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ABSTRACT

With the Directive 2009/28/EC, the EU has identified the strategic plans to combat climate change by proposing short and medium-term measures to be realized by 2020. Achieving this will require high shares of renewable energy supply (RES-E) in the electricity system. To this end, Italy has significantly encouraged renewable energy through a variety of support schemes. As a result, production of electricity from these green sources, in particular from wind and solar (variable renewable energy, VRE) has risen considerably over the past years. Because of their weather-driven nature, and their out-of-merit dispatch, large-scale installations of wind and solar power are playing an increasingly important role in the supply and demand balance of electricity. Ultimately, that balance determines electricity prices in market-based systems. A clear understanding of the price effects of renewable energy in market-based electricity systems such as IPEX is needed. In this thesis, I estimated the impact of the country's renewable energy policy on electricity prices and price volatility. I found evidence of the so-called merit order effect, MOE i.e. a short run electricity price reduction due to huge penetration of renewables, in the Italian electricity system and also taking into account the six zonal markets. The price reduction is also accompanied by an increase in electricity price volatility. Without further development of renewable electricity regulation and market adaption, these results can lead to market imperfections determining investments below the optimal level.

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INTRODUCTION

The worldwide demand for electricity has been growing considerably since the global industrialization. The growth of the global economy has been achieved at the expense of the environment, as most of the produced electricity is generated by fossil-fuel fire plants that harm the environment. This process of unsustainable growth has led to significant, unforeseen, and some extent to irreversible environmental damages. In the last couple of decades, we have seen two major development in the Italian electricity market. First, there has been a deregulation of the market leading to enhanced competition, and second a shift to electricity generation from renewable energy sources. Liberalization has been advocated and implemented precisely with the aim to increase efficiency, avoiding the monopolist distortion and letting market competition to rule and to increase transparency, disposing of the opaque cross-subsidization mechanism implicit in the management of the vertically integrated monopolist. With the Directive 2009/28/EC, the EU has identified the strategic plans to combat climate change by proposing short and medium-term measures to be achieved by 2020. The first target is to cut the greenhouse gas (GHG) emissions by 20% below the 1990s levels. The second target is to increase the energy consumption from renewable energy sources (RES) to 20% of the total demand. Given the difficulties of decarbonizing transport and heating, the electricity sector will continue to bear a significant burden arising from economy-wide decarbonization. Achieving this will require high shares of renewable energy supply (RES) in the electricity system, in light of the limited opportunities for expansion of hydropower and widespread resistance to nuclear power. Fortunately, rapid technological progress in wind and solar energy suggests that a high-RES electricity system is not only a necessary outcome of the 2020 policy targets but also a realistic future scenario. The advent of variable RES with high upfront capital costs but very low short-run running costs has led to a reduced role for the market in guiding investment. Governments now dominate by setting the subsidy regimes and capacity mechanisms that determine new generation investment.

Italy put in place a variety of support scheme to develop RES. They go from green certificates to feed-in tariffs and premium tariffs. The Italian RES incentives created a huge surge in installed capacity, especially in solar and wind. The promotion of renewable energy can increase electricity supply security, encourage the development of technology, support the national industry and create employment in the green economy. However, the expected increase in renewable energy is also creating a debate about its costs. System operators and market participants face two main challenges as more renewable energy capacity is added. First, electricity generated by variable RES (wind turbines and photovoltaic panels) is intermittent and hardly adjustable to electricity demand. Therefore, variable renewable electricity generation cannot simply replace conventional energy sources. Second, Italy's renewable energy policy grants priority dispatch, i.e renewable electricity can be fed into the grid whenever it is produced, regardless of energy demand, and feed-in can be switched off only if grid stability is at risk. High levels of variable renewable electricity production can be balanced by adjusting the output from conventional power plants or by exporting excess electricity. Similarly, during times of too little wind or sunshine, sufficient dispatchable capacity has to be available to meet energy needs. The large increase which is to take place in these years brings about concern on how the cost of renewable policies may affect electricity prices. One of the prominent lines of research attempts to look at the impact of increased renewable energy target on electricity prices. Theoretical results affirm that an increase in renewable energy penetration should lower electricity prices since renewable energy has lower marginal costs and they displace marginal technologies with higher marginal costs (fuel, gas or coal). The reduction essentially shifts rents from conventional electricity generators to consumers. Relatedly, wholesale price volatility increases. This potential reduction of electricity prices is very appealing for a political point of view. Indeed, it is being used as an argument for or against the deployment of renewable energy in many energy debates all over the world.

The aim of this thesis is to further investigate the effects of intermittent renewable generation on the electricity price development in Italy. I’ll adopt a multivariate regression analysis and a seasonally adjusted autoregressive moving average (SARMA) model to explore the effect of renewable energy generation on the level and volatility of electricity prices.

My work is structured as follows. Section 1 retraces the main steps that led to the definition of the structure of today's Italian electricity market. Section 2 illustrates the trend of renewables and the political-economic context in which we are heading. Section 3 offers some critical issues of the Merit-Order effect in the market structure. Section 4 performs the analysis of the Italian renewable efforts on the weekly electricity price level and volatility analyzing the impact at a national level and then at the zonal level.

Chapter 1

ELECTRICITY SYSTEM

1.1 LIBERALIZATION PROCESS

Electricity industry started at the end of the 19th century when local suppliers produced electricity for consumers near the production site, public illumination, and transportation. In order to develop the industry governments got involved in many ways in the industry: in Europe nationalization of the transmission and distribution systems became the most common way of acting after World War II.

In Italy nationalization arrived in the 60s at the height of the economic boom, when politicians realized that electricity could be a great deal for an energy-consuming country like Italy. The Law of 6 December 1962, n. 1643 (so-called Nationalization Law), pursuing a unification of the national electricity system, put an end to a fragmentation of the electricity market that caused problems of stability, continuity, and quality of the services provided. About 1250 private electric companies became of state property and management was entrusted to ENEL (National Agency for Electricity), an institute with the function of "ensuring, with minimum operating costs, the availability of electricity suitable for quantity and price to the needs of a balanced economic development of the country[1]".

Electricity is not easily accumulated[2] (it can not be stored and consumption must take place at the same time as the supply), the demand is subject to temporal and random variations, for transport it is possible to use only the already existing transmission network (the construction of new lines require time and considerable investment) and it is a good that needs ancillary services essential for the technical functioning of the electricity system and high investment costs, sustainable only with strong economies of scale. Because of these constraints, the electricity sector was almost a "natural monopoly[3]". This choice is understandable if one considers the reasons mentioned and the objective difficulties of creating an electricity market that would safeguard simultaneously strategic role and social power, the single tariff and the characteristic of public service.

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[1] Law n. 1643 of 6 December 1962

[2] If not with pumping systems that require modern and big technologies investments.

[3] Production activity (and service) which by its nature had to be carried out by a single subject.

Thanks to the monopoly it was possible to achieve objectives otherwise impossible, as the almost complete electrification of the country together to the unification of the cost of electricity.

At the end of the last century, the institutional, organizational and management structure of the electricity (and gas) industry has been profoundly innovated following the implementation of reforms aimed at improving supply essential services for economic development and social welfare.

The European directive n. 92 of 19 December 1996, in order to open up the electricity market to competition, paying attention to environmental protection and wishing to enhance the efficiency of the electricity supply chain, imposed three principles: " i) the prohibition of granting exclusive schemes for production activities, import and export of electricity, and for the construction and use of lines transport; ii) freedom of access to transmission networks; iii) the gradual opening of the market, through the introduction of the figure of suitable customers, or users free to choose their supplier ".

With the d.lgs n. 79 of 16 March 1999 (Bersani Decree[4]), Italy has implemented the Community Directive 96/92 / EC, providing that "the activities of production, import, export, purchase and sale of electricity are free ... The transmission and dispatching activities are reserved to the State and assigned in concession to the national transmission grid operator ... Electricity distribution is carried out under the concession regime issued by the Minister of Industry, Trade and Crafts". It is only with the Bersani decree that, in Italy, it we can talk about the liberalization of the electricity sector.

Before the Bersani decree, ENEL's monopoly covered all phases of the electricity supply chain. ENEL dealt with the generation of electricity and the transmission and dispatching phases: the national transmission network, in fact, unique by nature, was owned and managed entirely by the monopolist. Regarding the distribution of electricity, the local networks were under concession and active both in sales and distribution. The sale carried out by the distributor, provided for regulated tariffs. Furthermore, it was not possible for the end customer to choose the supplier.

Following the first liberalization, the generation and sales phases are open to competition, while the transmission phase is a natural monopoly. TERNA, since November 2005, owns and manages the network. The transmission and distribution phases are regulated and the tariffs, established by the AEEG, are applied uniformly throughout the national territory. The GRTN

[4] This decree was adopted in compliance with art. 36 of the l. n. 128 of 1998, in which it was arranged that "in order to promote the liberalization of the energy sector, the Government is delegated to issue, within one year from the date of entry into force of this law, one or more legislative decrees to implement Directive 96/92 / EC of the European Parliament and of the Council and to redefine all relevant aspects of the national electricity system ".

becomes GSE. There purchase and sale of electricity take place within the Electricity Exchange, managed by the GME according to the bidding system, or through bilateral contracts.

The post-liberalization of the electricity sector is configured as follows:

- The activities of production, import, export, purchase, and sale of electricity are free. So, manufacturers, sellers, and importers are increasing and operating in competition. Many companies are involved in the generation such as Enel, Edison, Endesa Italia, ENI Group, Edipower, Tirreno Power, Acea Electrabel, Saras Group, AEM.
- The transmission and dispatching activities are attributed to the State and to TERNA, owner of more than 90% network, and its remuneration is established by the AEEG.
- The electricity distribution activity is carried out under a concession regime. The distribution is carried out by ENEL Distribuzione, SET Distribuzione, AEC, SECAB, and some Municipal

1.2 THE SUBJECTS OF THE ELECTRICAL SYSTEM

The main subjects that contribute to the functioning of the electricity system - each with a specific role expressly defined by the legislation - are, in addition to the Parliament and the Government:

- the *Ministry of Economic Development (MSE)* which, among other things, defines the strategic and operational guidelines for ensuring the safety and economy of the national electricity system;
- the *Authority for Electricity and Gas (AEEG)*, which guarantees the promotion of competition and efficiency in the electricity and gas sectors, with regulatory and control functions. With regard to the activity carried out by GME, the AEEG is responsible, inter alia, for the definition of the rules for dispatching economic merit and mechanisms for controlling market power;
- *Acquirente Unico*, a joint-stock company set up by the National Transmission Grid Operator (currently the Energy Services Manager - GSE), which is assigned the task of purchasing electricity on the most favorable conditions on the market and selling it to distributors or retailers, supply to small consumers who do not buy on the free market. To this end the AU can buy electricity on the power exchange or through bilateral contracts;
- *Terna S.p.A.*, which safely manages the national transmission grid and electricity flows through dispatching, i.e. balancing energy supply and demand 365 days a year, 24 hours a day;

- *Gestore dei Servizi Energetici (GSE)*, a public limited company with a central role in the promotion, incentive, and development of renewable sources in Italy. The sole shareholder of the GSE is the Ministry of Economy and Finance, which exercises the rights of the shareholder jointly with the Ministry of Economic Development. The GSE controls the companies *Acquirente Unico (AU S.p.A.)*, *Gestore dei Mercati Energetici (GME S.p.A.)* and *Ricerca sul Sistema Energetico (RSE S.p.A.)*.
- *Gestore dei Mercati Energetici (GME)*, which organizes and manages the energy market, according to criteria of neutrality, transparency, objectivity, as well as competition between producers

1.3 THE ELECTRICITY SUPPLY CHAIN

The national electricity system is an organized network system in which, in a free energy market, the activities that characterize it are distinct and carried out by different subjects. The activities concern the production, transmission, and distribution of electricity. The energy production, a liberalized activity, involves the transformation of the primary sources of energy into electricity in the power stations, i.e. in the production centers, and then transferring it to the consumption areas through a network system composed of lines, power stations, and transformation stations. The transmission, regulated activity, allows the transport of energy from production centers scattered throughout the territory or imported from abroad, to consumption centers. The network functions as a system of communicating vessels, in which all the energy injected is withdrawn, without it being possible to establish from which system the energy consumed comes from. The last phase that concludes the supply chain of the national electricity system is represented by the distribution, also regulated activity, which consists of the delivery of medium and low voltage electricity to users.

SYSTEM SEGMENTS	STRUCTURE	PRICE REGIME	MAIN OPERATORS
Production and import	Free	Market price	Enel, Endesa, Edipower, Enipower, Tirrenopower, ACEA Electrabel, ACEGAS, AEM Milano, AEM Torino, ASM Brescia, EDF, EGL, Atel, Verbund, HSE

Transmission and dispatching	National monopoly	Administered by AEEG	Terna S.p.A
Distribution	Local monopoly	Regulated, price cap defined by AEEG	Enel distribuzione, ACEA distribuzione, AEM Milano, AEM Torino, ASM Brescia and other local distributors
Sale	Free	Market price	Enel eneria, ACEA trading, AEM trading, Edison trading…

Table 1 Phases of the electric system. Source: tpg.unige.it, 2016.

1.3.1 PRODUCTION

Electricity is a secondary energy source: as long as we cannot directly capture and use lightning, we will have to continue producing it. Production is the main function involved in the electric system: generating electricity is a complex task and can derive from a variety of sources. Electricity is usually generated at a power station fueled by chemical combustion or nuclear fission but also by other means such as the energy of owing water and wind. Electricity can also be generated by solar photovoltaic and geothermal power.

The thermoelectric plants are the most widespread in the world and the common threesome of fuels most used as a source of heat is also common: coal (the most used in the world), oil and natural gas (today the most used in Italy). Today the advantages of the traditional thermoelectric are those typical of a mature technology and with numerous consolidated "variants" - the gas turbine power plants, the combined cycle and others - that make it possible to make exploit the better of the fuel, polluting less, and arriving to supply power order of the Gigawatt (GW) continuously and for prolonged periods of time. The disadvantages are basically three: the same source of energy, which is not renewable but destined to run out; the variability of the fuel price, which affects the price of energy; the pollution produced by burning oil, coal and, to a lesser extent, natural gas (methane), with all that follows in terms of environmental impact at the local level (smog and dust) and planetary (global warming and climate change). Among the most interesting technologies, there is a very efficient evolution of the gas plant: it is the combined cycle (CCGT, Combined Cycle Gas Turbine). Recovery is the concept that underlies this solution: in short, the hot mixture of air and gas (at 500-600 ° C) that rotates the gas turbine, leaving the first system still contains enough energy to operate a steam turbine. There is not just one type of combined cycle, but in general, for all its variants, the overall effect is more than

50% compared to 30-35% of traditional steam turbines. This level of efficiency allows reducing both consumption and emissions compared to conventional systems.

SOURCE (GWh)	2012	2013	2014	2015	2016
Thermoelectric production	205.075	176.897	157.439	172.658	179.839
Solids	49.141	45.104	43.455	43.201	35.608
Natural Gas	129.058	109.876	93.637	110.860	126.023
Oil products	7.023	5.418	4.764	5.620	4.127
Others	19.852	16.499	15.583	12.976	14.081
HYDRO pumping	1.979	1.898	1.711	1.432	1.825
Production from RES	92.222	111.999	120.677	108.904	107.654
HYDRO	41.875	52.773	58.545	45.537	42.250
WIND	13.407	14.897	15.178	14.844	17.648
Solar	18.862	21.589	22.306	22.942	22.104
Geothermal	5.592	5.650	5.916	6.185	6.289
Biomass and waste	12.487	17.090	18.732	19.396	19.363
TOTAL PRODUCTION	*299.276*	*290.794*	*279.827*	*282.994*	*289.318*

Table 2 Production from sources. Source: Elaboration of AEEGSI Terna's data.

There are also systems that achieve even higher returns (80-85%), for example, the so-called cogeneration, where a common internal combustion engine - for example, that of a car - is applied directly to a power generator and exhaust gases they are used to heat water for sanitary use or for heating. The size of these solutions is however limited, from a few kilowatts to a dozen Megawatt, suitable for a local production (small industries, condominiums), and have for now little diffusion.

Production from renewable sources has grown significantly in recent years. Renewable energies - solar energy, solar (thermal and photovoltaic), hydraulic, WIND, geothermal and biomass - are a fundamental alternative to fossil fuels. Their use makes it possible to reduce not only greenhouse gas emissions from energy production and consumption but also the country's dependence on imported fossil fuels (in particular gas and oil).

1.3.2 TRANSMISSION AND DISPATCHING

The network system, which characterizes the national electricity system, provides that transmission and dispatching activities are subject to very stringent technical constraints, such as:

- The request for an instant and continuous balancing between the quantities of energy fed into the network and those taken from the network, net of transport and distribution losses;
- The maintenance of the frequency and the voltage of the network energy within a very narrow range, to protect the safety of the plants;
- The need for the energy flows on each individual power line not to exceed the maximum permissible transit limits on the power line itself.

Even minimal deviations from any of the above parameters, for more than a few seconds, can quickly lead to systemic states of crisis. The characteristics of the technologies and the ways in which electricity is produced, transported and consumed make compliance with these constraints even more complicated.

In particular, the difficulties arise from three factors:

1) variability, inelasticity, and non-rationality of the demand: the power demand on the network exhibits considerable short-term (hourly) and medium-term variability (weekly and seasonal);
2) absence of storage and dynamic constraints to the real-time adaptation of the offer: electricity cannot be stored in significant quantities, if not indirectly, and in the case of the type of "basin" hydroelectric plants, through the quantity of water contained in the basins themselves; moreover, electrical systems have minimum and maximum limits to the power that can be supplied, as well as minimum activation times and variation in the power supplied;
3) externalities on the network: once injected into the network, the energy engages all the available power lines as in a system of communicating vessels, sharing itself according to complex physical laws determined by the balance of inputs and withdrawals; this makes the path of energy untraceable, so that any local imbalance, not promptly compensated, spreads across the entire network through variations in voltage and frequency.

Transmission it is the activity of transport and transformation of electricity on the interconnected high voltage network and very high voltage[5] for the purpose of delivery to customers, distributors, and recipients of self-produced energy. This activity is carried out by Terna. In order for this to happen, lines, power stations, and transformation stations are needed, that is, the elements that make up the Transmission Network[6] a collection of over 72,000 km of lines owned and managed by Terna.

The high degree of complexity and coordination necessary to guarantee the functioning of the system require the identification of a central coordinator with control over all the production facilities belonging to the system. This subject, known as a dispatcher, is the fulcrum of the electrical system and has the task of ensuring its operation in conditions of maximum safety to ensure continuity and quality of service. In fact, it ensures that production always equals

[5] AAT-AT= 380 kV - 220 kV - 150 kV

[6] The transmission network (RTN) is formed, therefore, from very high and high voltage lines, from transformation and / or sorting stations, as well as from interconnection lines that allow the exchange of electricity with foreign countries.

consumption and that frequency and voltage do not deviate from optimal values, respecting the limits of transit on the networks and the dynamic constraints on the generation plants.

Terna carries out dispatching activities, i.e. the task of balancing the system in real time. The necessary balance between inputs and withdrawals in every moment and in every node of the network is guaranteed by the automatic regulation and control systems of the production units (so-called primary and secondary reserve), which increase or reduce the input into the network in order to compensate for any unbalance on the network itself. The dispatcher actively intervenes - by sending to the tertiary reserve units orders for ignition, increase or reduction of the power supplied - only when the operating margins of the automatic control systems are lower than the safety standards in order to reintegrate them.

The electrical system is divided into portions of transmission networks - defined zones - for which, for the purposes of the safety of the electrical system, physical limits of energy transit exist with the corresponding neighboring areas. These transit limits are determined on the basis of a calculation model based on the balance between electricity generation and consumption. The Italian electricity system is therefore divided into market zones, aggregates of geographical and/or virtual areas, each characterized by a zonal energy price.

The process of identifying the areas of the relevant network takes into account the Triennial Development Plan of the National Transmission Grid. The areas of the relevant network can correspond to physical geographic areas, to virtual areas (i.e. without a direct physical correspondent), or be limited production poles, i.e. virtual areas whose production is subject to constraints for the safe management of the system electric.

For the purpose of verifying and removing any congestion caused by the injection and withdrawal schedules - whether they are determined on the market or in execution of bilateral contracts - GME uses a simplified representation of the network, which only shows the most relevant transit limits, or the transit limits between the national geographical areas, the foreign areas and the limited production poles.

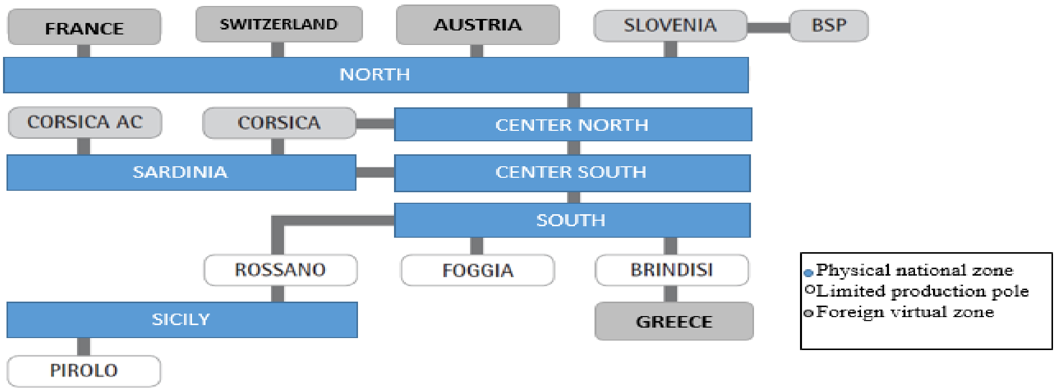

Figure 1 Virtual areas and geographical areas of the transmission network, source VADEMECUM DELLA BORSA ELETTRICA, 2009.

The national transmission network is interconnected with abroad through 22 lines: 4 with France; 12 with Switzerland; 1 with Austria; 2 with Slovenia and 1 cable in direct current with Greece, in addition to the SACOI direct current connection connecting Sardinia to the continent via Corsica and to a further AC[7] cable between Sardinia and Corsica, and to the SAPEI direct current connection which connects Sardinia with the peninsula. The conformation of these areas is functional to the management of the transits along the peninsula taken by Terna which can be summarized as:

Figure 2 Six geographical areas. source VADEMECUM DELLA BORSA ELETTRICA, 2009.

- 6 geographical areas (Center - North, North, Center - South, South, Sicily, Sardinia);
- 8 virtual foreign areas (France, Switzerland, Austria, Slovenia, BSP, Corsica, Corsica AC, Greece);
- 4 national virtual zones representing limited production poles, i.e. interconnection capacity with the network is lower than the installed power of the units themselves.

1.3.3 DISTRIBUTION AND SALE

The distribution networks represent the capillary extension on the territory of transmission lines and transfer electricity to all final customers. These networks serve consumers, which go from big industrial plants (connected often to high voltage network) to domestic customers.

The sale of electricity can take place either through bilateral bargaining between seller and buyer (the sale takes place directly between the two parties) or through the negotiation on the Power Exchange between seller and buyer (electronically).

[7] Alternative current.

1.4 ITALIAN ELECTRICITY MARKET

The Italian Power Exchange (IPEX[8]- Italia Power Exchange), established in Italy from 1 April 2004 and fully operational since January 2005, constitutes the place where the supply of producers meets consumer and wholesaler's electricity demand. It represents an organized system able to favor both competitions in relation to the production and sale of electricity, and the protection of end customers thanks to maximum transparency guaranteed by the unified coordination of the electricity market entrusted to the Electricity Market Operator (GME).

It is a telematic marketplace in which electricity is traded wholesale. The price of electricity is that of equilibrium that arises from the encounter between supply and demand. Unlike other European energy markets, IPEX is not a purely financial market aimed solely at determining prices and quantities, but it is a real physical market where the where the electricity supply and withdrawal programs are defined in (and from) the network according to the criterion of economic merit.

The Electricity Market includes: the spot market (MPE), the forward market with the obligation of delivery and collection (MTE) and in the Platform for the physical delivery of financial contracts concluded on IDEX.

1.4.1 THE SPOT MARKET (MPE)

Is divided into three sub-markets:

1) *THE DAY AHEAD MARKET (MGP)*

The Day Ahead Market (MGP), is a market for the exchange of electricity for the next day. The MGP is organized according to an implicit auction model and hosts most of the electricity demand and supply transactions.

The MGP session opens at 08.00 on a ninth day before the day of delivery and closes at 09.15 of the day before the day of delivery. Then according to the economic merit order criterion and to the capacity limits of the transmission lines between zones, offers and bids can be accepted. The accepted supply offers are evaluated at the clearing price of the zone. This price is the equilibrium price determined on an hourly basis by the intersection of the demand and supply curves. Hence the zonal market clearing prices are those prices observed on several zones or areas, and they can differ across zones if a proportion of the grid becomes congested and so

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[8] Name with which the Italian electric stock exchange is known abroad. The platform is the main instrument through which implement the provisions of the legislative decree n. 79/1999 for the realization of the free market Energy.

separated from the entire network (Weron, 2006). On the other hand, the accepted demand bids are evaluated at the single national price (Prezzo Unico d'Acquisto, PUN) which is the purchase price for end customers and it is computed as the average of the zonal prices weighted by zonal consumptions.

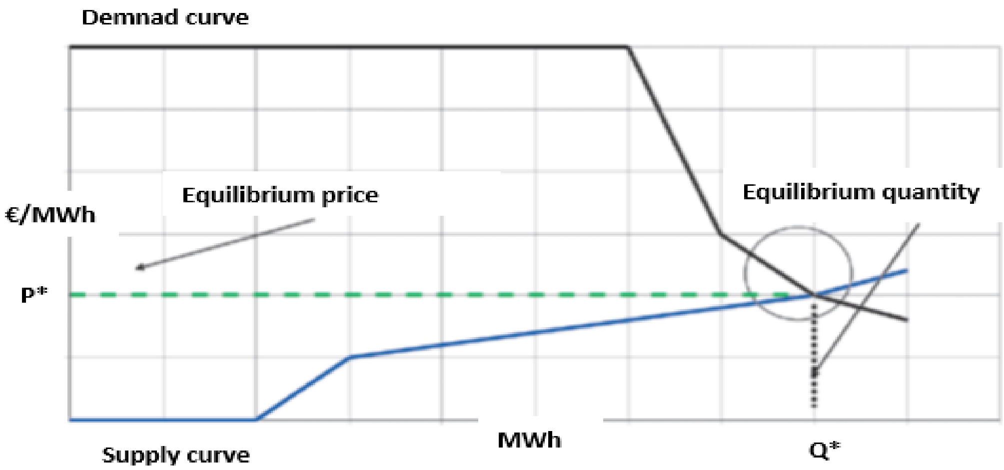

Figure 3 Determination of the equilibrium price. source VADEMECUM DELLA BORSA ELETTRICA, 2009.

Analyzing figure 4, the intersection of the two curves determines: the total quantity exchanged, the equilibrium price, the accepted offers and the input and withdrawal programs obtained as the sum of the accepted offers referred, in the same hour, to the same point of supply.

- If the flows on the network deriving from the programs do not violate any transit limit, the equilibrium price is unique in all areas and equal to P *. The accepted offers are those with a sales price not higher than P * and with a purchase price not lower than P*.
- If at least one limit is violated, an algorithm "separates" the market into two market zones - one in export that includes all the zones upstream of the constraint and one in import that includes all the areas downstream of the constraint - and repeats in each of them the crossing process described above, constructing, for each market area, an offer curve (which includes all the sales offers presented in the same area as well as the maximum quantity imported) and a demand curve (which includes all offers of purchase presented in the area itself, as well as a quantity equal to the maximum quantity exported). The result is a different zonal equilibrium price (Pz) in the two market zones. In particular, the Pz is larger in the importing market area and is smaller in the exporting one. If as a result of this solution further transit restrictions are violated, within each market area, the process of subdivision, or "market splitting", is repeated even within this area until an outcome compatible with the network constraints.

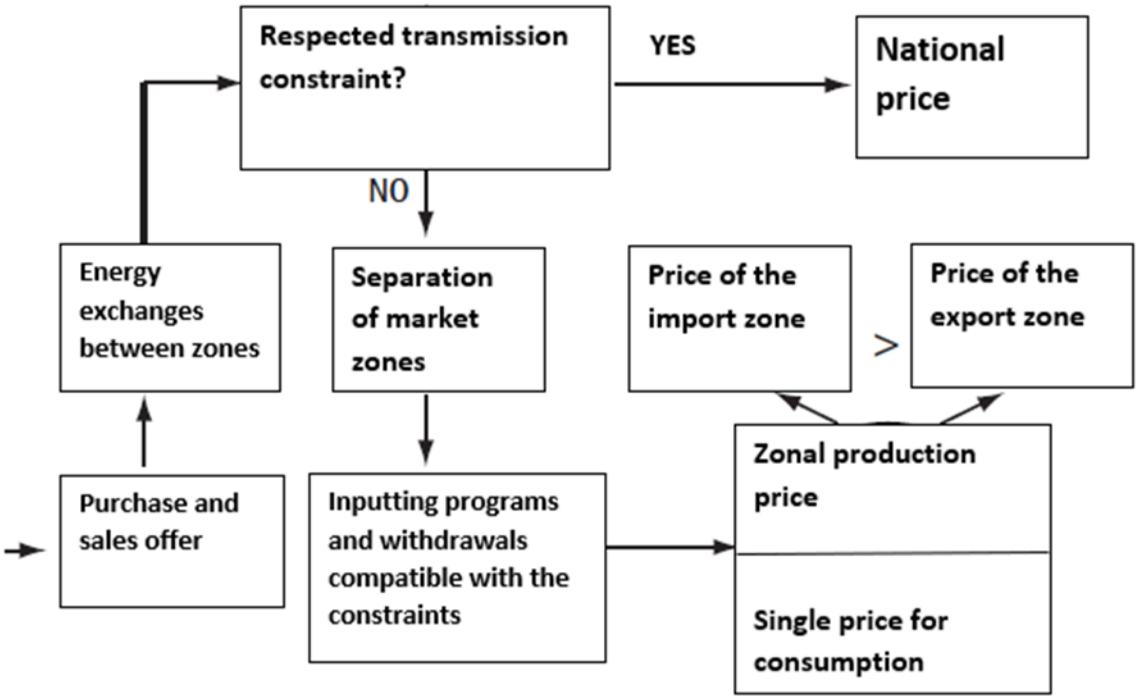

Figure 4 Zonal price algorithm with a single price for consumers. Source: own elaboration on VADEMECUM DELLA BORSA ELETTRICA, 2009.

OTC CONTRACTS: The energy exchanged by virtue of bilateral negotiations recorded on the PCE[9] participates in the process described above, both because it helps to commit a share of the available transport capacity on the transits, and because it helps to determine the weighting amounts of the National Single Price. The programs registered on the PCE are sent to the MGP in the form of offers and contribute to the determination of the outcomes of the MGP itself.

2) INTRADAY MARKET (MI)

Allows operators to update sales and offers of purchase and their commercial positions with a frequency similar to that of a continuous negotiation with respect to the variations of information on the status of production facilities and consumption needs. Now the zonal prices are used to evaluate the accepted purchase bids

The MI[10] takes place in four sessions: MI1, MI2, MI3, and MI4: the first two organized on the day d-1 after the MGP (MI1 and MI2)[11], and the second two intraday sessions (MI3 and MI4)[12] are organized on the day d[13].

[9] Electricity Account Registration Platform (PCE): Entrusted to GME, it is the platform for the registration of electricity futures contracts, concluded outside the MPE and, in particular, on the MTE or on a bilateral basis (so-called over the counter or OTC) and the corresponding input and withdrawal programs.
[10] Introduced with the law 2/09
[11] operational since October 31, 2009
[12] introduced from 1 January 2011
[13] Delivery day

The sessions are organized in the form of implicit energy auctions with different closing times and in succession, through which the operators can both carry out a better control of the state of the production plants and update the withdrawal programs of consumption units, taking into account more up-to-date information about the status of their production facilities, the needs for energy for the next day and market conditions.

At the end of each session of MI, GME, as it did for the conclusion of the MGP, communicates to Terna the relevant results for the purposes of dispatching with transits and updated schedules of imputing and withdrawals.

3) ANCILLARY SERVICES MARKET (MSD)

It is the instrument through which Terna SpA, in the role of the network manager, procures the resources necessary for the management and control of the system (resolution of intra-zonal congestions, the creation of the energy reserve, real-time balancing). On the MSD, Terna stipulates the purchase and sale contracts for the procurement of resources for the dispatching service and acts as a central counterparty to the negotiations. In the MSD, offers/bids are accepted by economic Merit Order, taking into account the need for ensuring the correct operation of the system. Offer/bids accepted in the MSD are valued at the offered price (Pay as bid[14]). On the MSD the offers can be referred only to the offer points enabled for trading on this market and must be submitted only by the respective and direct users of the dispatching without the possibility of using the institution of delegation.

The MSD is divided into a programming phase (ex-ante MSD) and the Balancing Market (MB). On MSD ex-ante, offers/bids are selected for the relevant periods of the following calendar day to the one in which the session ends. On the ex-ante MSD, Terna accepts offers to purchase and sell energy for relieving congestions and creating an adequate reserve margin[15]. The ex-ante MSD is articulated in particular in three programming sub-phases: MSD1, MSD2, and MSD3. The Balancing Market (MB) concerns offers/bids that Terna has accepted in real time for balancing injections and withdrawals (by sending balancing commands); it takes place in several sessions, according to the provisions of the dispatching regulations.

[14] Valuation rule adopted on the MSD, based on which each offer is valued at its offer price.

[15] Capacity margin with respect to forecast demand that Terna S.p.A. creates to offset deviations between electricity generation and consumption.

	MGP	MI1	MI2	MSD1	MB1	MB2	MI3	MSD2	MB3	MI4	MSD3	MB4	MB5
Day	D-1				D								

Table 3 Structure of the spot market's (MPE) session. source VADEMECUM DELLA BORSA ELETTRICA, 2009.

	MGP	MI	MSD	
EXCHANGED RESOURCE	energy	energy	Energy for resolution of intra-zonal congestions	Energy for real-time balancing
UNIT ADMITTED TO PARTICIPATE	Offer points		Offer points enabled for dispatching services	
OPERATORS	Market operators	Market operators	Dispatching users	Dispatching users
PRICE	Equilibrium price	Equilibrium price	Offer price	Offer price

Table 4 Organizational scheme of MPE. Source: own elaboration on VADEMECUM DELLA BORSA ELETTRICA, 2009.

1.4.2 FORWARD ELECTRICITY MARKET (MTE)

It is the venue for the negotiation of electricity futures contracts with the obligation of delivery and withdrawal of the same, which can be attended by all the operators admitted to the Electricity Market.

On this market, GME acts as a central counterparty and registers on the PCE - at the end of the relevant trading period, or, during the same period, following a specific request by the operator - the net delivery position, corresponding to the purchases and sale concluded by the operator on the MTE, being GME a qualified market operator and for this holder of an energy account on the PCE.

Two types of contracts are tradable on MTE, which underlying amount of energy is set by GME at 1 MW, multiplied by the relevant periods underlying the contract. The types are:

- Baseload, whose underlying is the electricity to be delivered in all the relevant periods of the days belonging to the delivery period;

- Peakload, whose underlying is the electricity to be delivered in the relevant periods from the ninth to the twentieth of the days included in the delivery period, excluding Saturdays and Sundays.

These types of contracts are negotiable with the following delivery periods: month, quarter and year.

The operators participate presenting proposals in which they indicate the type and period of delivery of contracts, number of contracts, price at which they are willing to buy/sell.
GME organizes a trading book for each type of contract and for each delivery period. On this book, the offers are ordered on the basis of the price: in descending order for the purchase offers and in increasing order for the offers of sale. At the same price, the time priority for placing the offer is valid. Offers without price limit have maximum price priority.

1.4.3 PLATFORM FOR PHYSICAL DELIVERY OF FINANCIAL CONTRACTS CONCLUDED ON IDEX (CDE[16])

GME has entered into a collaboration agreement with Borsa Italiana SpA[17], which manages the energy derivatives market - IDEX -, in order to allow, through the electricity market managed by GME, operators participating in both markets, to regulate by means of physical delivery, the financial contracts with an electric sub-fund concluded on IDEX.
The agreement drawn up between GME and Borsa Italiana for the integration between the derivatives market managed by Borsa and the Electricity Market managed by GME, provides that operators who have an open position on IDEX can exercise, on this market, an option of physical delivery, requiring in this way that its position is regulated by physical delivery through the GME market.
With reference to the position that the operator has accrued on IDEX for the following month, the physical delivery option can be exercised on the third trading day before the start of the relevant delivery month.
The exercise of the physical delivery option entails for the trader, in relation to the transfer of his position to GME, the conclusion, on the platform for the physical delivery of derivatives on the energy of the electricity market - CDE -, of a transaction of purchase / sale of the underlying energy of the delivered position, which has GME as its counterpart. This transaction is valued at the settlement price of the fourth trading day before the month of delivery, plus VAT, where applicable.

[16] With the publication of the Decree of the Ministry of Economic Development, 29 April 2009, the Ministry set the guidelines for the evolution of GME's organized futures markets. In particular, the art. 10 paragraph 6 established that GME should seek forms of "collaboration with the management company of the regulated market of derivatives on electrical underlying".
[17] Regulated market management company authorized by Consob to exercise the stock exchange market for the trading of financial instruments

1.5 RESULTS OF THE LIBERALIZATION

The results brought about by liberalization, in the short term, were above all the improvement in the quality of the electric service, the reduction of supply interruptions and a greater qualitative standardization of the service from North to South. In addition, clearer rules have been defined to protect the rights of small consumers. The activation of new operators, both Italian and foreign, and the service of intermediation that these exercise, are, moreover, essential prerogatives for a competitive market. Regarding the tariffs, there has been a considerable reduction in production costs and service delivery, around 20%, the cost of raw materials, however, changes with the oscillation of world prices.

Investments in a generation were initially blocked due to uncertainty caused by the new change. They, however, resumed after the first five years, thus determining a greater efficiency and a relative reduction of the production costs. Finally, the establishment of the Power Exchange allowed for more transparent transactions and the possibility of collective purchase by a single entity (AU), to protect those (constrained) customers who, in the early years, have not been admitted at the free market.

The prices of the electricity market have undergone the reflection of several factors that accompanied liberalization. In the years immediately following liberalization, the amount of electricity that was placed on the liberalized market derived from importation at very low prices, especially nuclear purchased mainly from France. So, the first effect on the price, following the liberalization, was certainly positive.

Subsequently, domestic production in the country was added to low-price imports.

The electricity generation mix has been optimized with substantial investments addressed to the activation of high-efficiency gas plants. However, the (largely obligatory) recourse to electricity produced from renewable sources has led to a reduction in the time of use of gas power plants (modern and efficient). The final price, therefore, comes from the sum of the costs deriving from the production of energy from renewable sources, and the greater cost deriving from the reduced recourse to traditional power stations which, although efficient, remain under-utilized. The consequence of these factors has therefore led to an increase in production costs.

Regarding the long-term effects of liberalization today it is necessary to review the current organizational structure of the electricity system in terms of sustainability for the country, taking into account the global economic crisis and the changed priorities of energy policy.

The economic and financial crisis highlighted the risk of the substantial level of investment in generation capacity in the previous decade. This substantial growth in investments in generation capacity, however, was not accompanied by an equally high growth in consumption. This has led to an excess of production capacity compared to the actual need to cover the needs. Another contributing factor to the increase in supply capacity was the simultaneous increase in interconnection capacity with foreign countries.

The new energy policy priorities suggest a future growth in the riskiness of the investment in generation capacity. The increase in renewable production has led to a sharp decrease in the time (hours) of the operation of thermoelectric plants (coal plants, oil products, turbo gas, combined cycle, methane gas). Therefore, these plants are unlikely to cover fixed costs. Considering the reduced number of operating hours of these plants, this problem has a negative impact, especially for those companies that have activated the system of production plants for a short time, reducing the profitability of their investments at a short distance from their realization. This means incentives for renewables can be the cause of greater risk for both producers and those who have invested in generating capacity. The structure of the sector is therefore the result of an interaction between the investment choices that the operators take autonomously, and those induced by public intervention for the purpose of environmental sustainability. The increased production capacity from renewable sources also entails lower variable costs, or even negative, that characterize the supply curve. The direct consequence is an extremely variable electricity price.

In the following chapter, we are going to analyze the renewable energy policy and the status of renewables in Italy

Chapter 2

RENEWABLES IN THE ITALIAN ELECTRICITY MARKET

Processes like the production of energy, its transformation, and its use have an environment-impact as they release polluting substances into the atmosphere. In all the developed and emerging countries, we are witnessing a steady growth in the use of electricity, most of this produced some time ago by thermoelectric plants.

In the last decade, in order to reduce dependence on fossil fuels, due to the growing increase in concentrations of atmospheric pollutants, initiatives promoting the production of energy from renewable sources have become a priority. The advantages deriving from their use are the absence of polluting emissions into the atmosphere (with the exception of biomass) and their inexhaustibility. The renewable energy sources associated with these resources are therefore solar energy, wind energy, hydroelectric power, and geothermal sources, or those sources whose current use does not affect their availability in the future.

2.1 FROM THE EUROPEAN CONTEXT TO THE NATIONAL ONE: NREAP

The promotion of electricity produced from renewable energy sources (RES) is among the priorities of the European Union (EU) for reasons of security and diversification of energy supply, for reasons of environmental protection and for reasons linked to economic and social cohesion.

With the Directive 2009/28 / EC[18], the EU has identified the strategic plans to combat climate change by proposing short and medium-term measures aimed at the adoption of the following energy measures («20-20-20» of the Community) to be realized by 2020:

- + 20% of energy from renewable sources in final energy consumption[19];
- - 20% of energy consumption compared to the trend scenario, through efficiency energy;

[18] repealed Directive 2001/77 / EC on the promotion of electricity produced from renewable energy sources in the internal electricity market, which set the target of 21% of gross domestic energy consumption from renewable energy sources for member states by 2010.

[19] This is the overall target. Targets for renewable energy in each country vary from a minimum of 10% in Malta to 72% of total energy use in Iceland.

- \- 20% of emissions into the atmosphere.

Each Member State is required to adopt a National Renewable Energy Action Plan (NREAP), identifying strategies and implementing measures to improve energy efficiency in energy consumption and to increase the role of renewables in the transport sectors, electricity, and heat. Italy adopted its NREAP in June 2010. With the Legislative Decree 3/3/2011, n. 28 defined the methods and criteria for the implementation of the measures envisaged by the NREAP, in line with the indications of the European Directive 28 of 2009.

Among the general objectives they take on particular importance:

- the **security of energy supplies**, considering that Italy depends heavily on energy imports. Oil supply disruptions as a result of political events in Libya in 2011 and reductions in gas supplies from Russia through Ukraine are recent examples of the problematic situation;
- the **reduction of emissions** of harmful gases for the climate (**CO_2, CH_4**, ...) according to the commitments undertaken at the international level (Kyoto agreement and following);
- **improving the competitiveness of the national industry** through support for the demand for renewable technologies and the development of technological innovation. The development of renewable sources can be an element of economic development, employment, and investment for the country.

The areas of intervention of the lines of action are the transport, thermal and electrical sectors. The objectives of the NREAP are to be achieved by 2020; the percentage comparisons are calculated with respect to the values of 2005, a year taken as a reference at a European level.

Regarding the objectives for renewable energy, Italy has assumed for the year 2020 the objective to cover with energy from renewable sources 17% of gross final energy consumption. The expected total energy consumption in 2020 is 133.042 ktoe[20]. The amount of energy from renewable sources in the target year 2020 should be 22.617 ktoe. Italy's NREAP sets a target of the share of renewable energies to be 17,09% in the heating/cooling sector, 10,14% in the transport sector and 26,39% in the electricity sector by 2020. Therefore, the development of renewable sources in the production of electricity remains a strategic action line. To increase the percentage of electricity consumption covered by renewable sources while ensuring efficiency and acceptable costs, it is necessary that the electricity system is adequate in its infrastructure; in particular, it is necessary to aim at the realization of the so-called smart grids,

[20] The tonne of oil equivalent (toe) is a unit of energy defined as the amount of energy released by burning one tonne of crude oil. In electricity, 1MW= 0.187 toe.

capable of realizing efficient forms of storage, accumulation, collection and sorting of the electricity produced.

The table below illustrates the objectives that Italy intends to achieve in the three sectors - electricity, heat, transport - for the purpose of meeting the targets set, comparing the reference year 2005, the intermediate situation to 2008 and the forecasts for 2020.

	2005			***2008***			***2020***		
	RES Mtoe	GFC Mtoe	RES/GFC %	RES Mtoe	GFC Mtoe	RES/GFC %	RES Mtoe	GFC Mtoe	RES/GFC %
electric	**4,84**	**29,74**	**16%**	**5,04**	**30,39**	**16,58%**	**9,11**	**31,44**	**28,97 %**
heat	1,91	68,5	2,8%	3,23	58,53	5,53%	9,52	60,13	15,83%
transport	0,17	42,97	0,42%	0,723	42,61	1,7%	2,52	39,63	6,38%
total	6,94	141,2	4,91%	9	131,5	6,84%	22,3	131,2	17%

Table 5 Summary National Renewable Energy Action Plan (NREAP). Source: elaboration of Zanichelli on data from Ministry of Economic Development, 2012.

2.2 RENEWABLES SITUATION IN ITALY

At the end of 2016, 742,340 electric power plants powered by renewable sources were installed in Italy; this number is almost entirely made up of photovoltaic systems (98.6%). The gross efficient capacity of installed renewable energy plants exceeds 52,000 MW, with an increase compared to 2015 of almost 800 MW (+ 1.5%); this growth is mainly driven by solar sources (+380 MW) and wind (+250 MW). In the 13 years between 2003 and 2016, the gross efficient power installed in Italy rose from 19,663 MW to 52,273 MW, an increase of 32,610 MW and an average annual growth rate of 7.2%; the years with the greatest increases in power are 2011 and 2012.

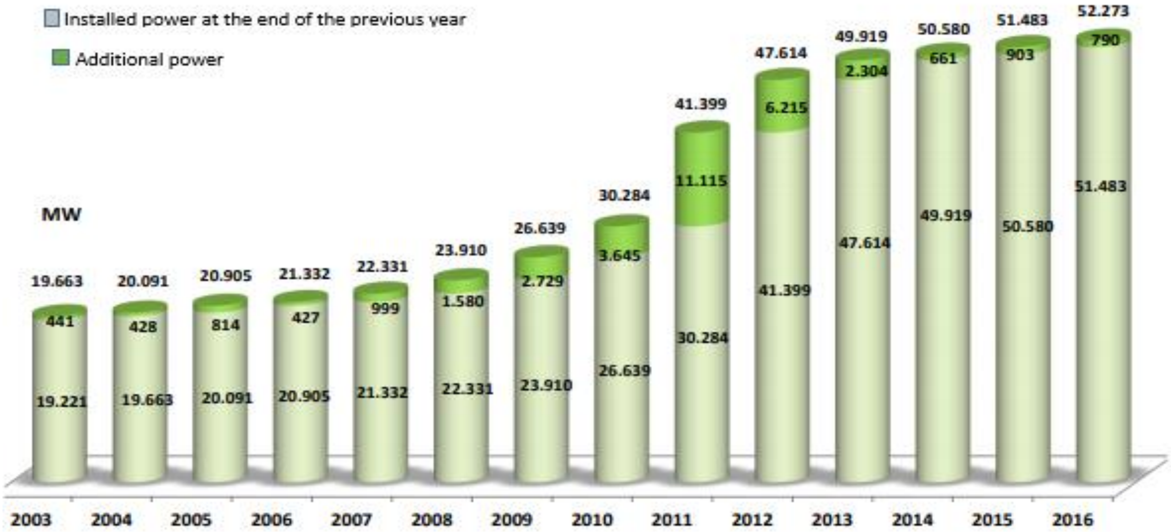

Figure 5 Evolution of the installed power of renewable energy plants. Source: Elaboration of GSE on Tena and GSE's data, rapporto statistico 2016.

Since the beginning of the 20th century, the national electric park has been characterized by the widespread diffusion of hydroelectric plants; in the most recent years, the installed capacity of these plants has remained almost constant (+ 0.7% on average per year), while all the other renewable sources have grown considerably thanks mainly to the various public incentive systems.

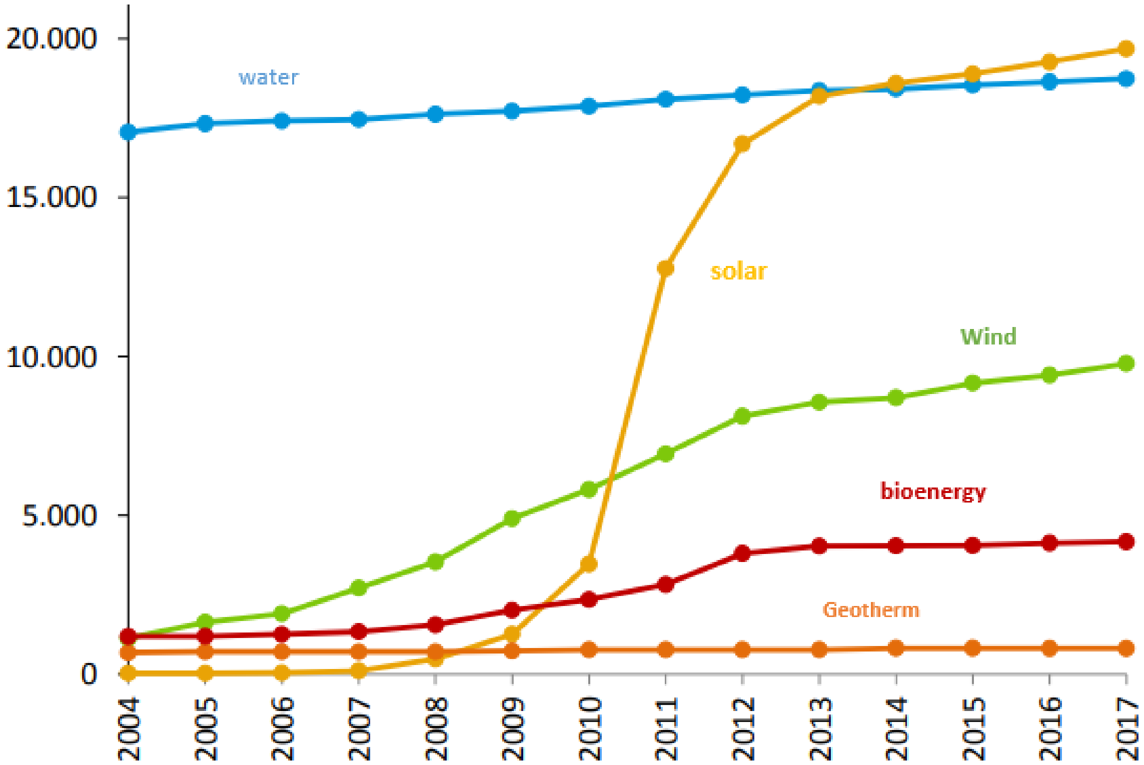

Figure 6 RES gross efficient power (MWh). Source: le rinnovabili nel 2017, GSE.

In North Italy, it is present the greater concentration of installed power of the country, with almost 50% of the national production. This result is driven by region Lombardy which accounts for 15.7% of the total installed power at the national level.

Electricity from renewable sources actually produced, calculated by applying the criteria established by Directive 2009/28 / EC, is equal to 110,528 GWh, of which renewables contributed 37.3% to the total gross production. Compared to Gross Domestic consumption (the difference between gross production and the external balance net of pumping production), on the other hand, in 2016, the actual electricity produced from renewable sources contributed 34.0%.

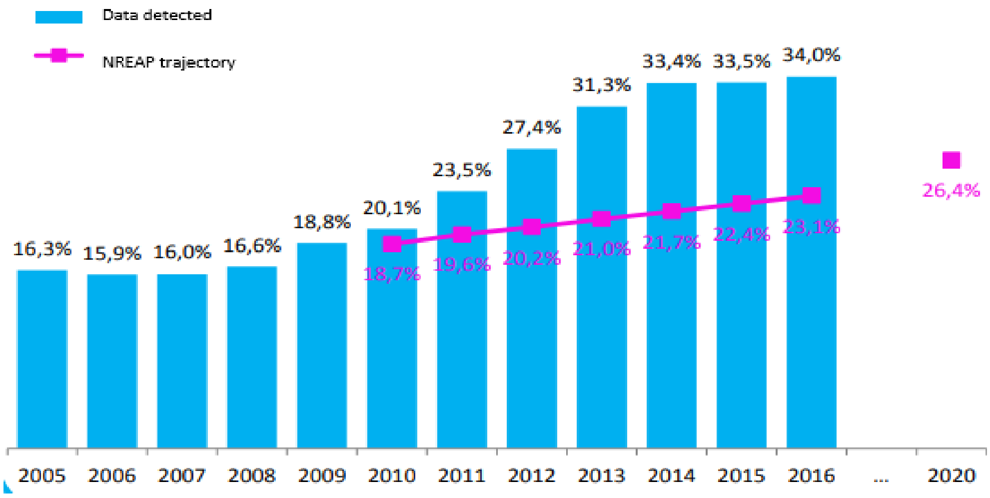

Figure 7Share of RES on GFC. Source GSE.

While up until 2008 the trend of electricity generated by RES was mainly linked to the hydraulic source, in recent years the importance of "new renewables" (solar, wind and bioenergy) has gradually increased.

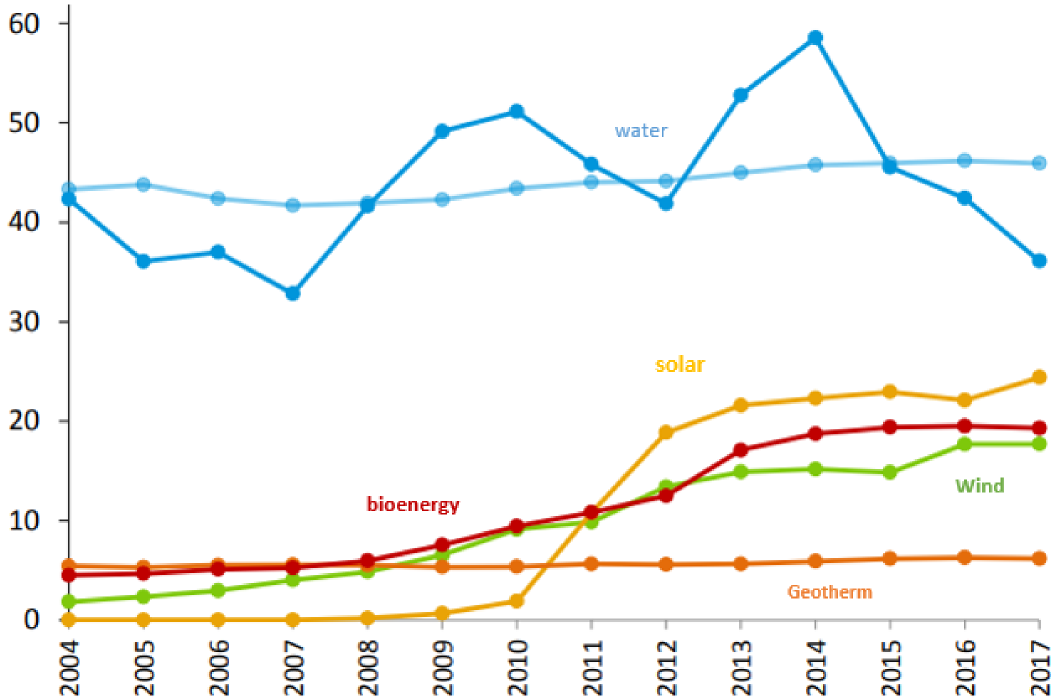

Figure 8 Evolution of production from renewable sources (TWh). Source: le rinnovabili nel 2017, GSE.

In 2016 Lombardy confirmed itself as the Italian region with the largest production from renewable sources: 16,330 GWh, equal to 15.1% of the 108,022 GWh produced in Italy. Two other regions of Northern Italy follow, namely Piedmont and Trentino Alto Adige, which account for 9.4% and 8.9% of production respectively national team of 2016.

Electricity generation from renewable sources is thus distributed among macro areas: Northern Italy 51.8%, Central 15.8%, South (including Islands) 33.2%.

Taking a look at the main renewable energy source in Italy:

2.2.1 HYDRO

A hydroelectric plant is a complex of hydraulic works, machinery, equipment, buildings, and services for the transformation of hydraulic energy into electricity.

In the transformation of the energy system towards renewables, hydropower[21] is strategic to grasp the objectives in 2030. In Italy, with about 18.5 GW of power it represents 36% of the entire renewable energy plant, it produces 20% of the total electricity and even 39% of the renewable one.

At the end of 2016, most of the hydroelectric plants are located in the northern regions (80.9%) and especially in Piedmont (820 plants), in Trentino Alto Adige (765) and in Lombardy (594). As a consequence, the same regions have the highest concentration of power (59.6%): the highest values are recorded in Lombardy (5.096 MW), Trentino Alto Adige (3,297 MW) and Piedmont (2,720 MW), i.e. the regions where the largest hydroelectric plants in the country are located. The regions of Central and South that are distinguished by the greater use of the hydraulic source are Abruzzo with 1,011 MW of installed power and Calabria with 771 MW.

hydroelectric production is mainly concentrated in the regions of Northern Italy. The regions of Northern Italy contribute 80.8% of the total renewable hydroelectric production, the central ones with 7.9%, the southern ones with 11.3%. In particular, Lombardy, Trentino Alto Adige, Piedmont and Veneto cover, together, 68.2% of the total hydroelectric production of 2016.

Meteorological factors are the main reason for the variability of hydroelectric production.

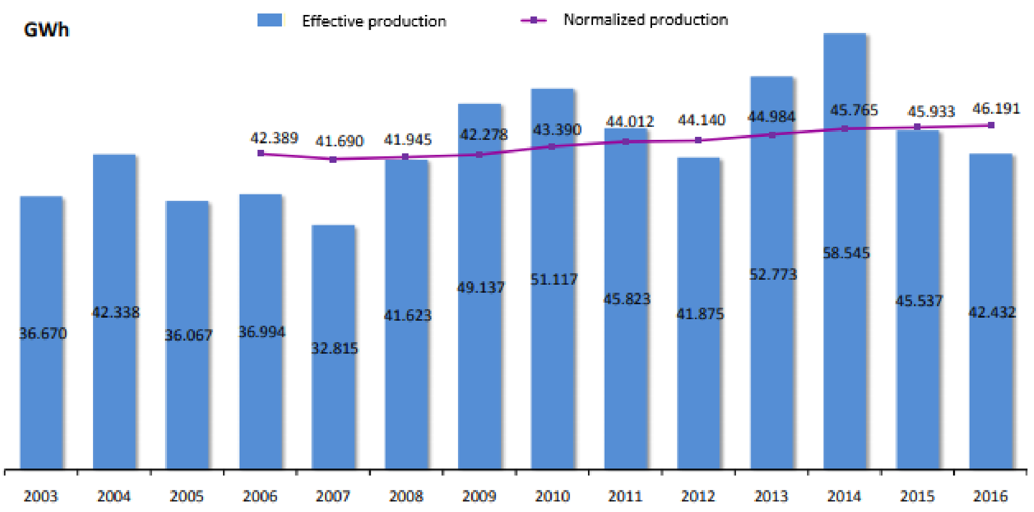

Figure 9 Evolution of HYDRO production. Source: gse rapporto statistico 2016.

The reduction in precipitation in recent years has led to a drop in hydroelectric production with bullish effects on the price of electricity and the import of fossil fuels from the Italian system.

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[21] Pursuant to the Community legislation, pure pumping systems are excluded because lectricity produced in pumping stations using water previously pumped upstream can not be considered renewable.

At present the sector has reached maturity and growth is possible almost exclusively for mini hydro, while the exploitation of the potential of large plants can only take place with an extensive renewal program (hampered by the Minimum Vital Wastes Directive - DMV which requires a minimum release of water from dams to preserve the ecosystem), the excessive growth of concession charges that increasingly diverges from the performance of operators' revenues. In the absence of adequate policies for the sector, there will be an inexorable decline.

2.2.2 SOLAR

A photovoltaic system means an installation able to obtain electricity by using sunlight.
At the end of 2016, 732,053 photovoltaic plants were installed in Italy for a total power of 19.3 GW. Overall, the power of photovoltaic systems represents 36.9% of that for the entire renewable energy plant. Although the difference in solar radiation (≈ + 20% in South than North), the PV plants are spread all over the country. The greatest concentration of installations is found in the northern regions (about 54% of the total); approximately 17% are installed in the Center, the remaining 29% in the South. The installed power is concentrated for 44% in the North, 38% in the South and 18% in Central Italy. Lombardy is the region with the highest number of installed plants (109.108), followed by Veneto with almost 100,000 plants. Puglia, on the other hand, is characterized by the greater installed power (2,623 MW), followed at a distance from Lombardy with 2,178 MW.
In the course of the year the production from solar source is equal to 22.104 GWh, 20.5% of the total electric production from renewable sources, for the first year there was a decrease in production compared to the previous year, equal to -3.7%, a phenomenon most likely due mainly to less radiation, but other reasons are to be considered, such as the quality of some plants, poor maintenance and decrease in the level of support.

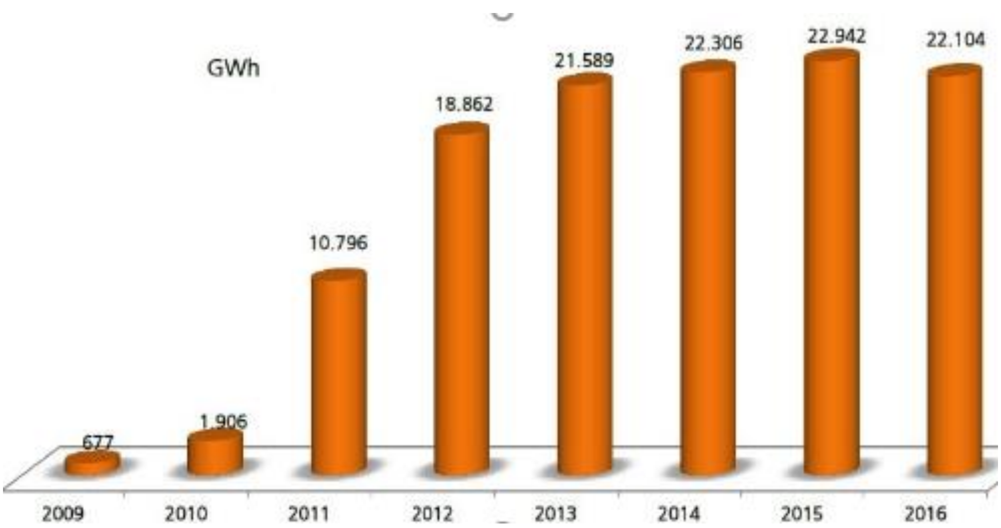

Figure 10 Annual production of photovoltaic systems in Italy, Source: gse rapporto statistico 2016.

Puglia, with 3,465 GWh, is the region characterized by the increased production from photovoltaic plants in 2016 (15.7% of the total). Following Lombardia with 9.8% and Emilia Romagna with 9.5%.

2.2.3 WIND

Wind power plants are generation plants based on devices such as wind turbines able to convert the kinetic energy of the wind into electrical energy.

At the end of 2016, 3,598 wind plants were installed in Italy with an installed capacity of 9,410 MW (18% of the total national renewable energy plant). Almost all wind plants in operation were built in the new millennium, with a growth that has become very strong (around 1 GW per year) from 2007 to 2012, when around two-thirds of the power today in service (9.5 GW) was installed (thanks to the Green Certificates system). For the construction and operation of wind farms, some environmental and territorial characteristics of sites such as windiness, orography, accessibility are particularly important. For these reasons, in Southern Italy, 96.7% of the national wind power is installed and 89.1% of the plants in terms of number. The region with the highest installed power is Puglia, with 2,440.9 MW; follow Sicily and Campania, with 1,795.2 MW and 1,350.6 MW respectively.

Between 2003 and 2016, the production of electricity from wind power rose more than tenfold, from 1,458 GWh to 17,689 GWh.

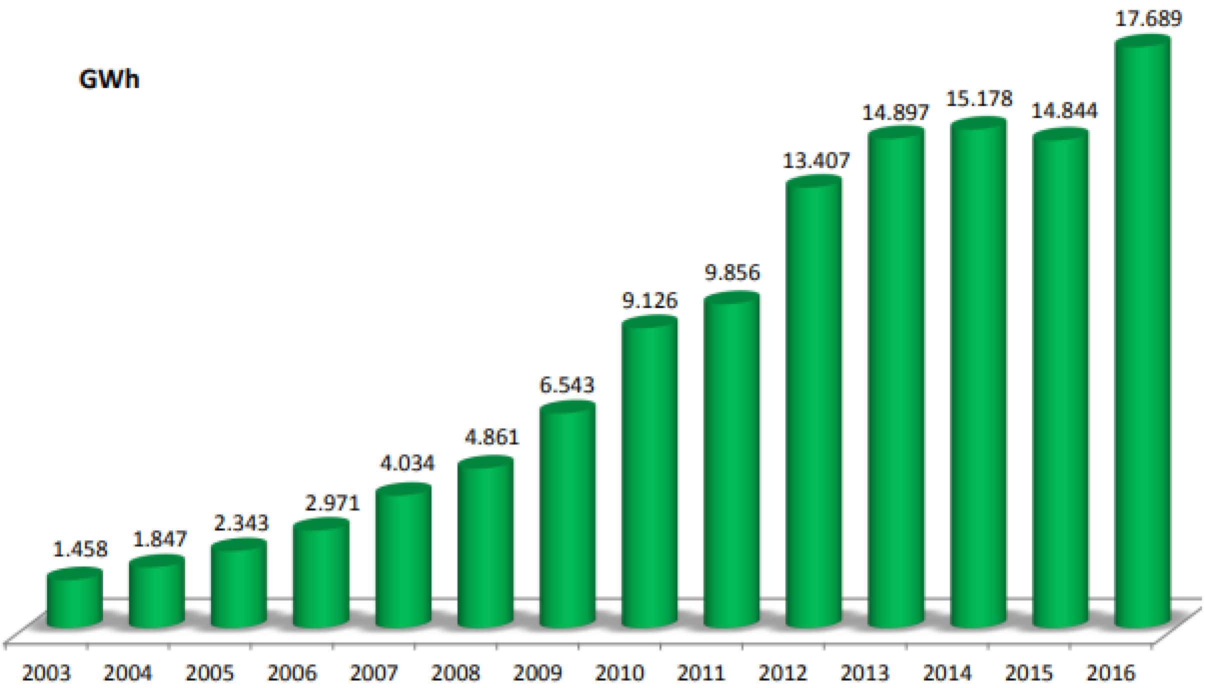

Figure 11 Evolution of WIND production. Source: gse rapporto statistico 2016.

Puglia with 4,787 GWh holds the record for wind production, followed by Sicily (3,058 GWh) and Campania (2,562 GWh). These three regions together cover 58.9% of the national total. In the north, there are modest values of production, due to the limited installed power.

2.3 LEVELIZED COST OF RENEWABLE ENERGY

There are many costs in generating electricity. They include, by naming only a few, construction, operation, maintenance, interest, fuel, insurance and taxes. These costs are incurred periodically. Capital expenditures occur in the initial phase of the power plant while operating, maintenance and fuel costs are due continuously. To simplify the comparison between competing projects, the leveled cost method reduces all costs to their current equivalent value, regardless of when they arise. The Levelized Cost of Energy (LCOE) is that price which equals the net present value of the revenues of the power plant with the net discounted value of costs. The main elements that make up the total cost of a plant's entire life are its production capacity, capital expenditure, operating and maintenance costs, and fuel costs.

Renewable power plants have lower values both in terms of production capacity and life-time. This combination gives traditional sources a great advantage in terms of LCOE because the reduced production of renewables reduces both the revenues and the quantity on which fixed costs can be spread, so the LCOE is higher.

The energies produced from renewable sources require initial investments (and therefore financing costs) of much greater than traditional sources; consequently, the LCOE of the various renewable energies are significantly higher.

Operating and maintenance (O&M) costs, can be divided into the two categories of variable and fixed costs.

Except for bioenergy, for all renewables, the cost of fuel is close to 0.

The 2012 Carson study used the values estimated by the U.S. Energy Information Administration.

Analyzing the table A1 in Appendix we can see how traditional technologies with a lower LCOE are the CCGT, that is the combined cycle natural gas ($ 0.051 / kWh) and supercritical coal ($ 0.062 / kWh). On the side of the carbon-free technologies the most economical is advanced nuclear ($ 0.065 / kWh), but among the actual renewables the only technologies that are close to compete with those mentioned above are geothermal ($ 0.068 / kWh) and onshore wind power ($ 0.073 / kWh).

The other element that is immediately noticeable is the different composition of the total LCOE between traditional and renewable technologies. In the former, the sum between O&M costs and fuel costs always exceeds the capital costs, while in the latter capital expenditures far exceed O & M costs everywhere, with fuel costs always equal to 0.

2.4 ROLE OF RENEWABLES IN THE ELECTRICITY MARKET

The development of electricity produced from renewable sources has a decisive impact, in Italy and in other European countries, both on the operation of electrical systems and on the results of the energy markets.

The renewed energy context is made more complex by the presence of some economic factors, such as the gradual reduction in electricity consumption, a constant increase in the contribution of renewable sources - especially on the distribution networks on which most photovoltaic and wind plants are located - and a significant decrease in the hours of use of traditional combined cycle plants. In this new scenario, destined to evolve further to the advantage of renewables, the consequences that occur in the electricity market become interesting.

The behavior of RES, which differs from the conventional sources, requires each country to adapt its energy policy. The main features of renewables are:

- Intermittency: RE production needs priority of dispatch because it can hardly be foreseen and electricity generated cannot be stored. This may also lead to an increased need for spare peak production capacities to be available to cope with the increased intermittency in the grid,
- Segmentation: most RE plants are small and widely distributed within a country, which requires grid reinforcement works.

The effects of RE generation on electricity markets are still unclear and certainly dependent on each country's energy mix.

In Italy, in the sessions of the day-ahead market (MGP) organized according to the criterion of economic merit and with the enhancement of energy to the marginal offer, renewable sources, characterized by marginal production costs almost nil, displace the curve of fossil-based plants, thus helping to reduce the price of energy on the market. This phenomenon already studied in other countries and defined in the literature as "Merit Order Effect" (MOE), becomes more and more evident as the contribution of RES increases with respect to energy needs.

To analyze this effect elementary concepts such as demand and supply of electricity need to be defined.

As stressed in Chapter 1, the electricity market is an exchange platform aggregating supply and demand for electricity.

We consider the demand for electricity short-term and inelastic to price because consumers are supplied on long-term contracts. It represents the sum of all power which is transferred from high voltage transmission grid to the next lower level, which is the distribution grid.

Supply for electricity consists in an energy mix which can be divided into 3 categories:

- Baseload: such as nuclear and conventional thermal power, to sustain a constant level of production. It is unable to adapt to short-term variations in electricity demand. It typically has high fixed costs and low marginal costs;
- Mid-load: in between such as coal or combined heat and power ("CHP");
- Peak load: such as gas, to adapt to high sudden demand. Units are usually smaller with low fixed costs and high marginal costs. These production facilities are utilized only a few hours per year but charge high prices because of the instantaneous shortage in supply.

As electricity cannot be stored (except in some hydro installations, to a minor extent) there needs to be a perfect clearance at each time between the demand for electricity and power injected in the grid. The grid regulator tries to forecast demand, and different available power plants will adapt to this forecasted output: power plants with the lowest marginal cost will be tapped in first. In market environments, prices at a given time are determined by the most expensive power producers able to satisfy the demand (i.e. with the highest marginal costs) and are imposed on all other producers (since in a purely competitive market, the equilibrium between supply and demand is met when price equals marginal cost).

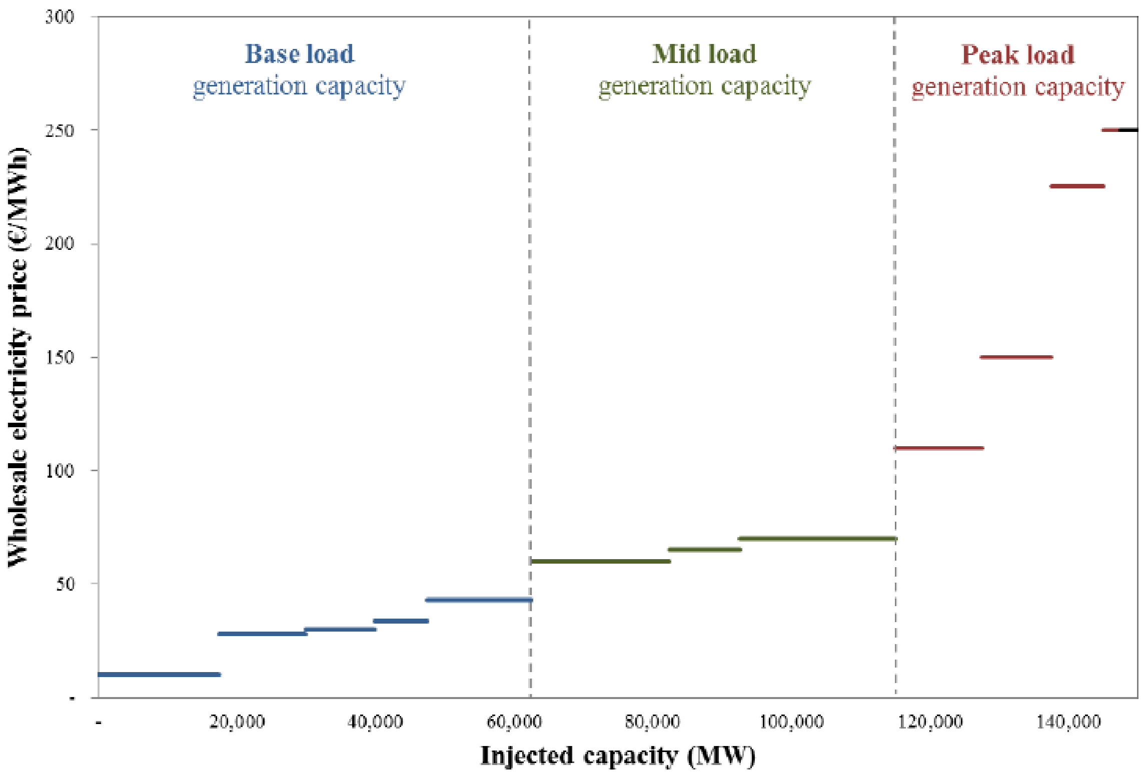

Figure 12 Merit Order Curve. Source Green Giraffe energy bankers, 2013.

In a perfectly competitive and transparent market, it is then possible to build the relationship between the electricity demand at a given time and the associated price by sorting energy sources in growing order of marginal cost. This step function is called the merit order curve ("MOC"). The width of each step represents the supply capacity of an energy source while its height is its marginal cost.

Electricity prices are determined by the intersection of the MOC and the short-term demand. The insertion of RES in the grid changes things. Power from renewable has to be sold too. RES, as mentioned before, have a different behavior than the baseload, midload and peakload conventional sources. Increasing the supply of renewable energy tends to lower the average price per unit of electricity because these have very low marginal costs: they do not have to pay for fuel, and the sole contributors to their marginal cost are operational and maintenance. With cost often reduced by feed-in-tariff revenue, their electricity is as a result, less costly on the spot market than that from coal or natural gas, and transmission companies buy from them first.

That means they lower the entrance price and push more expensive conventional producers down the merit order curve. This is defined as the MOE and displayed in the figure below.

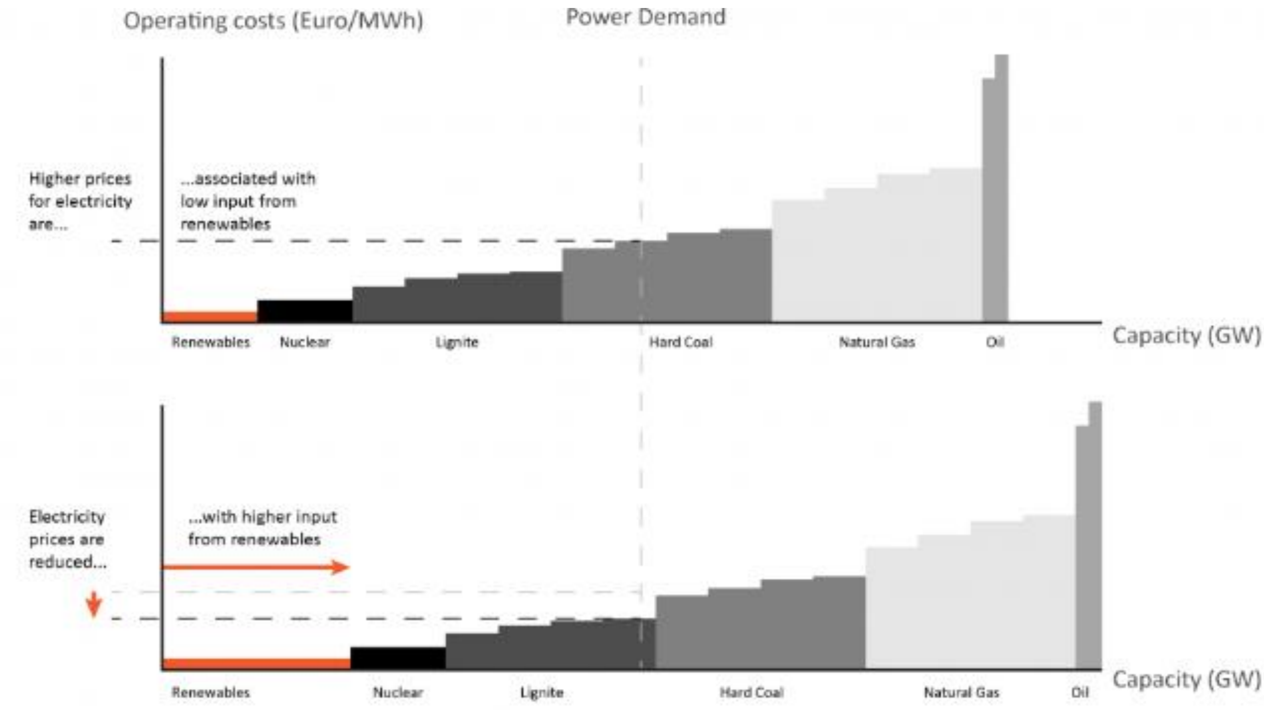

Figure 13 Electricity price fluctuation due to the Merit Order Effect. Source www.cleanenergy wire.org, 2015.

The market clearing power plant receives its marginal cost, while for the other plants the clearing price is higher than their running cost. The difference between the clearing price and the marginal cost is known as the inframarginal rent. Inframarginal rents are needed to recover fixed generation costs. Only if the market clearing price is higher than the sum of the marginal and fixed cost for most of the time, the technology will be attractive for investors

A study by eLeMens 2013 states how the growing role of RES affects margins' rate that the various sources and technologies have on the market during the day. Combined Cycles (CCGT) continue to maintain marginal technology supremacy and take advantage of the nightly peak of Demand, less influenced by RES with particular reference to photovoltaics, where CCGT plants form the price from 60% to 70% of the time, increasing prices to implement the so-called "night recovery": in particular, when the marginality of the CCGTs is higher at 60%, the average hourly PUN is above the 24-hour PUN average. However, when the price falls below € 50/MWh CCGT technology loses its record: coal (including also oil-coal plants) becomes the main source in terms of marginality for prices between 30 and 50 €/MWh, while with prices below 30 €/MWh it is the imported energy that determines the price as a marginal source for more hours than other technologies and sources.

If we define capital intensity the ratio between capital necessary for production and running costs, typically base-midload plants (coal and nuclear) and renewable source plants (excluding biomass) are characterized by a high capital intensity index. The imbalance towards the capital-intensive production of the national generation mix raises important questions about its adequacy in relation to the needs of the electricity sector. In a possible scenario of stagnant energy demand and further growth, albeit at much lower rates, of variable renewable sources, the general level of electricity market prices could fall further. However, this would result in an increasingly compressed role of the combined cycles causing a situation of simultaneous absence of signals for the development of new investments and scarcity of resources for the maintenance of system security. So they seem to change the new requirements of the electricity market: from the need for "energy" to the need for "capacity" available and ready to intervene to maintain system security. For this reason, capacity payment mechanisms appear to be increasingly important in the guidelines of the Regulator because it lowers the investment risk in generation capacity.

Chapter 3

THE MERIT ORDER EFFECT IN THE MARKET

In Italy, like in many other countries, the liberalization has lead to the creation of energy-only markets i.e energy generators receive revenues for selling electricity but not for providing capacities. This kind of markets can experience investments below than their optimal level (creating a sort of "missing money problem", i.e. when prices do not fully reflect scarcity in tight market conditions, reducing profitability and leading to underinvestment in capacity over the longer haul) due to markets imperfections and inadequate regulations. Issues include limited demand-side flexibility, inadequate spot prices during scarcity events due to regulatory price limits, investment risks due to volatile prices and coordination failures (Cramton and Ockenfels, 2012; Edenhofer et al., 2013).

While an increase in RES does not lead by itself to a failure of energy only markets, the rise in RES share, especially VRE share, worse these markets failure in two ways. First, higher renewable shares lead to lower average prices. While a low average price is advantageous from the consumer perspective, over the long run, this MOE, affects investment incentives of fossil-fuel generators, which are in the medium term needed to provide firmness and flexibility to the system, thus potentially undermining the security of supply. From the viewpoint of conventional generators, the "merit order effect" exacerbates the problem of missing money. More RES can also weaken the role of forward contracting in alleviating market power in wholesale electricity markets and lead to higher prices in situations where the RES capacity factor is low. Second, VRE increases price volatility and thus investors might be discouraged or require higher risk premiums.

As consequence reserve margins shrink and scarcity events occur more frequently. In addition, the revenues from renewables decline at rising shares of VRE if other factors are kept constant. Nevertheless, renewables are supported in many countries due to their expected beneficial effects such as emission reduction or employment creation (Groba and Breitschopf, 2013). A variety of support schemes is employed for increasing electricity generation from renewables (Ragwitz and Steinhilber, 2014). These differ regarding the degree to which plant operators are affected by market prices.

However, promoting renewables could lead to a paradox in that successful penetration of renewables could fall victim to its own success. With the current market architecture, future deployment of renewable energy will then necessarily be more costly and less scalable.
In this chapter, we will analyze this three possible issues that can arise from a too much injection of renewables in the market system.

3.1 MARKETABILITY OF VARIABLE RENEWABLE ENERGY

For the renewables, the merit-order effect leads to a lower income from electricity markets. Electricity systems with limited intertemporal flexibility and a high share of VRE penetration could induce the MOE not only to reduce the electricity price but also the MWh value of VRE. Variable renewables are disproportionally affected by the lower market prices as their generation often occurs in hours with low prices. A more metaphorical description for declining VRE market revenues with an increasing share is the term ‘cannibalism effect’.
Private investments in VRE technologies seem to be profitable if their LCOE is below the specific individual retail electricity price. This concept, which however ignores important economic facts, is called ‘grid parity’. Based on this consideration, the concept of ‘marketability’ is defined: a generation technology is marketable if the average revenues on competitive wholesale electricity markets during its lifetime are high enough to cover its average total generation costs, the LCOE, without recourse to regulatory remuneration schemes. In the case of VRE, this would mean that an investment in VRE would be profitable even if there were not any regulatory mechanisms (Zipp, 2017).

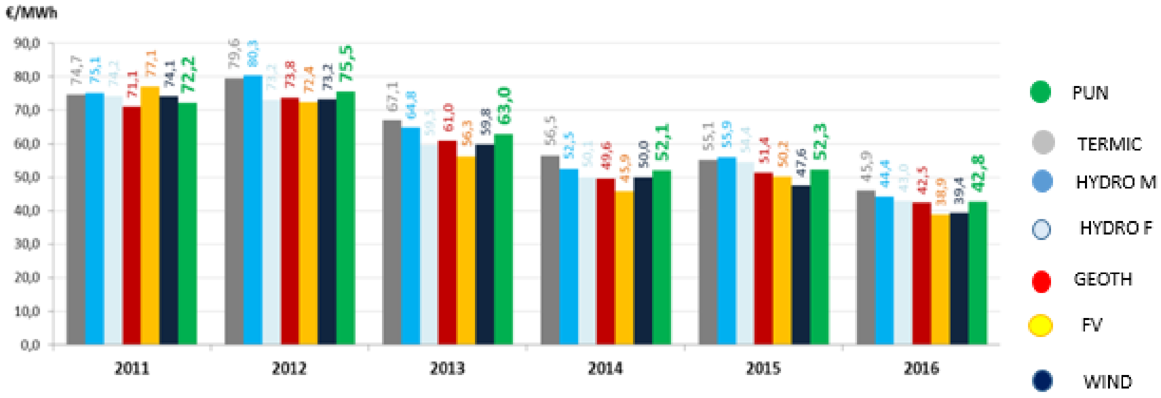

Figure 14 Evolution of the source market price. Source GSE 2017, Il valore dell’energia rinnovabile sul mercato elettrico.

Evidence from GSE shows how the drop in electricity market prices verified in recent years has been even more pronounced for VRE valued in recent years at prices lower than the PUN: the wind and PV market price in the last few years has had a negative spread compared to the PUN between 2 and 6 € / MWh; the geographical concentration and the simultaneity of the wind and PV productions create high supply conditions that drastically reduced marginal prices.

The development of the average market revenues for wind and PV plants is of crucial importance for reaching their marketability. If the revenues keep declining with the expansion of VRE generation, the LCOE will need to decline faster. Typically, fixed costs make up a large part of the LCOE of VRE technologies, which require no fuels and therefore have small variable costs[22]. Price indices for the elementary cost components of PV and wind plants reflect a considerable decline of the LCOE of VRE generation in the past but there is still a large potential for further cost depression. Further solutions must to be taken into account such as the market conditions and the regulatory framework which should be adapted to the intended future electricity system with a high share of VRE. Possibilities for decreasing the specific merit order- effect while increasing the market revenues for VRE technologies may be interesting topics for future research in the field of power system design. First promising approaches are strengthening the emission allowances price signal[23] (Koch N. et al, 2014), reducing subsidies to non-renewable energy sources[24](Lehmann P., Gawel E., 2013), improving the flexibility of thermal generators, the electricity storage capacity and the short-term price elasticity of demand as well as adapting the trading conditions and products and incentivizing system friendly renewables. If these, or other measures, prove not to be sufficient for increasing the average VRE revenues, or at least lowering their decline rate, further research in the design of long-term remuneration schemes for VRE electricity generation should be undertaken. Researchers, as well as policy makers, should take the possibility of a limited role for solar and wind power into account and should not disregard other greenhouse gas mitigation options too early.

3.2 IMPACT OF SUPPORT SCHEMES ON PRICES

Renewables are supported in many countries due to their expected benefits. For governments, it is often a struggle to produce a renewable policy that achieves all its objectives because they usually compete against each other. The success of any renewable policy as such can be measured through three parameters:

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[22] The module cost are responsible for about half of the investment cost of small scale PV plants, in case of larger PV plants the cost share can be even higher. In case of wind power plants, the turbine is the highest cost component with a share of about 75% of the investment cost.

[23] The price for EU Allowances (EUAs) went from 28€ per ton of carbon dioxide (tCO_2) in mid-2008 to 5€/tCO_2 in 2013. The widely-held view among market participants, academics and policy-makers is that three main causes can be put forward to explain the weak EUA price signal: (i) the deep and lasting economic crisis in the European Union, , (ii) the overlapping climate policies, e.g. feed-in tariffs for renewables and (iii) the large influx of Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs) in the EU ETS. The coexistence of EU ETS and RES deployment targets, however, creates a classic case of interaction effects. Theoretical work suggests that the overlapping policies work at cross-purposes, since RES injections displace CO_2 emissions within the EU ETS and thereby reduce the EUA demand and price.

[24] The use of non-renewable energy technologies has also been promoted by enormous direct subsidies. These subsidies reduce the cost of non-renewable energy sources and make them inefficiently cheap. The first-best solution would be to abolish the subsidies.

1) Total cost per MWh

2) Amount of renewable deployed over the lifetime of the policy

3) The speed at which the renewables are adopted

Renewable policies cannot achieve all three objectives at the same time. There are trade-offs between the cost of a policy, the speed of adoption and total deployment.

The kind of support instrument can, however, influence the degree to which renewables influence the market. The support scheme influences both the trading behavior and the plant design by the degree to which plants are dependent on price developments and thus demand conditions on regular electricity markets (Jägemann, C., 2014).

FIT (feed-in tariffs) consists of a fixed tariff that is paid to the plant operators for each unit of electricity they produce independently of the demand situation of the electricity system. Thus, neither investments decisions nor short-term generation patterns are adapted to the demand situation. It grants constant payment per unit of electricity generated and entails low risk for plant operators and low capital cost. The height of FIT should correspond to the LCOE and so should adequately compensate VRE investors and producers. However, government need a lot of information to set the FIT at the right height otherwise there is a risk of over/under compensation. The existence of FIT generally also contributes to a more continuous and stable RES market development. FIT provides an incentive to maximize the production of RES electricity because they are output-based. In many countries, they have proven their ability to stimulate rapid and large-scale RES market development as well as the development of less mature RES technologies and the participation of small and medium scale RES electricity producers. In Italy the main feed-in tariff is represented by the Tariffa Omnicomprensiva (TO), which supports small RES installation excluding PV. The tariff both includes the incentive and the value of electricity feed into the power grid.

The FIP (feed-in premium) is defined as a fixed amount, on top of the electricity market price, for each MWh generated. FIP can either be fixed (i.e. at a constant level independent of market prices) or sliding (i.e. with variable levels depending on the evolution of market prices). This amount moves in parallel with electricity prices. Plant operators sell their electricity on the market and are therefore incentivized to react to market signals i.e. to produce electricity when demand is high and/or production from other energy sources is low. Plant operators face opportunity costs equal to the premium payment when they reduce their output due to market conditions. In Italy, we have the Conto Energia (CE) for solar energy production. Almost all of the success of PV production in Italy derived from this incentive which is one of the highest in Europe and consequently the most costly[25].

For quota schemes, the opportunity costs are determined on the certificates markets. The main advantage of RES quota and certificate systems is that RES policy targets can be achieved in a very cost-efficient way because the certificate prices are determined by market forces. Utilities that have to fulfill a RES quota have a strong incentive of doing this in the most cost-efficient way possible. This minimizes the overall costs of the support scheme for electricity consumers. In Italy, we have the Certificati Verdi[26](CV) which is a tradable asset granted by the GSE[27] at the request of the RES producers in proportion to the energy produced. One CV corresponds to 1MWh of electricity produced. Each operator producing or importing more the 100 GWh of electricity from conventional sources, must satisfy the RES obligation: it must produce or introduce in the following year a quantity of RE equal to the defined quota (2%) of energy produced or imported exceeding the threshold the previous year. The power producers can meet the quota either producing the RE obligation by their own or by purchasing CVs. RES producers can accumulate the CVs and sell them at higher prices in case of high demand or resell them to GSE at a buy back price. The drawback of this incentive is represented by the high risk for plant operators due to double marketing on electricity and certificates markets.

Capacity based support scheme is the market mechanism that rewards the most flexible plants, also for the power they make available rather than just for production. It enables undistorted market participation as the support is paid independently from generation. It is however extremely challenging to design such a scheme without reducing the incentives for plant output maximization resulting from undesirable plant designs. Furthermore, depending on the concrete support scheme design the incentive for generating renewable electricity under a capacity-based support scheme is reduced. Thus reaching generation based targets might imply the need for higher installed capacity and therefore potentially higher policy costs. In Italy, AEEG started a capacity market in 2017 where producers have to guarantee the availability of electricity production capacity that protects the system from the risk of generation deficits or critical situations. The quantities of capacity to be made available will be determined by the grid operator on the basis of expected consumption and reserve requirements, also taking into account the effects of energy efficiency measures and production from renewable sources.

[25] As a result of the last amendment in 2012, the has been a restructuring of the entire CE system and the legislator decidedand the legislator decided that the scheme ceases to provide incentives to new capacity once the cumulative cost of incentive reaches the level of 6.7 billion euros per year like happened in july 2013.

[26] It substituted in 2001 the CIP6 which was a FIT scheme with a guaranteed price for 15 years. GSE purchase RES at the guaranteed price and sell it into the market at the market price.

[27] State owned company responsible for implementing the policy aimed at promoting RE in Italy

The choice of the support scheme impacts the degree to which the merit order effect takes places as it changes the bidding behavior of renewables.

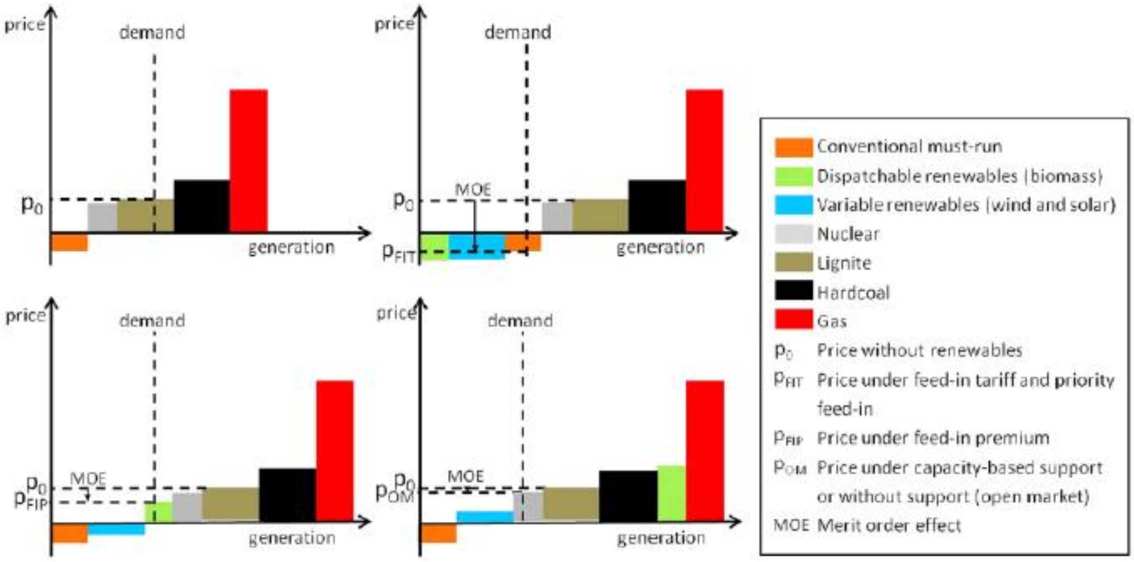

Figure 15 MOE under different support schemes for a situation with low demand and high renewable generation. Source Winkler J. et al 2016.

Differences between support schemes are only significant in situations with low demand.

Under FIT scheme with priority dispatch of renewable sources all renewable electricity is put into the market independently of occurring costs and generation is maximized at all times independently of demand situation.

A FIP or quota scheme reduces the MOE slightly as the reduction of electricity output becomes an economic option at very low electricity prices and variable generation costs become relevant for electricity output. Under a capacity based support scheme renewables bid at marginal costs which means that plants are only dispatched if the variable costs are below those of other possible conventional plants. Renewable plants with substantial variable costs are affected more heavily by changes in the support system. However, the change to support systems with a higher degree of market participation for renewable with very low marginal cost avoids extremely low prices and thus also leads to higher average electricity prices.

Some electricity markets allow for negative electricity prices. These occur if inflexible conventional plants, e.g. those contracted in balancing markets, needs to stay online in times of low residual demand and therefore accept to pay for generating electricity. Price volatility is influenced by different support scheme mainly due to the extent of negative prices. Under the capacity based-support scheme, renewables bid at zero or positive prices and thus negative prices occur very rarely. Under feed-in premiums and quota schemes, negative prices are less extreme than under feed-in tariff schemes as renewable generators rather reduce output than accepting very negative prices. Therefore price volatility is expected to be highest under feed-in tariffs and lowest under capacity based schemes or without support given a certain installed renewable capacity.

In general, we conclude that capacity based support scheme, which is generation independent, reduce the impact of renewables on electricity prices particularly in systems with high must run requirements. When choosing the appropriate instrument for supporting renewables not only the degree of market distortion needs to be considered. More market-oriented support schemes are generally riskier and can result in higher support costs. Also, designing capacity based support schemes that do not result in reducing electricity generation and perverse incentives regarding the plant design is very challenging. Furthermore, market-based reduction of electricity generation from renewables is higher under the capacity based support schemes especially if system flexibility is low. For these reasons sliding feed-in premiums might be a good compromise between a certain degree of market participation and comparably low risks for plant operators (Winkler et al. 2016).

3.3 IMPACT OF RENEWABLES ON THE LIBERALIZED MARKET STRUCTURE

Till now we know that the more the penetration of renewables the larger the shift in merit order curve (and consequently greater the merit order effect on price) and the increase in the price volatility.

Although, renewables with their minor marginal cost of dispatch, could fall victim to their own success after capturing a large share in the liberalized power market. With the existing liberalized market structure, future stationing of renewables could be more costly and less scalable due to the impact on electricity prices. This somehow means that a too rewarding renewables policy and incentives could reduce the efficiency and effectiveness of such future measures.

To understand this intuition, we need to clarify the relationship between liberalized market and promotion of renewables and their compatibility.

Liberalization has been advocated and implemented precisely with the aim to increase efficiency, avoiding the monopolist distortion and letting market competition to rule and to increase transparency, disposing of the opaque cross-subsidization mechanism implicit in the management of the vertically integrated monopolist.

The liberalized structure of the market is based on two assumptions:

1) Positive marginal costs
2) Dispachability of power.

Neither of these two assumptions is applicable to renewable energy as they are largely intermittent, non-programmable and have almost zero marginal costs.
In this circumstances, incentive schemes become more expensive and lead to less deployment. There is a sort of paradox which originates from the market design and the renewables policies and that leads to less successful outcomes the more the share of renewables increase in the energy mix.
From the market's perspective, this paradox is the outcome of several elements:

- The (almost) zero marginal cost of renewables which explains the main reason for the priority in the order of dispatch. Although renewable technologies are often not the cheapest in terms of total cost. This leads to a divergence between the true cost of the system (what end consumers pay) and the evolution of the price of electricity in the wholesale market
- The intermittent nature of renewables
- The interplay between price volatility and renewable technologies. Price volatility is an inherent characteristic of electricity markets due to the lack of reliable and meaningful storage. Thus the presence of any non-dispatchable generator would force conventional thermal power producers to make sudden adjustments to their production which leads to sharp changes in electricity prices. Now, this volatility is worsened by the presence of unpredictable and intermittent technology.

Falling and more volatile electricity prices are certainly not ingredients for the long-term growth of renewable technologies unless costs are declining more quickly than the combination of market price drops and financing cost hikes.
Moving to a policy side perspective we start from two simplistic assumptions: i) we assume the goal of a renewable energy policy is to deploy renewable capacity at the lowest cost possible and ii) and we assume it already exists a critical mass of renewable energy in place that distorts the standard price formation in the liberalized markets. This means accommodating a small quantity of renewables in the system can be achieved without distorting prices, profits or incentives for investments.
Our point is that implementing incentives in the market with decreasing but volatile prices can lead to less deployment than the initial expectation or to more expensive policy support (Blazquez et al 2016).
In fact, investing in new renewable capacity is less attractive in a time of lower electricity prices, as they reduce expected profits and also private investors are likely to demand higher rates of return as the volatility raises the uncertainties over their projects (Gross et al. 2010). The combination of these two factors, lower expected profits and higher profits requirements, will reduce the number of projects commisioned in the absence of additional policy support. The

level of feed-in premium, for example, will need to be higher than otherwise in order to maintain a given level of investments.

Feed-in tariff could be a potential way to deal with this problem since by fixing price it guarantees a stable flow of revenues. However, this instrument would lead to an increasing level of support as wholesale prices decline due to the penetration of new renewable capacity.

Taxpayers (through government) or consumers (through a surcharge on their bills) would need to compensate generators to better cover the difference between fixed and spot prices in the market. In the short term, consumers may benefit from the decline in electricity prices, while the equity value of incumbent generators may deteriorate.

In longer-term investors will not reinvest o recapitalize electricity markets without sufficient guarantees on return. This additional cost will be born by taxpayers or consumers. In Italy, the sustainability promotion activities managed by the GSE have resulted in a total investment of 16.1 billion euro (about 1% of national GDP) over the last year, financed through the energy bills of companies and families.

A power sector which relies on 100 percent of renewables is not sustainable given the current design of the market as conventional technologies provide important price signals. There is a cap to the capability of the decentralized market to deliver with transparency the proper market signals. In fact, in the case of full decarbonization, prices would be at renewable marginal cost i.e. equal to zero for long periods. These prices would not be capturing the system's cost nor would they be useful to signal operation and investments decisions. Thus, non dispatchable technologies need to coexist with fossil fuels technologies.

New market mechanism needs to be designed, based on two main pillars. First, it is necessary to reform the market in order to capture the full renewable cost structure. Second, it is necessary to more accurately compensate for conventional technologies. This is crucial to convey the correct market signal to new investors in both technologies: on the one side, renewable investors need to know the social value of renewable generation for environmental goals and, on the other side, conventional sources investors need to know the correct value of their contribution to security and reliability system management (Blazquez et al, 2018).

In the next chapter, we will empirically compute the effect of renewable energy sources in the Italian wholesale day ahead electricity prices and the measure the effects also on the electricity price volatility. Investors future investment decisions, the risk premium on projects and further policy implication can be based on the empirical results of the following analysis.

Chapter 4

MODEL

The electricity production from renewable energy sources (RES) has increased in most European member states over the past 10-15 years. The investment incentive for RES is mainly driven by policy support measures such as feed-in tariffs, which guarantee a fixed price per unit of renewable electricity generated, while other generators must sell their electricity in a spot market. However, the influence of RES on electricity spot market prices is growing with the increasing share of renewable electricity deployed. This is due to the how spot prices are determined as a function of supply and demand. The supply curve, the so-called merit order, is derived by ordering the supplier bids according to ascending marginal cost. The intersection of the demand curve with the merit-order defines the market clearing price i.e. the electricity spot market price. The feed-in of renewable energy sources with low or near zero marginal cost results in a shift to the right of the merit-order. This shift moves the intersection of the demand curve and the merit order to a lower marginal price level and thus the electricity price on the spot market is reduced. This reduction in price is called the merit-order effect.

4.1 LITERATURE REVIEW

There is a considerable literature on this issue now, so it is possible to take stock and draw some general conclusions. However, this is not an easy endeavor because the measurement of price effects depends on several diverging factors contemplated in the different studies (technological mix in the electricity system, market conditions etc.).

We can group the existing literature in 2 categories:

1) simulation based approach which employs real/past or hypothetical data,
2) the empirical analysis which use real, past data to create econometric models.

While simulation is often used for welfare evaluation of renewable support policy by comparing simulated price in hypothetical nonrenewable scenarios with empirical price data, regression analysis are used for the estimation of MOE with a straight focus on the price and distributional effects. Using an electricity market model requires careful calibration and especially the definition of a reasonable counterfactual scenario. Regression analysis, on the other hand, can employ actual historical data and does not have to make assumptions about alternative developments. At the same time, only rather short-term merit order effects, based on the current electricity market and power generation structure are calculated. Moreover, issues such as the costs for new power plants or network development are not considered.

4.1.1 SIMULATION-BASED STUDIES

This approach has been applied to a number of countries and regions to explain the effects of renewables on electricity prices.

Starting with Germany, Sensfuss et al. (2008) use a model of the electricity market to run several simulations for situations with and without renewable production. They find that the average electricity price for Germany was reduced by 1.7 to 7.8 €/MWh due to the electricity production of renewables for the years 2001 and 2004 to 2006. In a subsequent application, Sensfuss (2011) uses the same technique for the 2007-2010 period, showing that the 2010 effect is found to be at least (i.e. in a conservative calculation) between 5 and 6 €/MWh. In a subsequent exercise, Weigt (2009) models the German electricity market to investigate the potential of wind generation to replace traditional fossil capacities. While doing so, he calculates electricity prices for the scenarios with and without wind generation and finds lower prices for the former between January 2006 and June 2008. The price effect of wind generation also grows over time. The study reports an average price effect of approximately -10 €/MWh for the studied period. With a somewhat different approximation, Fürsch et al. (2012) model are capable of reflecting international cross-border flows and also allows for a changing electricity mix as a response to growing renewable participation in the mix. The results are forecasts for 2015, 2020, 2025 and 2030 that compare a scenario of the German energy market with a counterfactual of frozen renewable capacity at 2010 levels.

There are also some simulation studies on this question for Spain, another leading European supporter for renewables. Linares et al. (2008) use a simulation model of the electricity market to obtain results, up to 2020, for different scenarios: with and without a European carbon emission scheme and with or without additional national renewable support (or both). Given the actual existence of the EU ETS, that scenario may be used as counterfactual for the alternative situation where additional renewable support results in an expanded renewable capacity of 21.81 TWh in 2020. As a consequence, electricity prices would decrease by 1.74 €/MWh. In another simulation analysis, Sáenz de Miera et al. (2008) show that WIND energy input significantly reduced Spanish electricity prices between 2005 and 2007 (amounts vary from -7.08 €/MWh to -12.44 €/MWh between the periods).

Lastly, Holttinen et al. (2001) carry out a simulation study for Nordpol (the Nordic electricity market that comprises Denmark, Finland, Norway, and Sweden) to estimate the impact of WIND

generation on market prices. Using wind data from 1961 to 1990 to calibrate the model, in a 2010 forecast scenario the model yields spot price reductions of 2 €/MWh for every 10 TWh of additional wind production in the space of one week.

4.1.2 EMPIRICAL STUDIES

Actual price effect of expanding renewables are computed through different econometric approaches and techniques taken advantage of the growing availability of ex-post data on electricity prices and renewable capacity in several countries.

Starting again with Germany, although with very limited empirical evidence (that justifies carrying out our ad-hoc exercise later in the paper), Neubarth et al. (2006) set up a univariate regression model to investigate the effect of wind power production on day-ahead spot prices in Germany from September 2004 to August 2005. They find that the day-ahead electricity price falls by 1.89 €/MWh for each additional GW of wind production.

Gelabert et al. (2011) use daily production quantities of different electricity generation types for Spain to investigate how they affect electricity prices during the 2005-2009 period. They find that each GW of additional renewable electricity production reduced Spanish electricity prices by roughly 2 €/MWh. A similar result was obtained by Sáenz de Miera et al. (2008), after picking three arbitrary days of February 2006 to perform an exhaustive comparison of electricity prices and wind energy production. They actually follow this approach to produce a ceteris paribus situation for all other influences except wind input, such as electricity demand, fuel prices, hydro production, etc.

Nieuwenhout and Brand (2011) use wind and weather data from the Netherlands to reconstruct day-ahead wind generation figures for 2006-2009 and divide the data to create groups that correspond to low or no-wind production intervals. They find that average day-ahead prices at the Dutch electricity exchange were roughly 5% higher during the no-wind intervals with respect to the average of the entire sample for the analyzed period.

The effect of wind production on electricity prices has been heavily investigated in Texas due to the increasing relevance of renewables there Two of the first exercises use high-frequency data (hourly and 15 min intervals, respectively), which in Nicholson et al. (2010) are used to analyze the 2007-2009 period with explanatory variables that include wind generation, production from gas plants, temperature, and past values of the electricity price. They find a range of decreasing effects of wind generation on balancing electricity prices of 0.67 to 16.4 US$/MWh per additional GW of wind production (depending on the year, time of the day, and the area in the Texas network). Woo et al. (2011) study the 2007-2010 with a similar approximation, that includes nuclear generation, system load, price of gas, and a set of time dummies as additional explanatory variables, and finds that a 1 GWh increase in wind generation (during 15 minutes) decreased Texas balancing electricity prices between 13 and 44 US$/MWh9.

Unfortunately, these studies have not contemplated two important features of the effect of renewables on electricity prices. First, that this effect should just be temporary: when the decrease in electricity prices takes place, it reduces the long-term signal for investment and thus deters future investments, bringing about a subsequent increase in electricity prices due to restricted supply. In addition, when traditional producers may exert market power, they may bid higher in order to maintain the price level. These two elements are difficult to predict in theoretical analyses, where many assumptions have to be made about these issues. Hence, the actual relevance of these features may only be revealed through the analysis of real markets.

4.2 METHODOLOGY AND DATA

It is particularly interesting to see how these results related to the Italian market, which also features an important scheme for renewable support. Our analysis tries to close the research gap due to the shortage of studies of the merit order effect in the Italian market.

Italy has experienced a massive growth of installed RES capacity over the past years. It is thus possible to measure the MOE behavior with respect to the RES penetration rate. The Italian electricity market is considered as efficient (overall prices reflected through electricity market mechanisms) and shows a diverse energy mix which leads to a MOC that is easily extractable and most importantly invariant.

In our application, we carry out a full ex-post empirical analysis, by looking at use of technologies and weekly hourly prices between 2012 and 2018 to provide a more general understanding of the actual effect of the introduction of renewable sources of energy on the Italian wholesale electricity prices. We believe that it is particularly interesting to perform this empirical study in Italy where electricity pricing is currently at the center of intense social and regulatory debate.

We will use an empirical approach consisting in a multivariate regression similar to Gelabert et al. (2011) and Winkler et al (2016) to estimate the average effect of RES on the electricity prices in Italy.

Our analysis will go through two stages:

1) We will estimate the impact of the variation in the production of renewable energy sources on the changes in the Italian electricity price. Consequently, we will use the Single National Price (PUN)
2) We will re-estimate the same model in the previous stage using as dependent variable the zonal price taken from each geographical zone. We know from chapter 1 that in the formation of the electricity prices, in case of violation in the transmission constraints the market is split into two areas, one in import and the other in export. The result is a different zonal equilibrium price (Pz) in the two market zones. Power-generating companies receive the zonal prices, whereas buyers pay the Prezzo Unico Nazionale (PUN). GME uses a simplified representation of the network, which only shows the most relevant transit limits, or the transit limits between the national geographical areas, the foreign areas and the limited production poles. We will then consider only the national geographical areas: North, Center North, Center South, South, Sardinia, and Sicily. Then only to improve the refinement of the results obtained in this we'll implement a panel model that will take into account the 6 zones in order to estimate a more precise impact of the increase in RES share on the zonal electricity prices.

We will use weekly data from the day-ahead market for the last 6 years (from week 19 of 2012 to week 26 of 2018), for a total of 321 weekly observations.

Our dependent variable will be the average weekly hourly price of electricity.

To model the average weekly electricity price, we will use as independent variables the weekly electricity demand (TOTEM) composed as the sum of the total volumes purchased and unpurchased on the day-ahead market. Then we will consider the volumes sold by renewable energy source in the same market, in particular, we'll take into account the average weekly[28] volume sold of hydro (HYDRO), eolic (WIND) and solar (PV). The last two would also be labeled in our analysis like as variable renewable energy source (VRE[29]) characterized by a variable production dependent on the availability of the main natural power resource , very low marginal costs and large fixed costs. Although hydro generation is also a renewable energy source we do not incorporate it in the VRE because of the use of water, which can be stored and therefore shifted in time to profit from higher prices and has a positive opportunity cost.

Finally, we include the price of fossil fuels, which have an impact on the price of electricity. We opt for the price of gas because it improves the explanatory power of our model and it results significantly.

[28] Hourly weekly averages computed as the sum of the daily average prices/quantities of the week, divided by 7.
[29] In our analysis VRE is the sum of wind, pv, geothermal and a small quantities of other res sources.

These variables are exogenous because the demand for electricity is inelastic, while the volumes sold by the various renewable sources, especially those that are not programmable, depend on external factors such as atmospheric conditions and are fully brought to the market because of priority feed-in.

The other traditional sources (gas, coal and other fossil fuels) have not been included because they create endogeneity and are often not significant in the model.

variable	explanation	source
$PRICE^{30}{}_{w}$	Weekly hourly (zonal) electricity price (€/MWh)	Gestore dei Mercati elettrici (GME)
$WIND_w$	Hourly average sold from WIND during week w (GWh)	"
PV_w	Hourly average volume sold from solar during week w (GWh)	"
$HYDRO_w$	Hourly average volume sold from HYDRO during week w (GWh)	"
RES_w	Hourly average volume sold from RE[31] of the average demand of the week w. (GWh)	"
$TOTDEM_w$	Hourly average electricity demand of the week w. (GWh)	"
$PGAS_w$	Average gas price during week w (€/MWh)	Thomson Reuters: nat. gas PSV Italia 1st position

Table 6 Data Description.

4.2.1 STAGE 1: ESTIMATION OF THE MOE IN NATIONAL SYSTEM USING PUN

Before proceeding with the analysis, let us have a look at the evolution of our variables.

[30] For the national level: average of Zonal Prices in the Day-Ahead Market, weighted for total purchases and net of purchases for Pumped-Storage Units and of purchases by Neighbouring Countries' Zones.

[31] Sum of wind, solar, bioenergy and geothermal.

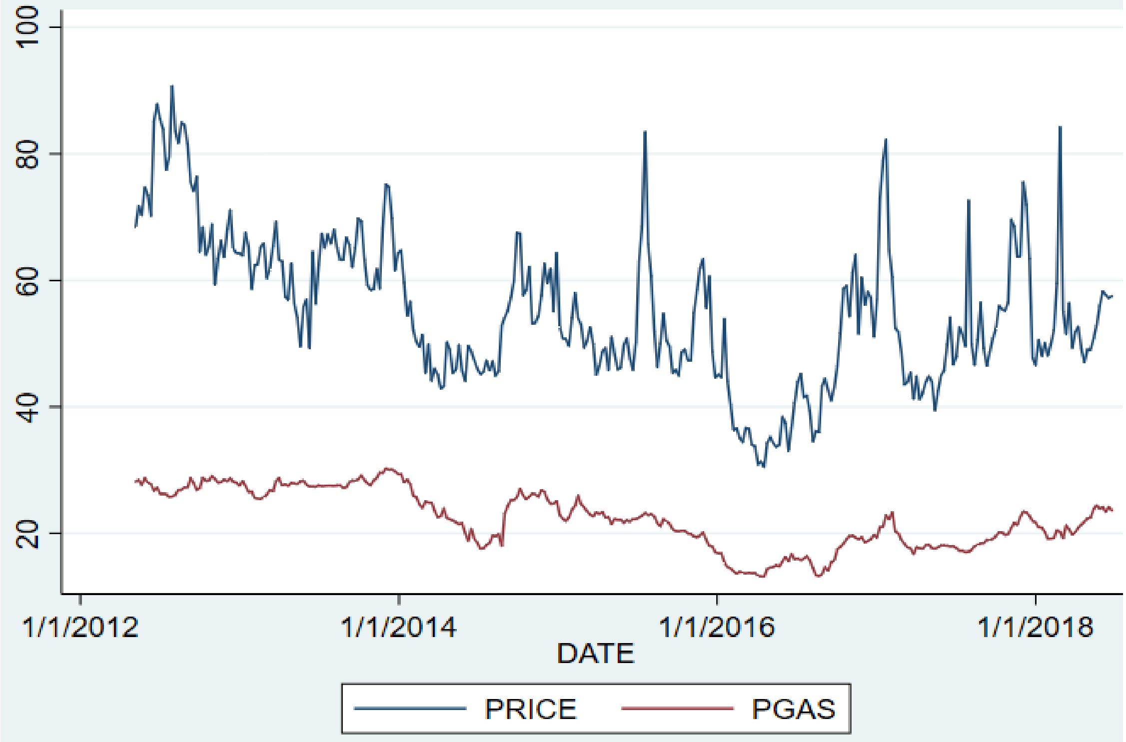

Figure 16 Evolution of PUN, PSV Italia. Own elaboration on GME and Thomson reuters 's data.

The price that we'll consider in our analysis is the baseload-price, that is the average of the on-peak and off-peak price[32].

Starting in 2008, a period of the recession began with a consequent reduction in consumption and this was also reflected in the price of wholesale energy, with the exception of the two-year period 2011-2012 in which there was a slight recovery (initial part of the graph).

In the following years, the decrease in the price of electricity is always due to the decline in electricity consumption but also to the increase in renewable sources, which produce energy at lower costs than conventional power plants.

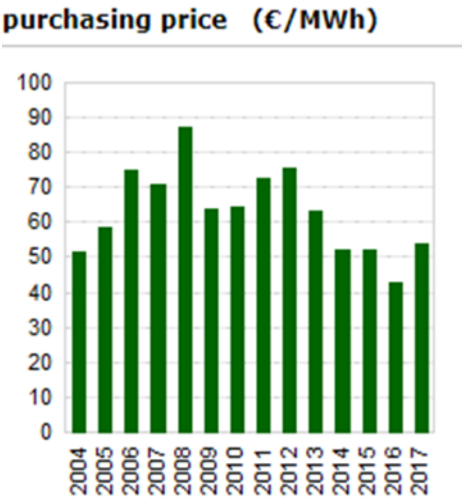

Figure 17 Source GME statistiche 2017.

As shown in the bar plot, after 2012, the price has always been lower in recent years, with the exception of 2017. The causes of the decline are in the economic situation of the country and in the poor recovery of the most energy-intensive sectors. In 2016, the lowest annual average value of the year was recorded, equal to approximately € 42 €/MWh, with a historic weekly

[32] we have the so-called "on-peak price" that coincides in working days only, the hours from 08:00 to 20:00, i.e. the applicable periods from 9 to 20; and the "off-peak price" defined as all the hours of non-working days (holidays); on working days, the hours from 00:00 to 08:00 and from 20:00 to 24:00, i.e. the applicable periods from 1 to 8 and from 21 to 24.

minimum in 18th April 2016 with 30,4 €/MWh (the monthly average was € 31.99 €/MWh). Only in the second half of the year, 2016 prices started to grow again.
In January 2017 there was a sharp rise in the PUN due mainly to the blocking of nuclear power plants in France[33], from which Italy imports energy, the low production from hydroelectric power and the winter temperatures that raised the price of methane gas.
The 2017 PUN values were nevertheless higher than the year before, re-aligning with the values of the two-year period 2014-2015.

Our electrical system is still largely based on the use of fossil fuels so it is normal that changes in the price of these probably affects the price of electricity. Typically, the price of other energy goods is another valuable price indicator for electricity. Considering the price of natural gas, from fig. 16 we can see how the price of the PSV[34] fell in 2009 (from € 29 to € 18.4 / MWh) and then stabilized around € 28 €/ MWh in the following years until 2014. Afterward, the price of gas has decreased, even in the main international hubs, following the trend registered worldwide (the United States and Asia). In Italy, the average price of the PSV in 2015 was € 22.2 €/ MWh, decreasing by 5% compared to 2014. In contrast to what was recorded in 2016, which saw spot prices down on 2015, 2017 closed with average spot prices in the main European hubs, with spot prices at the Italian PSV rising by 25%. This trend contributed, in conjunction with other factors, to the rise in electricity prices. The beginning of 2017 was characterized by the presence of a rigid climate - which increased the demand for gas for heating systems - and by the reduction of electricity exports from France, which led to greater use of combined cycle production. The upward trend continued during the current year. The price of gas naturally has seasonal fluctuations based on consumption. The gas demand is higher during the winter period due to the heating of the houses and decreases with the arrival of the hot season in the summer. At the end of our analysis period, PSV recorded a substantial growth on an annual basis (+5 € /MWh, + 28.4%), reaching 23.38 € / MWh, at the highest level since 2014 for the summer months April-September.
Table 7 shows the descriptive statistics of the variables for each of the five full years in our analysis. Table 8 shows the descriptive statistics for the whole analysis period. The weekly average electricity price declined constantly reaching its minimum in 2016, with a partial

[33] At the end of September 2016, the Autorité de Sureté Nucléaire (ASN) ordered the precautionary suspension of 18 nuclear power plants for suspicions of excessive carbon content in steel enclosures
[34] The index relating to the prices of the Italian gas spot market is called PSV (Punto di Scambio Virtuale). It is not a real exchange with a central counterparty and with transparent price formation mechanisms, but it is an exchange platform managed by GME where the supply and demand of the operators meet. The prices expressed by the index are those referring to the physical delivery of the gas at the national trading point.

recovery in 2017. This decline can be traced back to multiple factors, including the reduction of the weekly average demand for electricity and the reduction in the price of some commodities, e.g. gas (and coal). Hydroelectric generation has declined through the years; PV after the peak in 2014 faced a two years decrease and recovered in 2017 and finally WIND alternate years of increase and decrease in production.

N=52	**2013**		**2014**		**2015**		**2016**		**2017**	
	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
PRICE	62.94	5.31	52.17	6.82	52.63	7.34	42.18	9.15	53.84	10.71
TOTDEM	37.63	2.39	36.19	2.61	34.81	2.73	34.25	2.34	33.97	2.51
HYDRO	5.17	1.41	5.75	1.23	4.93	1.18	4.84	1.46	4.33	1.20
PV	3.05	1.02	3.42	0.91	3.08	0.71	2.82	0.76	2.95	0.91
WIND	1.62	0.67	1.67	0.60	1.5	0.63	1.61	0.77	1.58	0.8
PGAS	27.8	1.11	23.51	3.25	21.93	1.69	15.82	2.07	19.28	1.93

Table 7 Descriptive statistics for the years 2013-2017. Own elaboration on GME and Thomson Reuters's data

N=321	**MEAN**	**ST.DEV.**	**MAX**	**MIN**
PRICE	55.12	11.81	90.7	30.5
TOTDEM	35.50	35.5	37.43	27.38
HYDRO	5.041	1.42	8.821	2.33
PV	3.039	0.88	4.95	1.47
WIND	1.599	0.72	4	0.33
PGAS	22.27	4.541	30.3	13.15

Table 8 Descriptive statistics. Own elaboration on GME and Thomson Reuters data.

Before proceeding to estimate the model, we test for the existence of unit roots in our series using the Augmented Dickey-Fuller (ADF) test (Dickey Fuller, 1979). The test statistics in table A2 of the Appendix indicate that four of the time-series are I (1) with a 5% critical value. As a consequence, the regression model will be estimated in first differences.

Before turning to the ols results just a few comments on the correlation matrix of the variables included in the analysis.

	Δ PRICE	**Δ TOTDEM**	**Δ HYDRO**	**Δ PV**	**Δ WIND**	**ΔPGAS**
Δ PRICE	1					
Δ TOTDEM	0.353	1				
Δ HYDRO	0.039	0.26	1			
Δ PV	-0.081	0.041	0.18	1		
Δ WIND	-0.24	-0.005	0.068	-0.08	1	
Δ PGAS	0.178	0.032	0.012	-0.17	0.066	1

Table 9 Correlation Matrix. Own elaboration on GME and Thomson Reuters's data

As expected, changes in the volume sold by variable renewable energy source are negatively correlated with the weekly average electricity price. Correlation is positive for changes in the volumes sold by HYDRO. This is because, although the variable cost for this technology is low, production from hydro plants is generally associated with periods of high demand since hydro electricity can be stored and used to equalize marginal cost for producers. We observe a positive correlation of price with the total electricity demand and the price of fossil fuels. This is consistent with the fact that the electrical system still depends largely on the use of fossil fuels so variation in the price of these technologies correlates in the same direction with the moves of the wholesale electricity price.

The correlation matrix indicates that there are no problems of pairwise multicollinearity[35]. According to the calculations of the variance inflation indicator (VIF) for the estimated regressions is smaller than the often-used critical value of 10 for every case. This implicates that problems related to multicollinearity are very unlikely to exist.

Under weak dependence of the variables, weak dependence of the residuals and the independent regressors we have a consistent OLS estimate (Woolridge, 2003).

In order to control for the well-known seasonality of electricity prices, the model includes, in addition to a constant, three dummy variables indicating the season (summer, autumn, and winter.

We thus estimate the following two models:

1) $\mathbf{\Delta} PRICEt = \beta_0 + \beta_1 \mathbf{\Delta} TOTDEM_t \ + \beta_2 \mathbf{\Delta} HYDRO_t \ + \beta_3 \mathbf{\Delta} VRE_t \ + \sum_{k=1}^{3} \beta_{k+3}\, sm_{kt} + u_t$
2) $\mathbf{\Delta} PRICEt = \beta_0 + \beta_1 \mathbf{\Delta} TOTDEM_t \ + \beta_2 \mathbf{\Delta} HYDRO_t \ + \beta_3 \mathbf{\Delta} PV_t \ + \beta_4 \mathbf{\Delta} WIND_t \ + \beta_5 \mathbf{\Delta} PGAS_t \ + \sum_{k=1}^{3} \beta_{k+5}\, sm_{kt} + u_t$

Where delta represents the difference operator, sm_{kt} (k=1,..,3) are the seasonal dummies.

We use Durbin Waston (Durbin, 1970) to test for the existence of serial correlation in the OLS errors. According to the test statistics and the corresponding p-values (see Table 10), the null hypothesis of no autocorrelation of order 1 in the residuals is rejected in each case. As a consequence, Newey-West standard errors that are robust to heteroscedasticity and autocorrelation are used for the estimations.

The final model of Equation 1 is constructed in various steps to present results for several variations (Models 1A to 1C) in a procedure that provides further details on specific issues and

[35] The frequently used critical values for pairwise multicollinearity lies between a correlation factor of 0.8 and 0.9.

also serves as a robustness test. The first two variations (1A and 1B) implement a reduction of the dataset to the upper quarter of high-demand weeks and the lower quarter of low-demand weeks. This is done to verify the hypothesis that renewable production has a much higher impact on electricity prices when the electricity system is closer to full capacity as observed by other papers (e.g. Ostergaard et al., 2006; Jonsson et al., 2010; Gelabert et al., 2011). The last variation (1C) estimates Equation 1 using monthly average instead of weekly averages.

Model 2 involves a separation of solar and wind electricity sources through the use of separate coefficients that intend to identify the different production patterns of these technologies. We also add the weekly spot price of natural gas.

The results for all model variations are reported in the following table.

Table 10 Ols estimation of weekly changes in electricity prices.

	Model 1	**Model 1**	**Model 1B**	**Model 1C**	**Model 2**
Dependent variable	$\Delta PRICEt$	High demand $\Delta PRICEt$	Low demand $\Delta PRICEt$	Monthly $\Delta PRICEt$	VRE split up $\Delta PRICEt$
$\Delta TOTDEM_t$	0.932 *** (0.218)	5.37*** (2.06)	3.632*** (1.359)	0.87** (0.31)	0.917*** (0.128)
ΔVRE_t	-1.916*** (0.347)	-3.59** (1.34)	-2.47*** (0.625)	-1.67** (0.75)	
$\Delta HYDRO_t$	-0.110 (1.00)	-0.96 (1.26)	-1.277** (0.354)	-0.79 (0.78)	-0.577 (0.727)
ΔPV_t					-2.08* (1.01)
$\Delta WIND_t$					-1.953*** (0.398)
$\Delta PGAS_t$					1.455*** (0.36)
Season dummies	yes	yes	yes	yes	yes
Observations	320	81	81	72	320
Adj. R-squared	0.1843	0.174	0.195	0.1802	0.238
dw	2.116	2.26	2.28	2.07	2.09
p-value	0.000	0.000	0.000	0.000	0.000

Notes: all models include an intercept; standard errors in parenthesis are robust to heteroskedasticity and serial correlation (Newey West 1987). dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals.

*** indicates p-value<0.001, **p-value<0.01, *p-value < 0.05, **.** p-value<0.1

In line with the theory of merit order effect and the previous research conducted in other countries, the coefficient for the variable renewable production variable is always negative and significant. Ceteris paribus, day-ahead electricity prices for Italy decrease by roughly 2 €/MWh for each additional expected GWh produced by variable renewable energy sources. The coefficient of the variable TOTDEM is positive and significant (in all models) in line with the economic theory that says that higher consumption increases the price of the product. This model explains the 18% of the weekly electricity prices. This merit order effect merely corresponds to an electricity decrease of 3.6% since the average price was about 55 €/MWh for the period under study.

More interesting results arise from the comparison of high and low-demand weeks (Model 1A and 1B). Evidence shows that when demand is high, the electricity price is determined by the cost of a high variable-cost technology, while when the demand is low the price is determined by the variable cost of a cheaper technology. So, we expect electricity generation under variable renewable energy sources to have a stronger negative effect on electricity prices when demand is high due to the fact that in these cases, these technologies are replacing technologies with a higher variable cost. In our findings the effect of renewable production on the electricity price appears to be more pronounced for high-demand weeks: while a 1GWh increase in electricity production by VRE decreases electricity prices by almost 2.47 €/MWh in the lowest demand, it decreases electricity prices by almost 3.6 €/MWh in the highest demand. This means that the negative effect is almost 30% stronger in the subsample of weeks with the highest demand with respect to the one with the lowest demand.

This result is in line with evidence (e.g. Ostergaard et al., 2009; Senfuss et al., 2008, Weigt et al., 2009; Woo et al., 2011).

Model 1C results indicate that the importance and magnitude of renewable production remain unchanged varying the frequency of our observations. The VRE coefficient is somehow smaller, which is not surprising because the valuable information could be lost when expanding the intervals into monthly observations and because we are smoothing the effects.

As expected, model 2 shows that for any given level of electricity demand, if the volumes sold by PV and WIND increase by 1GWh, electricity price decreases on average of respectively 2.08€/MWh and 1.95 €/MWh, with the coefficient of WIND very significant. Moreover, as expected, the positive and significant coefficient of the spot price of gas indicates that positive variations in this price increase wholesale electricity price.

Since RES production varies over time, we run equation 1 and 2 on a yearly base. In this way, we take into account that the impact of RES (more specifically WIND and PV) may differ over time as the accumulated level of VRE electricity production increases. Results are presented in the following tables.

Table 11 Results of equation 1 in the single years.

	2013	2014	2015	2016	2017	12-18
			DEPENDENT VARIABLE: $\Delta PRICEt$			
$\Delta TOTDEM_t$	0.63*	0.25*	1.84***	1.01***	2.26***	0.932 ***
	(0.27)	(0.14)	(0.35)	(0.27)	(0.42)	(0.218)
$\Delta HYDRO_t$	0.31	-3.11**	-0.49	-1.08	-1.57	-0.110
	(1.54)	(0.96)	(1.86)	(1.38)	(2.53)	(1.00)
ΔVRE_t	-3.17**	-3.16**	-1.95*	-1.49*	-2.20**	-1.916***
	(1.02)	(0.64)	(0.86)	(0.64)	(0.81)	(0.347)
Season dummies	yes	yes	yes	yes	yes	yes
Observations	52	52	52	52	52	320
Adj. R-squared	0.20	0.47	0.43	0.30	0.52	0.1843
dw	2.02	1.97	2.25	2.08	2.02	2.116

Table 12 Results of eq. 2 on a yearly basis.

	2013	2014	2015	2016	2017	12-18
			DEPENDENT VARIABLE: $\Delta PRICEt$			
$\Delta TOTDEM_t$	0.61*	0.28*	1.26**	0.94**	2.63	0.917***
	(0.24)	(0.165)	(0.44)	(0.26)	(0.38)	(0.128)
$\Delta HYDRO_t$	1.39	-2.9**	0.13	-0.76	-3.02.	-0.577
	(1.42)	(0.98)	(1.69)	(1.36)	(1.54)	(0.727)
ΔPV_t	-2.4	-5.13***	-2.55	-2.5	-0.29	-2.08*
	(2.35)	(1.04)	(2.64)	(2.20)	(0.85)	(1.01)
$\Delta WIND_t$	-3.44**	-3.05***	-1.89**	-1.66*	-1.85*	-1.953***
	(1.03)	(0.43)	(0.61)	(0.69)	(0.88)	(0.398)
$\Delta PGAS_t$	3.68**	0.005	2.62**	1.67	2.67***	1.455***
	(1.28)	(0.41)	(1.18)	(0.83)	(0.71)	(0.36)
Season dummies	yes	yes	yes	yes	yes	yes
Observations	52	52	52	52	52	320
Adj. R-squared	0.29	0.49	0.43	0.32	0.56	0.238
dw	2.27	2.01	2.24	2.12	2.01	2.09

Notes: all models include an intercept; standard are in parenthesis are robust to heteroskedasticity and serial correlation (Newey West 1987). dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals

*** indicates p-value<0.001, **p-value<0.01, *p-value < 0.05, **.** p-value<0.1

Starting from table 11 we detect MOE effects of renewables in each year in line with our expectations. We stress how the impact of VRE on electricity price was quite stronger in the first years and then faces a strong reduction in its impact from 2015 due to the slight decrease of VRE generation in the last years. Moving to table 12 we detect the highly significant role of WIND in electricity price reduction, also here we note a decrease in WIND impact over the years. PV was highly significant only in 2014 at its peak in production.

We also re-estimate model 2 (results in table A3 Appendix) considering other fossil fuels in place of the price of natural gas that could have an impact on electricity prices. Considering the price of coal[36], results are very similar to the one obtained in our analysis, although we preferred the model with the price of natural gas due to the low importance of coal in the Italian electricity system. Taking into account the price of oil[37] and CO2 allowances (EUA[38]) evidence that these fossil fuel prices are not significant.

Summing up, the estimation results are quite robust across models. Significant coefficient always has the same sign and the effects of renewable production on prices are also consistent. Our results provide an empirical support to the theoretical prediction that, ceteribus paribus, an increase in electricity generation under VRE, in the analysis interpreted as an increase in the volume sold on the day-ahead market, reduces electricity prices. More precisely, we found that an increase of 1 GWh in electricity production under these sources is associated with an average decrease of 1.92 €/MWh. Our findings are quite compatible with MOE observed in other European electricity markets.

[36] We took as reference the COAL ICE API 2 (source Thomson Reuters: COAL ICE API 2 CIF ARA Euros Per Metric Tonne).

[37] We took as reference Brent, which is the leading global price benchmark for Atlantic basin crude oils. It is used to price two thirds of the world's internationally traded crude oil supplies (source Thomson Reuters: Crude Oil BFO M1 Europe FOB).

[38] The EU-ETS is an economic instrument of environmental policy, "cap and trade" applied to greenhouse gas emissions, which sets a cap on emissions for companies and consists of a market of emission permits. The cap or maximum emission limit is expressed in the number of permits to be issued (EUA) which are distributed at auction or in free allocation to plant managers (Source: Thomson Reuters: EUA)

4.2.2 STAGE 2: ESTIMATION OF THE MOE IN THE SIX GEOGRAPHICAL ZONES

As mentioned in the introduction to the chapter, the electrical system is divided into portions of transmission networks - defined zones - for which exist, for the purposes of the safety of the electricity system, physical limits of energy transit exist with the corresponding neighboring areas. These transit limits are determined based on a calculation model based on the balance between electricity generation and consumption. The Italian electrical system is therefore divided into zones of the market, aggregates of geographical and/or virtual areas, each characterized by a zonal energy price. The process of identifying the areas of the relevant network takes into account the three-year Development Plan of the National Transmission Network.

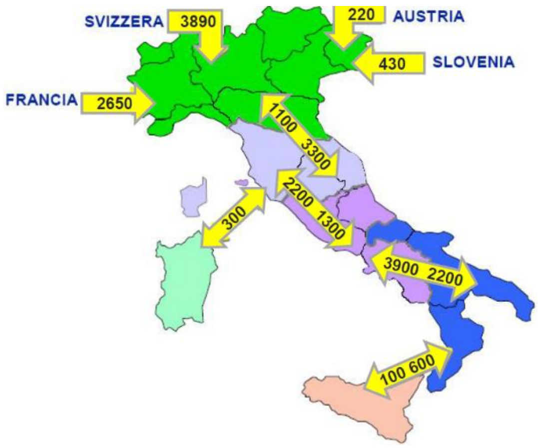

Figure 18 Maximum transits between geographical areas. Source: tpg.unige.it, 2016.

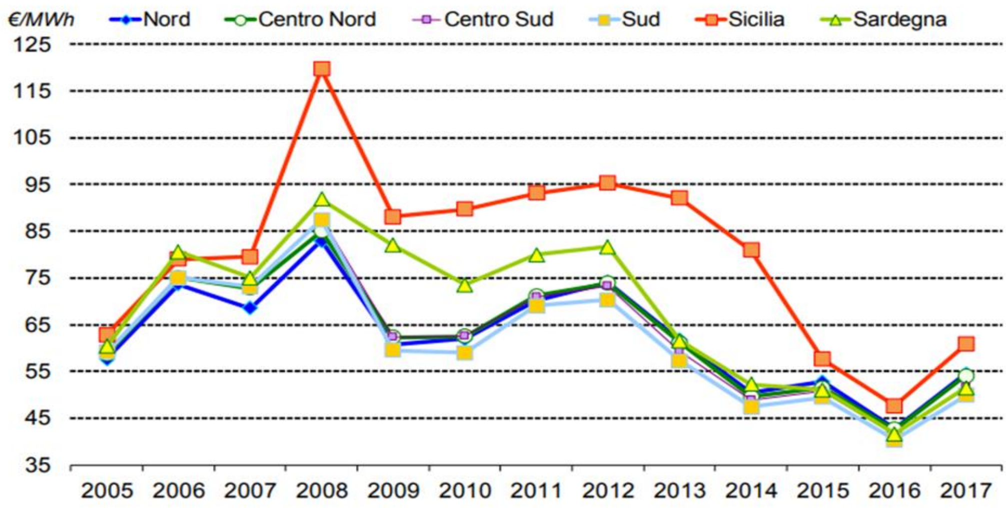

Figure 15 Evolution of the zonal prices. Source: GSE rapporto statistico 2017.

In the last ten years, there has been an evolution of the dynamics of wholesale prices. The growing availability of incentive renewable energy must be considered among these factors. However, in recent years, there has been a gradual convergence of zonal prices, attributable to multiple factors, including the following:

-development of electrical infrastructures thanks to some regulatory framework adopted in recent years (e.g. Ministerial decree of October 19, 2016[39]).
-AEEGSI regulatory activities (dispatching, prices offered by relevant plants in Sicily, etc.)
-renewable increase and disposal of obsolete plants with higher marginal costs in market areas with historically higher prices.

€/MWh	PUN	NORTH	C.NORTH	C.SOUTH	SOUTH	SICILY	SARDINIA
MEAN	55.12	54.57	54.07	52.96	51.37	70.36	54.97
(SD)	(11.81)	(12.24)	(11.67)	(11.1)	(10.67)	(20.49)	(15.1)
MIN	30.5	28.62	31.04	31.05	30.37	34.00	31.05
MAX	90.7	91.19	87.91	85.28	83.21	139.78	157.22

Table 13 Descriptive statistics of the zonal prices. Own elaboration on GME and Thomson reuters 's data.

In this paragraph, we are going to use the same methodology adopted in the previous paragraph to estimate the effect of renewable energy production on the zonal electricity price. The frequency of the data is the same as the variables of the model. ADF tests and correlation matrix are presented in tables A4-A15 in the Appendix.
We will estimate the following equations:

1) $\boldsymbol{\Delta} PRICE_{it} = \beta_0 + \beta_1 \boldsymbol{\Delta} TOTDEM_{it} + \beta_2 \boldsymbol{\Delta} HYDRO_{it} + \beta_3 \boldsymbol{\Delta} VRE_{it} + \sum_{k=1}^{3} \beta_{k+3}\, sm_{kit} + u_{it}$
2) $\boldsymbol{\Delta} PRICE_{it} = \beta_0 + \beta_1 \boldsymbol{\Delta} TOTDEM_{it} + \beta_2 \boldsymbol{\Delta} HYDRO_{it} + \beta_3 \boldsymbol{\Delta} PV_{it} + \beta_4 \boldsymbol{\Delta} WIND_{it} + \beta_5 \boldsymbol{\Delta} PGAS_{it} + \sum_{k=1}^{3} \beta_{k+5}\, sm_{kit} + u_{it}$

[39] The decree is the legal basis for all national or regional administrations that want to promote investments for the adaptation and optimization of the electricity grid in the assisted areas of the national territory, under the conditions established by the same.
The provision regulates the criteria and modalities for the granting of aid for the financing of energy infrastructures functional to increasing the availability of the network and contributing to the dissemination of the generation distributed from renewable sources, through the support of:

- interventions for the creation of smart energy distribution networks (smart grids)
- interventions on transmission networks strictly complementary to the interventions on the distribution network.

Results of the estimation 1 are presented in the next table :

Table 14 Results of equation 1 for the zonal markets.

	NORTH	C-NORTH	C-SOUTH	SOUTH	SICILY	SARDINIA
			DEPENDENT VARIABLE: $\Delta PRICEt$			
$\Delta TOTDEM_t$	0.0018***	0.009***	0.007***	0.0025*	0.019***	0.015*
	(0.0002)	(0.001)	(0.001)	(0.001)	(0.004)	(0.006)
$\Delta HYDRO_t$	-0.0004	0.003	0.004	0.006	0.07*	-0.027
	(0.0008)	(0.005)	(0.005)	(0.005)	(0.033)	(0.036)
ΔVRE_t	-0.004*	0.017*	-0.01***	-0.006***	-0.031***	-0.015***
	(0.002)	(0.007)	(0.001)	(0.0006)	(0.0035)	(0.004)
Season dummies	yes	yes	yes	yes	yes	yes
Observations	320	320	320	320	320	320
Adj. R-squared	0.179	0.132	0.195	0.2015	0.228	0.065
dw	2.05	2.05	2.08	2.07	2.1	2.14

Notes: all models include an intercept; standard are in parenthesis are robust to heteroskedasticity and serial correlation (Newey West 1987). dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals
*** indicates p-value<0.001, **p-value<0.01, *p-value < 0.05, **.** p-value<0.1.

As expected, the MOE is evident also taking into account the zonal markets. The coefficients for VRE are all negative and statistically significant. The price reduction range from 0.004 €/MWh in the North zone to 0.031 €/MWh in Sicily. The coefficients of the total demand are all positive and significant in line with our expectations.

Splitting VRE in wind and PV, and adding the price of gas, results for equation 2, table 15, are the following:

Starting from the ***North*** zone, as we expected, also the wholesale electricity price of the North zone is negatively correlated with the renewable energy source, and positively correlated with the total zonal electricity demand and the price of fossil fuels (see correlation matrix in Appendix).

Analyzing the model, we can observe significant values for the total demand, PV and PGAS, while volumes sold from HYDRO and WIND are not significant.

These results are not surprising if we consider that in this part of the country is concentrated most of the PV plants, installed power and production with the leadership driven by Veneto and Lombardy, with the latter ranking in the first position for installed systems and production and second for installed power.

Results from this model show that a marginal increase of 1MWh of the hourly average weekly volumes sold by PV source reduces the weekly wholesale northern zonal electricity price of respectively of 0.0036€/MWh.

Moreover, as expected, the positive and significant coefficient of the spot price of natural gas indicates that a marginal increase in gas price increases wholesale zonal electricity price. The model has an explanatory power of 23%.

Results for the ***C-north*** are similar to the North zone, with a significant coefficient for PV but with opposite sign. Observing the result for this zone in table 16 in the appendix we detect an opposite effect of renewables on electricity prices in this zone. This shows no evidence of the merit order effect.

Considering ***C-South*** we detect a negative correlation between the wholesale electricity price and renewable energy source, and positive correlation with the total zonal electricity demand and the price of gas. Results from the model show that they are merely in line with the results found at the system level. We can stress the high significance of WIND, due to the high installed capacity and production of Campania. PV and HYDRO have no significant role in explaining the Central South electricity price decrease. The model has an explanatory power of 22%.

Considering ***South*** Italy, we observe from the correlation matrix only a negative correlation of price with PV and WIND. Moving to the model, as expected we observe a very high significance of WIND. The environmental and territorial characteristics of this part of the country such as windiness, orography, and accessibility make south Italy the main site of WIND production. In particular, the region with the highest production and installed power is Puglia (1188 production plants and 2494 MW of installed power). PV is quite significant due to region Puglia that has the highest installed capacity for this source in the country. The model has an explanatory power of 24%.

About ***Sicily***, analyzing the model, WIND, like in the previous models continue to have a significant impact on the electricity price reduction, this because Sicily is the second region in the country with the highest installed capacity and production from eolic source. HYDRO also is merely significant and have a positive effect on price, this can be plausible due to the particular nature of this source. For the first time, we found no evidence of the impact of fossil fuel price on electricity prices. The explanatory power of the model is 22%.

Finally, in ***Sardinia***, we find correlation results in line with the ones at the system level. Although when we analyze the outcome of the model, we see that only WIND is significant, while the other renewable energy source, albeit having a negative impact on price, have a non-significant coefficient.

Table 15 Results of eq. 2 for the zonal markets.

	NORTH	C-NORTH	C-SOUTH	SOUTH	SICILY	SARDINIA
			DEPENDENT VARIABLE: $\Delta PRICEt$			
$\Delta TOTDEM_t$	0.0018***	0.009***	0.007***	0.002*	0.019***	0.017**
	(0.00031)	(0.001)	(0.001)	(0.001)	(0.004)	(0.006)
$\Delta HYDRO_t$	-0.0026	0.002	-0.001	0.004	0.063.	-0.026
	(0.001)	(0.005)	(0.005)	(0.005)	(0.03)	(0.035)
ΔPV_t	-0.0036*	0.025 ***	-0.008	-0.005*	0.001	-0.037
	(0.0021)	(0.007)	(0.006)	(0.0031)	(0.025)	(0.048)
$\Delta WIND_t$	-0.035	-0.032	-0.0108***	-0.006***	-0.03***	-0.016***
	(0.152)	(0.037)	(0.001)	(0.0007)	(0.003	(0.004)
$\Delta PGAS_t$	1.35**	1.73***	1.35***	1.45 ***	0.211	2.06***
	(0.5)	(0.4)	(0.37)	(0.34)	(0.67)	(0.59)
Season dummies	yes	yes	yes	yes	yes	yes
Observations	320	320	320	320	320	320
Adj. R-squared	0.213	0.188	0.22	0.241	0.226	0.094
dw	2.08	2.08	2.13	2.10	2.09	2.15

Notes: all models include an intercept; standard errors in parenthesis are robust to heteroskedasticity and serial correlation (Newey West 1987). dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals *** indicates p-value<0.001, **p-value<0.01, *p-value < 0.05, **.** p-value<0.1

Summing up: extending our main analysis to the zonal areas, results are merely in line with the analysis conducted on the whole country. VRE production decreases wholesale electricity prices everywhere (with an exception for C-North) with an interval ranging from 0.004€/MWh to 0.031€/MWh. Splitting VRE we can detect the importance of PV and WIND in the price formation of each zone and this represents also a key to understand the results found in the previous stage. WIND seems to be the main driver of the MOE in the majority of the zone, especially in those areas with high production and installed capacity from this source. PV is quite relevant in the North and C-North only. HYDRO, as expected, has no relevant role in the zonal MOE as observed also in the national analysis.

4.2.3 PANEL ANALYSIS

Now we organize our data from stage 2 to combine two dimensions: spatial (cross-sectional) and temporal (time series). In this way, we obtain a solution to the difficulties involved in interpreting the partial regression coefficients in the framework of a cross-section only or time series only multiple regression. The obvious benefit is in terms of obtaining a large sample, giving more degrees of freedom, more variability, more information and less multicollinearity among the variables. Another advantage comes with the possibility of controlling for zonal or time heterogeneity, which the pure cross-section or pure time series data cannot afford.

There are two methods that come before us: fixed effect and the random effect. The choice of the best methodology is not simple and trivial in our case. Taking into account the fixed effect, it assumes that a correlation between the zonal specific effect and the explanatory variables, i.e the volumes sold by the various technologies, in our model. This could be possible if we think about the link in wind production and the southern regions due to their specific environmental and territorial characteristics of sites such as windiness and orography. Considering random effects, its assume instead that the variation across zones is assumed to be random and uncorrelated with the independent variables included in the model. Also this sounds good if we take into account solar production and the northern regions, in this case, we have a great concentration of PV production in areas where solar irradiation are not so powerful like in other regions. We are then in front of two valid alternatives, which present pros and cons. We resort to the help of the Hausman test to take a final decision.

We then run four types of panel estimation: the classic fixed effect and random effect and to each of them we add dummy variable which controls for the year of the sample detecting some changes in the regulatory framework in renewables incentives. The Hausman test (result presented in TEST 2 Appendix) strongly suggests using the random effect model. This means we are assuming that the variation across zones are assumed to be random and uncorrelated with our independent variables included in the model and we suggest that differences within the zones can have some impact on the formation of the zonal electricity prices.

We will estimate the following random effect model with the inclusion of year dummies γm_{kt} (k=1..6):

$$\Delta PRICE_{it} = \partial \quad + \beta_1 \Delta TOTDEM_{it} + \beta_2 \Delta HYDRO_{it} + \beta_3 \Delta PV_{it} + \beta_4 \Delta WIND_{it}$$
$$+ \beta_5 \Delta PGAS_{it} + \sum_{k=1}^{6} \beta_{k+5}\, \gamma m_{kt} + v_i + u_{it}$$

$\text{Cov}(u_{it}, \Delta TOTDEM_{it}, \Delta HYDRO_{it}, \Delta PV_{it}, \Delta WIND_{it}, \Delta PGAS_{it}) = 0$

$\text{Cov}(v_{i}, \Delta TOTDEM_{it}, \Delta HYDRO_{it}, \Delta PV_{it}, \Delta WIND_{it}, \Delta PGAS_{it}) = 0$

Results of the estimation are presented in the following table (to be compared also with the results of table A17 in the appendix).

Results are quite similar, within the various panel data estimation and in comparison with the estimates obtained in the previous stages. We see a negative effect of renewables on price effects with the coefficient for WIND very significant and much stronger than PV, also significant. HYDRO has no significant role in electricity price reduction while PGAS seems to have, as witnessed previously, a positive impact on electricity prices.

Table 16 Random effect estimation results.

randomdumyear	
DEPENDENT VARIABLE: $\Delta PRICEt$	
$\Delta TOTDEM_t$	0.02278*** (0.005)
$\Delta HYDRO_t$	0.01 (0.0158)
ΔPV_t	-0.0059** (0.002)
$\Delta WIND_t$	-0.099** (0.045)
$\Delta PGAS_t$	1.03 *** (0.34)
Year dummies	yes
Observations	1920
R-squared	0.1328
Wald chi2	437.22
Prob> chi2=	0.000

*** indicates p-value<0.001, **p-value<0.01, *p-value < 0.05, **.** p-value<0.1

4.3 EFFECT OF RENEWABLES ON ELECTRICITY VOLATILITY

Results from the previous section stressed that renewable energy sources with zero marginal costs decrease Italian electricity prices. Now we want to estimate the effect on volatility.

While the dampening effect of renewable energy generation on electricity prices level is well-studied in many papers, the literature on how this power generation affects electricity price volatility is scarce and inconclusive. Not only the number of studies is insufficient to make an appropriate conclusion, neither there is a similar approach on what price volatility measure to use (daily, weekly, monthly).

Intuitively, there is a solid explanation for the question about why electricity prices become more volatile when the renewable energy capacity increases. It is known that controlling the energy output from intermittent energy generators is harder than doing this for conventional energy sources. If there are difficulties in meeting the market demand in time, electricity grid operators may have to purchase extra energy to supply the market and to avoid shortages. In such a scenario, the equilibrium market price will be higher compared to the price when a grid operator provides the necessary supply in time without purchasing it from somewhere else. With an increasing share of the intermittently available energy resources, this should be happening more frequently since the electricity supply is becoming less predictable.

In the paragraph, I will investigate whether the increased share of energy produced by renewables leads to the above-described inefficiencies in the Italian (and zonal) electricity market. In particular, I will study whether prices have become more volatile in response to the more unpredictable nature of the energy supply.

Empirical studies of electricity price volatility have been conducted in the US, Canada, some European countries, Australia and New Zealand.

The paper by Woo et al. (2011) on the Texas electricity market, after demonstrating the negative relationship between an increase of wind generation and the level of electricity spot prices, shows one more valuable insight: increases in wind power output tend to enhance the daily spot-price variance. The magnitude of the increases in price volatility varies across different electricity markets: from less than 1% to 5% in response to a 10% increase in the installed capacity of wind generation.

When reviewing empirical studies in Europe, one cannot overlook the German electricity market. There is a recent paper by J.Ketterer (2014) that uses a generalized autoregressive conditional heteroskedasticity (GARCH) model to test whether changes in wind power output have an effect on price volatility. The approach is not new[40], but very appropriate since a GARCH model can replicate the volatility behavior properly.

In the paper by R.Green et al. the British (2010) electricity market is studied. The study considers daily variation in electricity prices and it is able to make insightful inference about price behavior during the day, however, no conclusions can be made about the impact of increased wind power generation on price volatility in the long-run, as such a relationship is not studied in the paper. Additionally, the paper finds out that the effect is more persistent during the summer months. This particular finding is also recorded in the study of the Australian electricity market by H.Higgs et al. (2015) throughout September, November, December, and January (summer in Australia), the price volatility is higher than it is in the rest of the year.

Electricity price volatility behavior has been recently studied for the German and the Danish electricity markets by T.Rintamäki et al.(2014, 2017) and the findings are different when the daily or weekly electricity price volatility is considered. Weekly volatility is increasing in both electricity markets when intermittently available generators are introduced. Daily volatility, on contrary, behaves differently: in Denmark, it is decreasing and in Germany, it is increasing when the WIND power output is growing. One way to explain the inconsistency in the results for the daily volatility is to remember that German and Danish electricity markets have different renewables generation mix: while Denmark has only wind power, Germany has both wind and solar energy. As solar power is produced only during peak hours, this decreases daily price volatility by decreasing high peak hour prices. As wind and solar power have opposite effects on volatility, the results for German electricity daily volatility is inconclusive.

In the following section, I will continue on the path traced by T.Rintamäki et al to compute the effect of intermittent renewable energy (WIND and PV) on the wholesale weekly electricity price volatility in the day ahead market. I will adopt the methodology based on Mauritzen (2010) who modeled the variation of daily prices as a seasonal autoregressive moving average model (SARMA) in which wind power production was an exogenous regressor. He conducted his studies on the Danish market and found that that Danish wind power decreases the daily volatility of prices. The benefits of this methodology are that its results are straightforward to interpret, and that one-day ahead forecasts for electricity prices can be developed based on the data from previous days and information on regular consumption patterns.

[40] Previously, GARCH modelling was used to examine the relationship between trading volume and price volatility or to explore how changes in market design affect the volatility of price.

4.3.1 METHODOLOGY AND DATA

To estimate the effect of exogenous variables such as wind and solar power on a dependent variable of interest such as electricity price volatility, we use the seasonally adjusted autoregressive moving average (SARMA(p,q)(P, Q)[s]) model:

$$v_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \, v_{t-i} + \sum_{i=1}^{q} \beta_i \, \epsilon_{t-i} + \sum_{i=1}^{P} \alpha_{i\,\cdot\,s} v_{t-i\cdot\,s} + \sum_{i=1}^{Q} \beta_{i\ \,s} \epsilon_{t-i\cdot\,s} + \epsilon_t + \gamma^T x_t \quad (1)$$

Where v_t is the dependent variable during time period t and x_t a vector of exogenous variables, There are p autoregressive (AR) terms v_{t-i}, q moving average (MA) terms ϵ_{t-i}, P seasonal autoregressive (SAR) terms $v_{t-i\cdot\,s}$ with periodicity ofa s, and Q seasonal moving average (SMA) terms $\epsilon_{t-i\cdot\,s}$ with periodicity of s wa ith the coefficients α_i, β_i, α_i • s, and β_i • s, respectively. In other words, the terms v_{t-i} are lagged values of v_t and ϵ_{t-i} Gaussian white noise error terms. The impact of the exogenous variables on price volatility is estimated by the parameter vector γ using R.

Our data for the national level and the six zones consist of the average weekly hourly national prices (in €/MWh), the average weekly hourly volumes of wind, solar, hydro sold in the day ahead spot market. We account for fuel prices by including the weekly natural gas spot price (in €/MWh, PSV Italia). The dataset spans from 7 may 2012 to 26 June 2018.

Our measure of price volatility for week w is the logarithm of the standard deviation calculated from daily average prices p_d and weekly average prices $p_w = \frac{1}{7}\sum_{d=1}^{7} p_d$.

$$v_w = \ln\left(\sqrt{\frac{1}{7}\sum_{d=1}^{7}(p_d - p_w)^2}\right)$$

We take the natural logarithm to make the time series stationary and to improve the model fit. Also, all exogenous variables x_t in Eq. (1) are transformed into natural logarithm form (except pgas which is in first difference), and, thus, their coefficients γ can be interpreted as elasticities. This assumption of constant elasticity between the exogenous variables and price volatility is more reasonable than assuming that changes in demand, for example, lead to equal changes in price volatility at different demand levels (Rintamaki et al. 2016).

The table below list all the variables included in the model.

Then we will conduct our analysis first considering the system as a whole and then we will take into account each zone to detect the effect of variable renewable energy on the weekly electricity price volatility.

variable	role	explanation
v_w	Dependent variable	The standard deviation of the daily average prices during week w.
$wind_w$	Exogenous variable	Average volume sold from WIND during week w
pv_w	“	Average volume sold from solar during week w
$hydro_w$	“	Average volume sold from HYDRO during week w
$wind\_pen_w$	“	The share of average volume sold by WIND of the average demand of the week w.
pv_pen_w	“	The share of average volume sold by solar of the average demand of the week w.
$hydro\_pen_w$	“	The share of average volume sold by HYDRO of the average demand of the week w.
$pgas_w$	“	Average gas price during week w

Table 17 Exogenous variables in our models. We take the natural logarithm of all variables with the exception of the price of gas, which is in the first difference.

4.3.2 RES EFFECT ON PUN VOLATILITY:

We confirm the stationarity of the time series by applying the augmented Dickey-Fuller (ADF) test.

variable	ADF test
v_{IT}	-5.452
$wind_{IT}$	-3.74
pv_{IT}	-4.8401
$hydro_{IT}$	-3.85
$wind\_pen_{IT}$	-3.7934
pv_pen_{IT}	-4.0659
$hydro\_pen_{IT}$	-3.80
$\Delta pgas_{IT}$	-5.9555

Table 18 ADF results, all the weekly time series passed the test at the 5% level.

A way to specify the order (p,q)(P, Q)[s] of the model can be observing the autocorrelation (ACF) and partial autocorrelation functions (PACFs) of the dependent variable.

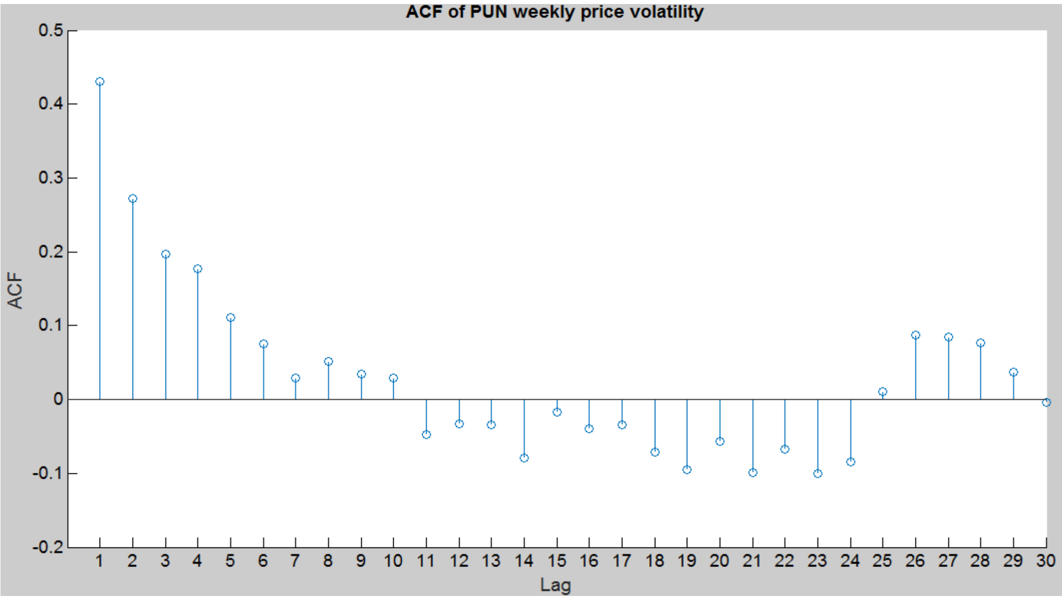

Figure 16 ACF of PUN weekly price volatility. Own elaboration on GME's data.

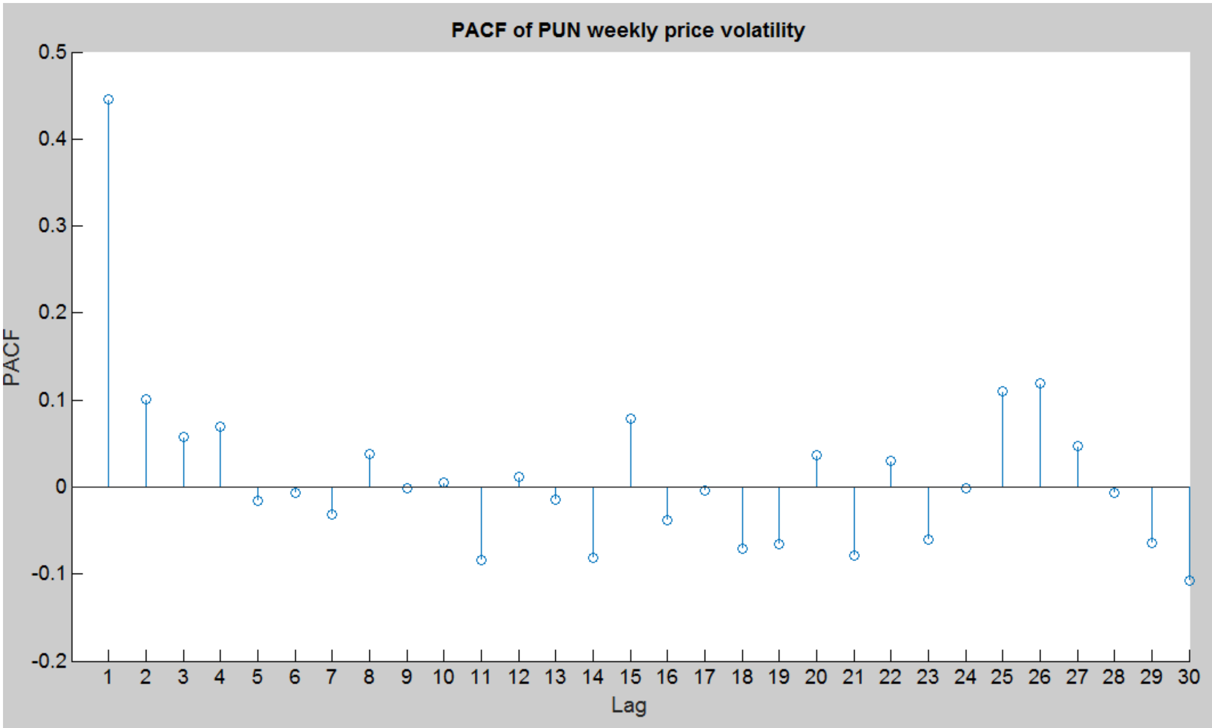

Figure 17 PACF of PUN weekly price volatility. Own elaboration on GME 's data.

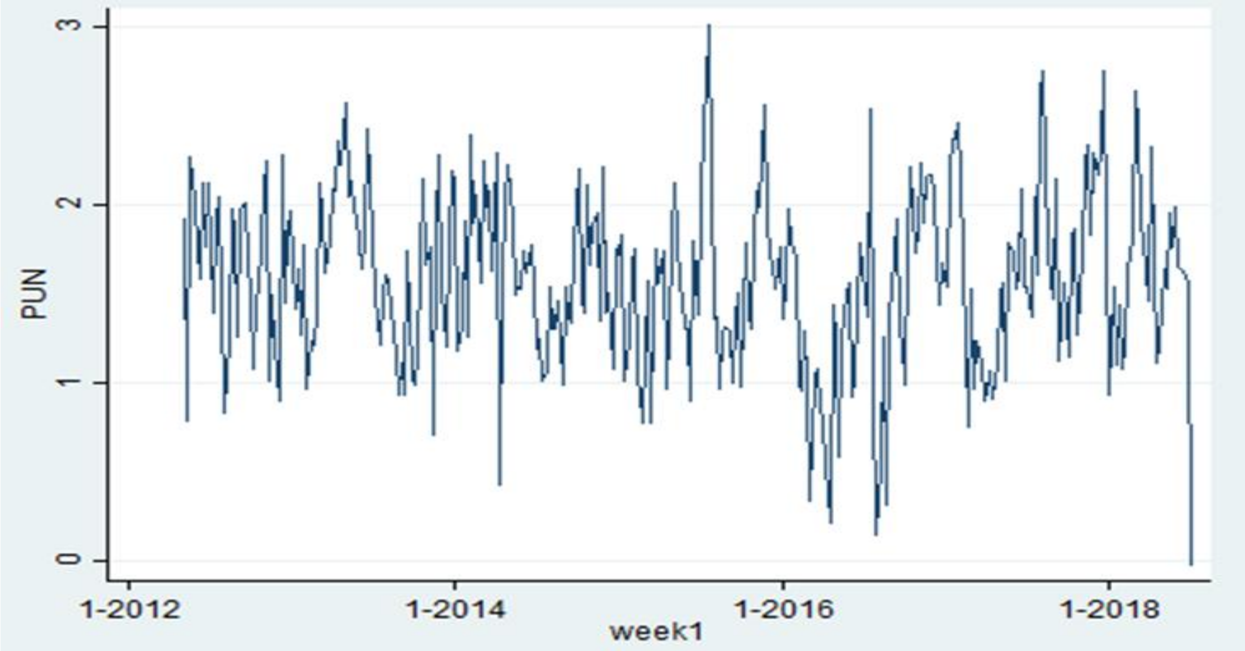

Figure 18 The natural logarithm of the weekly price volatility of PUN. Own elaboration on GME 's data.

The autocorrelation function has a downward trend as older data are less relevant.

In both graphs, we observe high peaks at the first lag and then near multiples of seven indicating a sort of seasonality that coincides with the start, mid and end of each season (especially in the ACF).

We choose the optimal model by stepwise addition of independent variables starting from a simple AR(1) and MA(1) and then try also a seven-week seasonality. In the selection process, we omit all exogenous variables x_t and require all coefficient α, β to be significant at a 5% level. If a variable in a particular model becomes statistically insignificant, then we do not add other variables because they are likely to be insignificant. Also, if the addition of a new variable does not improve the Akaike Information Criteria (AIC) compared with the previous model, then we stop.

To compare the candidates in this process, we evaluate the AIC score, perform the Ljung-Box (L-B) test for the residual autocorrelation, and examine the ACF and the PACF of the residuals of the models.

We report the model iteration:

MODEL	AIC	L-B
SARMA (0,1)(0,0)[7]	406.37	4
SARMA (1,0)(0,0)[7]	389.67	30
SARMA (1,0)(1,1)[7]	388.65	30
SARMA (1,1)(0,0)[7]	387.43	30
SARMA (1,1)(1,1)[7]	386.96	30

Table 19 Statistically significant and AIC-improving iteration steps. We have omitted models that failed to improve the AIC score or have insignificant variables.

We run the following regression to estimate the impact of different explanatory variables on the Italian electricity price volatility. We adopt a SARMA (1,1)(1,1)[7] as suggested by the model iteration in the previous table.

The AR(1) accounts for the short-term price volatility development, the SAR(1) deals with seasonality in the data. Adding MA(1) and SMA(1) provide stochastic parts to the development of the price volatility and improves the fit of the model. Various exogenous variables with the associated parameters are added to the RHS of the equation.

$$v_{IT} = \alpha_0 + \alpha_1 v_{w-1} + \alpha_7 v_{w-7} + \epsilon_w + \beta_1 \epsilon_{w-1} + \beta_7 \epsilon_{w-7} + \gamma^T x_t$$

In models 1 to 7, we specify separately each subset of exogenous variable x_t and the in model 8 we consider the effect of the intermittent renevable energy and HYDRO.

Our main findings from the above equation are that the coefficient for WIND in model 1 is statistically significant at a 5% level according to the Z-test. The interpretation is that increasing the amount of weekly volume of WIND sold on the day ahead spot market by 1% increases the weekly volatility of prices by 0.35%. We see a slightly lower impact on the price volatility when we take into account model 3, which considers the share of WIND in the total volumes sold from the various technologies; here the increase is only of 0.15%. Results from PV are not straightforward because results from model 2 highlight a negative but not significant impact of a unitary percentage increase in the volume sold by this source, but considering PV penetration in the market in model 5, we observe a slightly significant effect (10% level) of 0.25%. Considering hydroelectric in model 3 and 6, we see negative effects on the price volatilities which by the way are not significant. With model 7, we test for the impact of first difference on natural gas price and find a slightly positive impact on the weekly price volatility, although highly non-significant. In fact, weekly changes in the natural gas spot prices are small, and, thus, they are unlikely to affect the short-term volatility of the prices. Finally, combining WIND, PV and HYDRO in model 8 confirm our main finds, i.e. a significant positive effect of WIND on the weekly price volatility and no statistically significant effect of PV and HYDRO on the dependent variable. This means that when the installed capacity of WIND increases, the available supply increases and the parallel shifts are larger, and this contributes to growing weekly volatility. This impact can be amplified by highly clustered power farms. However average weekly solar and hydro power are not found to contribute to the weekly price volatility. In all the models (with some few exceptions) the AIC improves after adding the exogenous variables. We also report the lag at which the Ljung-Box test fails at a 1% significant level.

All models perform well with all lags.

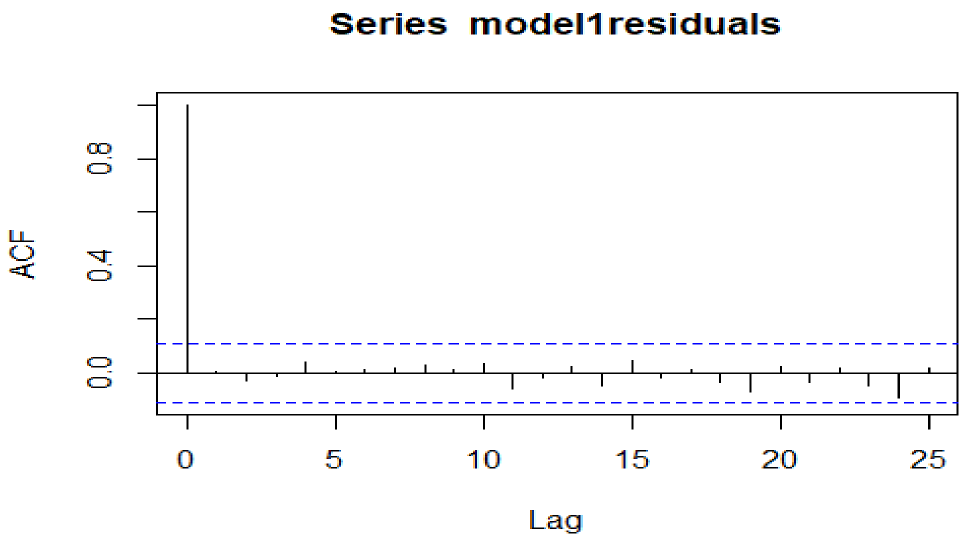

Figure 19 ACF of model 1 residuals.

Following we have the table with the effect of explanatory variables on the Italian price volatility. The coefficients α and β are al significant at least 5% level. All estimates parameters and external variables are robust.

variable	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	model 8
$wind_{IT}$	0.357 ** (0.13)							0.329 * (0.137)
pv_{IT}		-0.506 (0.341)						-0.322 (0.35)
$hydro_{IT}$			-0.224 (0.371)					-0.1821 (0.482)
$wind\_pen_{IT}$				0.142* (0.057)				
pv_pen_{IT}					-0.246 . (0.13)			
$hydro\_pen_{IT}$						-0.168 (0.15)		
$\Delta pgas_{IT}$							0.00021 (0.013)	
α_1	0.664	0.659	0.679	0.661	0.666	0.664	0.666	0.666
α_7	-0.25	-0.277	-0.270	-0.246	-0.288	-0.267	-0.277	-0.254
β_1	0.78	0.938	0.826	0.801	0.940	0.935	0.935	0.793
β_7	-0.855	-0.999	-0.892	-0.872	-0.99	-0.999	-0.999	-0.862
AIC	382.4	386.74	386.6	383.44	385.72	387.88	388.97	385.47
L-B	30	30	30	30	30	30	30	30

Table 20 Estimation results. The coefficients α and β are al significant at least 5% level. All estimates parameters and external variables are robust.

3.3.4 RES EFFECT ON ZONAL PRICE VOLATILITY

Now we go deep in our analysis trying to get the drivers of weekly electricity price volatility in each of the six zones. The external variables we will consider are those of model 8. Similarly, as the previous chapter, we will use the variables related to each zonal market and take the natural logarithm. Figure 3 and table 18 in the appendix show the volatility pattern and some summary statistics.

We will consider each zone specific SARMA model, selecting the optimal equation for the price volatility following the same process implemented previously. The model selection results (AIC score) are presented in the table below.

model	North	C-North	C-South	South	Sicily	Sardinia
SARMA (1,0)(1,0)[7]	403.42	380.45	410.88	434.58	563.23	502.18
SARMA (1,0)(0,1)[7]	402.83	379.49	410.82	434.52	561.14	502.09
SARMA (1,1)(0,0)[7]	400.8	376.67	409.56	423.62	539.16	495.17
SARMA (1,1)(0,1)[7]	400.22	376.13	410.58	424.62	538.01	496.85
SARMA (1,1)(1,1)[7]	394.97	375.57	413.04	424.46	537.60	498.7

Table 21 Statistically significant and AIC-improving iteration steps. We have omitted models that failed to improve the AIC score or have insignificant variables.

For North, C-North, and Sicily we adopted the same SARMA model of the previous step, i.e. a SARMA (1,1)(1,1)[7], while for C-South, South, and Sardinia the AIC score suggests using a SARMA (1,1)(0,0)[7].

1) $v_i = \alpha_0 + \alpha_1 v_{w-1} + \alpha_7 v_{w-7} + \epsilon_w + \beta_1 \epsilon_{w-1} + \beta_7 \epsilon_{w-7} + \gamma^T x_t$

2) $v_i = \alpha_0 + \alpha_1 v_{w-1} + \epsilon_w + \beta_1 \epsilon_{w-1} + \gamma^T x_t$

Results are presented in table 19.

Our main finding is that the coefficient for WIND power is statistically significant in every zone except for North and C-North where we know from the previous section that the production from this source is marginal. Increasing the amount of weekly WIND production by 1% increases the weekly zonal volatility from 0.16-0.85 %. The effects are stronger in South

Italy and Sicily, most likely due to the combination of higher WIND capacity in these areas. These results are in line with the one found at the national level.

PV follows the same pattern seen in analysis on the effect on prices, i.e. we have a merely significant impact in the areas where we have relevant production and installed capacity from this source. In particular, we observe a significant positive impact in the North where we have the greatest concentration of production of solar. A 1% increase in the volume sold in North Italy increases the zonal weekly electricity price of almost 1 percent. We observe a strong positive impact also in the south of the peninsula and this is explained by the high installed capacity from southern regions like Puglia. In general, PV is insignificant in most areas, and this is a result in line with the one obtained at the national level.

Considering HYDRO, we note coefficients statistically insignificant, except for North and Sicily. This is plausible if we consider the high production, plants and installed capacity in these areas. The impact of a 1% increase in the volumes of HYDRO sold in these zonal markets has opposite effects, in North Italy, we observe an increase in price volatility, the opposite in Sicily. For all the other zones we observe non-significant coefficients. This result is in line with the one found in the price impact analysis.

For all areas, with few exceptions, the AIC score improve after adding these external variables. We also report the lags at which the Ljung-Box test fails at a 1% significant level. Models for C-North and C-South have some autocorrelation at low lags but the models of the other zones perform well with all lags.

In conclusion, our analysis suggests that wind power production at the national and zonal level have statistically and economically significant effect on the day ahead weekly price volatility. In the short run, Italian weekly price volatility is higher when there are more volumes sold by this source in the market. This effect finds evidence at all zone (except for North and C–North). In periods with high price volatility, producers and consumers need to optimize their generation and demand allocation to maximize their profits and to minimize their costs, respectively. From the power system point of view, the adoption of more wind power production requires mechanisms to cope with intermittent supply and to decrease balancing costs (Kunz, 2013).

On the consumer side, enhanced understanding of the causes of volatility can be used to design tariffs that incentivize demand response (Dupont et al., 2014), which is likely to mitigate the costs of balancing caused by the intermittency of wind. The rise in VRE generation further enhance for a greater cross-border integration and raises the value of more interconnection with the near European countries. The interconnection can supply more backup power when VRE are unavailable; by connecting areas with uncorrelated wind, they reduce the variability of that source and dampen the volatility of the power prices. Sharing reserves across borders reduces the cost of ensuring reliability.

A subject for further research could be to use different modeling techniques. Following Ketterer (2014), we can estimate the impact of RES power on price volatility using a GARCH model. On the other hand price volatility can be explored as a function of time and RES penetration using the non-parametric regression model of Jónsson et al. (2010). Also, the link between RES generation levels and supply curve elasticities can be established more formally using real supply and demand curve data (see Dillig et al., 2016) or agent-based or complementarity models.

	North	**C-North**	**C-South**	**South**	**Sicily**	**Sardinia**
WIND	-0.046	0.16	0.26 *	0.701 ***	0.859 ***	0.34***
	(0.095)	(0.097)	(0.02)	(0.13)	(0.157)	(0.102)
PV	0.93 *	0.022 **.**	-0.288	0.49 **.**	0.23	-0.07
	(0.418)	(0.29)	(0.29)	(0.26)	(0.346)	(0.431)
HYDRO	0.36*	-0.086	-0.091	-0.2	-0.82 ***	0.09
	(0.217)	(0.264)	(0.283)	(0.25)	(0.21)	(0.208)
$\boldsymbol{\alpha_1}$	0.667	0.69	0.602	0.700	0.758	0.801
$\boldsymbol{\alpha_7}$	-0.22	-0.301			-0.478	
$\boldsymbol{\beta_1}$	0.88	0.505	-0.22	-0.4	0.72	-0.35
$\boldsymbol{\beta_7}$	-0.99	-0.613			-0.659	
AIC	393.5	378.43	409.05	401.87	508.92	489.32
L-B	19	9	9	30	30	30

Table 22 Estimation results. The coefficients α and β are al significant at least 5% level. All estimates parameters and external variables are robust.

CONCLUSIONS

This work tries to contribute to a very relevant line of research in the assessment of the impact of an increase in renewable energy in electricity markets, particularly on the electricity prices and its volatility. I thought it was particularly interesting to perform this study in Italy, where an active system of public support to renewable sources is leading to a considerable expansion of these energy sources and electricity pricing is at the center of intense debate.

To detect the impact electricity prices, I developed a full ex-post empirical analysis for Italy and the country's zonal markets using a multivariate regression. I considered data on the weekly use of technologies and electricity prices from May 2012 to June 2018. As a major finding, my work reports that a marginal increase of 1 GWh of electricity volumes sold in the Italian day ahead-market by RES (in particular the variable renewable energy, VRE) decreases the Italian electricity price of almost 1.9€/MWh. I tried then to understand the impact of the main components of the VRE, wind and solar, on electricity prices reduction and found a negative impact of respectively 1.95€/MWh and 2.08€/MWh. No evidence is found for idroelectric source for electricity price reduction. VRE is proved to caused electricity price reduction also in the zonal markets, where the effects range from a decrease of 0.004 €/MWh in North to 0.031 €/MWh in Sicily. Decomposing VRE, it is interesting to stress how the impacts of wind and PV vary across zone depending on the specific zone installed capacity and production: wind is the main driver of the electricity price reduction in the southern zonal areas while solar has a more significant decreasing impact in the northern zone price. Lastly, I implemented a random effect panel model to get rid of the difficulties involved in interpreting the partial regression coefficients in the framework of a cross-section only or time series only multiple regression. Results of the panel analysis confirmed the negative and significant impact of wind and PV in the zonal prices reduction.

In the second part of my empirical analysis, I focused on the volatility of electricity price trying to understand the effect of the increase of renewables in the market on price volatility. Through a seasonally adjusted autoregressive moving average (SARMA) model I demonstrated how unitary percentage increase in the volumes sold by wind increases the weekly volatility of the Italian electricity price by about 0.30%, I didn't found statistically significant evidence for solar and hydro. Repeating the same methodology taking into consideration the 6 zones, I found that increasing the amount of weekly wind sale by 1% increases the weekly zonal volatility from 0.26-0.85 % in all zones except North and C-North. Solar in contrast with the analysis at a national level reveals to be a driver of electricity price volatility increase in the zones where the production from this source is consistent.

Combining our two results we can conclude that the sources responsible for the MOE, i.e the electricity price reduction are also the main drivers for the increase in electricity price volatility. Given the EU policies, renewable capacity will continue to increase in Italy. Given the recently adopted renewable energy target, 2030 “Framework for climate and energy”, based on the 2020 framework, renewable goals are set at a threshold of at least 27% share of energy consumption. The price impacts I have presented depend on the total amount of production and the variations in it. Hence, the impacts become stronger unless the production mix or market design changes. Lower electricity prices do not encourage new investments in electricity generation. In addition, higher price volatility in longer-term introduces uncertainty which increases risk. As installed capacity increases and technology matures, renewable electricity regulation should be developed and adapted further, towards a more market-oriented structure that remunerates renewable electricity during phases of high electricity prices (Ketterer 2011).

Further extension of my work can entail the use of peak and off-peak prices and quantities. My impossibility to get this kind of data subdivision induced me to conclude that renewable energy and other market fundamentals have a constant impact in time on the electricity price formation process. I was not able to distinguish between different diurnal impacts of VRE, fossil fuel prices and demand, although it is known that the load level shows different patterns within one day, which implies different production design.

With the availability weekly peak and off-peak data I could have derived the following results:

- For renewable energies, starting from the observation of a Duck Chart and the relative net load (normal load minus wind and PV generation) evidence would show how the “belly” of the duck is most pronounced in off-peak hours (night and early morning) for wind and in peak hours (noon) for solar. In this sense, analyzing separately the two sources, I can expect negative signs and expect highly variable price adaption process to wind infeed, particularly for the night hours, and this occurs because of the need to meet low demand during night hours with a low marginal cost of production technology and because of the excess electricity produce versus low demand during these hours. For PV the coefficient magnitude will be higher over noon, given the high sunshine intensity.
- Responses for fossil fuel prices, in particular for gas, is expected to be higher in the noon-peak hours when many fuel plants situated to the right of the merit-order curve are turned on.

Further impacts of VRE on wholesale power prices can be investigated such as temporal (e.g., diurnal or seasonal) and geographic (e.g., between price hubs and individual nodes) patterns of prices, and a greater frequency of low or negative prices.

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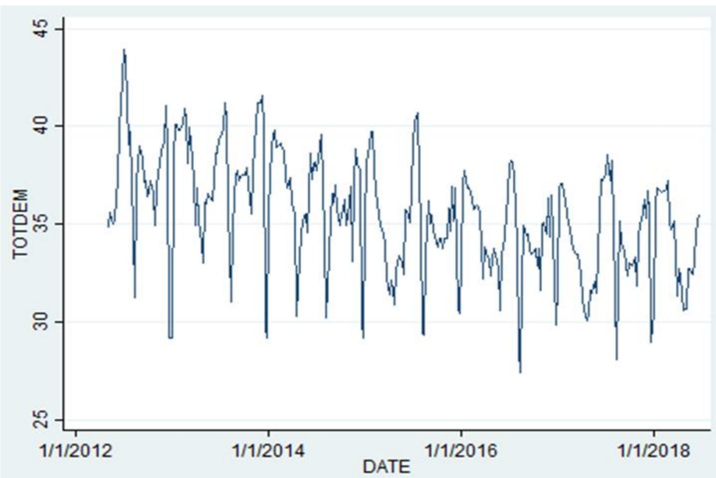
APPENDIX

Technology	Costo capitale/kWh	Costi di O&M/kWh	Costi per il combustibile/kWh	LCOE totale/kWh
Supercritical Coal	$0,029	$0,008	$0,025	$0,062
Advanced Nuclear	$0,047	$0,009	$0,008	$0,065
CCGT	$0,011	$0,004	$0,036	$0,051
OCGT	$0,017	$0,007	$0,044	$0,068
Solar PV (Utility Scale)	$0,306	$0,020	$0,000	$0,326
Solar PV (Commercial)	$0,295	$0,022	$0,000	$0,317
Solar PV (Residential)	$0,589	$0,027	$0,000	$0,616
Solar CSP (without storage)	$0,168	$0,028	$0,000	$0,196
Solar CSP (with storage)	$0,121	$0,025	$0,000	$0,147
Onshore Wind	$0,061	$0,011	$0,000	$0,073
Offshore Wind	$0,123	$0,029	$0,000	$0,152
Geothermal	$0,046	$0,022	$0,000	$0,068
Hydropower	$0,067	$0,015	$0,000	$0,083
Wave	$0,319	$0,090	$0,000	$0,409
Tidal	$0,117	$0,069	$0,000	$0,187
Ocean Thermal	$0,139	$0,081	$0,000	$0,220
Biomass	$0,059	$0,021	$0,000	$0,080

Table A1 Division of components of the real LCOE to 2011 (Carson 2012).

Figure A1 Total demand of the weekly electricty price. Own eleboration on GME's data.



In the years after the substantial fall in demand (-5.9%) occurred in 2009, due to the crisis, there was a two-year period (2010-2011) of partial recovery of volumes, but a new three-year period (2012-2014) took place. The contraction brought electricity demand to levels comparable to those in 2002. A turnaround is registered in 2015, followed by a slight decline the following year, and the final recovery in 2017.

Table A2 ADF Tests.

	ADF-levels	ADF-1st difference
PRICE	-3.94	-8.31
TOTDEM*	-8.76	-10.67
HYDRO	-2.87	-5.93
PV	-4.8097	-4.396
WIND	-7.57	-9.998
PGAS	-1.76	-6.359

Notes: MacKinnon(1996) critical value for rejection of hypothesis of a unit root are -2.57(for 10% confidence level), -2.86 (for 5% confidence level), and -3.43 (for 1% confidence level) for the models with drift only; -3.12(for 10% confidence level), -3.41(for 5% confidence level), -3.96(for 1% confidence level) for models that include also trend. We include a trend in the specification of the model in those cases where it was significant (*).We search for the number of lags to be included in the model such that Rsquare is maximized while minimizing at the same time the Akaike Information Criterion.

Table A3 Results of model 2 using the price of alternative fossil fuels

		Model 2	
Dipendent variable		RES split up $\Delta PRICEt$	
$\Delta TOTDEM_t$	0.97*** (0.22)	0.95*** (0.21)	0.93*** (0.13)
$\Delta HYDRO_t$	-0.81 (0.73)	-0.69 (0.74)	-0.577 (0.727)
ΔPV_t	-1.52. (0.9)	-2.49* (1.03)	-2.61* (1.101)
$\Delta WIND_t$	-1.87*** (0.37)	1.87*** (0.36)	-1.87*** (0.398)
$\Delta PCOAL_t$	0.55*** (0.15)		
ΔOIL_t		0.21. (0.12)	
ΔEUA_t			-1.03 (0.643)
Season dummies	yes	yes	yes
Observations	81	72	320
Adj. R-squared	0.2319	0.2057	0.238
dw	2.08	2.06	2.09

.

Notes: all models include an intercept; standard are in parenthesis are robust to heteroskedasticity and serial correlation (Newey West 1987). dw indicates the results of the Durbin Watson test after correcting for serial correlation in the residuals
*** indicates p-value<0.001, **p-value<0.01, *p-value < 0.05, **.** p-value<0.1

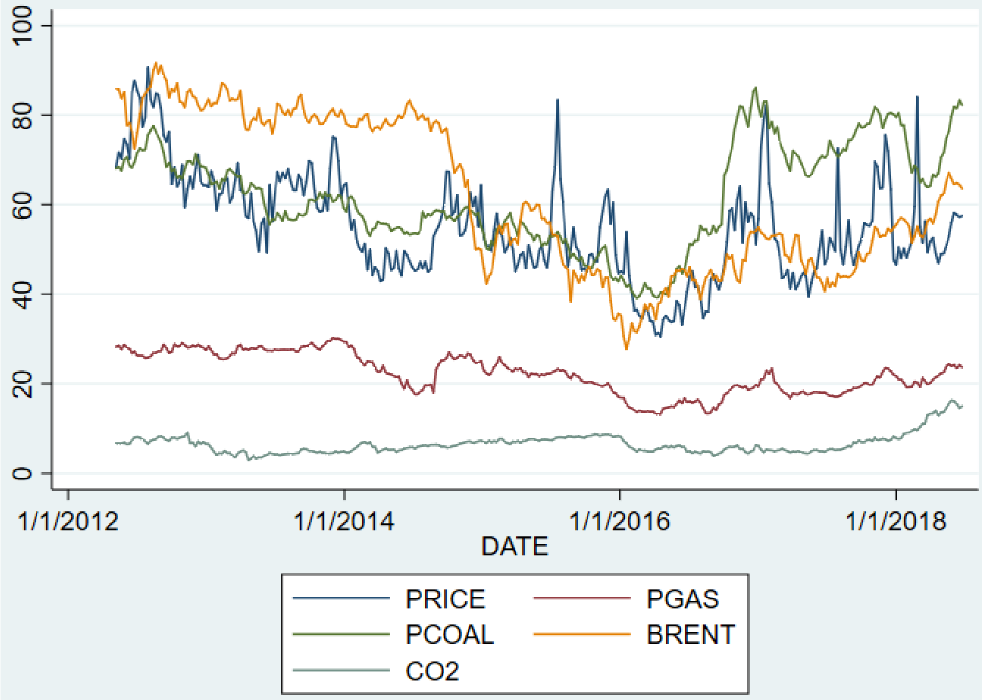


Figure A2 Evolution of fossil fuels prices. Own elaboration on GME and Thomson Reuters's data.

	Δprice	**Δtotdem**	**Δhydro**	**Δpv**	**Δwind**	**Δpricegas**
Δprice	1					
Δtotdem	0.384	1				
Δhydro	-0.043	0.244	1			
Δpv	-0.090	0.070	0.21	1		
Δwind	-0.010	0.056	0.054	-0.15	1	
Δpricegas	0.193	0.04	-0.04	-0.13	-0.04	1

Table A4 Correlation matrix North. Own elaboration on GME and Thomson Reuters's data

	ADF-LEVELS	**ADF-1ST DIFFERENCE**
PRICE*	-4.68	-8.43
TOTDEM	-8.76	-11.07
HYDRO	-3.18	-6.1
PV	-2.28	-4.12
WIND*	-5.43	-8.03
PGAS	-1.76	-6.359

Table A5 ADF results North.

	Δprice	Δtotdem	Δhydro	Δpv	Δwind	Δpricegas
Δprice	1					
Δtotdem	0.323	1				
Δhydro	0.109	0.125	1			
Δpv	0.186	0.0013	0.091	1		
Δwind	-0.091	-0.024	0.061	-0.26	1	
Δpricegas	0.1721	0.0204	0.006	-0.15	0.073	1

Table A6 Correlation matrix C-North. Own elaboration on GME and Thomson Reuters's data.

	ADF-LEVELS	ADF-1ST DIFFERENCE
PRICE	-4.19	-8.07
TOTDEM*	-6.14	-9.00
HYDRO	-4.24	-7.69
PV	-3.1	-5.87
WIND*	-7.22	-8.65
GEOTERM	-4.84	-9.25
PGAS	-1.76	-6.359

Table A7 ADF results C-North.

	Δprice	Δtotdem	Δhydro	Δpv	Δwind	Δpricegas
Δprice	1					
Δtotdem	0.3026	1				
Δhydro	-0.026	-0.035	1			
Δpv	-0.0268	0.0285	0.114	1		
Δwind	-0.3141	-0.004	0.142	0.007	1	
Δpricegas	0.1467	-0.051	0.030	-0.065	-0.038	1

Table A8 Correlation matrix C-South. Own elaboration on GME and Thomson Reuters's data.

	ADF-LEVELS	ADF-1ST DIFFERENCE
PRICE	-3.19	-8.30
TOTDEM	-5.06	-8.031
HYDRO	-2.99	-6.38
PV	-2.78	-5.39
WIND	-8.51	-10.12
PGAS	-1.76	-6.359

Table A9 ADF reults C-South.

	Δprice	Δtotdem	Δhydro	Δpv	Δwind	Δpricegas
Δprice	1					
Δtotdem	0.067	1				
Δhydro	0.029	0.028	1			
Δpv	-0.121	-0.036	0.111	1		
Δwind	-0.428	0.024	0.099	0.068	1	
Δpricegas	0.173	-0.023	-0.008	-0.153	0.044	1

Table A10 Correlation matrix South. Own elaboration on GME and Thomson Reuters's data.

	ADF-LEVELS	ADF-1ST DIFFERENCE
PRICE	-3.78	-7.96
TOTDEM*	-4.84	-8.59
HYDRO	-3.45	-7.94
PV	-3.1	-6.75
WIND	-8.05	-10.38
PGAS	-1.76	-6.359

Table A11 ADF results South.

	Δprice	Δtotdem	Δhydro	Δpv	Δwind	Δpricegas
Δprice	1					
Δtotdem	0.167	1				
Δhydro	-0.029	0.089	1			
Δpv	0.167	0.0689	0.155	1		
Δwind	-0.428	0.0449	0.196	-0.24	1	
Δpricegas	0.066	0.052	-0.105	-0.07	0.075	1

Table A12 Correlation matrix Sicily. Own elaboration on GME and Thomson Reuters's data.

	ADF-LEVELS	ADF-1ST DIFFERENCE
PRICE*	-5.3	-9.60
TOTDEM*	-4.026	-6.72
HYDRO*	-3.16	-7.93
PV	-2.97	-4.9
WIND	-7.02	-8.74
PGAS	-1.76	-6.359

Table A13 ADF results Sicily.

	Δprice	Δtotdem	Δhydro	Δpv	Δwind	Δpricegas
Δprice	1					
Δtotdem	0.153	1				
Δhydro	-0.013	0.037	1			
Δpv	-0.0279	0.015	0.094	1		
Δwind	-0.254	-0.175	-0.027	-0.007	1	
Δpricegas	0.144	-0.0704	0.021	0.057	0.087	1

Table A14 Correlation matrix Sardinia. Own elaboration on GME and Thomson Reuters's data.

	ADF-LEVELS	ADF-1ST DIFFERENCE
PRICE*	-4.86	-8.76
TOTDEM*	-3.97	-9.27
HYDRO*	-4.35	-7.51
PV	-2.96	-4.71
WIND	-8.6	-10.54
PGAS	-1.76	-6.359

Table A15 ADF results.

Table A16 Comparison of fixed effect and random effects outcome.

	fixed	fixdumyear	random	randomdumyear
DEPENDENT VARIABLE: $\Delta PRICEt$				
$\Delta TOTDEM_t$	0.002279***	0.002278***	0.002279***	0.002278***
	(0.0005)	(0.0005)	(0.0005)	(0.0005)
$\Delta HYDRO_t$	-0.009	0.01	-0.097	0.01
	(0.03)	(0.02)	(0.015)	(0.0158)
ΔPV_t	-0.0058.	0.0059 *	-0.0059**	-0.0059**
	(0.0034)	(0.0035)	(0.002)	(0.002)
$\Delta WIND_t$	-0.099.	-0.099.	-0.099**	-0.099**
	(0.059)	(0.058)	(0.045)	(0.045)
$\Delta PGAS_t$	1.044**	1.03***	1.044***	1.03 ***
	(0.35)	(0.35)	(0.35)	(0.34)
Year dummies	yes	yes	yes	yes
Observations	1920	1920	1920	1920
R-squared	0.1118	0.1121	0.1314	0.1328

TEST 1

We test for the significance of including year dummies using stata's testparm

testparm i.YEAR

(1) 2.YEAR = 0

(2) 3.YEAR = 0

(3) 4.YEAR = 0

(4) 5.YEAR = 0

(5) 6.YEAR = 0

(6) 7.YEAR = 0

Constraint 2 dropped

chi2(5) = 417.07

Prob > chi2 =   0.0000

We regect H0 and conclude the the inclusion of year dummies are significant.

TEST 2

In table A17 we present the alternative estimate of fixed and random effects of our equation 2 in order to choose the most suitable method.

Judge, et al. (1988) propose the following simple rules:

1. If T is large and N small, there is little difference in the parameter estimates of FE and RE models. Hence computational convenience prefers FE model.

2. If N is large and T small, the two methods differ. If cross-sectional units in the sample are random drawings from a larger sample, RE model is appropriate; otherwise, FE model.

3. If the individual error component, μ_i, and one or more regressors are correlated, RE estimators are biased and FE estimators unbiased

4. If N is large and T small, and if the assumptions of RE modeling hold, RE estimators are more efficient.

A simple solution is to run a Hausman test to see whether a fixed-effects or random effects model is more appropriate.

Hausman test is a test of

H0: random effects would be consistent and efficient, versus

H1: random effects would be inconsistent.

The test revealed a prob> chi2=0.96 >0.05 so we accept the null hypothesis and conclude that RE is more suitable. The tests imply that the zone effects though present in the data set are not correlated with the explanatory variables, and can very well be taken as random; the RE estimators will be consistent and efficient.

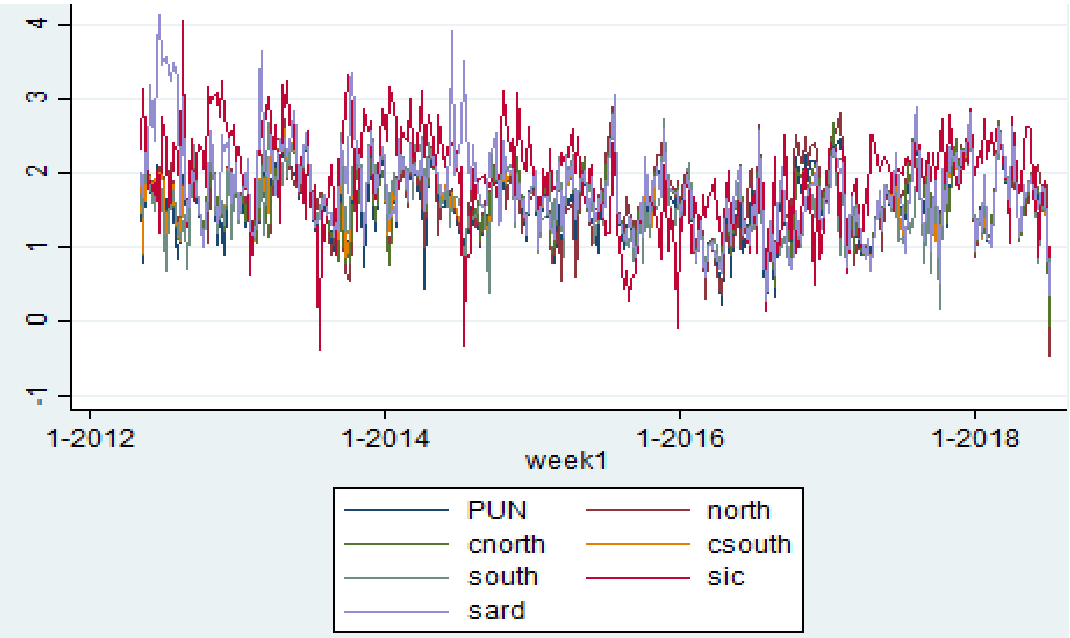


Figure A3 The natural logarithm of the weekly zonal price volatility. Own elaboration on GME and Thomson Reuters's data

	Italy	North	C-North	C-South	South	Sicily	Sardinia
Mean	1.582	1.642	1.634	1.6331	1.595	1.943	1.794
(Sd)	(0.489)	(0.522)	(0.483)	(0.498)	(0.509)	(0.657)	(0.628)
Max	3.014	3.042	3.042	3.050	3.055	4.047	4.14
Min	-0.028	-0.487	-0.090	-0.25	-0.152	-0.394	0.26

Table A17 Descriptive statistics of the weekly zonal price volatility. Own elaboration on GME's data.

As we can see from the table, all zones present, on average, higher weekly price volatilities than the national weekly price volatility. In particular, Sicily and Sardinia exhibit greatest zonal price volatility.