience outside of incentives and dedicated withdrawals.
Unfortunately, as already said several times, costs are still too high compared to competing sources but a change in the current market structure could be the solution.
First of all by going to certify in a definitive and safe way the energy produced from renewable sources, so as to reward the producers who rely on these technologies and the companies in the retail sector that provide this energy to end consumers.
Secondly by going to make the whole system transparent, especially to the end user, increasingly aware of the environmental problems that assail the planet but unable to make a real contribution that should come through a conscious choice of the type of electricity that consumes and purchases.

2.4 Network Congestion

In this paragraph it will be explained the shortcomings in the efficiency of the electricity sector and then observe the perception of the final consumer who plays a crucial role from which it will be possible to understand if and when the energy transition is possible and successful.
In fact, it is the end user who could drive the change and push companies to a more transparent management of electricity supply. Currently, as it will be seen with the help of

a survey made to a sample of people, consumers may not have a complete view of the market but may be very eager to have it in order to get more information.

Initially, it is important to clarify that in the electricity sector, efficiency means the ability to manage the system in compliance with safety, adequacy and quality requirements, at minimum overall cost to the end consumer.

Safety refers to the ability of the electricity system to withstand changes in the state of operation following sudden disturbances, without any violation of the system's operating limits.

Adequacy, on the other hand, refers to a system with sufficient production, storage, demand control and transport capacity to meet the expected demand, with a margin of adequacy in any given period. It therefore measures the capacity to meet the load at any given time, taking into account fluctuations in demand, the potential unavailability of thermoelectric plants and the uncertainty of non-programmable energy production plants.

Finally, living in a society in which the presence of electronic components is increasing and in which the objective remains more and more the electrification of consumption, the quality of service understood as the ability to ensure continuity of service (lack of interruptions in the supply of electricity, frequency and voltage within the permissible ranges) and the quality of the same (voltage level, waveform, etc.) is fundamental for an efficient electrical system.

The efficiency and so the management of these three aspects has always been complex in Italy but now it is even more difficult to keep up with the current energetic transition. The impacts of these factors combined with the Italian context can be seen on various levels and first of all, at the level of the National Transmission Grid.

The Italian Electricity System presents some unique characteristics, linked to its geographical configuration. As a matter of fact, Italy borders with Continental Europe only through the Northern border and is crossed longitudinally by mountain ranges and has two large islands. As a result, almost all the interconnection capacity with foreign countries is located on the northern border, while at national level there are structural bottlenecks between the different areas of the country, which cause difficulties in optimizing energy flows, causing the already mentioned network congestion.

The low level of transmission capacity, as we have already explained above, determines the need to separate the electricity system into different "market areas".

The current design of electricity markets in Italy provides, in fact, in line with the European framework, a representation of the National Transmission Grid through a simplified structure that appropriately aggregates the nodes of the electricity grid. The possible exchanges of energy between adjacent market areas are opportunely limited in order to implement, in the algorithms of selection of offers for the energy markets, the constraints arising from the limited network transport capacity. Instead, energy trading within each market area is free from constraints.

Precisely to solve these problems, in 2018, TERNA completed, in accordance with the European Regulation, a review process after which ARERA approved a process of progressive adaptation of the zonal structure to the new needs and evidence of the National Electrical System. In particular:

- In 2019 the limited production hubs of Brindisi, Foggia and Priolo were eliminated; as we have already explained in the previous chapter, Italy consists of 6 market areas, North (NORTH), Centre North (CNOR), Centre South (CSUD), South (SOUTH), Sicily (SICI), Sardinia (SARD), plus the Rossano limited production hub.
- In 2021 the Rossano limited production pole will be replaced by the Calabria area and the Umbria region will be moved from the Central North to the Central South area.

The exchange capacity between the different zones depends on the availability conditions of the network elements as well as the load and generation conditions.

TERNA takes into account the signals coming from the electricity market in the planning process of the National Transmission Grid, in order to solve the problems related to the presence of grid congestion. In this regard, the planning objectives mainly consist in reducing congestion between market areas and intra-zonal congestion, in order to allow a better use of the national generation park and a greater integration and competitiveness of the market.

However, the management of these congestions, which have been greatly amplified due to the advent of renewable energy production in a decentralized manner and the inversion of electricity flows from South to North, is very complex and in order to achieve this goal a technological push would be needed as well as a revision of the zonal structure.

2.5 Distributed generation management

As already widely exposed, the development of renewable plants and the way in which it is happening involves a radical change for the electricity system. What is going to be impacted is the traditional structure of electricity generation in Italy. In fact, it is moving from a "one-way" system based on a few large thermoelectric plants connected to high and very high voltage networks and located far from consumption points, to a "multidirectional" system, where energy production is increasingly decentralized and extremely complex to manage. In Italy, in fact, there has gone from about 3,000 production units at the beginning of 2000 to over 800,000 connected to the electrical system today. Almost all the generation systems (over 99%) are installed on Distributed Generation (medium and low voltage networks), which has 837,000 and, as already mentioned, photovoltaic represents the largest share with 822,000, covering over 65% of the installed power.

Speaking just of generation power distribution, the situation is different. In this case Distributed Generation covers about 25% of the Italian generation power, that is about 28 GW compared to about 117 GW installed in total (Figure 30).

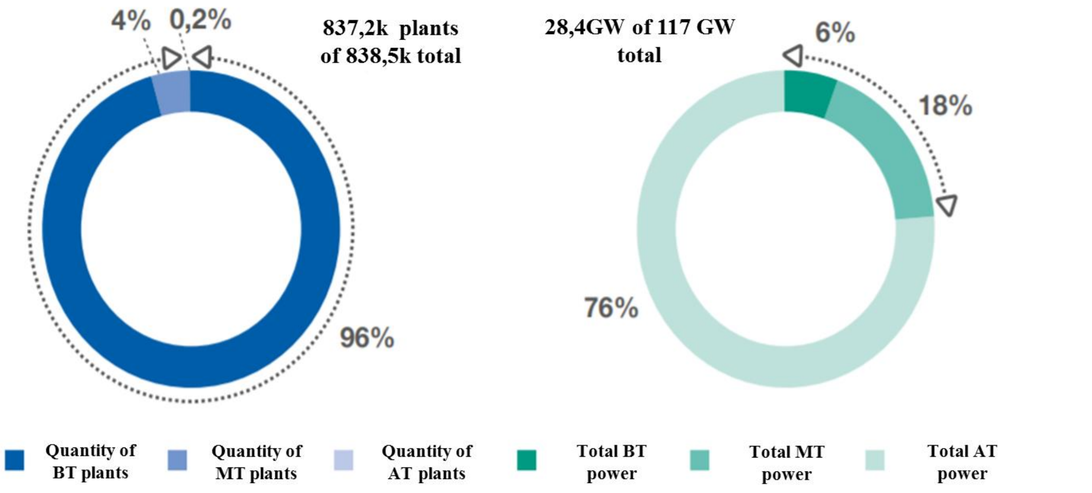

Fig.30 Distribution systems by network voltage level (number and power) (Source TERNA)

As far as electricity production is concerned, in recent years, distributed generation has assumed a significant weight, reaching, in 2017, to cover about 22% of gross national production (over 64 TWh) (Figure 31).

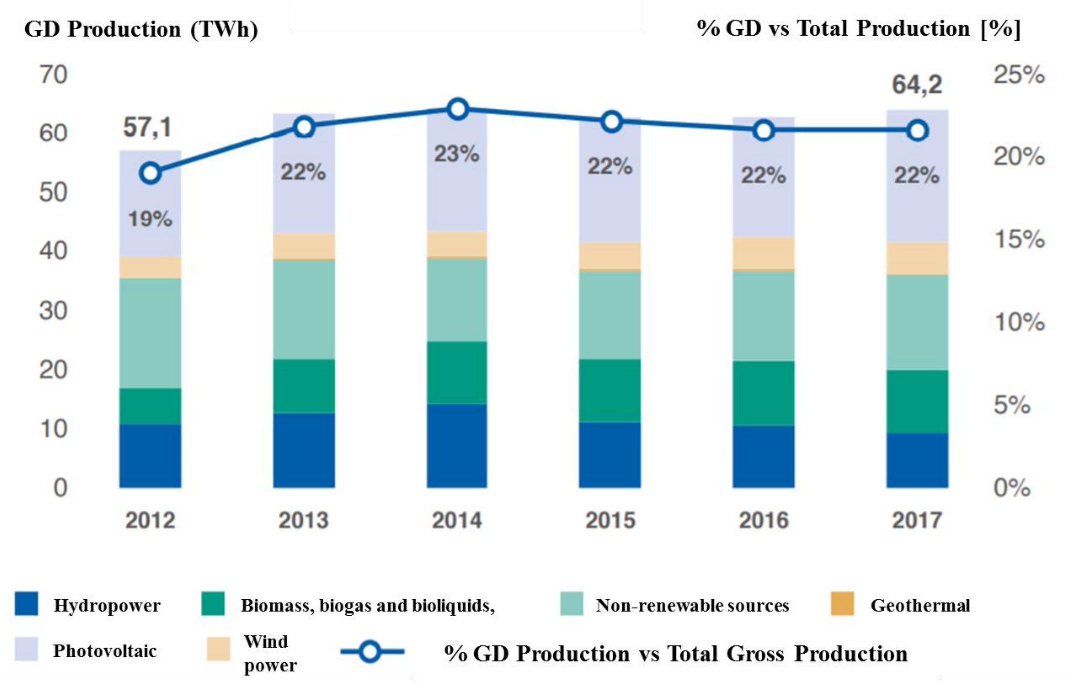

Fig.31 GD gross production per source (Source TERNA processing on ARERA basis)

It is therefore clear that the role of Distributed Generation in the electricity system is growing and will grow further in the coming years, especially in view of the evolution scenarios foreseen in the proposed Integrated National Energy and Climate Plan (PNIEC). This phenomenon of decentralization of generation brings with it a series of relevant implications related to the security of the system that will have to be managed at the lowest possible cost in order to ensure the efficiency of the sector.

Together with Distributed Generation and decentralization, the self-consumption of energy, which has increased in the last 7 years with an average rate of 2.5% and represented, in 2018, about 10% of final electricity consumption, is becoming increasingly important (Figure 32).

However, it is not yet structured in order to promote renewable production and the only existing incentive is implicit and corresponds to the exemption from payment of system and transport charges, as the regulation provides for the coverage of these charges through a tariff proportional to energy withdrawals.

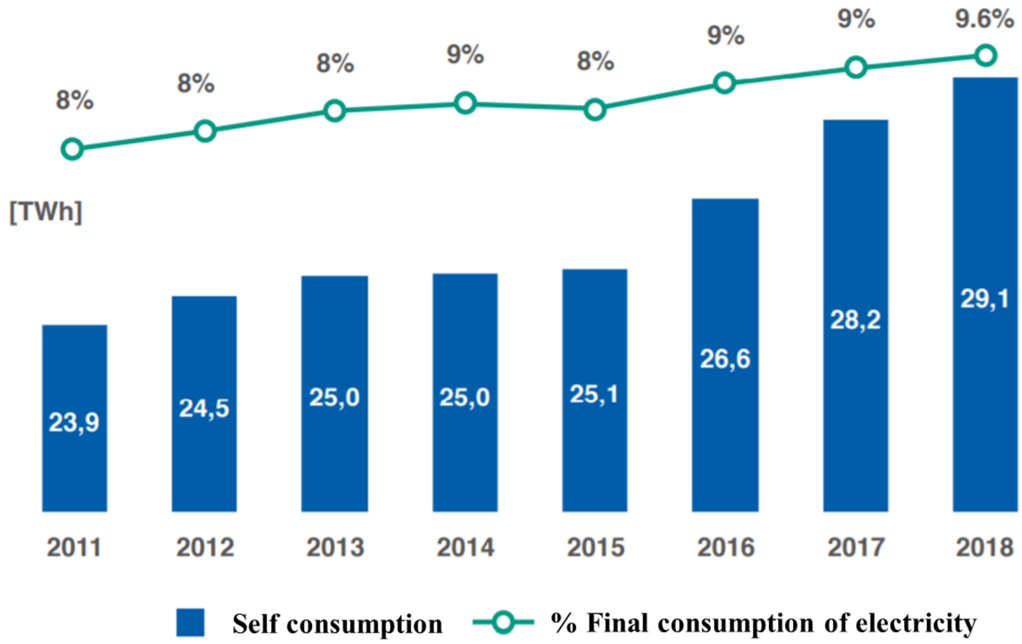

Fig.32 Self-consumption trend and share of gross electricity consumption (Source TERNA)

2.6 Real prices not reflected in the bill

A further impact resulting from the spread of the supply of electricity from renewable sources is at the level of prices.

In fact, the price profile that is formed on MGP has changed. In particular, while historically the highest prices were formed in the daytime hours, corresponding to the maximum demand for electricity in the grid, currently the highest prices are formed in the pre-evening hours ranging from 17:00 to 21:00, i.e. during the hours when photovoltaic production gradually ceases. Figure 33, avoiding to represent the influence of other factors such as the trend of the price of natural gas through the deviation of the average hourly PUN compared to the average annual PUN, shows the radical change in the price profile on the Power Generating Module occurred between 2011 and 2013 and its subsequent stabilization. Although the average price differences between the different hours of the day, on an annual average basis, have been mitigated, the maximum positive deviation from the annual average PUN continues to be more evident in the pre-evening hours, while the maximum negative deviation, which still occurs at night, continues to be comparable with what is recorded in the early afternoon hours.

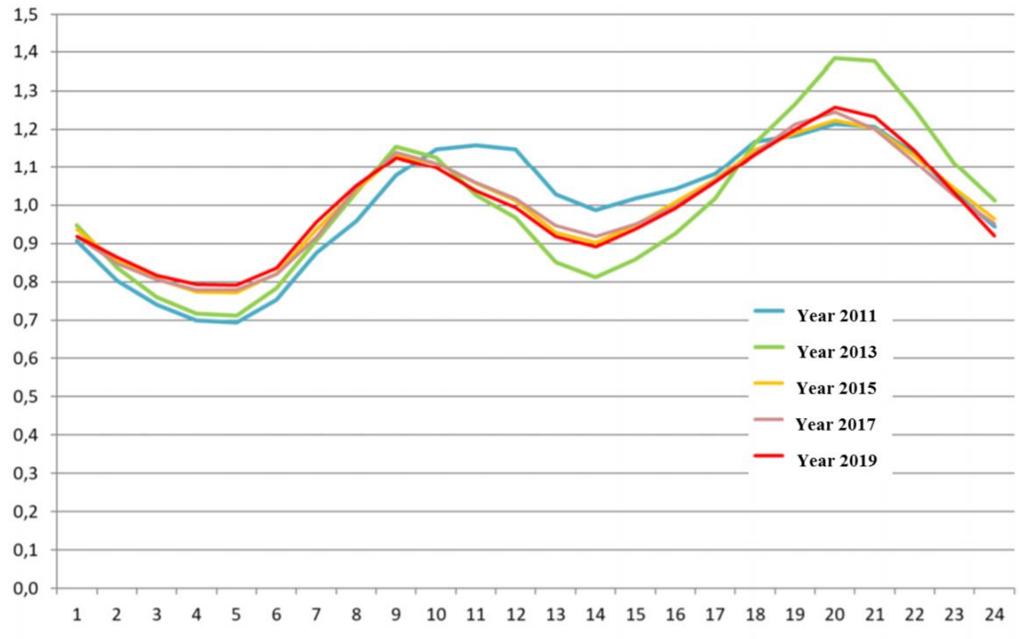

Fig.33 Ratio between the average hourly PUN and the overall average PUN (Source ARERA)

Figure 34 instead, highlights the trend of the average PUN for some recent years. The chart confirms what has been said previously, going to highlight even more the increase of the prices in the pre-evening hours.

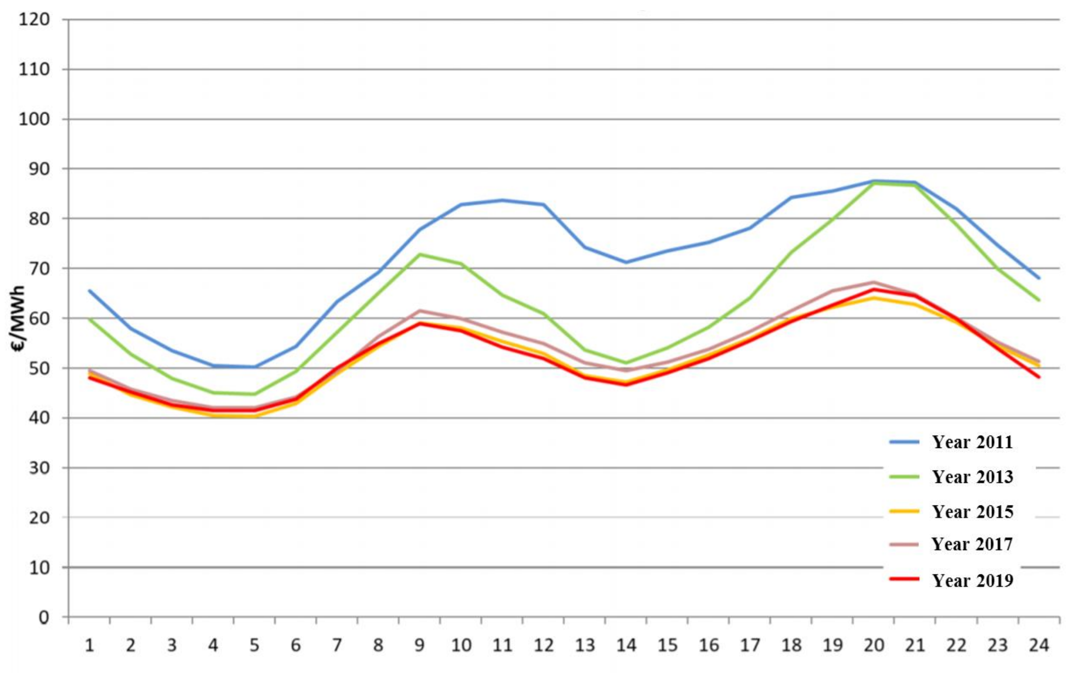

Fig.34 Average PUN trend in recent years (Source ARERA)

This is a problem that has obvious consequences directly on the final consumer because more and more the real price of electricity does not correspond to what the user goes to pay in his bill.

In fact, the expense items on the bill in most cases are divided as follows:

- Transportation and meter management expenses, system charges and VAT expenses. All these items are closely related to the players in the energy supply chain such as distributors, operators and the international market and are mandatory and equal for all suppliers.
- The expenditure for energy represents the specific cost for consumption. It is based on a price that is defined by the supplier according to his own strategies and, of course, according to the prices paid for the purchase of energy in the energy market.

Among the different items included in the bill, the latter is the only one managed and defined only by the supplier, so it represents the real price difference between the offers and it is precisely here that this misalignment between costs and tariffs is created.

The tariffs that can be chosen vary depending on whether the user chooses to stay in the Market of Greater Protection where only single and dual tariffs are offered and depending on whether he takes the decision to switch to the free market where he can choose not only for the previous two but also for tri-hourly tariffs.

The single hourly tariff provides a cost of energy, measured in kWh, equal at any time and for all days of the week, both weekdays and holidays. This means that no change in price is reflected in the bill so as not to allow the end user to consume intelligently and according to the different price ranges that are formed during the day.

The two hourly tariffs, on the other hand, provide for a different energy cost depending on the time of day and day of the week. There are three time bands: F1, F2 and F3. The latter two have been merged into a single band, and this is why we speak of a two hourly tariff.

The F1 tariff, relating to daytime hours on weekdays, applies from 8 a.m. to 7 p.m., Monday to Friday (excluding public holidays) and is usually the one with the highest cost per kWh.

F2/3 applies between 7 and 8 p.m. and 8 a.m. on weekdays and at all hours of holidays and weekends and is the one that is associated with the lowest cost.

As mentioned earlier, the cost of electricity actually reaches its highest peak in the pre-working hours of the F2/3 range and this highlights even more this separation and misalignment that there is between consumers and sellers.

2.7 End user poorly included and informed

The link between the end consumer and the rest of the electrical chain has always been a delicate aspect. Here even more than in other sectors, the end user represents the weak part of the chain, being able to run into information asymmetries and therefore to buy the goods from a certain company without being sufficiently informed. However, as mentioned above, the consumer can generally represent the very element that can trigger the spark of change.

The preferences and opinions on social issues of the end user group have an enormous weight and in some cases can and have forced a sector and companies within it to evolve and adapt in a very short time. See only the number of companies that have launched environmental sustainability campaigns such as H&M in the textile sector with the launch of the Conscious Exclusive line or that have taken steps to reduce the use of plastics. Even a giant like McDonald has had to evolve in order to take on board the increasingly disruptive concerns and protests of people in favor of environmental issues.

The survey that I carried out on a sample of 204 people (in Appendix is depicted the complete survey) had precisely the purpose to highlight the point of view of the electricity consumer and show how there is a clear desire to be more informed on aspects concerning costs and sources used for production in the electricity sector.

The objective was therefore to show that the end user, in addition to being ready for the energy transition, will be able to drive it by pushing more and more towards greater transparency, a greater exchange of information between the various key players in the sector and an increasing promotion of renewable electricity production.

Going more specifically, the survey has showed how important sustainability issues have become in today's society, in fact as shown in Figure 35 more than 95% of people are not indifferent to recent issues on sustainable development and in particular more than 60% follow it with great interest.

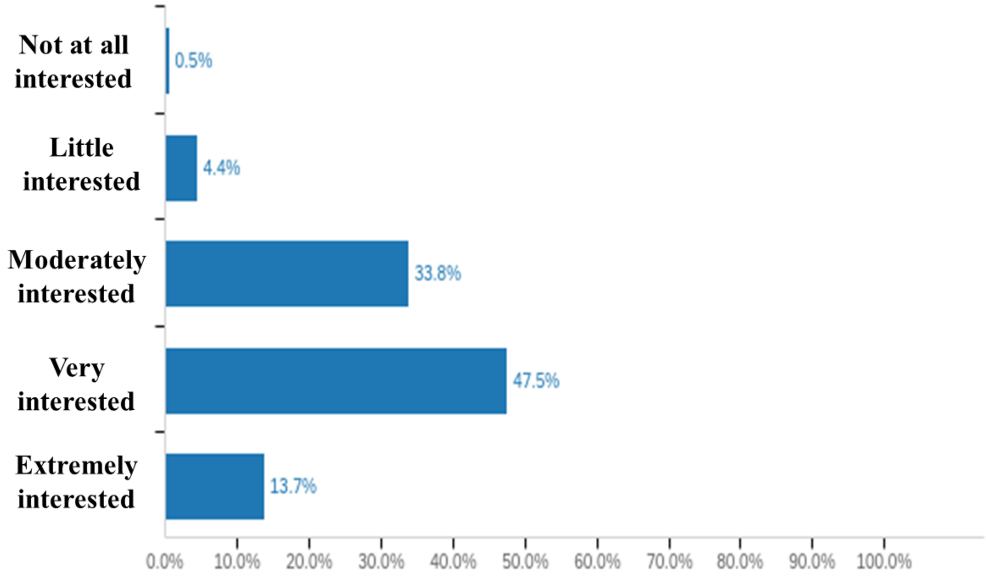

Fig.35 How interested are you in the latest sustainable development issues? (Source L. Mocchetti Survey)

In addition, the consumer is now increasingly critical of the seller and for almost 90% of the sample, it is important that they are actively involved in initiatives to promote the production of renewable energy (Figure 36). This shows how the end user feels the pressures of environmental issues and considers it important that the companies around him act responsibly.

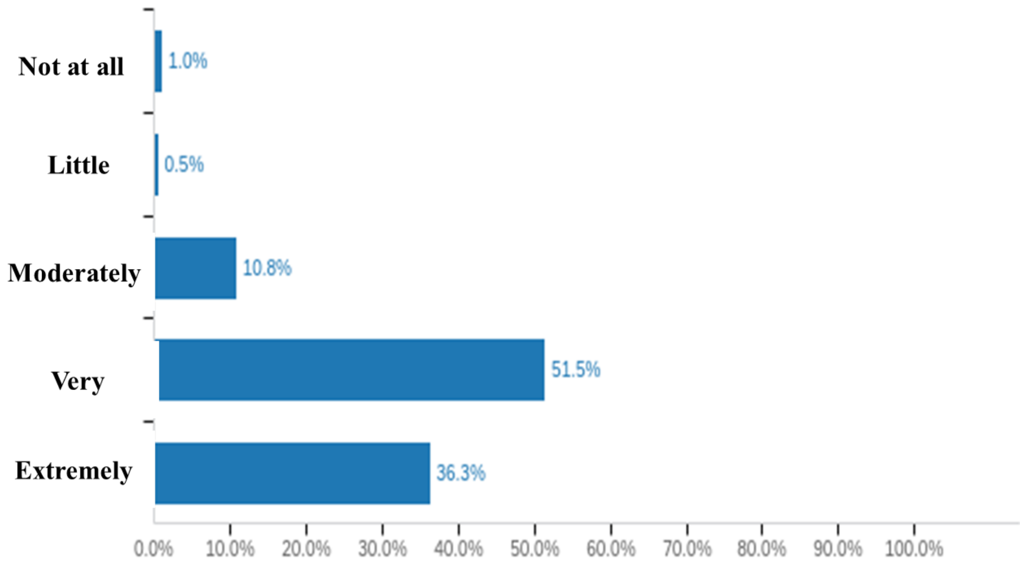

Fig.36 How important is it for you that the company that supplies you with electricity is committed to promoting the production of energy from renewable sources? (Source L. Mocchetti Survey)

However, it is interesting to appreciate how much people believe they can actually contribute to aspects such as reducing greenhouse gas emissions and whether they actually put their efforts into the right actions. The survey has showed that more than 50% of the people surveyed are convinced that their individual actions could lead to a significant reduction in greenhouse gas emissions (Figure 37).

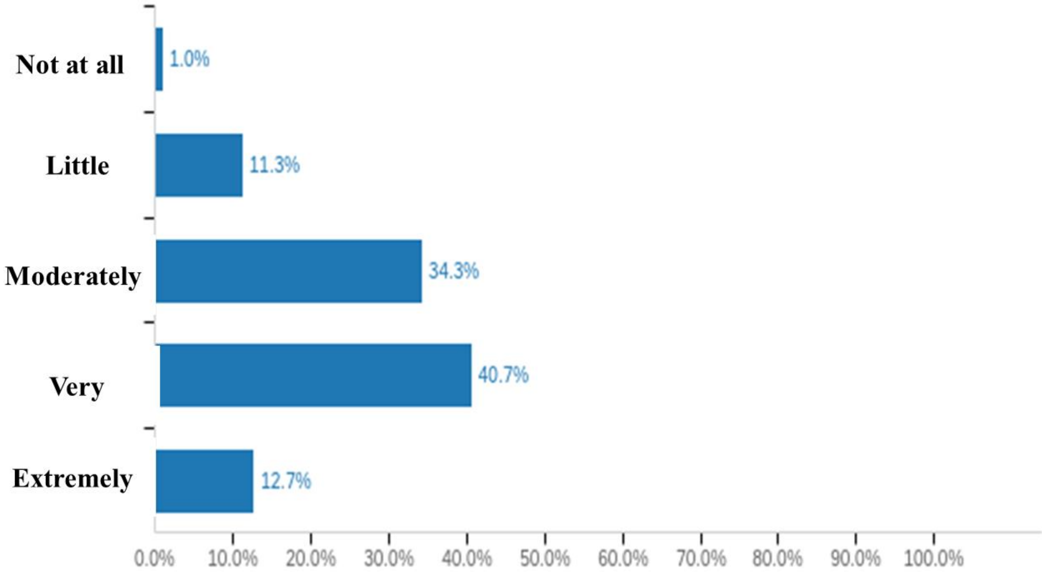

Fig.37 How much do you think your individual actions can impact on the reduction of greenhouse gas emissions? (Source L. Mocchetti Survey)

But what is surprising is that only 15% of them are aware that the sector that emits the most greenhouse gases is the electrical one. In particular, there is a widespread belief that the sector that causes the most emissions is transport (Figure 38).

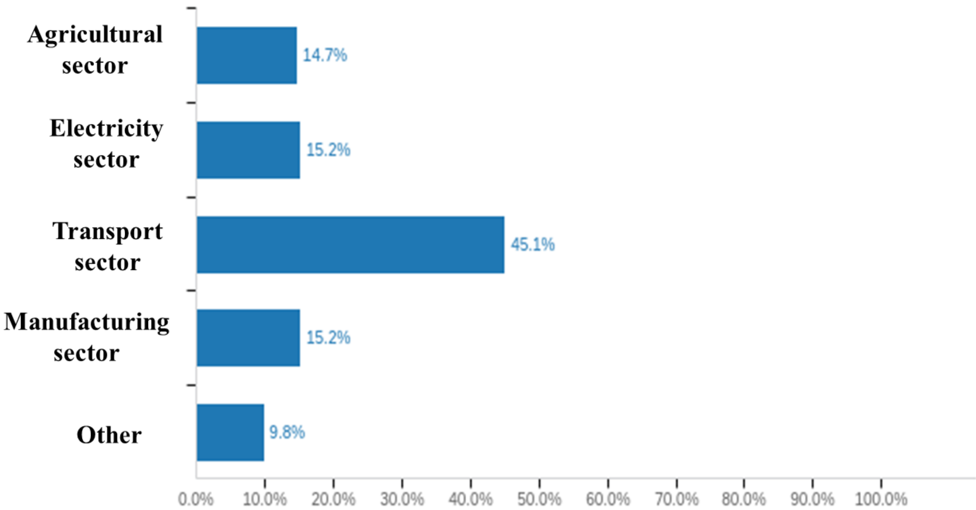

Fig.38 Which sector do you think is the one that causes the most greenhouse gas emissions? (Source L. Mocchetti Survey)

This interesting result shows that people are convinced that they are currently able to contribute a lot to solving environmental problems but that they could actually do much more by focusing on issues related to the electricity sector.

In fact, as it has been previously analyzed, the sector problems are very complex and one of the main concerns is transparency at all levels of the chain.

The survey shows how immediately people see themselves more helpless in the face of the reduction of emissions caused by the electricity sector (while before, more than 50% were convinced that their individual actions weighed heavily on the reduction of emissions, now only just over 20% believe they could contribute to the decrease caused by the electricity sector) and this is explained by the fact that they perceive an information asymmetry and a lack of knowledge of the dynamics within it (Figure 39).

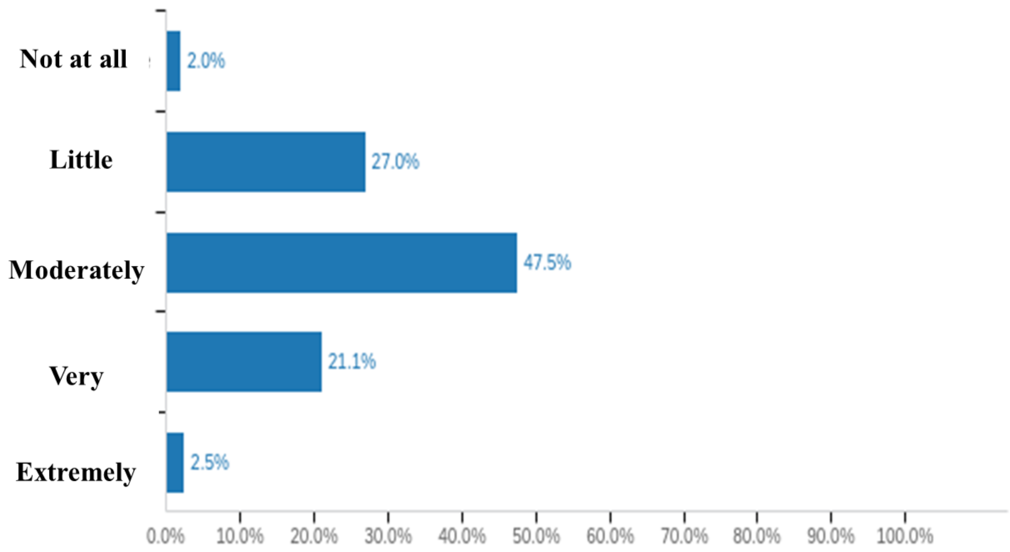

Fig.39 How much do you think you can contribute to the reduction of greenhouse gas emissions caused by the electricity sector? (Source L. Mocchetti Survey)

In fact, one of the most evident data of the survey is that nobody considers himself extremely informed about the world of electricity and only 8% believe he is very well informed (Figure 40).

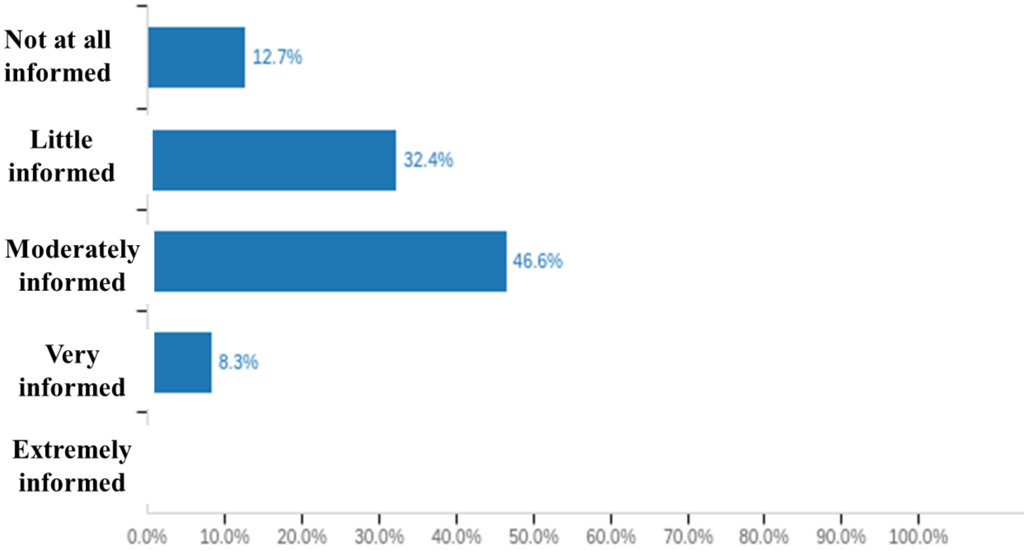

Fig.40 To what extent do you feel informed about the world of electricity? (Source L. Mocchetti Survey)

This perception is reflected in one of the aspects that should be more under control for a buyer: the cost of the good and in this case of electricity. Almost 55% of people say they are poorly informed about how prices are composed on their bill and only 12% believe they are very informed (Figure 41). This shows that information and transparency in the sector is still far behind although the end user is increasingly eager to have control over the management of costs and the type of energy they consume.

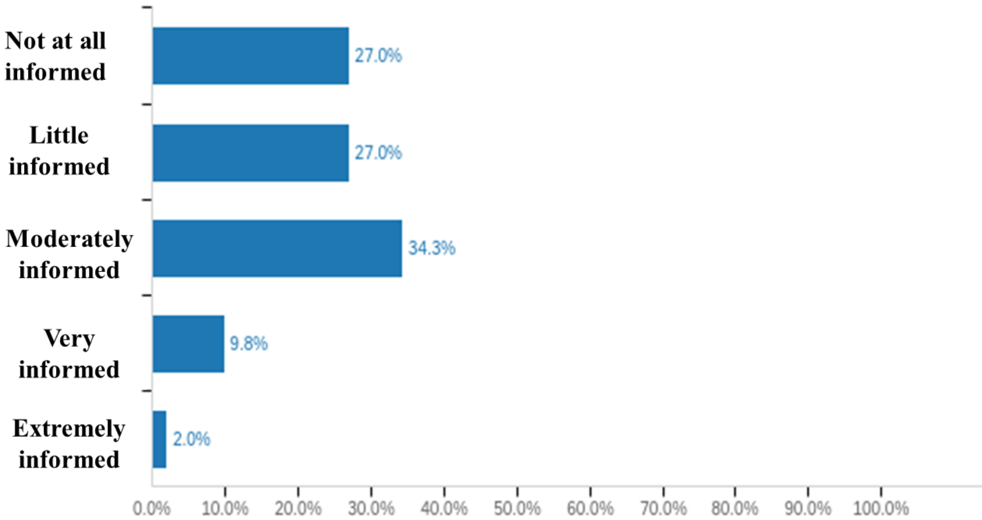

Fig.41 Are you aware of exactly how the costs are divided up on your bill? (Source L. Mocchetti Survey)

In fact, as it can be seen in the charts, about 60% of the users show a lot of interest in having more control and visibility of the electricity cost (Figure 42) and even more than

70% to have more information about the energy sources they consume (Figure 43). This highlights how the user's top priority is now in sustainable issues and how management costs, although very important, has moved to second place.

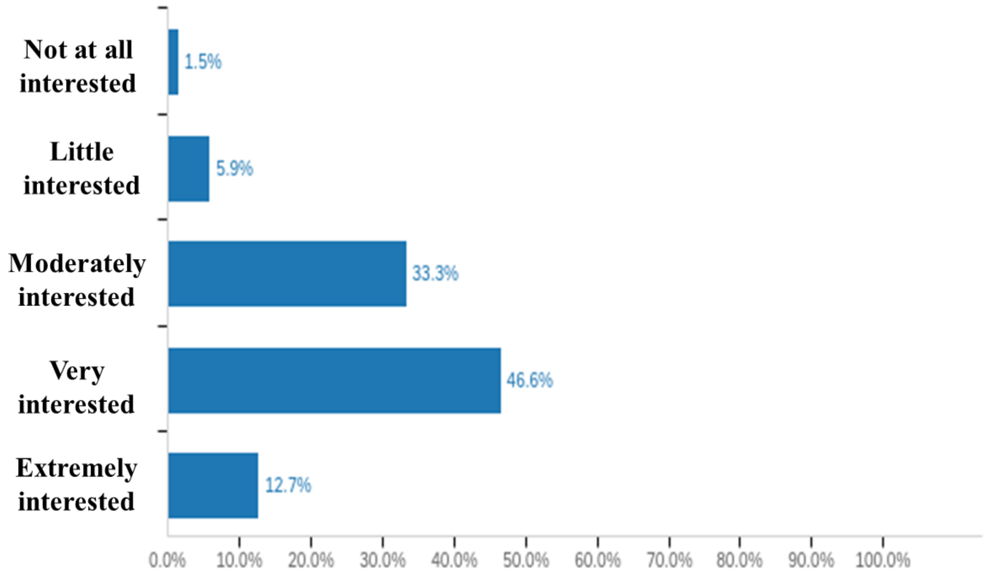

Fig.42 To what extent would you be interested in having more control and visibility of the cost of electricity? (Source L. Mocchetti Survey)

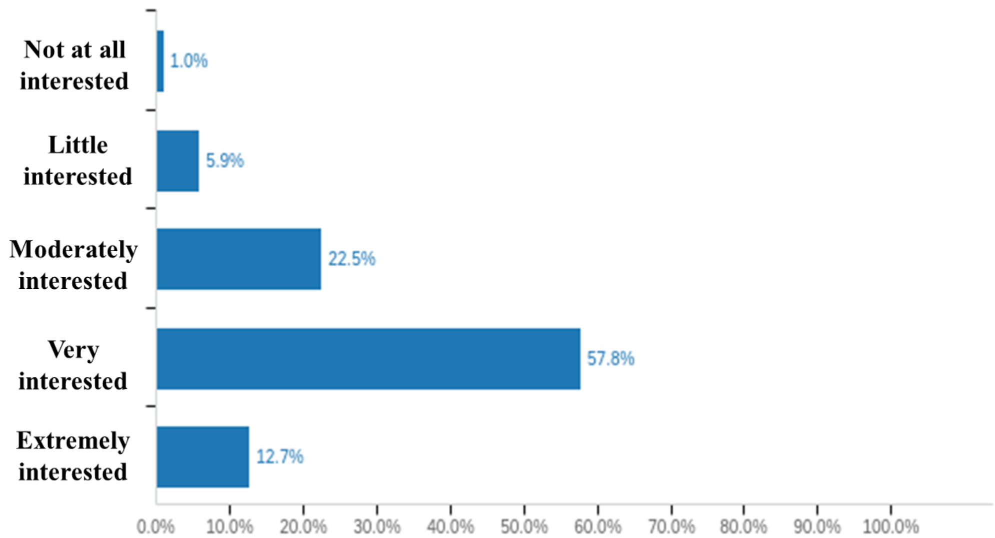

Fig.43 To what extent would you be interested in more information about the energy sources you consume? (Source L. Mocchetti Survey)

In conclusion, what can be deduced from the survey as a whole is that in a society increasingly in search of technological progress and progressively more connected with everything, where the consumer has a central role and is eager to have control over every aspect of his daily life, the split in the electricity sector between the end user and the rest of the chain is no longer acceptable. The lack of knowledge of such trivial aspects as the cost of electricity by most consumers shows that there is enormous room for improvement in the quality of service and transparency in the sector. In order to see a definitive technological progress at all levels of the chain, the end user must acquire a central role and the survey has showed that it is interested to be more involved in the dynamics of the sector. In this way, also its growing concern about environmental issues can be transmitted to all companies within the sector, thus beginning to have a push not only on the regulatory side but also on the consumer and public opinion side. All this will definitely open the doors to new technologies able to promote the efficiency and development of renewable energy production.

Chapter 3. BLOCKCHAIN TECHNOLOGIES AND APPLICATIONS IN THE ELECTRICITY SECTOR

3.1 Blockchain

In their book "Blockchain Revolution", Alex Tapscott and Don Tapscott (two of the first experts in digital economy) define the Blockchain "Protocol of trust" in opposition to the way transactions on Internet have been carried out to date. In fact, the exchanges on the net are made thanks to an intermediary in the middle of the transaction who certifies it and in exchange earns both a commission and the buyer and seller data. Therefore, only the intermediary has the knowledge of the personal data of the two parties, while the latter do not know each other and do not even have the possibility to verify their real identity. The most important services on the Internet (for example Amazon or payment companies such as PayPal) are based on this system feature, allowing a trusted third party to play the role of middle man, to whom the information is provided with the task of arbitrating an exchange. The Blockchain aims is to overcome this imposition, creating a protocol that allows, through a set of technologies and rules, to ensure the origin and integrity in the transmission of data without recourse to a trusted third party, but relying on a peer-to peer system.

The Blockchain is a secure, transparent and decentralized block chain. "Safe" does not mean that it tries to hide information; it simply means that no one will tamper with the data on the Blockchain without sending alarm signals that would be noticed very quickly by the developers.

The Blockchain is designed to use a cryptographic hash and timestamp which are unalterable once created. This allows experts to inspect the records to determine the facts of a given transaction or to detect attempts to tamper with the ledger.

The Blockchain decentralized log ensures that no party in a transaction will have to trust any single third party. While this technology can be used to create an effective automated escrow deposit, the basic system will not disappear with your money or deny you access to your account. This gives for example Bitcoin its power as a currency that can cross borders, provide rapid settlements and avoid being controlled by any centralized authority.

The maintenance of the Blockchain is based on the operation of multiple nodes that are able to store transaction data and constantly validate new information with the use of processors; think about nodes as completely equal servers that regularly update each other with new data and make it possible for authenticated clients to connect with them if desired.

If a node malfunction occurs, IT staff can work with a Blockchain expert to isolate the server and fix the problem on that node to determine what went wrong. Common malfunctions usually result in a node failing to transmit valid information, for example, you can transmit blocks of data that make no sense to other nodes and in this case, an expert will ask IT staff to isolate the server from the rest of the network until it can solve the problem.

If a node works poorly and must be isolated for maintenance in a business that relies on real-time data access, the result is not a waste of time and revenue when the business uses Blockchain applications. As a matter of fact, the result is that the remaining nodes and consumers can quickly reconnect to a working node. This is good for a business owner who does not want to explain to consumers why a server in a centralized network is down.

It is easy to isolate an "evil" node for troubleshooting without compromising the rest of the system. Nodes that work correctly can continue to work, creating new valid records and making them available to anyone who wants to use them, while the Blockchain expert investigates what went wrong with the node that worked incorrectly. Then, once the issue is clarified, the “fork” (separation of the original Blockchain into two different Blockchains) can be resolved and the repaired node can be added back to the network. The discarded block is called “Orphan Block”.

No centralized institution makes the decision on which Blockchain branch is valid but the dispute will resolve itself normally. In fact, a fork can persist for several blocks and when this happens, there is a rift in the network, so some miners (typical participants in the Public Blockchain with the task to employ resources to enable the creation of the blocks) believe that one branch is the legitimate Blockchain, while others follow the other. The protocol then determines that the correct Blockchain is the longest, so miners have an incentive to stop working in a branch as soon as it is clear that you will get to the Orphan Block, because work on it would be wasted and therefore, the forks resolve quickly (usually in one block). The average number of forks in the Blockchain of Bitcoin was about 2% that is to say on average a fork every 50 blocks.

Transactions included in the blocks of a fork are not lost: when a fork is resolved and a branch is discarded the transactions of that branch are introduced back into the memory set of unconfirmed transactions, ready to be included in the next extracted block.

Within the Blockchain protocol, two different types of fork are possible:

- Hard fork.
- Soft fork.

The Hard fork is a scenario in which the net changes the consensus rules: it is called hard fork, because after the fork, the net does not merge on a single chain but will evolve independently. Hard forks occur when a part of the network operates according to a different set of consensus rules than the rest of the network; it can happen because of a bug or a deliberate change in the implementation of the participation rules. Hard forks can be used to change the consensus rules, but they require coordination between all participants in the system. Nodes that do not switch to the new rules cannot participate in the consensus mechanism and are pushed into another Blockchain at hard fork time.

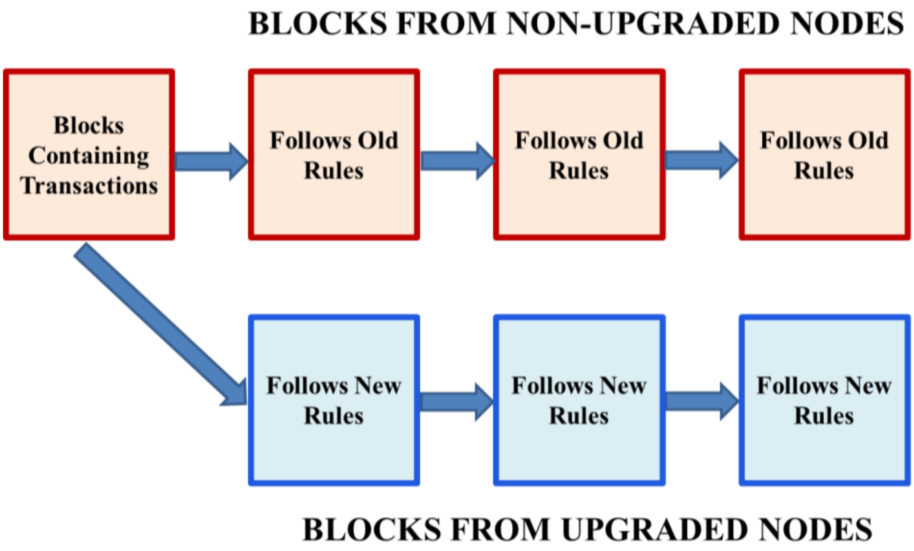

Fig.44 Hard Fork (Source Masterthecrypto)

Only incompatible changes with the previous system cause a hard fork and not all changes to the consensus rules. If the change is implemented in such a way that a node that does not update the system still sees the transaction or block as valid under the previous rules, the change was implemented without a fork.

The term Soft fork was introduced to define a change compatible with the consensus rules that allows outdated clients to continue to operate in accordance with the new rules. One aspect of a Soft fork is that updates can only be used to limit the consensus rules, not to expand them. To be compatible, transactions and blocks created according to the new rules must also be valid according to the old rules, but not the other way around. New rules can only limit what is valid, otherwise, if rejected according to the old rules, they will result in a Hard fork. Soft forks can be implemented in several ways and define a set of methods that all have in common not to require the update of all nodes or the expulsion of not updated nodes outside the network.

3.1.1 Types of Blockchain

The Blockchain was originally designed to be a decentralised system that keeps track of debts and credits. The existence of thousands of Bitcoin nodes on six continents demonstrates Blockchain's ability to effectively become the "World Wide Web" of several sectors.

There are three types of Blockchain:

- Public Blockchain: this Blockchain is freely accessible to anyone. There are no restrictions on reading transactions, making them and on the possibility of participating in the consensus mechanism. This is the model on which the Bitcoin Blockchain has been designed to disintermediate the mechanisms of trust, and as such does not place specific requirements on the network participation, rather encouraging for its expansion through mechanisms that gratify those who make resources available. Participants in this type of Blockchain are typically called "miners" because their task is to employ resources to enable the creation of the blocks.
- Blockchain consortium members: the consensus mechanism on transactions is controlled by a set of pre-selected nodes. These nodes have a greater influence than the others and through various mechanisms (usually voting) determine which transactions can be included in the blocks. In reading a consortium Blockchain can be accessible to the public or limited to participants. In summary, these types are partially decentralized Blockchain, the nodes are called "contributors" and are not placed on the same level.
- Completely private Blockchain (closed): it is a Blockchain in which write permissions are kept centralized at a single organization. It is a vertical type Blockchain where only one person is able to validate transactions that are recorded on the chain. The Blockchain read permissions can be public or discretionary limited.

A private Blockchain has a number of advantages over the public one such as the ability to change the rules, restore transactions, change balances. It is certainly less vulnerable to cyber-attacks and can be used for applications and in some public administration areas where it is necessary to maintain a centralized government of transactions that are recorded and the role of formal control and legitimacy must remain firmly in the hands of the administrative authority.

On the other hand, the public Blockchain also have undoubted advantages by wanting to apply them in the management of "public affairs". First, a public Blockchain cannot be manipulated by a small group of subjects; this ensures transparency and reliability about the content of transactions and guarantees users the certainty of their rights, given the unchangeability of recorded transactions and the widespread mechanism of consensus creation.

The consortium Blockchain, finally, represents a hybrid between the two models closed and open. It is suitable for cases of use where it is necessary to keep the government on the transcription of transactions, but it is possible to make public the consultation of the Blockchain. For example, all distributed public registers, where more public administration participate in entering (or validate) information that by their nature are intended for publicity. It could be imagined in the administrative procedures in which several public administrations participate, through a conference of services, and in which each of them has an administrative role and power. The validation of information, through the mechanism of the "vote of the few", would allow to record on a consortium Blockchain the results of individual evaluations of public administrations.

On the other hand, the disclosure of information would guarantee the transparency of administrative action, without the possibility of “ex post” modification of the various stages of the procedure.

The size of the Blockchain has steadily grown with the increase in use. One of the criticisms often raised against the Bitcoin Blockchain is that it is not scalable enough to handle a transaction rate comparable to that of normal payment processing networks. Currently, the blocks include an average of 2100 transactions. In fact, the growing adoption of crypto-currency has raised many concerns about their ability to scale. Since Bitcoin is a self-adjusting system that works by extracting blocks at regular intervals, its growing volume of transactions clashes with the maximum size limit of each block relative to the interval in which it is undermined. The increasing trend of block size on Bitcoin suggests a potential problem that would materialize if the system even goes so far as to delete transactions due to both the slow speed at which the blocks are mined and the size of the block relative to the number of transactions. As a result, the community has long been discussing techniques to improve the scalability of Blockchain, particularly Bitcoin. These discussions are very heated and have led to internal splits, without having outlined a clear path to address the problem of scalability. The Bitcoin Blockchain takes 10 minutes or more to confirm transactions, reaching a flow of up to 7 transactions per second (tps).

In comparison, a traditional payment process such as the Visa credit card makes a transaction in a few seconds and processes on average 2000 transactions per second, with a peak of 56,000 tps: there is too big gap between the current situation of Bitcoin and the scalability of traditional payment systems. Therefore, the key questions are if the Blockchain can scale like a traditional payment system and how to get there. For Bitcoin, the best strategy to have a number of tps like VISA is to move transactions out of the Blockchain. It would be useful and productive if Bitcoin supports an almost unlimited number of transactions per second with extremely low rates for micropayments, which can be sent sequentially between two parties to allow money transfers. To achieve this, it would be necessary to drastically reduce the amount of transaction fees on the Bitcoin Blockchain.

3.2 Smart Contract

The beginning of the 21st century has been characterized by many innovative technologies that have had a substantial impact on the new data-based economy and the most important are Cloud Computing, Big Data, Internet of Things and Blockchain. The latter technology, began to have a meaning of its own. However, governments and companies around the world are mostly perplexed about the possible implementation of Blockchain in many areas of life, not associated with the use of crypto-currency. One of the most promising areas of Blockchain application is the creation of fully automated contracts that is to say agreements that are executed without human involvement. In the IT environment, these are called "Smart contracts". There is no universally accepted definition of a "Smart" contract and this is due both to its innovative nature and its complex technological basis.

According to the simplest definition, it is a contract whose execution is automated. For Nick Szabo, one of the pioneers in the analysis of automated self-execution agreements, the smart contract is a computerized transaction algorithm that executes the terms of the contract. However, this definition can hardly capture the difference between smart contracts and some well-known contract constructs that implement automated execution, such as vending machines. The latter are defined as autonomous automatic machines that deliver goods or provide services when inserting coins or making payments in other forms (e-cash, credit card).

The vending machines are programmed with certain rules that could be defined in a contract. The degree of novelty and the presence of some special features in smart contracts become particularly relevant in exchange markets, where automated trading systems are widely used. For example, in these markets, trading operations are often executed by a computer system based on a trading strategy calculated using an algorithm and not by the trader. Since 2014, more than 75% of the stocks traded on the US stock exchanges have come from automated trading system orders, so automated contracts are not new. It is appropriate to refer to another smart contract definition provided by Gideon Greenspan: "A smart contract is a piece of code that is stored on a Blockchain, activated by transactions on Blockchain and that reads and writes the data in the database of that Blockchain". This definition is more concrete, since it emphasizes the Blockchain as one of the key features of the smart contract. The Blockchain can be considered a "paradigm shift" in the contract because it allows automating the process of execution of the contract of both parties.

The vending machines automate the performance of only one part, requiring at least some personal involvement on the other side (e.g. the insertion of coins or a credit card). When the performance of both parties can be fully automated, the question arises as to whether there is still a contract in the legal sense or something else. The organizational theorist Arthur Stinchcombe wrote that contracts are only miniature organizations and, by extension, all organizations are only complexes of contracts. Companies are created using a series of contractual arrangements, ranging from employment contracts for employees, relationships with suppliers, obligations to their consumers, lease agreements, and the sale and purchase of equipment. Traditionally, these contractual obligations are quite expensive because they must be enforced through a reliable legal system and through law enforcement. However, with a smart contract based on a Blockchain, much of these costs are significantly reduced or eliminated. This makes Blockchain-based organizations more efficient, cost-effective and competitive than traditional companies in the market. All this shows that smart contracts go far beyond existing bargaining models and represent a new paradigm of interaction in cyberspace. Smart contracts make it possible to create pools of resources and allocate them according to concerted criteria, which can be particularly relevant for crowd-funding activities or insurance contracts. In the first case, smart contracts can keep track of the amount of funds belonging to a crowd-funding project and, once the necessary amount is reached, it is transferred to the beneficiary, otherwise, the funds are returned to the donors. In the second case, a group of farmers could put together a pool of resources as insurance against drought, floods or other natural disasters. Once such a disaster occurs, the contract would ascertain it according to the procedure specified in the contract (e.g. by checking the weather or news in predesigned sources) and would allocate resources. The smart contract provides the highest degree of transparency and verifiability, mitigating the risks associated with the intermediary's decision-making process and the "human factor", as well as time delays.

Although the execution of the smart contract is automated, it still requires the presence of the contracting party's will to become effective. The person expresses his/her consensus on the terms of the contract and the manner of its execution at the time of its conclusion and will not be able to influence the execution of the contract once it has been concluded; consequently there should be a certain trust, which gives rise to a sort of "trust" relationship in the smart contract. But differently from the classic contract, where the trust is placed in the counterparty, in smart contracts this trust is placed in the computer algorithm that underlies the contract ("trust without trust").

3.2.1 Smart contracts characteristics

Based on the current understanding of smart contracts it is possible to outline the following characteristics:

- Exclusively electronic nature: classic contracts can exist in various forms (i.e. in oral or written form). The development of e-commerce has greatly increased the number of agreements concluded in electronic form, the most obvious examples of which are the various "clickwrap" agreements (digital prompt that offers individuals the opportunity to accept or reject a digitally-mediated policy). However, even in the case of e-commerce contracts, some classic paper documents, such as invoices, receipts or delivery certificates, may still be needed, especially when such electronic contracts cover the purchase of goods or services offline. Sometimes, these documents are the only proof or expression of the existing contract in electronic form. On the contrary, smart contracts can only exist in electronic form. It is also characterized by a specific object that can be a digital asset (i.e. a crypto-currency) or a digital manifestation of an offline asset recorded on Blockchain. This differentiates the smart contract from most "clickwrap" contracts, which also exist in electronic form, but only impose certain negative obligations on the user (i.e. not to perform certain activities while using the service or not oppose to certain activities carried out by the provider). Moreover, the smart contract by its very nature requires the use of electronic digital signatures, based on encryption.

- Software implementation: the smart contract has a dual legal nature; it acts as a "document" governing the contractual relations between the parties and it is also the subject of intellectual property rights. Therefore, the programming of some smart contracts according to the consumer's needs can be treated as a software development process, while the distribution of rights after the contract must be carried out within the license/assignment of intellectual property rights.
- Greater certainty: since the software code represents the essence of the smart contract, its terms are expressed in one of the computer languages characterized by a strictly defined semantics and syntax. The computer language does not allow discretion in its interpretation. The terms are interpreted by a computer based on Boolean logic, unlike the classical contract, where the interpretation of terms is performed by the human brain on the basis of subjective criteria. Therefore, the accuracy of programming languages is able to mitigate the possible problems associated with the unpredictable interpretation of contractual terms by the contracting party. Consequently, the existing rules on contract interpretation do not apply to the smart contract. Smart contracts are to be understood as separate agreements, not subject to interpretation by external entities or jurisdictions. The code itself is intended as the final arbiter of the "agreement" it represents. Given the technical complexities and the need to possess advanced programming skills, in many cases smart contracts will be created by specialized companies based on the client's request. Because of the separation between those who program the code and those who intend to use it in their business activities, there is a risk of misunderstanding the terms of the future agreement. Moreover, since it is only the computer code that governs this type of contract, the latter automatically becomes subject to various defects and bugs. The recent hacker attack on one of the smart contracts of the Ethereum platform is a good example: in June 2016 the attackers

exploited software vulnerability and stolen millions of Ether. In an open letter to the Ethereum community, the attacker stated that he did nothing illegal, but that he "used this function explicitly coded according to the terms of the smart contract". Therefore, it can be said that smart contracts are still vulnerable to coding errors, which probably needs to be addressed by the new rules of interpretation.

- Conditional nature: it has previously been asserted that the smart contract is written in one of the programming languages. Conditional statements are fundamental for computing: the computer code is based on statements such as "if x then y" that allow the contract execution.
- Self-application: once the smart contract is concluded, its execution no longer depends on the will of the parties or third parties, nor it requires further approval or action on their part. The computer verifies all conditions, transfers the goods and enters in Blockchain the data relating to such transfers. Therefore, the contract is technically binding on all parties, no longer depending on the human intermediary, which is subject to errors and subjective discretion.
- Self-sufficiency: the smart contract does not need legal institutions to exist, or the corpus of legal norms, as is the case for classic contracts. Self-sufficiency is particularly important in international transactions, as it makes linguistic differences, national laws and their interpretation irrelevant: the same rules are applicable worldwide. Based on these features, it is possible to define the smart contract as a software code, implemented on Blockchain platform, which ensures self-sufficiency and autonomy of its terms based on conditions defined in advance and applied to goods that are on Blockchain. Among the benefits of smart contracts it can be counted their ability to reduce many of the transaction costs that accompany normal contracts. Also the costs associated with the involvement of the intermediary in the execution of the contract (e.g. bank or insurance organization) are excluded in smart contracts because of their disintermediate nature. However, it would not be correct to assume that these new contracts are cheaper than regular contracts: the infrastructure required for their implementation and the costs associated with the development ("drafting") of their terms are still quite high. Smart contract platforms have already emerged and have gained popularity and recognition. The most obvious example is Ethereum, which is an open source computing platform based on Blockchain, with smart contracts creation capabilities. Differently from the Bitcoin ecosystem, which does not allow the

exchange of any object other than crypto-currency, Ethereum allows the exchange of any class of assets that can be transferred over the Internet.

3.3 Blockchain in the Electricity Sector

After explaining the Blockchain and smart contract functioning, it is now time to analyze their possible applications within the electrical sector so as to understand the problems they could solve and the benefits they would bring.

The Blockchain presents itself as a potential facilitator and catalyst of energy transition, representing a source of opportunity for all players in the industry, particularly through its combination with other technological means such as smart contract and techniques for the management and interpretation of mass data. The still limited maturity of energy sector projects using the Blockchain offers companies in the sector the opportunity to position themselves as pioneers of this technology.

The energy transition is synonymous with the global creation and transformation of the actors in the sector and their behavior. Production is becoming more volatile and decentralized, consumers can become producers, and suppliers can be aggregators, while other intermediate actors have to adapt to these changes. This local volatility induces a dual role for the grid: a role of guarantor of stability in the face of new intermittent sources such as renewables, and a role of balancing supply and demand that are increasingly fluctuating at the local level and require the reallocation of unexpected production surpluses.

All these developments raise the question of how to structure the market in the most appropriate way for the sector, so that the right signals are sent to investors to bring stability and sustainability to the system, both locally and globally.

The characteristics of the Blockchain that would perfectly adapt to the needs of the industry are as follows:

- Its ability to keep a distributed record and manage transactions efficiently. The Blockchain allows recording and storage distributed and secure energy transactions without the need for a trusted third party or central control body. Each energy transaction is recorded and stored by Blockchain on all nodes/computers that are part of its network (such as microgrid). All participants are informed in real time of each transaction made and their computers control each other to prevent fraud within the system.

- The ability to ensure transparency and real-time monitoring.

  The Blockchain would store energy transactions, tracked in real time, allowing more detailed management and live monitoring of energy consumed through new generation meters (so-called 2G meters) and the exchange of this data between the various players in the energy system. It could allow a community to have a report of the entire energy infrastructure and to identify the buildings with the highest energy consumption.
- The ability to ensure secure, automatic and real-time billing, payment and remuneration by reducing management costs.

  The Blockchain could intervene in the payment of energy bills through real currency or through crypto-currencies such as Bitcoin and Ethereum paving the way for almost real-time billing through micropayments rather than monthly as it is currently the case. A smart contracts system could enable the implementation of an automated and flexible system that pays consumers in real time and regulates demand at a given time. A large number of projects are based on the existence of Solar Coin, an encrypted currency assigned to a photovoltaic electricity producer based on production evidence.
- The ability to trace an information flow in every step.

  In local energy circuits it could be possible to trace the origin and the exact path of green energy by certifying its provenance. In addition, the exchange of electricity on a local circuit would be facilitated by the automation of transactions, the monetary or crypto-monetary valuation of energy transfers between producers and consumers without passing through an intermediary.

3.3.1 Electricity System Management

One of the main problems that had been highlighted in the previous chapter was the need to manage the electricity system more safely and quickly and to deal with the growing problems of network congestion.

In this case, through the Blockchain it could be possible to manage much more effectively the mains voltage and related overloads by reducing any type of abnormal event connected to a voltage drop. This is because, taking advantage of the immutability of the Blockchain it could be safely recorded a timely and automatic report if the voltage on the grid reduce in the event of an overload and then communicated to the TSO.

The process would take place by creating the following new way of managing the loads present on the grid: the TSO, based on the offers accepted on the Market for the Dispatching Service, would send requests for voltage variation to the appropriate plants, these sales companies would have to accept to provide for the voltage reduction that would be promptly notified to the TSO and send the offer of variation to the consumers.

The end users modifying their consumption would accept to take part to the voltage variation and it would be also notified and shared with the network. The actual register on the Blockchain would take place once the voltage reduction is measured by the meter.

Instead, in order to ensure the certainty of the conditions required to accept the reduction of tension from the various parties involved, smart contracts would be used, which would automatically activate various benefits to the consumer in return, such as reducing the cost of the bill or other premiums and would release the fee to the sales companies by recording and communicating everything to the TSO.

3.3.2 Decentralized energy trading

Another crucial issue highlighted in the previous chapters was that of fostering more the development of renewable energies they bring such as the increasing spread of distributed generation and self-consumption.

The need for the Blockchain lies in the most recent trend of renewable energy production at the city level, particularly thanks to the presence of photovoltaic systems installed above the roofs of homes. This aspect is bound to increase over time as highlighted in the survey I conducted. In fact, about 85% of consumers find the idea of being able to produce renewable electricity themselves very interesting, as can be seen in Figure 45.

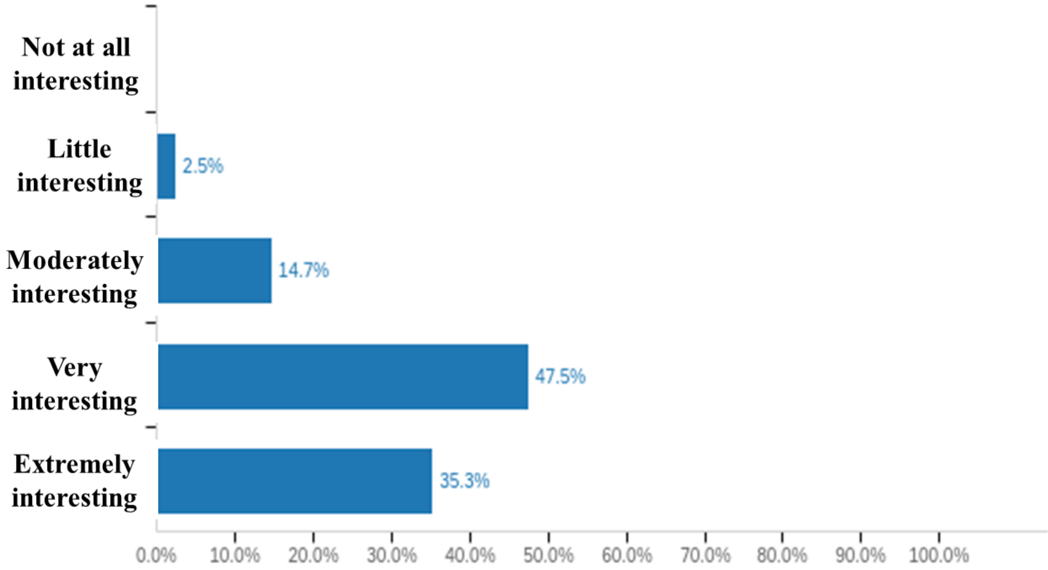

Fig.45 How would you evaluate the possibility of producing renewable energy on your own? (Source L. Mocchetti Survey)

This shows how the consumer is more and more predisposed to become a major player in the electricity sector by feeding the phenomenon of distributed generation and going to spread the need to consume and exchange energy locally what is currently not possible except in specific cases. In fact, today a consumer who does not produce electricity independently is forced to buy the electricity he needs only from the sales company with which he has signed a contract, even if a few meters from his house lives a neighbor who owns a photovoltaic system and that at certain times of the day is able to generate a surplus of electricity, produced at a considerably lower cost than that taken from the grid and with considerable environmental benefits.

The Blockchain looks like that mechanism that allows automatic and traceable to bring together small producers-consumers (the so-called prosumers) and energy consumers, with clear benefits for both parties. In this perspective, millions of homes could become small power plants, able to automatically sell their excess power to the highest bidder, thus creating a Peer to Peer system that would work as follows: The Prosumer that produces electricity from renewable sources would see his production recorded in tokens and assigned to his personal wallet. Part of the energy would be consumed by seeing the wallet reduced by the corresponding tokens while the excess energy could be fed into the grid or stored making available the remaining tokens to other users of the microgrid.

The consumer according to his needs, using an application would set the maximum price for the energy supply he needs and the smart contract would associate all the energy offers of prosumers that meet the required price going to generate and notarize the transaction on the Blockchain. The bill would thus be generated automatically and payment would be made by transferring the fees from the consumer's wallet to the prosumer's wallet, as specified in the smart contract. Finally, the network would supply the Prosumer's energy to the consumer and the token linked to that energy would become unusable.

A virtuous example of the concrete application of this Blockchain-based microgrid system is the Brooklyn Microgrid Project. In 2012 it was only part of one of many collective self-consumption projects: 4 houses, equipped with photovoltaic panels, belonging to the same neighborhood in Brooklyn, each of which produced its own electricity and stored it using batteries powerful enough to conserve the energy to consume it later without any electricity supplier. Of these local microgrids there are many in the United States (103 are in New York State).

The Brooklyn Microgrid Project was born when solar energy specialist Lo3 Energy decided to turn to bitcoin specialist ConsenSys to apply the Blockchain to the management of excess electricity exchanges in this neighborhood. In order to manage energy flows from their entry to their exit from the grid, maintaining the history of the energy produced and the resulting transactions, the two startups, brought together within the Transactive Grid, implemented in 2016, a platform based on Ethereum, a Blockchain protocol distinct from Bitcoin.

The Brooklyn Microgrid Project currently involves 300 homes or small businesses and 50 production sites, almost all solar. In total, these generators have an installed capacity of about 1.5MW, which of course corresponds to only a small fraction of the needs of Brooklyn residents. However, the goal is not to replace the entire network, but to show that small networks can bring many benefits to local communities and support their economy by reducing greenhouse gas emissions. The logic is that a prosumer who produces more green energy than he consumes has a surplus of energy that can be sold back to the grid in exchange for a solar energy credit. In the electricity market you can access it through an app on your phone called Brooklyn Microgrid Mobile App. These credits can then be exchanged locally and are an energy currency that works similar to Bitcoin.

This concept of solar energy credits supported by the Blockchain to increase the value of solar energy exchanges is also the origin of the SolarCoin project: a solar energy conversion currency that would allow people to buy or sell their energy through the associated Blockchain. The SolarCoin Foundation is the origin of this virtual currency, which is paid to producers, individuals or companies, owners or investors, of solar energy. SolarCoin certifies the photovoltaic origin of the energy produced by the plants, equipped with sensors connected to the Blockchain ElectricChain. The production of one MWh of solar electricity involves the allocation of a SolarCoin, which can then be exchanged. SolarCoins can also be converted into a currency such as the dollar or euro.

3.3.3 Renewable energy certification

Another aspect in which Blockchain technology presents itself as a solution is the improvement of renewable energy certification. It would serve to ensure that the nature of electricity, the subject of transactions in the electricity system, is effectively decarbonized. The willingness of end users, as shown in the survey, is that the electricity supplied comes from renewable sources in their entirety. The consumer would have this certainty because the Blockchain can give the opportunity to trace, moment by moment, the origin of the electricity that is supplied, from the moment of generation to the final destination of consumption finally going to reduce that gap between consumer and the rest of the chain and thus providing that much sought transparency. The supply of renewable electricity could thus also be flexible to the needs of the consumer and above all visible to all actors.

The guarantee that what is being exchanged comes from renewable sources can be applied to the world of electricity certification, specifically to the system of certificates for renewable energy. The properties contained in each certificate can be registered within the Blockchain, hopefully public, so as to ensure access to the largest number of participants: in this way, on the one hand, the sales possibilities for producers are expanded and on the other, consumers can choose between an increasing number of offers of electricity from renewable sources and at an affordable price.

Currently, the certification system requires that the renewable generator produces electricity and sends the data to the bodies designated to create the certificate, which then authenticate the origin of the electricity generation and issue it. For the purchase and sale, there is the figure of an intermediary who connects the individual buyer and the individual seller of certificates. Once these are issued, they are subject to an annual check by the certifying body. The limits of the current system are clearly the high administrative costs due to the presence of an intermediary, the difficulty in meeting the needs of all actors and the lack of real transparency of the whole process. This is because the certification system that verifies the renewable generators are in compliance with the regulations requires that it takes place annually to avoid double counting and the traceability system that must ensure compliance with the regulations is consequently costly both in terms of time and expense. This arrangement would cut out of the market the micro-producers that are becoming numerous and increasingly essential for a local economy.

The introduction of the Blockchain in the new model of certification of renewable energy would solve the main problems concerning the issuance of certificates and traceability and transparency of each phase of their existence thanks to one of the main characteristics of this technology: immutability. The encryption of the movements that take place in each block and the distributed consent mechanism would increase transparency and accuracy in the tracking and exchange of data when certifying renewable energy. Smart contracts, on the other hand, would make the acquisition of certificates immediate by solving the risk of double emissions, saving costs arising from the controls carried out annually and the costs of the presence of an intermediary.

Conclusion

In conclusion, the electricity sector has been described as a complex sector where every step of the chain has main players and points that can be improved. The main problems analyzed were the impending rise of renewable energy production plants in response to environmental issues and their difficult management, the unique characteristics of the Italian distribution and production system that clash with the topography of the Italian peninsula and create inconveniences such as grid congestion. It was also analyzed the new challenge of the management of a network increasingly decentralized and tending towards distributed generation. It was highlighted, through a survey, how consumers are still too cut off in the sector and how they are increasingly interested in sustainable development issues and want to be included and informed about the issues of electricity costs and especially the sources used to produce the energy they consume. But above all, the willingness on the side of the end user to become part of a more transparent sector and to be able to finally drive it towards progress by finally playing a leading role has been underlined. The positive side of the majority of these issues is that they are almost all related to the difficult management of an ongoing change. This means that a crucial sector such as the electrical industry is currently still too far behind in terms of its importance and these changes can only reassure us in the future. Obviously in order to be completely confident, it is necessary to hope that companies will seize the opportunities and the appropriate revolutionizing technologies that will be able to accelerate definitively towards efficiency and renewable energy. I believe that these technologies are in particular those of Blockchain. Although still a little unripe to be applied to the electricity sector, not easy to adapt on all levels and very expensive in economic terms, it has been shown in this thesis that it would present itself as the solution to all the problems identified. In fact, it has been widely demonstrated how it would make the management of the electricity system more transparent and secure from the producer to the consumer, how it would be able to promote the development of a figure such as prosumer and local microgrid powered by the production and exchange of renewable energy and how it would be able to improve the certification system of the latter. Its characteristics allow to provide an added value to the electricity sector, which now has a huge need to take a step forward towards progress. Not exploring these technologies and not trying to apply them to the sector risks turning out to be a fatal mistake for the actors of the electricity system.

Synthesis

Humanity has undergone numerous changes over the years. One of the biggest has certainly been the worldwide spread of electricity. Since Benjamin Franklin's early studies in the 700s and the subsequent discoveries of such prominent figures as Alessandro Volta and Michael Faraday many years of research, huge economic investments and numerous failures have passed before we get to the point of receiving electricity even in households as we see it today. The turning point was in 1883 when the electric scientist Nikola Tesla built the first prototype of induction motor.

It was precisely from here that the idea of alternating current was born, which today supplies our homes. The rich entrepreneur George Westinghouse had confidence in the idea of Tesla. Sensing the potential of the discovery, he founded Westinghouse Electric.

Although with some modifications, the model of electricity distribution that is used today is exactly what Westinghouse Electric came up with. From those years of the late 1800s this innovation made enormous changes in the evolution of society and in people's lifestyles. In fact, the spread of electricity and the enormous increase in its consumption since the mid-twentieth century are closely related to many phenomena such as the increase in population and global welfare or the discovery of revolutionary technological innovations in any field.

However, as in all revolutions, there are of course also numerous negative consequences that can no longer be ignored over the years. One of the most important is at an environmental level. In fact, data confirm that the electricity sector is today the one that causes the greatest emissions of greenhouse gases which, as now proven by numerous studies, are those waste products harmful to the planet and widely recognized as the cause of significant environmental and climate impacts, including the increase in average global temperature and the intensification of catastrophic natural events. For this reason, the electricity sector for some years now is entering a new era of changes and increasingly important drives towards the production of electricity from renewable sources in order to meet the recent issues of environmental sustainability. Nevertheless, the energy transition towards green energy is less simple than it may seem and puts a strain on the solidity and efficiency of the current electrical system because it brings out new problems and new dynamics that could upset all the fixed points of the actors within it.

One of the aspects that are definitely to keep an eye on in order to successfully face the changes, are the new technologies that could act as a support in the sector. The 2000s have seen the spread of many technological innovations that have radically changed society but one of those that today arouses much curiosity is the Blockchain. The latter is associated by most people with crypto-currency and especially Bitcoin but the reality is that it is also a very valuable tool within countless sectors, primarily in finance but increasingly also in government, logistics and utilities. Its unique characteristics could prove to be very useful for the electrical sector but all this change must absolutely be accompanied by receptivity from all actors in the chain, from the energy producer to the end user.

Therefore, the objective of this thesis is to demonstrate how Blockchain technologies are able to promote sustainability and efficiency in the electricity sector.

First, this will be possible by an in-depth analysis of the electricity sector.

For instance, the Electricity Supply Chain is the set of all the stages that makes up the electricity production cycle up to the final consumption.

From a pure technological point of view, the electric supply chain consists of four different phases:

- Generation.
- Transmission.
- Distribution.
- Metering.

The Electricity Supply Chain, however, includes not only the technological aspects but also those of the market as follows:

- Wholesale Market.
- Retail Market.

Generation takes place always by conversion of a primary source of energy (e.g., wind, natural gas, fossil fuels, etc...). Furthermore, there are multiple production systems which differ by primary source and production mechanism (thermoelectric, geothermal, and hydroelectric). However, the amount of energy produced cannot be unlimited due to the fact that electricity cannot be stored cost-effectively on a large scale and at any given moment its production must reach the consumption otherwise any imbalances would cause a blackout on the national electricity grid. For this reason, production and consumption units are always connected to each other. In Italy, TERNA is responsible for the aforementioned balancing.

We can identify three different types of plants as follows:

- Base load: Renewable energy sources, CIP6, Coal, Imports.

- Midmerit: Combined Cycle Gas Turbines (CCGT).
- Peak load: Hydroelectric pumping, Turbo gas.

The Wholesale Market is the National market in which the producers, the Single Buyer and the Wholesalers / Sellers that supply energy for their consumers (industry, individual citizens, etc...) interface.

The Wholesale of electricity take place through two ways as follows:

- Bilateral OTC (Over The Counter) contracts that are private bargaining between two operators.
- Buying and selling in central markets (Electricity Market). There is a single, transparent and public price for all transactions (market clearing).

As far as the Transmission is concerned, the electricity produced is conveyed to the distribution network to which consumers then connect. The Transmission phase is an example of Natural Monopoly. In such a context, there was a need to assign the network management to an independent entity (TERNA S.p.A.) with the purpose of ensuring access to the network under the same conditions between the various competitors (Marzano Law no. 239/04). For this reason, the real-time management of extra-high-voltage energy flows on the Italian's electricity grid, also called dispatching, occurs through the National Transmission Grid (RTN) which is handled by TERNA throughout the TERNA National Control Centre; the aim is to safeguard safety and efficiency.

The National Transmission Grid of electricity consists of:

- AAT (Very High Voltage) transformers that draw power from power plants.
- AAT and AT (High Voltage) lines that transport energy. They can be aerial, underground or submarine.
- Interconnection lines for foreign exchange of electricity.
- Transformation stations for the transfer of energy to distribution companies supplying electricity to end-users.
- TERNA National Control Centre, which monitors the operation of the electrical system ensuring safety and continuity

The distribution is the physical transport of energy by means of medium/low voltage networks, from the primary substation (delivery point of the transmission network) to the meters located at the consumption points. A complex network infrastructure allows the transport of electricity to the end user, through the primary substations (which transform

high voltage electricity into medium voltage electricity), the secondary substations (from medium voltage to low voltage) and the transformers.
The distribution companies, operating under concessions, operate local, low-voltage electricity grids and maintain them. It is a monopolistic activity at municipality level.
In addition to the distribution lines, the distribution network includes voltage transformers, safety systems and measurement systems.
The final stage of the supply chain is to sell to the final consumer. Within this stage, there are the sales companies that purchase electricity (mainly from the electricity market but sometimes also directly from the producers) and, on the other hand, the final consumers who purchase and consume the electricity. The final consumers, following the liberalization process, may be divided as follows:

- Customers of greater protection (the so-called "*maggior tutela*") or those who remained within the protected market. In this Market, the price of raw materials is established quarterly by the Authority on the basis of the evolution of raw material prices on the markets.
- Free market customers and customers of the safeguard service. It was created as a result of the market liberalization and is characterized by the presence of many private energy companies.

To make an exhaustive analysis of the sector's issues it is crucial to understand its environmental impact during the last and the next years.
Human activities have impact on different levels: by the consumption of natural resources (mining and water resources), as a modification of the ecosystem (through cementation or deforestation) and as the release into the environment of waste products or in other terms, the emissions of various types of wastes like greenhouse gas.
The reason why sustainability problems are related to the Energetic sector is because as indicators like the *Earth Overshoot Day* and the *Carbon Footprint* show, the emission of carbon dioxide and in general greenhouse gas represents the biggest threat for the planet and the process of energy creation is one of the main cause of those emissions.
The last years increase in emissions at this rate has seems to have no hope of being thwarted. The only solution is the recent decarbonisation programs and large investments in renewable energy which has led to a slight reduction in CO_2 emissions in Italy, Europe and United States.
However, the efforts done until now and this very limited decrease are not enough to support the increase in consumption and production of renewable electricity.

It seems clear that the current situation is very problematic and that there is a need for an acceleration of the implementation of international and national solutions.
The right way seems to focus more on the electricity sector through the electrification of the consumption, a key tool to reach the goals set by the United Nations and that could enable the transition to a decarbonised system. A greater penetration of the electric energy consumption in the residential, industrial and mobility sectors, together with the increase in the share of renewables in the energy production mix are crucial tools to change the energy paradigm and improve the quality of life.
However, there are some problems that slow down this energy transition that may relate to several matters.
One of the main characteristic that distinguishes renewable electric plants from traditional ones and that could lead to bigger problems is that by their nature, they are characterized by non-programmable production profiles. It means that the production depends on the presence or absence of the resource which by its nature is intermittent, such as the sun or the wind. This implies that the electricity produced by these plants does not follow the logic energy demand, but only dynamics related to the single energy sources. The main example is the photovoltaic production that is high in the middle of the day and null at night.
Moreover, concerning the specific geographic Italian case, the growth of Renewable Energy Source (RES) plants occurred unevenly on the territory and it was only based on the presence of the source and often not consistent with the location of consumption places. In fact, the construction of RES plants takes place according to logic that prefers the positioning in areas that offer the best conditions of production, availability of resources and simplicity of the authorization path. The wind energy production plants developed for more than 80% in the south of Italy and in the two islands and on the contrary, the photovoltaic energy plants are more distributed and still are more concentrated in the North of Italy with about 44% of the national photovoltaic power.
Then the location of Italian plants is also related to technological attributes. In fact, the development of wind and photovoltaic plants has taken place heterogeneously also in relation to the voltage levels of connection. The wind energy plants are installed for 90% only on the high-voltage grid and photovoltaic energy plants have been built for about 95% on the distribution networks (Medium and Low Voltage): 822.000 plants of the 837.000 total located in the distributed generation come from the solar technology.

All these issues concerning renewable energy production plants lead to several consequences.
Indeed, this led to a change in the last years flows of electricity in Italy on the National Transmission Network. In fact, the abundance of new renewable sources especially in the south where the electricity demand is lower causes an inversion of the flow on the transmission network: electricity no longer flows from north to south as in the past but from south to north and from islands to north.
This change in the electricity flow has also taken place on the distribution level. In fact, the spread of the distributed generation (realized for the purpose of using renewable sources, even distant from the places of production), increases the possibility that the electricity produced is not only self-consumed on site or locally. Therefore, the electricity fed into the low or medium voltage electricity networks must be transported elsewhere, raising it of voltage and involving the phenomenon called flow inversion: the electricity that historically flowed on the distribution networks from high voltage to medium and low voltage, can now rise in voltage to be transported and consumed elsewhere.
All these matters have increased the network congestion in the transmission and distribution grid.
Moreover, another impact of the increasing incidence of non-programmable sources and the simultaneous decrease of programmable ones is that as a result, reserve margins are reduced (the power available during the hours when it is necessary to satisfy the electricity consumption in the absence of other production plants), making the system not appropriate to cover the load, as well as the resources for the so-called ancillary services (services that require plants capable of modifying their production as necessary to ensure the correct grid frequency values and the correct voltage profile, as well as to cover the load at any time) which can be a problem for the safe operation of the electrical system.
Finally, plants powered by renewable sources and equipped with inverters mentioned earlier, are characterized by low inertia: this means that, in a system characterized by their presence after a disruptive event on the networks, the frequency decreases more and more quickly than in the case of a system with high inertia or with high presence of traditional plants requiring new and timely restoration.
The efficiency of the electricity sector has always been difficult in Italy but now it is even more difficult to keep up with the current economic transition. The impacts of these factors combined with the Italian context can be seen on various levels and first of all, at the level of the National Transmission Grid. The Italian Electricity System presents some unique

characteristics, linked to its geographical configuration. As a matter of fact, Italy borders with Continental Europe only through the Northern border and is crossed longitudinally by mountain ranges and has two large islands. As a result, almost all the interconnection capacity with foreign countries is located on the northern border, while at national level there are structural bottlenecks between the different areas of the country, which cause difficulties in optimizing energy flows, causing the already mentioned network congestion. The low level of transmission capacity, as we have already explained above, determines the need to separate the electricity system into different "market areas".

The current design of electricity markets in Italy provides, in fact, in line with the European framework, a representation of the National Transmission Grid through a simplified structure that appropriately aggregates the nodes of the electricity grid. The possible exchanges of energy between adjacent market areas are opportunely limited in order to implement, in the algorithms of selection of offers for the energy markets, the constraints arising from the limited network transport capacity. Instead, energy trading within each market area is free from constraints.

Precisely to solve these problems, in 2018, TERNA completed, in accordance with the European Regulation, a review process after which ARERA approved a process of progressive adaptation of the zonal structure to the new needs and evidence of the National Electrical System.

However, the management of these congestions, which have been greatly amplified due to the advent of renewable energy production in a decentralized manner and the inversion of electricity flows from South to North, is very complex and in order to achieve this goal a technological push would be needed as well as a revision of the zonal structure.

Another impact is in the traditional structure of electricity generation in Italy. In fact, it is moving from a "one-way" system based on a few large thermoelectric plants connected to high and very high voltage networks and located far from consumption points, to a "multidirectional" system, where energy production is increasingly decentralized and extremely complex to manage. In Italy, in fact, there has gone from about 3,000 production units at the beginning of 2000 to over 800,000 connected to the electrical system today. Almost all the generation systems (over 99%) are installed on Distributed Generation (medium and low voltage networks), which has 837,000 and, as already mentioned, photovoltaic represents the largest share with 822,000, covering over 65% of the installed power.

This phenomenon of decentralization of generation brings with it a series of relevant implications related to the security of the Electric System that will have to be managed at the lowest possible cost in order to ensure the efficiency of the sector.

A further impact resulting from the spread of the supply of electricity from renewable sources is at the level of prices.

In fact, the price profile that is formed on MGP has changed. In particular, while historically the highest prices were formed in the daytime hours, corresponding to the maximum demand for electricity in the grid, currently the highest prices are formed in the pre- evening hours ranging from 17:00 to 21:00, i.e. during the hours when photovoltaic production gradually ceases. This is a problem that has obvious consequences directly on the final consumer because more and more the real price of electricity does not correspond to what the user goes to pay in his bill.

The link between the end consumer and the rest of the electrical chain has always been a delicate aspect. Here even more than in other sectors, the end user represents the weak part of the chain, being able to run into asymmetries information. However, as mentioned above, the consumer can generally represent the very element that can trigger the spark of change.

The preferences and opinions on social issues of the end user group have an enormous weight and, in some cases, can and have forced a sector and companies within it to evolve and adapt in a very short time. The survey that I carried out on a sample of 204 people had precisely the purpose to highlight the point of view of the electricity consumer. What can be deduced is that in a society increasingly in search of technological progress and progressively more connected with everything, where the consumer has a central role and is eager to have control over every aspect of his daily life, the split in the electrical sector between the end user and the rest of the chain is no longer acceptable. The lack of knowledge of such trivial aspects as the cost of electricity by most consumers shows that there is enormous room for improvement in the quality of service and transparency in the sector. In order to see a definitive technological progress at all levels of the chain, the end user must acquire a central role and the survey has showed that it is interested to be more involved in the dynamics of the sector. In this way, also its growing concern about environmental issues can be transmitted to all companies within the sector, thus beginning to have a push not only on the regulatory side but also on the consumer and public opinion side. All this will definitely open the doors to a new technology able to promote the efficiency and development of renewable energy production.

The Blockchain is able to create a protocol that allows, through a set of technologies and rules, to ensure the origin and integrity in the transmission of data without recourse to a trusted third party, but relying on a peer-to peer system.

It is a secure, transparent and decentralized block chain. "Safe" does not mean that it tries to hide information; it simply means that no one will tamper with the data on the Blockchain without sending alarm signals that would be noticed very quickly by the developers.

The Blockchain is designed to use a cryptographic hash and timestamp which are unalterable once created. This allows experts to inspect the records to determine the facts of a given transaction or to detect attempts to tamper with the ledger.

The Blockchain decentralized log ensures that no party in a transaction will have to trust any single third party. While the technology behind the Blockchain can be used to create an effective automated escrow deposit, the basic system will not disappear with your money or deny you access to your account. This gives for example Bitcoin its power as a currency that can cross borders, provide rapid settlements and avoid being controlled by any centralized authority.

The maintenance of the Blockchain is based on the operation of multiple nodes that are able to store transaction data and constantly validate new information with the use of processors; think about nodes as completely equal servers that regularly update each other with new data and make it possible for authenticated clients to connect with them if desired.

If a node malfunction occurs, IT staff can work with a Blockchain expert to isolate the server and fix the problem on that node to determine what went wrong.

There are three types of Blockchain:

- Public Blockchain: this Blockchain is freely accessible to anyone.
- Blockchain consortium members: the consensus mechanism on transactions is controlled by a set of pre-selected nodes.
- Completely private Blockchain (closed): it is a Blockchain in which write permissions are kept centralized at a single organization.

One of the most promising areas of Blockchain application is the creation of fully automated contracts that is to say agreements that are executed without human involvement. In the IT environment, these are called "Smart contracts". It is appropriate to refer to smart contract with the definition provided by Gideon Greenspan: "A smart contract is a piece of code that is stored on a Blockchain, activated by transactions on Blockchain and that reads and writes the data in the database of that Blockchain".

After explaining the Blockchain and smart contract functioning, it is now time to analyze their possible applications within the electrical sector so as to understand the problems they could solve and the benefits they would bring.

The Blockchain presents itself as a potential facilitator and catalyst of energy transition, representing a source of opportunity for all players in the industry, particularly through its combination with other technological means such as smart contract and techniques for the management and interpretation of mass data. The still limited maturity of energy sector projects using the Blockchain offers companies in the sector the opportunity to position themselves as pioneers of this technology.

One of the main problems that had been highlighted in the previous chapter was the need to manage the electricity system more safely and quickly and to deal with the growing problems of network congestion. In this case, through the Blockchain it could be managed much more effectively the mains voltage and related overloads by reducing any type of abnormal event connected to a voltage drop. This is because, taking advantage of the immutability of the Blockchain could be safely recorded a timely and automatic report if the voltage is reduced on the grid in the event of an overload and communicate it to the TSO.

Another crucial issue highlighted in the previous chapters was that of fostering more the development of renewable energies and dealing with the increasing spread of distributed generation and self-consumption.

The need for the Blockchain lies in the most recent trend of renewable energy production at the city level, particularly thanks to the presence of photovoltaic systems installed above the roofs of homes.

The consumer is more and more predisposed to become a major player in the electricity sector by feeding the phenomenon of distributed generation and going to spread the need to consume and exchange energy locally what is currently not possible except in specific cases. In fact, today a consumer who does not produce electricity independently is forced to buy the electricity he needs only from the sales company with which he has signed a contract, even if a few meters from his house lives a neighbor who owns a photovoltaic system and that at certain times of the day is able to generate a surplus of electricity, produced at a considerably lower cost than that taken from the grid and with considerable environmental benefits.

The Blockchain looks like that mechanism that allows automatic and traceable to bring together small producers- consumers (the so-called prosumers) and energy consumers, with clear benefits for both parties. In this perspective, millions of homes could become small power plants, able to automatically sell their excess power to the highest bidder creating a Peer to Peer system. A virtuous example of the concrete application of this Blockchain-based microgrid system is the Brooklyn Microgrid Project.

Another aspect in which Blockchain technology presents itself as a solution is the improvement of renewable energy certification. It would serve to ensure that the nature of electricity, the subject of transactions in the electricity system, is effectively decarbonized. The willingness of end users, as shown in the survey, is that the electricity supplied comes from renewable sources in their entirety. The consumer would have this certainty because the Blockchain can give the opportunity to trace, moment by moment, the origin of the electricity that is supplied, from the time of generation to the final destination of consumption finally going to reduce that gap between consumer and the rest of the chain and thus providing that much sought transparency. The supply of renewable electricity could thus also be flexible to the needs of the consumer and above all visible to all actors.

The guarantee that what is being exchanged comes from renewable sources, can be applied to the world of electricity certification, specifically to the system of certificates for renewable energy. The properties contained in each certificate can be registered within the Blockchain, hopefully public, so as to ensure access to the largest number of participants: in this way, on the one hand, the sales possibilities for producers are expanded and on the other, consumers can choose between an increasing number of offers of electricity from renewable sources and at an affordable price.

In conclusion, the electricity sector has been described as a complex sector where every step of the chain has main players and points that can be improved. This means that a crucial sector like this one is currently still too far behind in terms of its importance and these changes that has been shown before can only reassure us in the future. Obviously in order to be completely confident, it is necessary to hope that companies will seize the opportunities and the appropriate revolutionizing technologies that will be able to accelerate definitively towards efficiency and renewable energy. I believe that these technologies are in particular those of Blockchain. Although still a little unripe to be applied to the electricity sector, not easy to adapt on all levels and very expensive in economic terms, it has been shown in this thesis that it would present itself as the solution to all the problems identified. In fact, it has been widely demonstrated how it would make the management of the electricity system more transparent and secure from the TSO to the consumer, how it would be able to promote the development of a figure such as prosumer and local microgrid powered by the production and exchange of renewable energy and how it would be able to improve the certification system of the latter. Its characteristics allow to provide an added value to the electricity sector, which now has a huge need to take a step forward towards progress. Not exploring these technologies and not trying to apply them to the sector risks turning out to be a fatal mistake for the actors of the electricity system.

Appendix

Detailed content of the survey conducted by Luigi Mocchetti:

Q1 - How interested are you in the latest sustainable development issues?

#	Answer	%	Counting
1	Not at all interested	0.5%	1
2	Little interested	4.4%	9
3	Moderately interested	33.8%	69
4	Very interested	47.5%	97
5	Extremely interested	13.7%	28
	Total	100%	204

Q2 - To what extent do you think the emission of greenhouse gases could be a problem for our planet?

#	Answer	%	Counting
1	Not at all	0.0%	0
2	Little	1.0%	2
3	Moderately	9.3%	19
4	Very	49.0%	100
5	Extremely	40.7%	83
	Total	100%	204

Q3 - How much do you think your individual actions can impact the reduction of greenhouse gas emissions?

#	Answer	%	Counting
1	Not at all	1.0%	2
2	Little	11.3%	23
3	Moderately	34.3%	70
4	Very	40.7%	83
5	Extremely	12.7%	26
	Total	100%	204

Q4 - Which sector do you think is the one that causes the most greenhouse gas emissions?

#	Answer	%	Counting
1	Agricultural sector	14.7%	30
2	Electricity sector	15.2%	31
3	Transport sector	45.1%	92
4	Manufacturing sector	15.2%	31
5	Other	9.8%	20
	Total	100%	204

Q5 - How much do you think you can contribute to the reduction of greenhouse gas emissions caused by the electricity sector?

#	Answer	%	Counting
1	Not at all	2.0%	4
2	Little	27.0%	55
3	Moderately	47.5%	97
4	Very	21.1%	43
5	Extremely	2.5%	5
	Total	100%	204

Q6 - To what extent do you feel informed about the world of electricity?

#	Answer	%	Counting
1	Not at all informed	12.7%	26
2	Little informed	32.4%	66
3	Moderately informed	46.6%	95
4	Very informed	8.3%	17
5	Extremely informed	0.0%	0
	Total	100%	204

Q7 - Do you know exactly how the costs are split on your bill?

#	Answer	%	Counting
1	Not at all informed	27.0%	55
2	Little informed	27.0%	55
3	Moderately informed	34.3%	70
4	Very informed	9.8%	20
5	Extremely informed	2.0%	4
	Total	100%	204

Q8 - How much do you think the electricity selling company puts you in a position to be fully informed?

#	Answer	%	Counting
1	Not at all	8.3%	17
2	Little	52.0%	106
3	Moderately	34.8%	71
4	Very	4.4%	9
5	Extremely	0.5%	1
	Total	100%	204

Q9 - To what extent would you be interested in having more control and visibility of the cost of electricity?

#	Answer	%	Counting
1	Not at all interested	1.5%	3
2	Little interested	5.9%	12
3	Moderately interested	33.3%	68
4	Very interested	46.6%	95
5	Extremely interested	12.7%	26
	Total	100%	204

Q10 - To what extent would you be interested in more information about the energy sources you consume?

#	Answer	%	Counting
1	Not at all interested	1.0%	2
2	Little interested	5.9%	12
3	Moderately interested	22.5%	46
4	Very interested	57.8%	118
5	Extremely interested	12.7%	26
	Total	100%	204

Q11 - How important is it for you that the company that supplies you with electricity is committed to promoting the production of energy from renewable sources?

#	Answer	%	Counting
1	Not at all	1.0%	2
2	Little	0.5%	1
3	Moderately	10.8%	22
4	Very	51.5%	105
5	Extremely	36.3%	74
	Total	100%	204

Q12 - How would you evaluate the possibility of producing renewable energy on your own?

#	Answer	%	Counting
1	Not at all interesting	0.0%	0
2	Little interesting	2.5%	5
3	Moderately interesting	14.7%	30
4	Very interesting	47.5%	97
5	Extremely interesting	35.3%	72
	Total	100%	204

Q13 - Sex

#	Answer	%	Counting
1	Male	54.4%	111
2	Female	45.6%	93
	Total	100%	204

Q14 - Age range

#	Answer	%	Counting
1	Less than 18	1.5%	3
2	18 - 30	30.4%	62
3	30 - 50	36.3%	74
4	51 - 65	29.4%	60
5	More than 65	2.5%	5
	Total	100%	204

Bibliography

- www.arera.it
- www.terna.it
- www.gse.it
- www.mercatoelettrico.org
- www.sciencedirect.com
- www.servizioelettriconazionale.it
- www.sorgenia.it
- www.luce-gas.it
- www.iea.org/topics/energy-efficiency
- Law decree n.91/2018
- Law decree no.162/2019
- Legislative Decree no.79/1999
- Marzano Law no.239/04
- Law no.108/2018
- Law no.124/2017
- Law no.481/95
- European 96/92/EC Directive
- Contract Law 2.0: "Smart" Contracts as the beginning of the end of the classic contract law Alexander Savelyev (2016)
- United Nations, Resolution adopted by the General Assembly on 6 July 2017, 70/1. Transforming our world: the 2030 Agenda for Sustainable Development
- Terna, "Contesto ed evoluzione del sistema elettrico" (2019)
- ARERA, Relazione 321/2020/I/EFR, "Stato di utilizzo e di integrazione degli impianti di produzione alimentati dalle fonti rinnovabili e di generazione distribuita" (2019)
- ARERA, Quadro Strategico 2019-2021, Mercati di incidenza, Energia elettrica, gas, telecalore, servizio idrico integrato, ciclo dei rifiuti (2019)
- ARERA, Relazione Annuale, Stato dei servizi (2019)
- www.treccani.it/enciclopedia/l-ottocento-fisica-tecnologie-dell-elettricita
- www.agnenergia.com/it/storia-distribuzione-corrente-elettrica-da-volta-tesla

- www.footprintnetwork.org
- www.overshootday.org/about-earth-overshoot-day
- www.minambiente.it/pagina/cose-la-carbon-footprint
- www.carbonfootprint.com/
- www.wwf.it/
- www.undocs.org
- www.unstats.un.org/sdgs/indicators/indicators-list
- www.ourworldindata.org/energy
- Larry Lohmann, Blockchain machines, earth beings and the labour of trust (2019)
- www.blockchain.com
- www.iea.org/reports/world-energy-outlook-2019
- www.blockchain4innovation.it/
- www.energyup.tech
- www.exergy.energy
- www.brooklyn.energy
- www.lo3energy.com
- Pwc, Tendances de la transition énergétique, La blockchain dans l'énergie, perspectives de déploiement et d'intégration, 2018
- McKinsey, Enrico Giglioli, Cosma Panzacchi, Leonardo Senni, How Europe is approaching the smart grid
- Osservatorio Blockchain & Distributed Ledger, "Le opportunità della Blockchain per lo scambio di energia P2P" (2018).
- www.gruppotim.it/it/innovazione/tecnologia/blockchain/blockchain-energia.html
- www.rinnovabili.it/energia/tecnologia-blockchain-settore-energetico
- www.sorgenia.it/guida-energia/luce-e-gas