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"The Benefits of the European Electricity Integrated Market: Evidence from Day-Ahead prices in Italy-North bidding zone."

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Firma (signature) ………………………………

Sarai sempre una parte di me

Grazie N.

Abstract

In the process of reshaping the Electricity market as a result of the liberalization impetus, increased importance is given to efficiency and security of supply.
Along with the introduction of Renewable Energy Sources generation technologies, due to the necessary action to preserve the environment, the integration of the European Electricity Market is proceeding.
An analysis of the technical and economic benefits brought by integration is proposed, with a focus on social welfare gains and price dynamics.
The reference area is the Northern Italian zone and the effects of electricity trades with the neighboring counties, France, Switzerland, Austria, Slovenia, and the Central Northern Italian zone.
The Day-Ahead wholesale electricity market is analyzed, in the period 2015-2020, finding empirical evidence of a negative effect of cross-border trades inflows on the prices. The dataset is divided into hourly time slots and examined only those of greatest interest, H4-H13-H19.
Summing up the results, an increase of 1000 MWh of incoming flows leads to a price decrease of 3.27 €/MWh in H4, 2.34 €/MWh in H13, and 3.74 €/MWh in H19, depending on the specific market dynamics.

Contents:

List of Abbreviations:

ACER = Agency for the Cooperation of Energy Regulators

aFRR = Automatic frequency restoration reserves

BRP = Balancing Responsible Parties

BSP = Balancing Service Providers

CACM GL = Capacity Allocation and Congestion Management guideline 2015

CNorth = Central-Northern Italy bidding zone

CRM = Capacity Remuneration Mechanisms

DA = Day-ahead market

DC NC = Network Code on Demand Connection 2016

DER = Distributed Energy Sources

DSO = Distribution System Operators

DSR = Demand-side response

EB GL = Electricity Balancing guideline 2017

EMO = Energy Market Operator

ENTSO-E = European Network of Transmission System Operators for Electricity

EoM = Energy-only market

ER NC = Electricity Emergency and Restoration Network Code 2017

ESC = Electricity Supply Chain

EUPHEMIA = Pan-European Hybrid Electricity Market Integration Algorithm

FBMC = Flow-based market coupling

FCA GL = Forward Capacity Allocation guideline 2016

FCR = Frequency containment reserve

FTR = Financial transmission rights

HVDC = Network Code on Requirements for Grid Connection of High Voltage Direct Current systems and Direct Current Connected power park modules 2016

ICTS = Information and Communication Technologies

ID = Intraday market

IGCC = International Grid Control Cooperation

IN = Imbalanced netting

IPP = Independent Power Producers

ITC = Inter-TSO compensation scheme

JAO = Joint Allocation Office

LCOE = Levelized Cost of Electricity

MARI = Manually Activated Reserves Initiative

MCO = Market Coupling Operator

mFRR = Manual frequency restoration reserves

MS = Member States

NEMO = Nominated Electricity Market Operators

North Italy = Northern Italy bidding zone

NRA = National Regulatory Authorities

NTC = Net transfer capacity

NU = Network user

OTC = Over the Counter

PICASSO = Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation

PPA = Power Purchase Agreements

PTR = Physical transmission rights

RES = Renewable Energies Sources

RfG NC = Network Code on Requirements for Grid Connection of generators 2016

RR = Replacement reserves

SDAC = Single Day-Ahead market coupling initiative

SIDC = Single intraday coupling

SG = Smart grids

SMP = System Marginal Price

SO GL = Electricity Transmission System Operating Guideline 2017

TERRE = Trans-European Replacement Reserves Exchange

TSO = Transmission System Operator

VER = Variable Energy Resources

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Introduction

The evolutionary process of the Electricity Market is facing various challenges that influence its momentum, answering new needs and introducing new technologies.
In particular, the process of liberalization of the different stages of the supply chain, from vertically integrated state monopolies to unbundled entities, has the objective to increase the efficiency of the system, the transparency of the markets, and to boost the technical development.
The discussion remains open on the effectiveness of the new market design in bringing short and long-term benefits, in particular to the more vulnerable consumers, with a focus on efficiency and, in the recent period, on security of supply.

One of the main elements contributing to the reshaping of the sector is the necessary action to preserve the environment, considering that electricity generation has always been a major contributor to pollution due to CO2 and other climate altering emissions production.
The electricity sector faces continuously growing demand and it is necessary to work on energy efficiency by decreasing per capita consumption and decreasing the carbon intensity of electricity production, in order to sustain this growth.
Climate change is winding up as a global challenge, for this reason remedial actions have become increasingly necessary and procrastination is no longer possible.
With the Paris Agreement in 2015, a milestone has been set in recognizing this challenge for the first time at a fully global level.
Based on the agreed global temperature limit threshold, national local remedies appear necessary to reach CO2 reduction targets.
The European Union leads the way globally setting very challenging targets, with a series of intermediate milestones, which set the deadline to achieve carbon neutrality in 2050.

To achieve these goals it is necessary to develop a new paradigm centered on three key principles: Decarbonization, Digitalization, and Decentralization.
The rapid transformation of the technological framework, which has taken place over the last few years, has led to the development of new technologies in the communication, monitoring, and management services, which have led to alterations in the electricity market.

The process of decarbonization of the power sector to counter the advance of climate change has seen an acceleration in the exploitation of renewable energy sources.
The characteristics of these technologies have led to the development of decentralized generation systems, which by interacting with the grid in an innovative way makes it necessary to strengthen the physical infrastructure and adjust the market operations.
A considerable effort still needs to be done to reach the installed renewable capacity to meet the 2050 targets, in addition to the possibility of storing the energy produced with the development of efficient storage systems.

One of the processes that is contributing to facilitate the introduction of renewable energy sources is the European electricity markets integration.
This process has several stages and degrees of development, has started with voluntary initiatives between countries, and has been progressively formalized at the European level.
The trade among different zones has been made possible by the development of the infrastructure connecting networks between states allowing cross-border electricity flows.
The benefits brought by integration are technical and economical, in particular, related to system stability, optimized infrastructure development, pooling of balancing resources, exploitation of complementarities between different systems, facilitating the integration of renewable sources generation, and social welfare gains.
The analysis is focused on the price dynamics brought by the introduction of renewable resources and the interconnection between markets.
Starting from the existing literature, a model is developed to determine the effects of cross-border transits on prices by conducting an empirical analysis, dividing the sample and considering three time frames of interest.
The reference area is the Northern Italian zone and the effects of electricity trades with the neighboring counties, France, Switzerland, Austria, Slovenia and in addition, with the Central Northern Italian zone.
The model takes into consideration several factors such as electricity demand, generation intensity from renewable sources and the influence of commodity prices in the determination of the wholesale price.
The results we have foreseen are in line with the theories of international trade, in particular transits should flow from the least expensive market to the most expensive market, expecting prices of different markets to converge in the absence of physical constraints.

There is still much to be done to build an industry that is able to grow without aggravating the environmental conditions, a first step in the right direction is the integration of the markets at European level.

The elaborate proceeds with an introductory chapter describing the liberalization process with a detailed description of the supply chain and the different market phases.
In the second chapter there are the changes brought by the introduction of renewable generation technologies pointing out benefits and limitations.
The third chapter describes the evolution of the European electricity market with a description of benefits, barriers, welfare effects, and price dynamics.
Finally, the fourth chapter focuses on the methodology overview, the model specification, and a description of the results obtained.

Chapter 1: “Introduction to the Electricity Markets”

1.1 Introduction

During the process of creation of a European Single Market, many industries were already engaged in transnational exchanges and the regulatory apparatus was being formed.
One of the primary causal forces of market integration was the increasing levels of cross-border transactions and communications by societal actors that have not left the energy sector untouched.
The electrical system is subject to specific physical requirements for proper and safe operation and is constrained by very high initial investment costs. These characteristics have made it develop as a natural monopoly in which the ***Electricity Supply Chain*** (ESC) was vertically integrated and the control was of the state authority.
The achievement of maturity, technical development, and political will in the sector have allowed an evolution from a state-owned regulated monopoly configuration, over the years, toward an unbundled regulated utility.
The political-economic environment of the different countries has determined the extent and speed to which this reform reshaped the market.
The drivers pushing the development have been various at the EU level and have involved different interest groups. (Joskow 2008)

The European directive n. 92 of 19 December 1996, opened up the electricity market to competition with the intent to enhance the efficiency of the ESC and highlight the importance of environmental protection. (Nylander 2001)
The Directive establishes common rules for generation, transmission, and distribution of electricity. It determines the rules concerning the organization of the electricity sector, market access, and procedures applicable to the system operations.
The objectives were the achievement of a competitive market in electricity through the prohibition of exclusive schemes for production activities, import and export of electricity, and the construction and access to transmission networks. (European Parliament and Council 1996)
The liberalization was permitted by technological advancement aiming to boost competition and energy efficiency for the benefit of lower prices, but many technical challenges still had to be addressed and solved. (Erdogdu 2014)

1.2 Electricity supply chain

The principal actors in the ESC following the classical *“Top-down approach“* can be divided into four vertical areas, Figure 1. (Cretì and Fontini 2019)

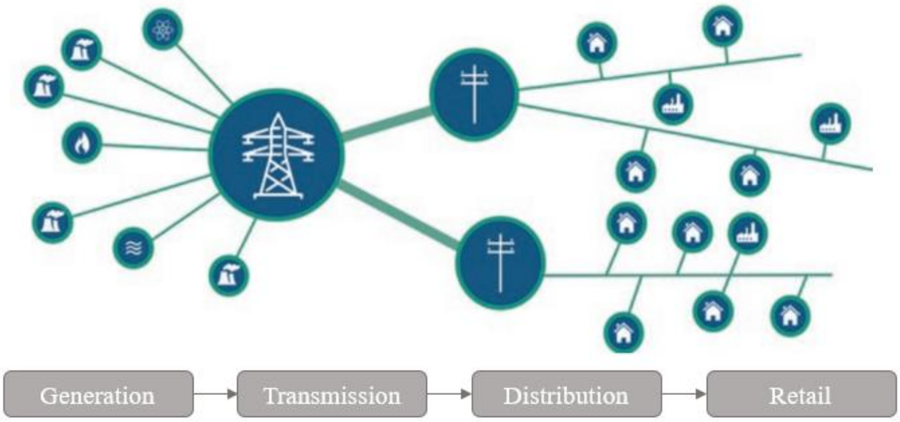
Generation: The production of electrical energy takes place in production facilities which are divided into various categories according to the methods used. It is possible to identify two macro-areas, the use of fossil fuels or the production of electricity from renewable sources.
An additional feature to evaluate production facilities is the amount of time in which they become operational or can vary electricity production to follow demand. The rigidity of this characteristic forces the electricity market to rely primarily on a forecasting mechanism and set a strategy to respond to demand in the medium and long term.

Transmission: High Voltage network. After being generated, electrical energy passes from the production plants to the grid. This step is managed by the system operator, which in the European framework is called ***“Transmission System Operator”*** (TSO).
Whose task is to transport the electrical energy in a safe way, avoiding variations in frequency and voltage that would lead to imbalances in the network.

Distribution: Low-Medium Voltage Network. From the grid, the electricity must be distributed to end-users by system operators, called ***“Distribution System Operators”*** (DSO), responsible for the quality of the distribution of electricity to end-users.

Retail: Is the last phase of the process where the electricity is sold by retailing businesses to the industrial or household consumers, technically called ***loads***.

Figure 1: The Electricity supply chain



Source: Barbiero, Blasi, and Schwidtal 2021

Other actors can be identified working in parallel at different levels of the ESC with the tasks of monitoring and taking the responsibility for the correct functioning of the electricity delivery. In particular, is important to mention the ***"Balancing Responsible Parties"*** (BRP) and ***"Balancing Service Providers"*** (BSP), which functions can be incorporated or kept separated from the other components of the ESC.

The key components of the regulatory reform were defined by different elements. First of all, the privatization of state-owned electricity monopolies had the objective to create hard budget constraints and incentives for performance improvements.
Vertically separating the components for which it was possible to compete in the market (generation, retail) from the segments that had to be kept regulated for the specificity of the business involved (distribution, transmission).
This mechanism made it possible to put in place the necessary measures against possible cross-subsidization effects between competitive and regulated businesses. (Nylander 2001)

Along with the vertical separation, came a horizontal restructuring in the generation segment to increase the competition and lower the market power of the bigger actors.
Was promoted the creation of wholesale markets for energy trading and market institutions were set up, aimed at defining the parameters and regulations for the exchange of products and services between the various market players.
Were instituted independent regulatory agencies with the ability to monitor and intervene with the authority to enforce regulatory requirements, in particular regarding the security of the systems and the tariff structure of the regulated entities. (Joskow 2008)

The market reform is a long-lasting process rather than an event, the results can determine different market design structures, characterized by different degrees of integration of the different phases of the supply chain. (IEA 2005)

1.3 Types of models configuration

In the ***"Vertically Integrated Industry Model"***, a single entity takes responsibility for all the activities from production to retailing, managing the grid, and the distribution.
There is the possibility that one company act as a single monopolist or more than one, connected to a single entity through contracts and agreement. The result is a monopoly with all the benefits and limitations of this kind of market form, in particular meeting the demand and the definition of a fair tariff.

In the ***"Single Buyer Model"***, the generation activity is separated from the others, some or all the power plants are owned and managed by several entities called *"Independent Power Producers"* (IPPs). The Single Buyer is responsible for all the other activities and acts as a monopsonist with respect to the IPPs.
A market is created in which the monetary exchange flows in opposite direction to the electricity, the contractual agreement established between the actors are called *"Power Purchase Agreements"* (PPAs). This model represents a first step into the liberalization process.

In the ***"Wholesale Market Model"***, the Single Buyer is split into different entities, one that operates the grid from one or more that bundle the activity of distribution, metering[1], and retailing.
The dispatching services[2], transmission and system services, and distribution services are remunerated by the load, but are kept distinct from the payment of the power itself.
The exchanges determined by demand and supply of electricity are brought as market asks and bids in the ***Wholesale Power Market***, structured in the form of pool or power exchange.
Both are organized in centralized marketplaces with an independent third party called "*Energy Market Operator"* (EMO) that supervises the settlements. Transactions can also be conducted *Over-the-Counter* (OTC) as Bilateral contracts between producers and buyers.

[1] Metering: is the activity of measuring the consumption of electricity.
[2] Dispatching: is defined as the scheduling of which plants will produce and how much they will produce to meet the demand provided by the estimates and asks.

The schedule of dispatching that results from the different kinds of agreements has to be communicated to the dispatcher that will organize the call-in production of the necessary power plants.

In the ***"Wholesale and Retail Markets Model"***, all the tasks performed by the different agents of the ESC are unbundled and attributed to different entities, in particular, the distribution and retailing are separated. Multiple retailing companies can enter the market creating a competitive environment.
This liberalized model can have different nuances in its composition and system operations, at the European level, countries can adopt differences with respect to the effective degree of competition that suppliers have in the retail markets. (Cretì and Fontini 2019)

1.4 Electricity Power Markets

To properly understand the peculiarity and the development of the Electricity Markets is necessary to accounts for the physical constraints of the product considered.
Electricity can be produced, stored, and transported in different ways, but it must always respect some physical principles of frequency and voltage, summarized in Kirchhoff's laws, which explain how the system must always be balanced.
This means that the effective power injected into the system must always be equal to the resistance given by the loads considering the losses. If there is a change in the system, any imbalances that could alter the frequency or voltage must be compensated, to avoid possible damage to the equipment connected to it. (Cretì and Fontini 2019)

Electricity moves at a speed close to the speed of light, this means that once produced it is consumed almost instantaneously. From an economic point of view, this means that it is impossible to carry out negotiations for the supply of electricity in real-time.
The exchange of electricity products can happen in two major forms OTC and through ***Power Exchange Platforms***.
In the first case, these contractual arrangements are called PPAs and allow the direct contractualization of electricity supply between the producer and the consumer for a long period of time, usually between ten to twenty years, at a fixed price. This type of contract is hedged against price volatility and can be an incentive for investments given the certainty of the return. (Harada and Coussi 2020)

In the power markets all the services necessary to deliver electricity in a safe and secure manner are exchanged, these markets take place in different time spans before the actual delivery.
The majority of trades are conducted before the physical delivery and therefore are based on estimates and forecasts of consumption and generation. It can happen that the demand and the scheduled production do not meet for various reasons, such as deviation from forecasts or the inability of a plant to produce the agreed quota.
In this case, operators have to enter the market and adjust their position with power products whose range is getting closer and closer to the actual delivery. (Meeus 2020)

It is possible to divide the electricity market into different phases distinguished by the type of services offered and by the time in which the negotiations and the supply of the service take place, Figure 2. (Cretì and Fontini 2019)

Capacity market: is the market where the long-term capacity to produce or reduce energy consumption is traded according to the ***"Capacity Remuneration Mechanisms[3]"*** (CRMs). It is a market in which the negotiations take place a long time before the actual supplies because it must take into account the time needed to develop and build the necessary infrastructure.

Day-ahead market (DA): is the market where the main negotiations take place for the supply of energy for the following day, which is based on forecasts and estimates.

Intraday market (ID): opens as soon as the DA closes, to allow its participants to adjust their position in the event that they are unable to fulfill their agreed obligations. It is divided into various time slots, closer and closer to delivery time.
During this phase of the market, trading takes place according to what is determined by the ***"Settlement agreement[4]"***.

Ancillary services market: is the market in which the ***ancillary services[5]*** are exchanged, namely the services for guaranteeing power delivery in a safe and secure manner.
There are different types of grid support services: ***balancing services***, ***reserves***, ***voltage control services***, and ***restoration services***.

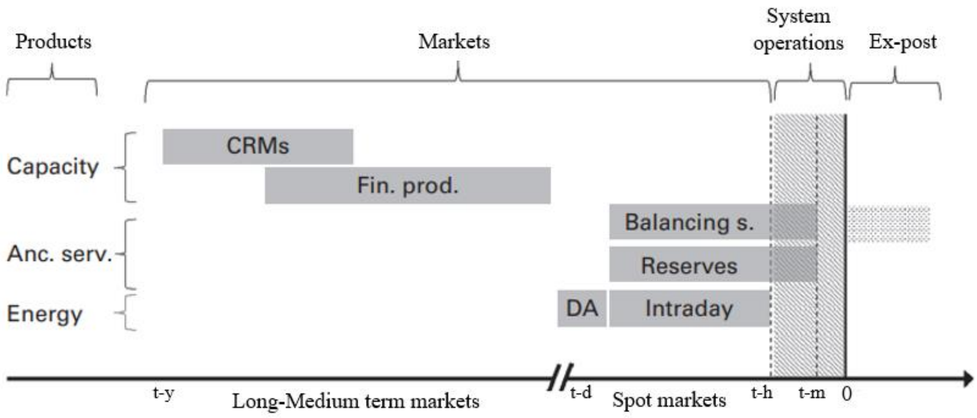
[3] Capacity Remuneration Mechanism: mechanisms that allow the remuneration of physical capacity.
[4] Settlement agreement: defined as the process whereby electricity producers who fail to produce the agreed quota, reimburse the cost of the missed production not at the price agreed upon during the DA, but at the new and increased market price given by the intraday market.
[5] Ancillary Services: are the services and products for guaranteeing a safe power delivery and a system stability

The ***balancing services*** are all those processes that allow the maintenance of the frequency within the system in a certain predefined interval. Can be provided by small production facilities, which are able to abruptly counteract the small variations, and by additional systems and control mechanisms that allow keeping the system balanced.

We define ***reserves*** as those systems that can provide electricity for a period of time in the event that there are fluctuations in the generated power that could threaten the stability of the grid.
Reserves are divided into various categories based on how quickly they can respond to these fluctuations. Called primary, secondary and tertiary reserves depending on the deployment timespan.
The market for these services is also ex-ante, in fact, contracts can be agreed upon for more or less long periods.

Voltage control and ***system restoration services*** are those technical auxiliary services that permit the correct functioning of the transmission network provided by capacitors and inductors.

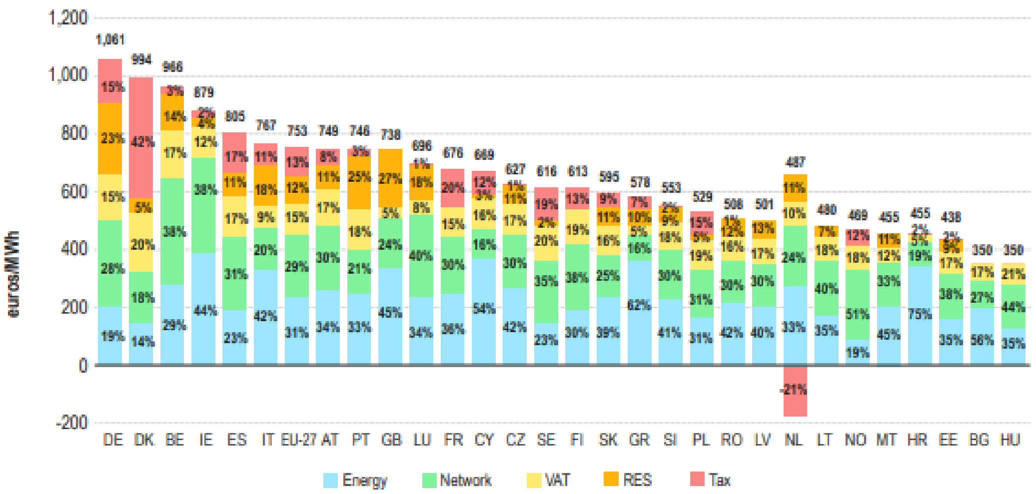
Figure 2: Power Markets temporal dimension



Source: Cretì and Fontini 2019

The tariff paid by the final consumer through the retailing contract has to consider also all the services and costs related to the transmission and secure delivery of the electricity in addition to the price at the wholesale market.
In particular, as shown in Figure 3, every economic system can have a different percentage allocation of costs, but the main items remain almost the same: wholesale or energy costs, network costs, environmental and social obligation costs, value added tax, and other taxes. (ACER 2021a)

Figure 3: Bill breakdown for Household consumers in European Countries, 2020



Source: ACER 2021

1.5 Electricity Economics

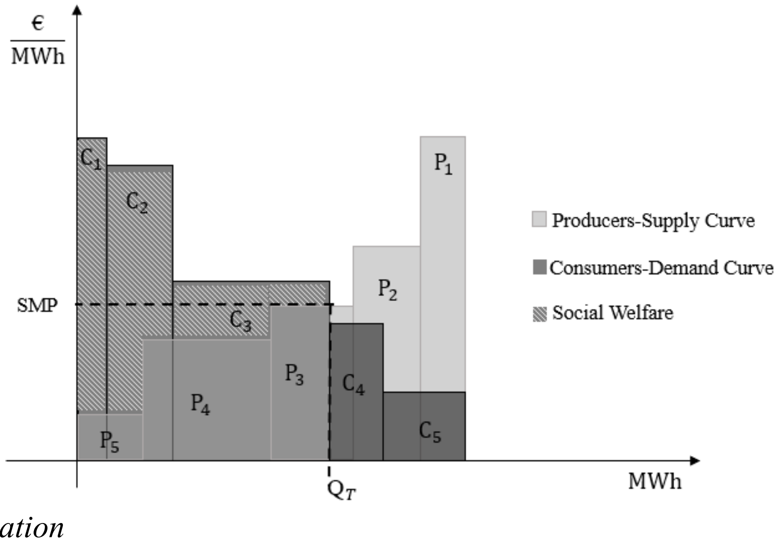
The demand for electricity has a complex trend defined by environmental dynamics and the propensity to consume by the consumers, resulting in different time patterns divided in daily, weekly, seasonal, and annual time frames.
Different levels of consumption can be seen in this framework, in particular, the minimum level of electricity that is always consumed is called ***baseload*** while the maximum level of electricity that is consumed for very short time periods is the ***peak load***. (Cretì and Fontini 2019)

The cost function defined in serving the load has a fixed and a variable component, the first refers to the cost incurred to install the capacity, the latter to all the costs incurred to the electricity produced.

From the ***total cost curve***, it is possible to define two average cost concepts expressed in terms of money per energy: ***Average Energy costs***[6] and ***Average Capacity Costs***[7].
In this market, the quantity and the ***System Marginal Price***[8] (SMP) is determined by the intersection of the supply and demand curves, defined by the aggregation of marginal utility of consumers from the highest to the lowest and by the marginal costs of the producer from the lowest to the highest. The intersection point defines the ***System Marginal Cost***[9] and the ***Value of Lost Load***[10].

When production plants have different production costs, the efficient solution of the cost minimization problem is to put the plants in order according to their increasing marginal cost, exploiting only those that allow to satisfy the demand and have the lowest marginal costs as determined by the ***"Merit Order Dispatching***[11]***"***, represented in Figure 4, determining different ***Capacity Factors***[12] for the power plants. (Cretì and Fontini 2019)
All plants with marginal cost below the SMC will exploit the full production capacity, plants whose marginal cost is equal to the SMC will produce at a capacity factor below one. Lastly, plants with marginal costs that are higher than the SMC will not be considered for production. Loads that differ on the basis of the willingness to pay across customers follow the same principles.

Figure 4: Merit Order Dispatching



Source: Own elaboration

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[6] Average Energy Cost (AEC): the cost per unit of energy produced or producible.
[7] Average Capacity Cost (ACC): the cost per unit of capacity installed or to be installed.
[8] System Marginal Price: the equilibrium price of the electricity market.
[9] System Marginal Cost (SMC): the cost for the electricity system of serving one unit more of the load.
[10] Value of Lost Load (VOLL): the value for the load, of having one marginal unit more of capacity installed in the electricity system.
[11] Merit Order Dispatching: the dispatching of power ordered from the least variable cost power plant to those with higher variable costs.
[12] Capacity Factors: the fraction of time over a total amount of time in which there is a given amount of load or generation.

The economic analysis has to focus also on power transmission and its coordination with electricity markets, given the physical constraints to which it is subjected, assessing how electricity and network services should be priced.

In this sense is necessary to highlight the role of the ***nodes***[13] which can be taken as reference points in the identification of different methods for calculating the price of electricity in the event of ***congestions***[14] due to the limited capacity of the transmission lines. Congestion can occur to internal or cross-border transmissions, but more frequently on cross-border lines. When there is no congestion the equilibrium price is equal to the marginal cost.

The flow of electrons within the transmission network does not follow the contractual dynamics, but the physical laws. For this reason, the flow of electricity does not necessarily coincide with the commercial flow of imported/exported electricity. Two kinds of flows can be considered, ***transit flows***[15] and ***loop flows***[16]. (Meeus 2020)

A cluster of nodes defines a ***bidding zone***, within which the electricity will have the same price and the transmission lines are not subject to congestion.

There are two main methods to define the market equilibrium price, the ***zonal price method***, and the ***nodal price method***, both have different strengths and weaknesses and their use is not unique. (Borowski 2020)

In the event that congestion occurs between two nodes, the market is split into two different zones that will have different prices called "***Locational Marginal prices***". Given that the electricity will be exchanged at different prices, the difference gives rise to so-called "***Congestion rent***", which according to the regulation will be taken over by the TSOs as part of the remuneration, to be spent on infrastructure investments to solve the congestion.

1.6 Italian market

The process of liberalization in the Italian Electricity Sector began with the d.lgs n. 79 of 16 March 1999 or "Bersani Decree" implementing the Community Directive 96/92 / EC.

The generation and retail were open to competition, while the transmission ownership and management were placed under the responsibility of TERNA Spa.

[13] Node: a point of a circuit where two or more elements of the circuit meet.
[14] Congestion: Reaching of the capacity technical limit on the transmission line.
[15] Transit flows: the physical flows due to the commercial relationships between one zone to another zone, on the basis of the contract path of electricity delivery.
[16] Loop flows: unwanted physical flows due to internal energy transfers in a given pricing zone.

The distribution activity was placed under a concession scheme and managed by different regional actors.
The Italian Power Exchange (IPEX) was established on 1 April 2004 and fully operational since January 2005, operated by the Electricity Market Operator (GME).
The Electricity Market consists of the Spot Electricity Market (MPE) and the Forward Electricity Market (MTE).
The Spot Electricity market is divided in Day-Ahead Market (MGP), Intra-Day Market (MI), Daily Products Market (MPEG) and Ancillary Services Market (MSD). (GME 2009)

The Italian Electrical system in 2020 is divided into six zones, as illustrated in Figure 5, North, CNorth, CSouth, South, Sicily, and Sardinia. With a further development programmed for the separation of the South zone into two distinguished zones. (Pototschnig 2020)

Figure 5: Italian bidding zones

Source: Own elaboration

Chapter 2: “Renewable Energy Sources Integration”

2.1 Introduction

The increase in the electricity demand is expected to continue due to the growing population and the increase in per capita consumption supported, in particular, by developing countries. (International Renewable Energy Agency 2021)
Great efforts have been made to increase energy efficiency and decrease the intensity of energy consumed, but this has not sufficiently compensated for the increase in demand. (IEA 2014b)

The choices of the individual countries determine how the demand is going to be met, although there is a common trend in the growing deployment of renewable production technologies.
This choice is partially explained by the increased attention to the sustainability and climate implication of energy production and also by political concerns regarding the dependence on few large fossil fuel suppliers. (International Renewable Energy Agency 2021)

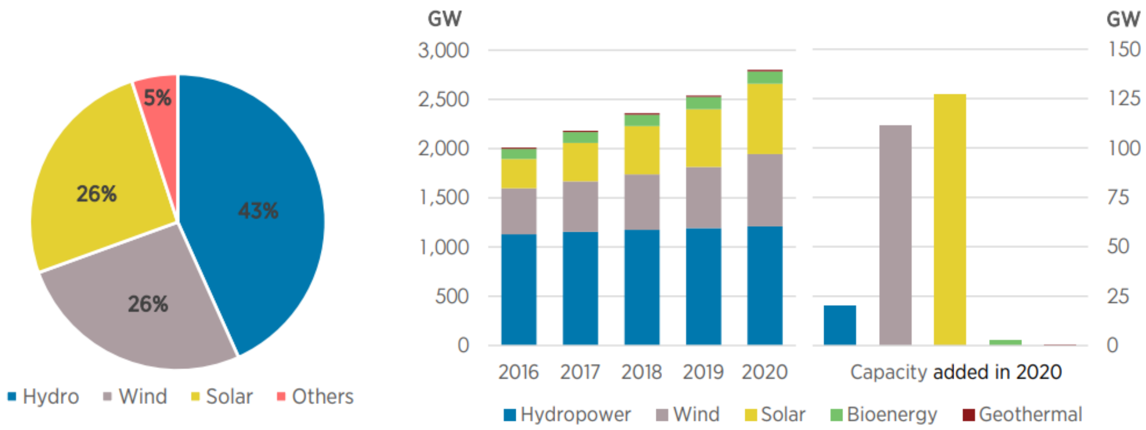
The strategy to decrease the level of pollution and mitigate the effects of climate change vert on three pillars: Efficiency, Electrification, and Exploitation of Renewable Energies Sources. (European Commission 2018)
In particular, the power sector accounts for one-third of the global pollution emission and needs to change radically to fulfill the new climate policy implementations. (Reichmuth, Schär, and Roth 2018)

This momentum has boosted the development of high performance technologies to exploit the ***Renewable Energies Sources*** (RES), up to the point that many of these technologies are now competitive with the power plants that exploit fossil fuels. (International Renewable Energy Agency 2020)
The integration of an increasing share of these production technologies represents a challenge to the power system that needs to adapt to address the characteristics of these resources and overcome the problems related to production and balancing. (Morales et al. 2014)
It is responsibility of the legislator and the competent authorities to mark the path and facilitate the development of a market that is able to explore the full potential of these technologies and to guide the investments of the different actors that are involved in the process.

2.2 Renewable Energy Sources

The global renewable generation capacity at the end of 2020 amounted to 2 799 GW. The most important source is hydropower followed by wind and solar energy which account for equal shares. Other renewables include bioenergy, geothermal and marine energy, with lower shares. The trend of growth in RES generation capacity is increasing, in 2020 the new capacity installed was 261 GW, +10.3% compared to 2019, as described in Figures 6 and 7. Solar energy continued to lead the capacity expansion followed by wind energy, these technologies account for 91% of all net renewable additions in 2020. (International Renewable Energy Agency 2021)

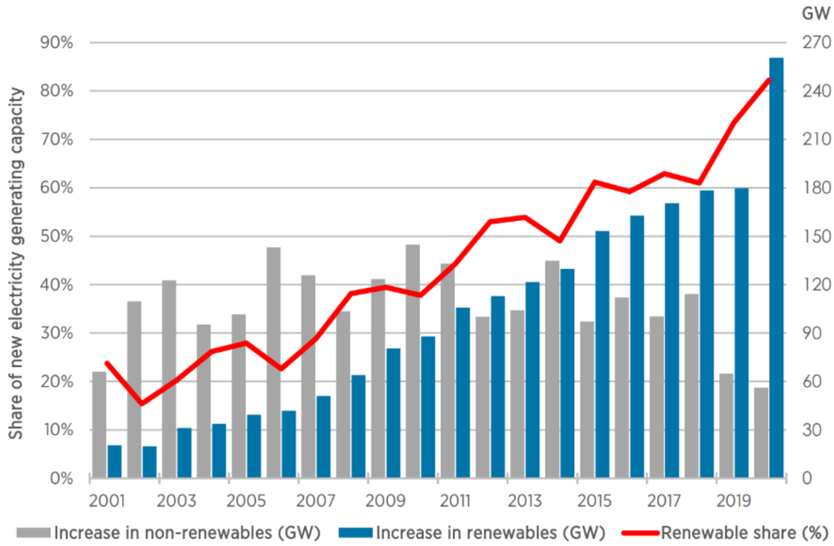
Figure 6-7: Renewable generation capacity installed and added by 2020



Source: International Renewable Energy Agency, 2021

The total share of RES generation capacity increased from 34,6% in 2019 to 36,6% in 2020. The higher growth in renewable generation is followed alongside by the diminishing new installation of non-renewable generation capacity, in particular, the new renewable generation reached 82% in 2020 compared to 73% in 2019 in the total capacity expansion, Figure 8. However, the changes are not homogeneous, while in Europe and North America the net decommissioning of non-renewable power plants is continuing, in the rest of the world the non-renewable capacity is still in expansion. To fulfill the objectives of the energy transition, the use of renewables needs to expand more than the growth in the demand, so less non-renewable energy need to be used. (International Renewable Energy Agency 2021)

Figure 8: Renewable share of annual power capacity expansion



Source: International Renewable Energy Agency, 2021

RES are characterized by different factors, but in common they have large fixed costs and low or zero variable costs. To measure and compare the competitiveness of different types of plants is possible to use the ***Levelized cost of Electricity***[17] (LCOE).

The LCOE represents the cost for MWh produced obtained as the sum of the investments and operating costs of a power plant over an assumed financial life and duty cycle.

In particular, using the LCOE is possible to compare the RES generation units with the fossil fueled plants whose costs depend highly on the cost of the commodities. (Sijm, 2014)

Another concept related to the competitiveness of the different production technologies that derive from the LCOE is called ***grid parity***[18].

In particular, this occurs to RES power plants when can generate electricity at an LCOE that is lower or equal to the price of acquiring power from the grid.

The technology becomes economically efficient once reaches the grid parity and the RES power plants become competitive when the LCOE is lower or at least equal to the conventional power plants. (Cretì and Fontini 2019)

Figure 9 shows how the technological progress and the economies of scale have permitted a decrease in the LCOE for the majority of the renewable power generation technologies, in particular, the solar photovoltaic and concentrating solar power plants have faced a tremendous decrease in the last 10 years.

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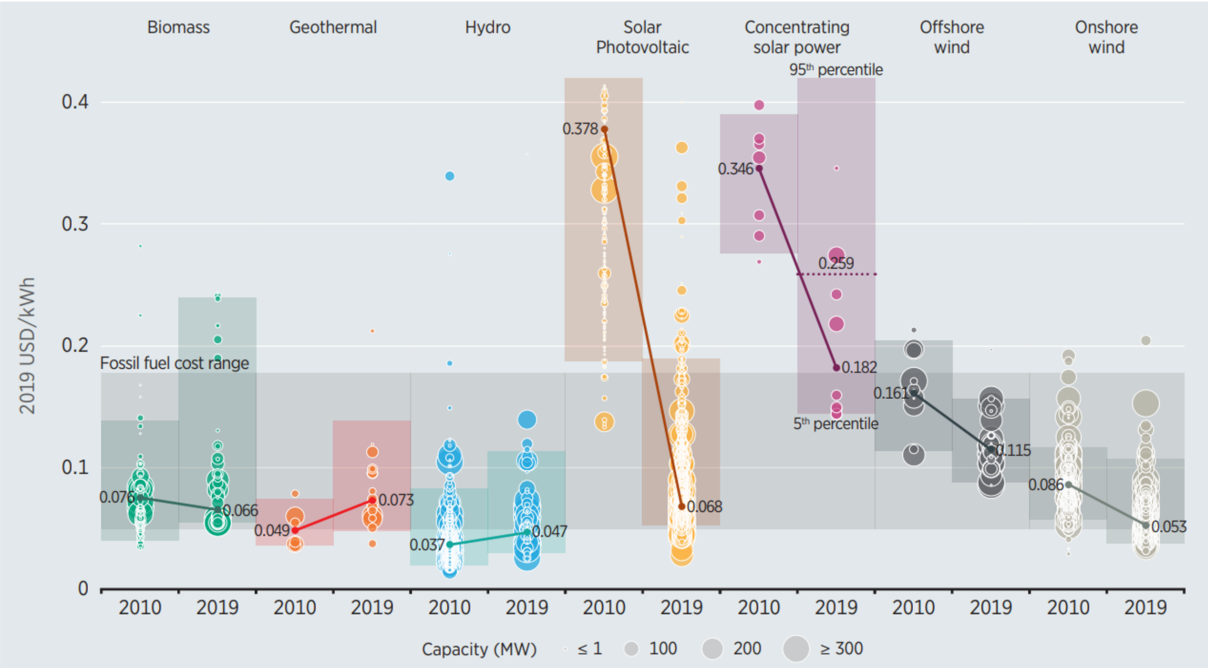
[17]LCOE: the present value of the total cost of building and operating a generating plant over an assumed financial lifetime and duty cycle, converted to equal annual payments, in real terms.

[18] Grid parity: occurs when a power plant can generate power at an LCOE that is less than or equal to the price of acquiring power from the grid.

While the hydropower plants are already below the fossil-fuel cost range, represented by the range of LCOE of the conventional power plants that are affected heavily by the prices of the commodities, other technologies like biomass, solar photovoltaic, and onshore wind are about to drop below the lower limit. When this point is reached it means that the deployment of these new technologies does not depend anymore on subsidies and becomes economically efficient. (International Renewable Energy Agency 2020)

Figure 9: Global LCOEs from newly commissioned utility-scale renewable power generation technologies, 2010-2019



Source: International Renewable Energy Agency, 2020

2.3 Variable Energy Resources

The growing exploitation of RES has significant advantages, first of all the almost zero environmental impact in the production of electricity, on the other hand, the integration of these sources of production presents significant challenges due to the unpredictable nature thereof. (Morales et al. 2014)

In particular, wind and sun are classified as ***Variable Energy Resources***[19] (VER).

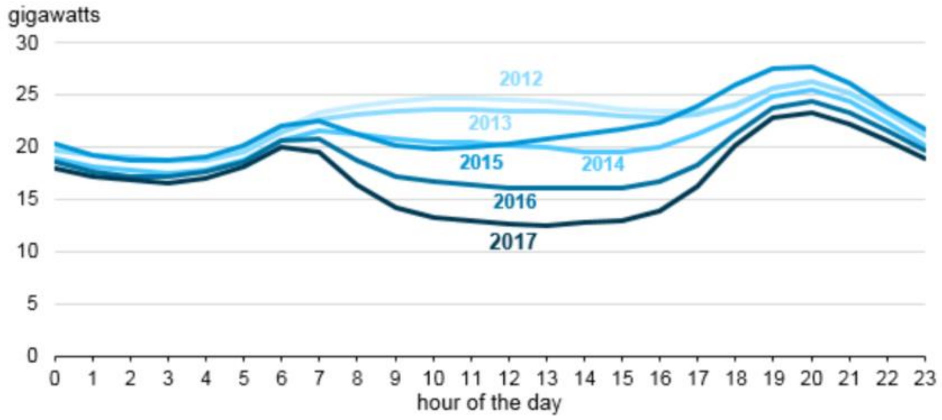
[19] VER: energy resources whose output is variable, uncertain, location specific, modular and with low short-run costs.

The ***variability*** depends on the fact that the power output can fluctuate depending on the intensity and availability of the energy sources, based on the weather conditions affecting wind speed and solar radiation.
The energy produced from VER cannot be dispatched by system operators based on the traditional economic criteria. One of the main differences with the conventional power plants is that cannot be turned on and off to supply electricity and other system services according to real-time power demand and other system needs. (Joskow 2011)
The ***uncertainty*** derives from the difficulties and estimation errors encountered to make precise weather forecasting. This causes the output of VER plants to be less predictable with respect to other power plants. However even if not predictable solar irradiation and wind speed fluctuation exhibit daily and seasonal cyclical patterns.
VER are ***location-specific***, meaning that are not evenly distributed geographically and unlike conventional fuels cannot be transported. This can affect the average annual production, siting decision, and transmission needs.
The ***modularity*** characteristic derives from the technology used to exploit the VER whose production unit is much smaller than the majority of the conventional plants. This feature can have an impact on the structure and operation of the transmission and distribution. (IEA 2014b)

To avoid confusion is important to point out that even if some RES comply with some of the mentioned properties not all of them can be considered VER, for example, hydropower cannot be considered a VER because the exploitation of the resource can be programmed.
The main difference with the fossil fuel power plants is the low short-run costs. After the initial investment, the marginal costs to produce electricity are close to zero. This property has a strong impact on the electricity market in particular on the merit order dispatching. (Cretì and Fontini 2019)

The combination of these characteristics, the increase in the exploitation and the penetration of VER production plants in the electricity sector have different consequences.
The first effect is the reshaping of the net load curve, which is the overall consumption net of VER. More VER resources are added to the production mix more the net load will decrease in determined moments of the day, in particular during the first hours of the day caused by higher wind speed and the middays for the higher solar irradiation intensity. This phenomenon is called “Duck Curve”, Figure 10. (Cabral, Booth, and Peterson 2017)

Figure 10: Impact of the VER increasing rate integration, in the Californian net load, period 2012-2017



Source: Cabral et al. 2017

Another effect caused by the integration of VER in the power system is the generation of additional costs, defined by the literature as the ***"VER integration costs"***. (Hirth 2013)
These costs have been defined using different methodologies and are divided into ***balancing***, ***grid related*** and ***adequacy*** costs. The magnitude depends on the absolute share of VER power generation and on the speed of growth in the system.

Balancing costs arise due to an increase in the amounts and frequency of changes in the net load and the increased incidence of the risk of forecasting errors. To address these problems there is the necessity for higher reserve requirements and higher flexibility availability, for instance, from the non-VER generators, through *ramping up or down*[20], *cycling*[21] and less cost-effective operations.
VER plants integration has grid-related impacts and costs, in particular, to extend and reinforce the network infrastructure and assure the transmission and distribution needs. This effect hinges on the location of the power plants, depending on the availability of the VER that can be far from where the electricity is consumed. (Sijm 2014)

Adequacy is the ability of the system to meet electricity demand at all times taking into account the fluctuations in supply and demand. The impacts and related costs arise because the increasing production from VER reduces the deployment of conventional power plants.

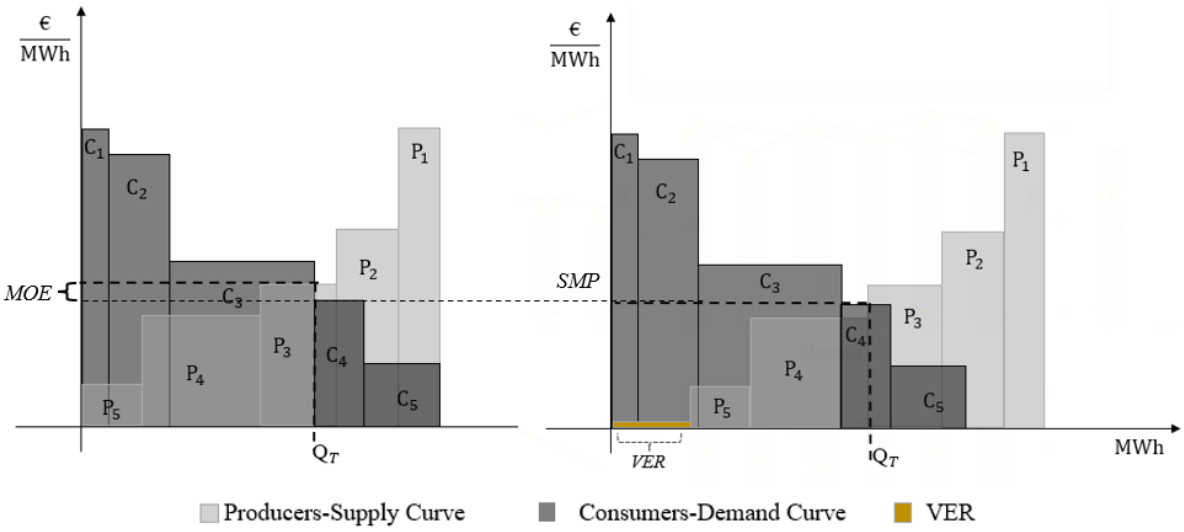
[20] Ramp up/down: increase or decrease the level of electricity produced.
[21] Cycling: changing the power output of conventional units.

The reduction of the deployment of traditional power generation does not coincide with the reduction in demand for ancillary services, since VER plants cannot contribute to maintain the system adequacy[22] to the same extent providing balancing services.
These costs tend to decline over time due to the adaptation and transformation of the power system, increased flexibility, reshaping and strengthening the grid infrastructure. (Agostini et al., 2020)

2.4 Merit order effect of renewables

In addition to the mentioned effect on the system costs, the VER integration has important impacts on the wholesale and balancing markets.
Starting from the concept of merit order, VER generation, when deployed, is prioritized in the merit order dispatching due to the marginal cost close to zero. This effect is called ***"Merit order effect of renewables"*** (MOE), represented in Figure 11. (Morales et al. 2014)
The addition of renewable energy offers located on the very left side of the supply curve will move the curve to the right lowering the SMP and cutting off the more expensive generators.

Figure11: Merit order effect of renewables



Source: Own elaboration

The magnitude of the VER impact on the SMP is not unique and depends on different factors such as the penetration rate, the slope of the merit-order curve and the type of VER technology, in particular, higher for solar with respect to wind, depending on higher fluctuations during the day.

[22] System Adequacy: the power system's ability to meet demand in the long term.

A larger geographical size of the price market can help to smooth the fluctuation, alleviating transmission constraints and reducing the effects of the VER integration. Moreover, improving the flexibility of the power system can absorb fluctuations, smoothing the effect on prices.
In addition, the production of electricity from VER can be subsidized by policymakers enlarging the merit order effect of renewables at the expense of conventional power plants. (Hirth 2012; IEA 2014b; Sijm 2014)

The integration of VER in the wholesale market will have a negative effect on the SMP, resulting in a lower day ahead price determination in comparison to the case when the VER are not considered.
Moreover, the increase in solar and wind generation impacts the price variance, increasing the variability. (Hirth 2013; Morales et al. 2014; Sijm 2014)
Many studies have tried to measure these effects using different methodologies and estimation techniques, the overall findings are that the effect is highly related to penetration rate and also depends strongly on local specificities such as grid structure and capacity, plant characteristics and costs, the existence and amount of interconnection and the load profile. (Clò, Cataldi, and Zoppoli 2015)

In addition to the average wholesale price, increasing RES shares also change the price structure. In particular, both conventional and renewable capacities contribute to the increase in the number of low and negative price hours.
Conventional power plants, especially base load units, are often inflexible. Their ramping is constrained by minimal-load requirements, for example operational requirements for nuclear reactors or the necessity to provide heat for combined-heat power plants.
This means that they must provide electricity to the market even during the lower price periods to be ready to operate in the hours when the price is higher, when the VER are not present, to make a profit and to repay the initial investment.
This effect can create a distortion in which the conventional power plants that will operate in the periods of time when VER generation is not present, can exert some market power and raise the prices even more due to the scarcity of production. (Antweiler and Muesgens 2021; Bigerna and Bollino 2016)

Different characteristics need to be considered to evaluate the influence of the VER in the balancing markets, for example, upward or downward balancing and the volumes of the imbalance. Balancing needs may be motivated by different reasons, for instance, errors in the

load forecast, outages in transmission lines and conventional generators, or due to errors in the forecasting VER availability.
The complexity of the balancing and intraday markets does not allow to completely disentangle the effect of VER introduction. (Gianfreda, Ravazzolo, and Rossini 2020)

The two main issues that need to be solved to facilitate the integration of VER are related to the need for flexibility and for the development of a new market structure to remunerate the investments.
Higher penetration of the VER will further depress the prices, in the short term, making it more difficult to recover the investments needed to maintain the system adequacy in the so-called ***"missing money problem***[23]***"*** or in this specific case ***"renewable energy policy paradox"***. (Blazquez et al. 2018)

From a theoretical perspective, the markets that rely just on electricity markets to provide generation adequacy[24] are called ***"energy-only markets"*** (EoM). In particular, the participants are remunerated for the electricity they produce, but not for their generation capacity, and is the remuneration of the power produced that in equilibrium pays all costs, including those to recover the investments.

In this market, all accepted bids are remunerated at a marginal price that fails to include the fixed part of the costs and considering that VER power plants are more capital intensive but have lower variable costs, higher share of VER generation tends to provide insufficient market signals to the actors.

To solve this issue, have been developed market designs in which generation capacity is explicitly remunerated, with ***Capacity Remuneration Mechanisms***.
According to European regulations, a capacity mechanism can only be introduced on a temporal basis if market or regulatory failures can be identified after an adequacy assessment and if the market cannot be expected to self-correct. (European Commission 2016)
Depending on the specificity of the problem to be solved (long-term investment, temporary market failures, concerns of local nature, or insufficient empowerment of the consumers) different capacity mechanisms can be adopted. (Meeus and Nouicer 2020)

[23] Missing money problem: Super-marginal profits do not cover investment fixed costs.
[24] Generation adequacy: Subset of system adequacy, referring to the ability of generation capacity to meet demand.

2.5 Distributed Energy Sources

The technological progress is aiming at mitigating the impacts and costs of the RES integration on the system and the markets, some solutions are already present and others are in development.

Firstly, the introduction of ***smart grids***[25] (SG) that allow monitoring and control of the grid's transmission system in real-time, ease the efficiency and optimization of the systems (Cretì and Fontini 2019)

SGs make use of new technological and communication components referred to as ***Information and Communication Technologies***[26] (ICTS) allowing to control the functionality of the network in real-time providing dynamic analysis and the ability to manage a bi-directional flow of energy and communications. These new systems can intervene autonomously to solve problems arising in the generation, transmission, distribution, and retail phases. (Farhangi 2010)

The development of ***Distributed Energy Sources***[27] (DER) and smart grids has allowed the end-users to become active players in the value chain, through decentralized energy production and ancillary services offering, reducing the dependence on existing sources, improving resource efficiency, increasing energy system resilience, and giving individuals and communities a stronger role in the decarbonization targets. (EPRS 2020)

The developed ESC is represented in Figure 12. These changes in the paradigm make it emerge the role of the ***prosumer***[28] allowing a more interactive relationship for the end-users with the market and the other actors. (EPRS 2016)

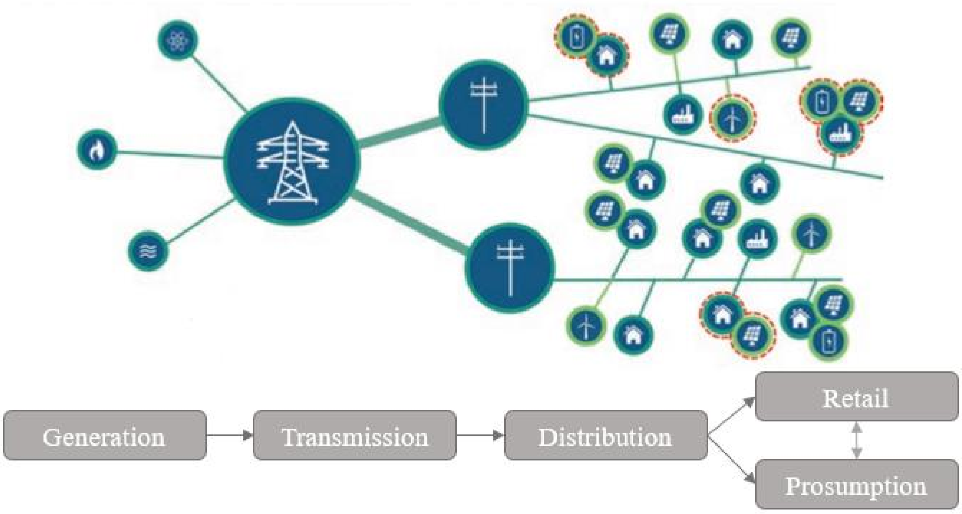
[25] Smart grid: a modern electricity network that monitors, protects and optimizes the operation of its interconnected elements.

[26] Information and Communication Technologies: electronic sensors, computer systems connected by rapid communication systems and microprocessors.

[27] Distributed energy resources: small technologies that produce, store and manage energy.

[28] Prosumer: energy consumers who also produce energy.

Figure 12: Electricity Supply Chain, DER introduction



Source: Barbiero, Blasi, and Schwidtal 2021

The principal solution to overcome the flexibility and ancillary services needs of the VER generation is represented by the storage. Different technologies are able to provide this service, for example, hydro storage, batteries, and power to X[29] systems. If the first technology is already economically efficient but has some capacity constraints due to the specific morphological needs, the last two technologies face still some limitations due to high costs. (Blanco and Faaij 2018)

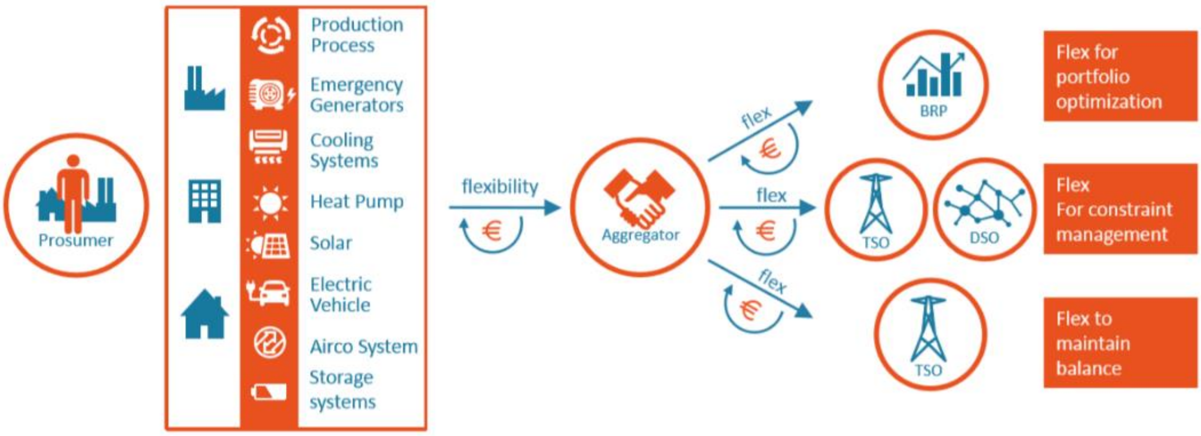
Other solutions that are currently being developed at the consumer level are represented by the ***energy communities***[30] and the ***aggregators***[31]. These legal entities have the purpose to aggregate small and medium consumers, producers, and prosumers with different production patterns and consumption needs to optimize the supply and demand equilibrium, reducing the impact of the VER variability.
In particular, enhancing self-consumption, the optimization of production and consumption of energy and ancillary services within the entity selling to the market those in excess. (Burger, Chaves-Ávila, Batlle, & Pérez-Arriaga, 2016; Interreg Europe, 2018).

[29] Power to X systems: technology that exploit the electrolysis of water to produce Hydrogen and store is or combine it with carbon to synthesize Natural gas.
[30] Energy community: a legal entity that is based on an open and voluntary membership, is autonomous, and is effectively controlled by the shareholders, or members, who are located in the vicinity of the renewable production facilities that are controlled and owned by this legal entity.
[31] Aggregators: legal entities that aggregate the consumption or generation of different units of consumption and production and have as their objective the optimization of the supply and consumption of electrical energy, both technically and economically.

The aggregator brings together a multitude of distinct subjects that have low contractual power and a scarce ability to generate value singularly, succeeding in supplying a series of services that the individual would not be able to propose, both to subjects that are part of the aggregation as well as to other players in the electricity market. (Verhaegen and Dierckxsens 2016)

It is in this framework that the concepts of ***demand-side response***[32] (DSR) and ***flexibility***[33] gain importance. The DSR is based on the possibility to offer electricity and ancillary services to the market thanks to the flexibility that the consumer is able to provide.
DSR provides an opportunity for consumers to reduce or adjust electricity usage depending on the opportunity cost of consumption, their willingness to pay for time-varying electricity prices and being remunerated by the market for flexibility and curtailment, as shown in Figure 13.
There are different kinds of flexibility: ***implicit demand-side flexibility***, which consists of the consumer's reaction to price signals, and ***explicit demand-side flexibility*** which is contracted ex-ante and dispatchable by the ***network users*** (NU).
DSR has a great impact on VER integration into the system as one of the solutions to overcome the problems related to the intermittency of these sources. (ACER 2021a)

Figure 13: Flexibility Supply Chain



Source: van der Veen et al. 2018

[32] Demand response: means the change of electricity load by final consumers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments, or in response to the acceptance of the final consumer's bid to sell demand reduction or increase at a price in an organized market, whether alone or through aggregation.
[33] Flexibility: the ability of a prosumer to vary demand and production thanks to flexible loads, controllable generation capacity and the possibility of storing energy.

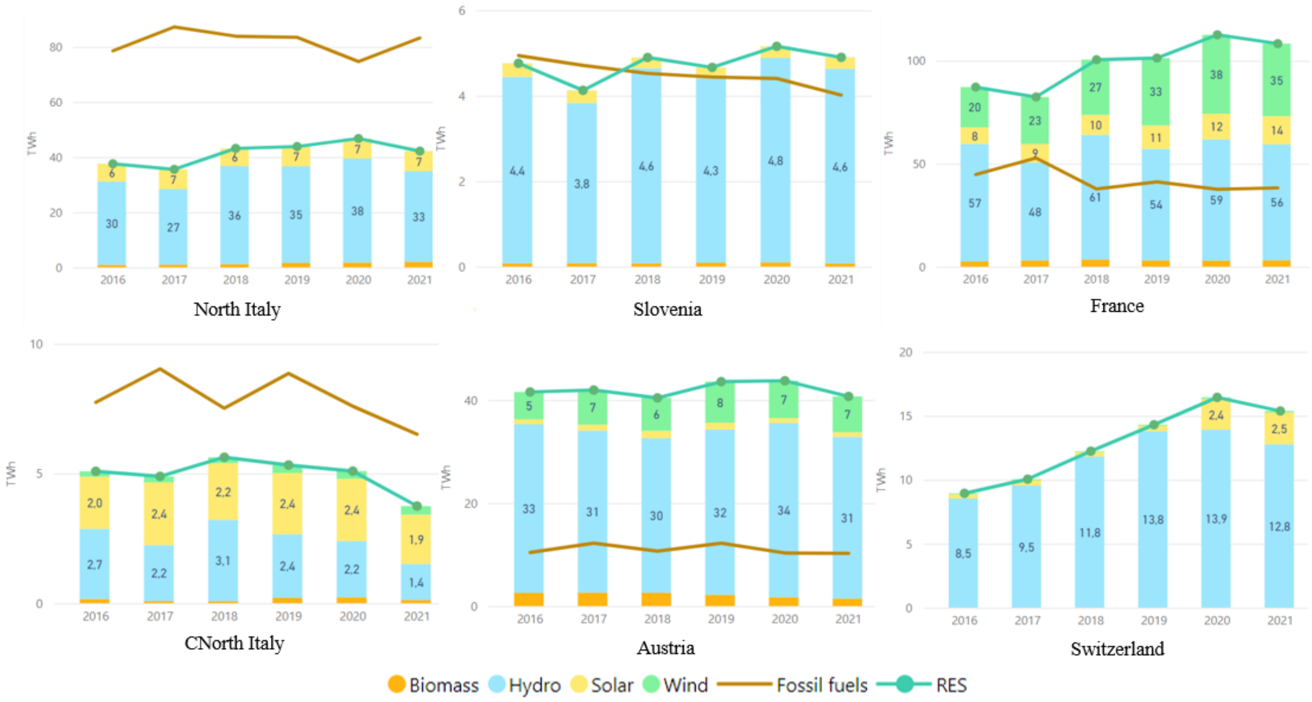
In the future, new ways to exchange electricity and flexibility could be used thanks to the development of the ***blockchain technology***[34] that allows peer-to-peer trades.
A blockchain permits the direct and local trade between prosumers and consumers removing the need for an intermediary because the exchanges databases can be kept and verified in a distributed form, by all the market actors, facilitating and optimizing real-time exchanges between prosumers. (Reichmuth et al. 2018)

The development of Hydrolysers[35] and the possibility to convert the electricity produced from VER into Hydrogen, blended with natural gas, converted, or stored, has opened the path to new flexibility management.
The necessity to increase renewable penetration by increasing flexibility or deploying decarbonized fuels has made re-emerged the concept of ***sector coupling.*** The energy system is considered from an integrated perspective and the optimization of demand, consumption and storage is carried out taking into account the energy sector as a whole. (Brear et al. 2020)

In the complexity of the electricity system, it is important not to forget that national borders can be overcome thanks to the implementation of infrastructures for the connection, transportation, and exchange of electricity.
The development of the Single European market has led to the integration of the electricity system at the European level.
Different projects have been put in place and many others are in development to reach ambitious targets of decarbonization, efficiency and security of supply, representing a challenge from an engineering, economic but also political perspective.
A market integration would allow to optimize different generation-mix and consumption curves combining a series of benefits starting from the increased resilience towards the integration of VER into the system.

[34] Blockchain technology: is a decentralized ledger of all transactions across a peer-to-peer network.
[35] Hydrolysers: equipment that permits the Hydrolysis of water into Hydrogen and Oxygen.

Figure 14: Evolution of generation from RES per type in selected countries, compared to fossil fuels generation (TWh), 2016-2021



Source: ENTSO-E Transparency Platform

Chapter 3: "European Integrated Market"

3.1 Introduction

The process of integration of the European electricity market has developed significantly as a result of the implementation of the regulatory framework following three main steps.
Initially, with the Treaty of Rome of 1957, the creation of a common market eliminated the trade barriers. Followed by the Single European Act and by the adoption of the Energy Policy Objectives for the European Community by the Council in 1986.
However, the process of electricity market integration has been implemented slowly due to the centralized structure of the state-owned companies, the limited infrastructures, and the insufficient regulations that allowed cross-border trade. (Meeus 2020)

In the following years, a series of legislative proposals called EU legislative Energy Packages have been developed to impart profound changes to the national energy sector.
The first three packages (First Package 1996, Second Package 2003, Third Package 2009) included a directive and regulations to manage the electricity and gas sectors. The fourth package, called "The Clean Energy Package" presented in 2019, was different from the previous ones because did not address the gas sector directly and pushed forward the development and deployment of renewable energy sources.

3.2 The evolution of the European Electricity Market

The First Package and Directive 96/92/EC (First Directive) started the liberalization process by separating the regulated part of the sector, the network, from the competitive parts, generation and supply. Member States (MS) had the possibility to make some changes that resulted in differences in the level of market openness. Moreover, The First Directive did not reach the level of liberalization expected.
The Second Package mandates to the Member States the creation of the ***National Regulatory Authorities*** (NRA) independent bodies to the electricity industry.
The Third Package increased the independence of NRAs from national governments and required TSOs to create the ***European Network of Transmission System Operators for Electricity*** (ENTSO-E) organization and to cooperate through this new institution at European

level. In addition, it mandates the creation of the ***Agency for the Cooperation of Energy Regulators*** (ACER). (Meeus, Purchala, and Belmans 2005)
The last part was the draft of the EU ***Network Codes*** and ***Guidelines*** in a process involving the European institutions, ENTSO-E, ACER, and many stakeholders from the electricity sector consisting of eight legislative acts entering into force between 2015 and 2017.

The network codes and guidelines can be divided into three groups depending on the subject of interest.
There are the ***Market codes***, in particular, the ***Capacity Allocation and Congestion Management guideline*** 2015 (CACM GL), the ***Forward Capacity Allocation guideline*** 2016 (FCA GL), and the ***Electricity Balancing guideline*** 2017 (EB GL).
The ***Connection network codes*** consist of the ***Network Code on Requirements for Grid Connection of generators*** 2016 (RfG NC), the ***Network Code on Demand Connection*** 2016 (DC NC), the ***Network Code on Requirements for Grid Connection of High Voltage Direct Current systems and Direct Current Connected power park modules*** 2016 (HVDC NC).
Finally, the ***Operating codes*** are broken down into the ***Electricity Transmission System Operating Guideline*** 2017 (SO GL), and the ***Electricity Emergency and Restoration Network Code*** 2017 (ER NC).
These documents are referred to as "***the grid codes***", four of the eight are guidelines (CACM GL, FCA GL, EB GL, and SO GL) and the other four are network codes (ER NC, RfG NC, DC NC, and HVDC NC).
Network codes and guidelines may cover the same topics, however, it is observed that some topics are more suited to guidelines than network codes and some vice versa.

The Clean Energy Package adoption resulted in changes for both existing and future generations of EU network codes and guidelines. The development process has seen a shift in roles and responsibilities. The strong role of ENTSO-E in drafting the network codes has been reduced increasing ACER's role in the development phase. Mandates the creation of an EU DSO entity to involve DSOs in the process of drafting new network codes and guidelines. (Meeus 2020)

The legislative effort to increase cooperation between MS is justified by many technical and economic benefits that the integrated market is able to provide. (ACER 2022)
In particular, the rapid and increasing deployment of VRE requires greater integration of national networks at the European level to overcome the difficulties that these production technologies pose to the system.

If other primary fuels have the benefit of being easily stored and transported, to exploit the power from solar and wind there needs to be a physical wire connection or ***interconnector***[36], that are the infrastructural backbone of cross-border trades in the electricity systems.
Transmission lines are the more economically viable way to transport power and to avoid interruptions or blackouts transmission planning needs to be taken into consideration.
The N-1 redundancy principle states that the system should always have some capacity reserve to prevent a full collapse if one of the pieces fails.
The optimal solution of the least-cost solution is not solved by the only use of interconnectors, but to ensure the system adequacy is possible to rely on a mix of solutions combining capacity generation, demand response, storage, and new transmission and distribution infrastructures. (Meeus 2020)

3.3 Historical privileges in cross border transmission

To be able to trade across borders is necessary to get the capacity rights that historically were granted to state-owned vertically integrated utilities.
With the adoption of The First Directive 96/92, newly created TSOs were required to provide non-discriminatory access to their network to different NUs.
However, the historical privileges of the utilities, consisting of long-term contracts of transmission rights with neighboring utilities, were still in force.
This led to a landmark court case[37] which resulted in the removal of transmission right privileges, but still, it was possible for MS to request a transitional exemption.
Different methodologies were put into practice to allocate transmission rights in a non-discriminatory manner: priority lists, pro-rata, explicit auctions, and market splitting. (Meeus 2020)

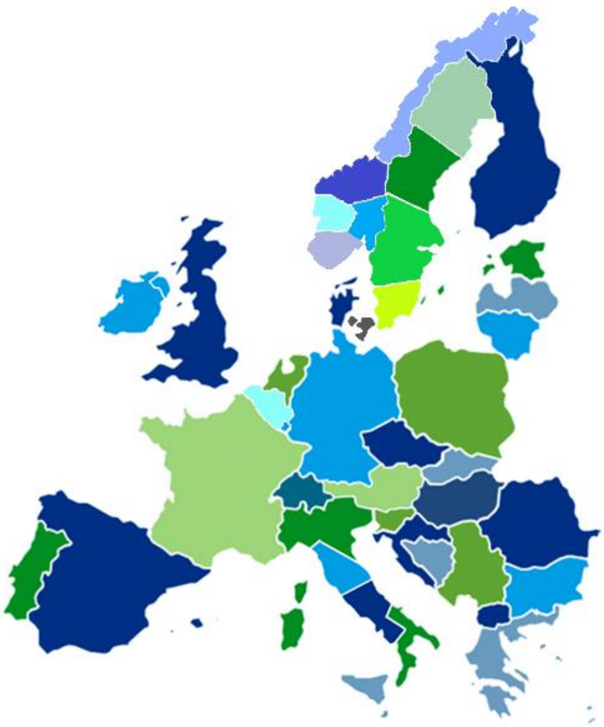
The following step was the development of a market-based approach to the allocation of transmission rights, as required by the introduction of Regulation No 1228/2003 included in the Second Package.

[36] Interconnectors: the physical link enabling the flow of energy between two zones and the physical integration of electricity markets, with finite capacity.
[37] The decision of DTE, the Dutch regulator, to reserve a significant portion of the rights to trade across the border for SEP, the former national vertically integrated utility, was challenged by VEMW, the organization representing the interests of large energy consumers in the Netherlands, the Amsterdam Power Exchange (APX), and ENECO, a large Dutch utility.

The model that predominated the allocation methodologies was the ***explicit auction*** where TSOs auction transmission rights separately from the electricity trading, for different timeframes, from year-ahead to day-ahead capacity products.
However, the separation between the auction for the transmission right and the electricity trading resulted in coordination issues, in fact, trades were constrained by the difficulty to predict hourly price differences in different countries for future time intervals.
The solution implemented was the development of ***implicit auctions***, or market coupling, in which the transmission rights were given to power exchanges and allocated to cross-border traders conditionally to the electricity trade. (EuroPex 2003)

In the European market expansion, the development of zonal congestion pricing has led to the definition of bidding zones at the level of national borders, as described in Figure 15. Some exceptions are present in the European continent such as Sweden, Norway, Denmark, and Italy, which are divided into several bidding zones, due to the morphological configuration, and Luxembourg, which shares a bidding zone with Germany.
Before the integration of the European market, national transmission systems had been developed to avoid constraints, but transmission lines for cross-border transit were not uniformly developed, leading to congestion at the borders. (Meeus and Glachant 2018)

Figure15: The bidding zone configuration in Europe, September 2020



Source: TenneT Web Page

3.4 Cross-Border Capacity Calculation

Initially, the ***"Net transfer capacity"*** (NTC) approach was used to calculate the net transfer capacities and TSOs had the task to calculate the amount of electricity that could be traded between the different bidding zones through the cross-border transmission lines. The task included predicting how the energy flow would be distributed over the different borders due to demand and consumption patterns and the relationship with other systems.
In a transmission network, there are multiple flow pathways between two points, and the flow will naturally spread over the grid. As a result, TSOs were cautious in calculating NTC values in order to avoid making mistakes and incurring in penalties for failing to provide the capacity they had declared available to the market, and therefore not being able to optimize and extract all the value given by the integration. (Meeus 2020)

The evolution toward **"*Flow-based market coupling*"** (FBMC) allowed the calculation of the virtual border capacity and the virtual flow distribution granting TSOs to exploit all the potential of the capacity to be made available.
FBMC is a process in which market clearing and cross-zonal transmission capacity allocation are done simultaneously that begins two days before real-time and terminates one day ahead. (van den Bergh, Boury, and Delarue)
The possibility of computing the interdependencies between the different bidding zones into the market coupling algorithm considering the virtual flow factor made it possible to maximize the welfare gain from cross-border trades. FBMC has become the primary approach for day-ahead and intraday capacity estimations, in compliance to the CACM GL.

3.5 Network charges

Network tariff is divided between ***connection charges*** and ***access charges****,* that in Europe are regulated and allow for the recovery of the network investments.
Connection charges are the charges for connection to the grid, that occurred at the time of connecting and consist of one-off payments that can be spread over time.
Access charges are paid on a monthly basis and are usually divided between ***transmission access charges*** and ***distribution access charges***.
The regulation prescribes these tariffs to be more cost reflective as possible meaning that the users should pay for the costs that are caused by their connection and use of the grid.

Under the ***inter-TSO compensation*** scheme (ITC) countries that host international transits are reimbursed by TSOs from countries that cause international flows by importing or exporting. This causes an increase in the national network tariffs of the latter while TSOs that receive money from ITC can lower their network tariffs.
Using this zero-sum game method, the transactions caused by transit flows are efficiently taken into account and the cost incurred by TSOs reimbursed.

Network investment costs between countries are shared following the *"**Ten-Year Network Development Plan"***. Projects can receive the status of ***"Project of common interest"*** when the development represents a step ahead in the European integrated market plan and follow the ***"Cross-border cost allocation agreements"***, which determine how network investment costs are shared between countries. (Meeus 2020)

3.6 Benefits and Barriers to market integration

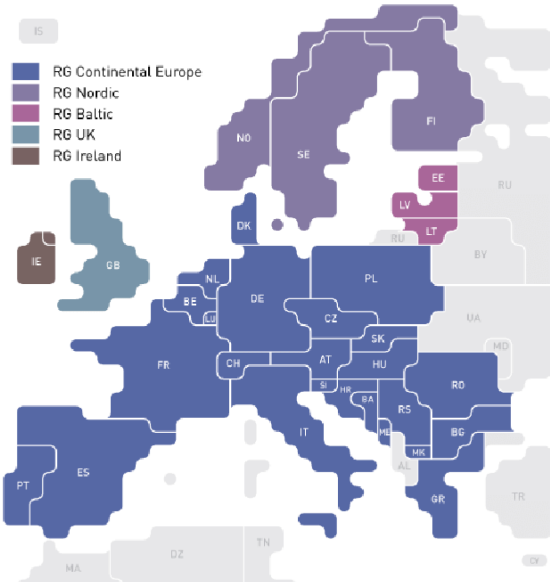
In the following paragraphs the main aspects of the European Electricity markets integration benefits are described, categorized in technical and economical. Moreover, the chapter continues with the principal barriers that can hinder market integration. Finally, a welfare analysis is conducted with a digression on prices, discerning the different effects for the various market players.

The balancing tasks of power system management require both frequency and voltage to remain between a level range, absorbing the unexpected imbalances between load and generation.
Electricity systems have been developed with similar technical standards and norms in Europe, all electrical equipment is designed to work at a frequency of 50 hertz.
One of the technical advantages of scaling up the network system, coupling different zones, is the higher level of inertia[38]. The more synchronously rotating machines are connected to a power system the more is stable, slowing down a frequency drop/spike immediately after a sudden mismatch between supply and demand that could damage the system equipment. Strong cooperation between system operators is required to keep the system secure in large

[38] Inertia: represents the ability of synchronously connected rotating machines to store and inject their kinetic energy into the system.

synchronous zone[39]. There are five synchronous areas in Europe: Continental Europe, the Nordics, the Baltics, Great Britain, and Ireland, Figure 16.

Figure16: The synchronous areas in Europe



Sources: Schittekatte and Pototschnig 2022

Another central factor in connecting different zones into a single synchronous zone is the possibility of pooling expensive capacity resources required to maintain reserve margins and the possible deployment of system security services by TSOs so that the severity of incidents decreases proportionally to the increase in zone size. (Artelys and Frontier Economics 2016) Providing access to a wider portfolio of power plants raises the possibility of finding the capacity needed to replace a power plant when it is no longer available due to scheduled maintenance, an unplanned outage, or a safety issue. This reduces the cost of maintaining adequate capacity by increasing the reliability of the electric system. (IEA 2014a)

The interconnection across different systems, in particular between different member states, permits more efficient use of energy resources and the optimal operation of the power plants. It helps to reduce the overall cost of the electric system by exploiting complementarities between cross-border consumption patterns and cost differences. (Newbery, Strbac, and Viehoff 2016)
The diversity of demand curves, due to different consumption habits, different heating and cooling technologies, and different seasonal time zone variations, allows the aggregation of

[39] Synchronous area/grid: pool of network lines where there is the same voltage and where electricity is synchronized.

different consumption patterns. Aggregate demand mitigates changes in demand, increases the proportion of baseload demand, and reduces the proportion of peak demand.
Instead of building capacity that would remain unused for many months of the year, sharing resources reduces the need for inefficient facilities on both sides of the border.
This effect increases the average load factor of the stock of power plants required to meet demand, driving down investment costs. (US Energy Information Agency 2012)

Market integration can offer benefits also on the generation side in terms of overall dispatching costs. The efficient solution to the merit order process can be extended cross-border taking into consideration power plants in different systems.
The energy policies of individual countries and different natural resources allow the development of different generation capacity mixes.
The overall generation costs are lower if merit order dispatching takes place over a larger and more diverse portfolio of plants and actors, such heterogeneity opens up many trading opportunities between countries. The reason applies to the day-ahead and intraday markets as well as to the balancing services markets. (Mott MacDonald 2013)

Moreover, enlarging the markets increase the competition between cross-border market actors, in particular, since many markets are still dominated by an incumbent operator inherited from the vertically integrated regulated monopoly, greater zonal market integration contributes to alleviating the situation by increasing competitive pressure and mitigating market power. (Booz & Company 2013)

As discussed in the previous chapter the integration of VER suffers from two main limitations: the availability of the source, wind and sun, in different locations and the different intensity with which occurs. Grid integration makes it possible to maximize the efficiency of VER investments in areas where the intensity of the resource is greater. Moreover, is possible to complement the different production curves between neighboring countries due to the specificities of intermittent renewable resources energy production given by the different technologies. Similarly, larger geographical areas make it possible to balance out the difficult-to-predict weather-induced fluctuations, smoothing the output variability.
The integration of the different geographical zones will be necessary to help the deployment of VER technologies to reach the decarbonization targets at the EU level. (Böckers, Haucap, and Heimeshoff 2013)

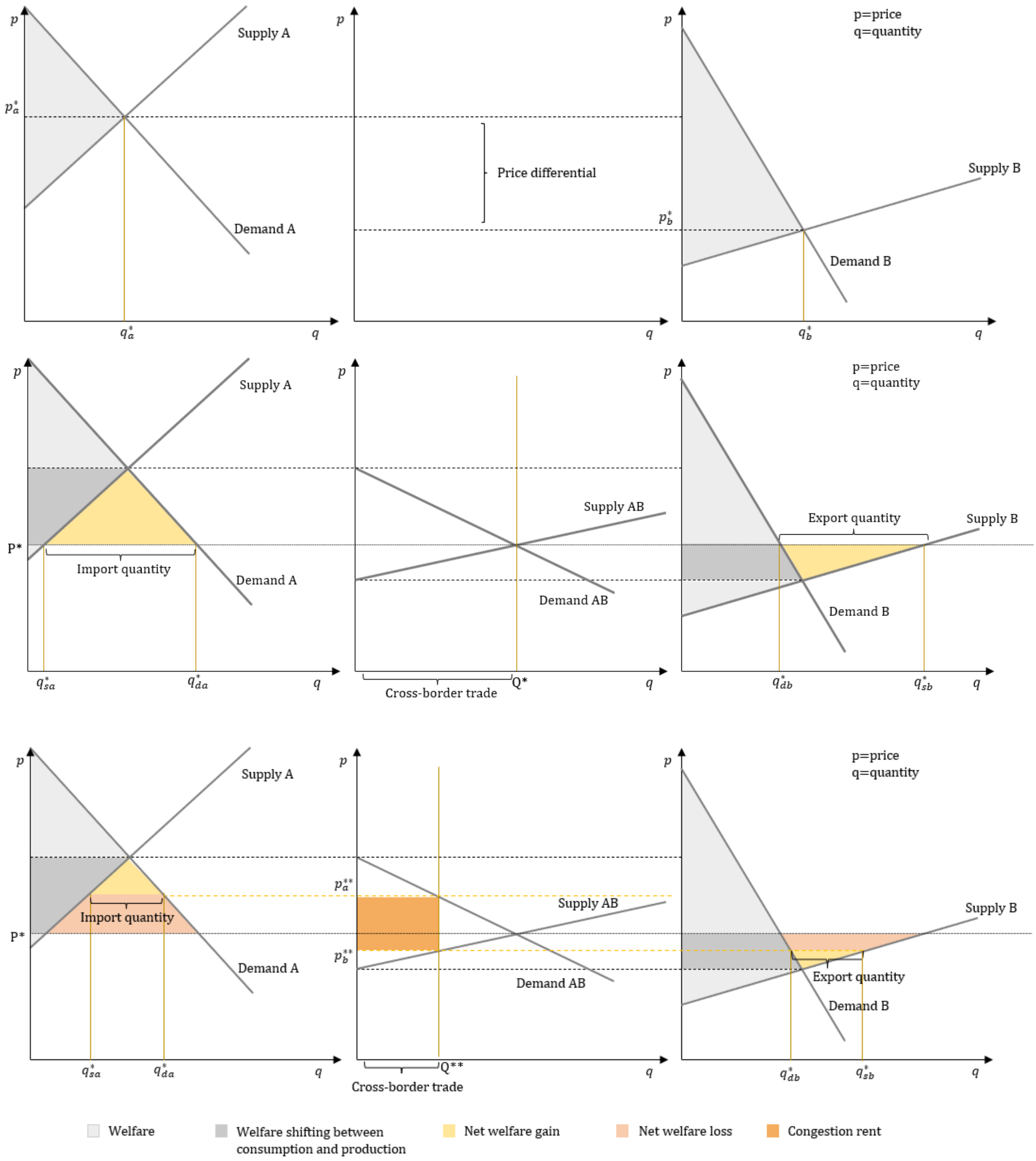
The principal barrier to market integration is given by the insufficient interconnections capacity which mainly results from two different reasons.
First, the inefficient use of the transmission network in cross-zonal capacity allocation, cross-zonal capacity calculation for long-term, day-ahead, intraday, and balancing timeframes, in addition, a possible wrong choice in the bidding zones delineation.
Second, market failures in the investments planning for the cross-zonal capacity of the electricity network infrastructure, hindering cross-zonal trade between areas with excess supply and areas with unfulfilled demand. While the lack of cross-border transmission lines often reflects regions' physical geography, it can also result from existing institutional barriers. (Glachant and Saguan 2007)

To overcome the reticence in the development of an integrated market, which is manifested by concerns about national energy security and distributional impacts, it is necessary to make evident the social welfare gains both domestic and international. To do this, it is essential to standardize or at least make the different national regulations compatible. (Booz & Company 2013; IEA 2014a; Meeus 2020)

3.7 Welfare gains and price dynamics

The electricity cross border trades respect the international trade theoretical framework and dynamics. (Dixit and Norman 1980)
In the following Figure 17, the three different scenarios of autarchy, full market integration, and interconnection capacity congestion are represented.
In autarchy no trade is conducted, the quantities (q) and the prices (p) in the two markets are different.
In full market integration there is a cross-border trade (Q*) and the prices converge (P*), there is also a welfare shift between production and consumption and a net welfare gain with respect to the previous scenario.
In the presence of an interconnection capacity congestion there is a constraint to the cross-border trades and a net welfare loss with respect to the previous case. The prices diverge (p_a^{**} ; p_a^{**}) and there is the possibility for the TSOs to gain a congestion rent.

Figure 17: Social welfare dynamics; autarchy, full market integration and interconnection capacity congestion scenarios

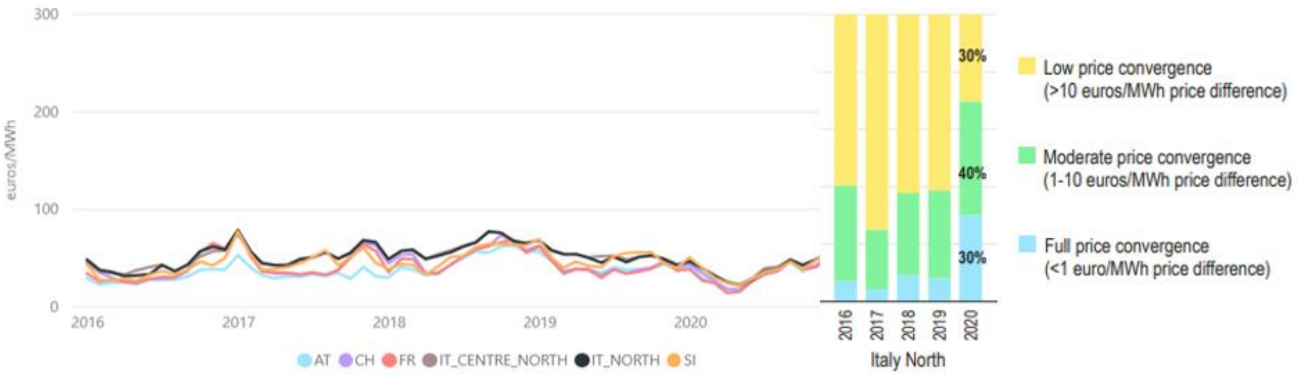


Source: Own elaboration

While these trades increase total welfare, the effects on prices are manifold and have significant distributive consequences for consumers and producers in different zones.
The dynamics depend on the net trades between zones, considering that the flows go from the low price zone to the high price zone, there will be an increase of price in the former and a decrease of price in the latter.
Wholesale price convergence between neighboring countries may be achieved when there is no congestion in the interconnector capacity connecting two zones, if a congestion is detected the prices diverge.
In addition, the price increase for exporting countries makes the social acceptance of such trades more complex creating obstacles to market integration.(Meeus 2020)

Figure 18 shows an overview of price convergence in a selection of countries with a focus on the Italy North bidding zone. Price convergence is expected to increase with higher degree of market coupling, network expansion, or other actions leading to an increase in commercial cross-zonal trades.
Nevertheless, given the electricity market dynamics, reaching full price convergence is not the final outcome as it would require overinvestment in network infrastructure.
Italy North zone experienced an increasing level of price convergence in the wholesale market, in particular, full price convergence rising to 30 %, moderate price convergence at 40%, and low price convergence to 30% of the timeframe in 2020. (ACER/CEER 2021)
Moreover, market integration helps to smooth the price variations induced by exogenous factors, as the commodity's price increases. (ACER 2021b)

Figure 18: Price Evolution of Selected Bidding zones and price convergence in the Italy North Zone



Source: (ACER/CEER 2021)

3.8 Single Day-Ahead market coupling initiative

The evolution of the market coupling passed through different phases and different regional initiatives.
Nord Pool's[40] ***"market splitting approach"*** consisted of two phases, the calculation of the Nordic system price and, if there was not enough transmission capacity, to split the market into smaller markets with different prices.
Another initiative was the ***"trilateral market coupling"*** between three power exchanges (APX, Belpex, and Powernext) and three TSOs (TenneT, Elia, and RTE), with the objective to implement market coupling without having a single power exchange. The system was implemented to run an optimization algorithm between the net export curves. This approach represented a first elegant evolution, but still with many limitations.
Third, ***"volume coupling"***, between Nord Pool (East Denmark) and EEX (Germany), the approach suffered from similar limitations to the trilateral market coupling and had a short application.

Lastly, the implementation of the ***"Single Day-Ahead market coupling initiative"*** (SDAC), which resulted from an evolution of the trilateral market coupling. Become binding for all markets with the adoption of the CACM GL in 2015.
The optimization algorithm used is called the ***Pan-European Hybrid Electricity Market Integration Algorithm*** (EUPHEMIA), the operator of the algorithm is called the ***Market Coupling Operator*** (MCO), which is jointly conducted by all the participating power exchanges that have to be certified as ***Nominated Electricity Market Operators*** (NEMOs).

Currently, NEMOs are alternatively running the function of MCO on a daily basis: one NEMO operates and run the system, another one coordinates announcing the official results and another one acts as a backup. In this process, the power exchanges need to cooperate even if they are still competing, for this reason, ACER hinted at the possibility of having a single independent MCO entity, but it has not been implemented yet.
The costs of operating and developing the MCO function are shared by the NEMOs with a contribution from the TSOs. (Meeus 2020)

[40] Nord Pool: is a pan-European power exchange.

SDAC includes more than 95 % of European electricity consumption, volumes over 1,500 TWh/y are calculated by the algorithm and the welfare gains estimated are above € 1 billion per year. (ENTSO-E 2020)

3.9 Single intraday coupling project

The ***"Single intraday coupling"*** (SIDC) project, called also XBID, has proceeded slower than the day ahead.

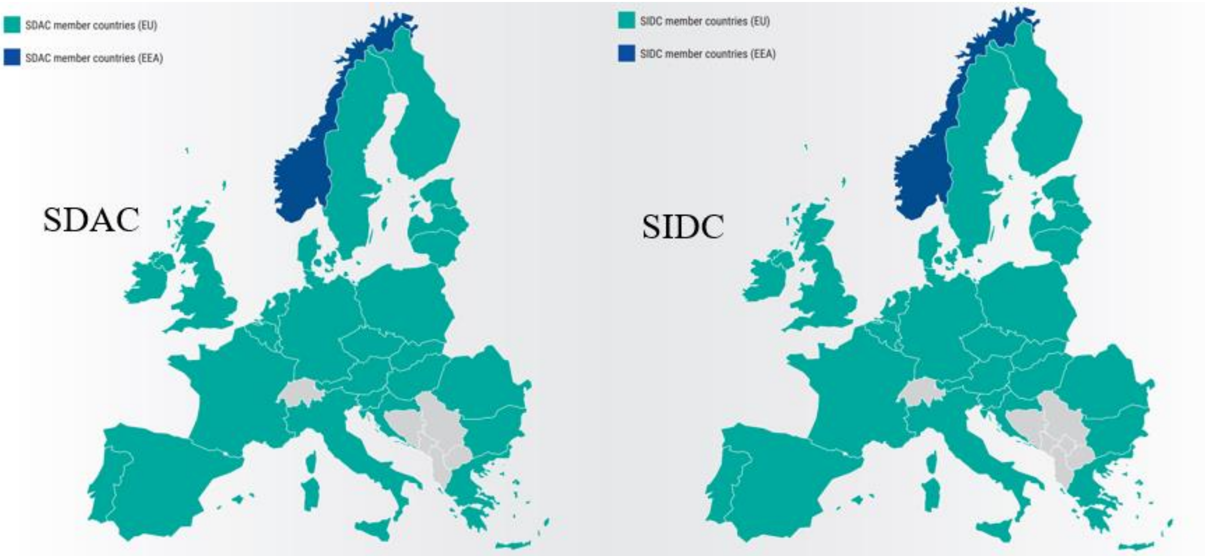
In particular, the traded volumes are smaller so the monetary benefits are of a minor order of magnitude, but at the same time, it is very important in terms of solving imbalances and therefore indispensable in the view of VER integration.

In this framework is very important the definition of the ***intraday cross-border gate closure***[41], the CACM GL recommend that shall be at most one hour before delivery, but national intraday markets often remain open after the intraday cross-border gate closure to allow further exchanges.

After the opening of the intraday timeframe to the cross-border markets, there was the necessity to allocate the transmission rights.

The CACM GL pushes for a unified methodology in the trades consisting of an implicit allocation with the introduction of three pan-European auctions on top of the continuous trade, making it possible for the transmission rights to be allocated efficiently.

Figure 19: Single Day-Ahead market coupling initiative & Single intraday coupling



Source: ENTSO-E 2020

[41] Intraday cross-border gate closure: deadline for the contractualization of intraday products, happen one hour before the delivery in the SIDC.

3.10 Forward capacity markets initiative

In the forward and futures markets, long-term transmission rights are still exchanged with explicit auctions and power exchanges offer platforms where is possible to exchange standardized future contracts in a continuous trade mechanism. (Meeus 2011)
TSOs started a collaboration via the ***"Joint Allocation Office"*** (JAO), a joint service firm comprising 20 TSOs from 17 countries with unified auction rules and timings, which helps traders minimize their transaction costs in purchasing transmission rights. With the introduction of the FCA GL, JAO becomes the single allocation platform for the whole of Europe.

The principal products exchanged through these platforms are called ***physical transmission rights*** (PTRs) or ***financial transmission rights*** (FTR). (ENTSO-E 2020)
In the PTRs method traders buy the rights to trade across the border and then nominate that trade to the TSO, which subtracts this capacity from the total volume of transmission rights that is left for the remaining timeframes.
If the transmission right is not nominated the trader is compensated for the value of the day-ahead auction, where other traders might be willing to purchase it in a use-it-or-sell-it mechanism.
The FTR method instead of a use-it-or-sell-it implements a sell-it-without-the-possibility-of-using-it mechanism in which market participants cannot nominate a cross-border flow ahead of the day-ahead timeframe, but can still hedge against the day-ahead congestion price differences between countries. (Meeus 2020)

Figure 20: Joint Allocation Office initiative

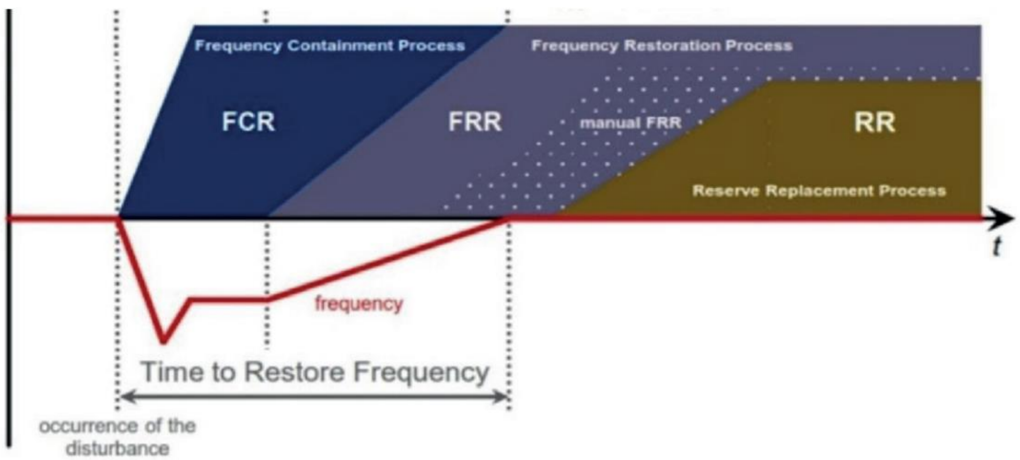
Source: ENTSO-E 2020

3.11 Balancing market coupling initiatives

The first step in integrating the markets for balancing and reserve services is to standardize the products offered in the markets for ancillary services in the different synchronous areas.
Following the introduction in 2017 of the EB GL, were defined a limited number of standard balancing energy products per balancing process. Primary, secondary and tertiary reserves have been renamed as ***frequency containment***, ***frequency restoration*** and ***reserve replacement processes.***
The list includes one standard ***automatic frequency restoration reserves*** (aFRR) product, two standard ***manual frequency restoration reserves*** (mFRR) products, direct and scheduled activation, and one standard ***replacement reserves*** (RR) product.

As represented in Figure 21, the first response to a frequency deviation is the ***frequency containment reserve*** (FCR), dimensioned to handle the loss of the largest generation unit in a system.
The SO GL formalized a mechanism of solidarity between TSOs to optimize the investment and deployment of the FCR, allowing to avoid redundant investments.
After the containment process, there is the activation of the frequency restoration reserves.
These reserves are operated by market participants that can balance their position through intraday markets.
Additionally, or alternatively, the RR are activated which need up to 30 minutes, this can be done by TSO that foresees an imbalance and try to counter it proactively.

Figure 21: Reserves activation after a frequency drop



Source: Schittekatte and Pototschnig 2022

The integration of balancing markets started regionally with different projects that have been extended to the European market improving efficiency and competition bringing down the costs.

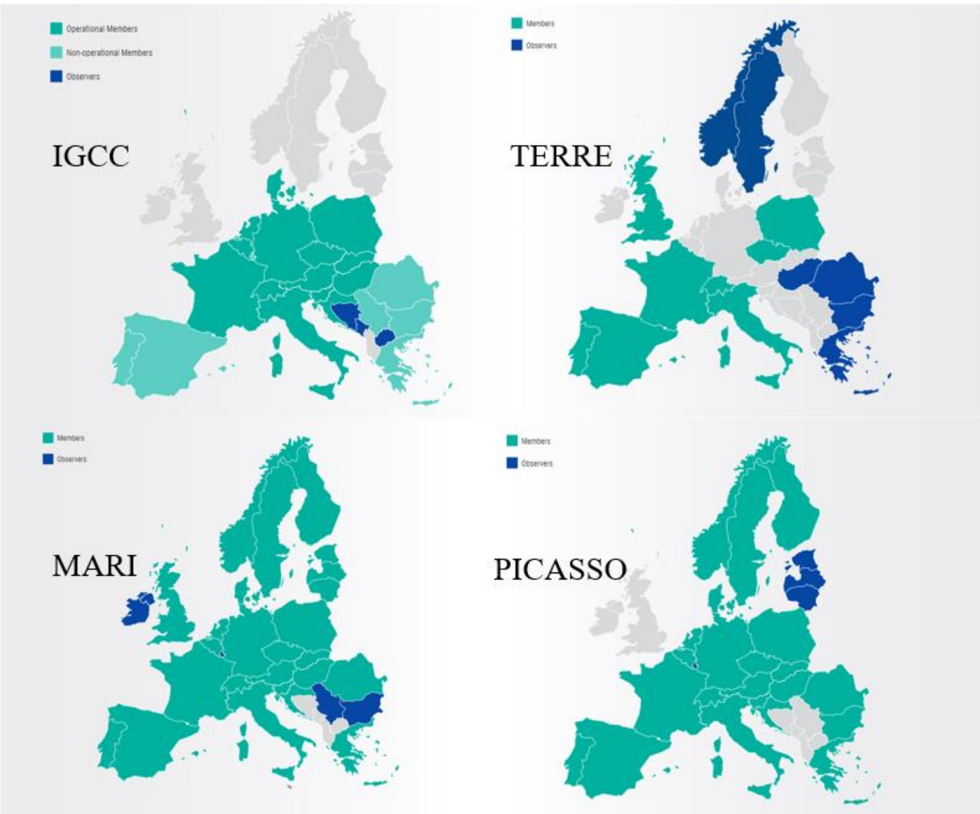
The first benefit allowed by the integration is called ***Imbalanced netting*** (IN), meaning the optimization of upwards and downward imbalances of different zones, which cancel each other's out. The IN can take place if there is enough transmission capacity available, after the netting BRPs need to activate additional reserves.

The platform through which the development has been carried out is called ***"International Grid Control Cooperation***" (IGCC) project. Developed initially by a limited number of TSOs has been then extended to the whole Core region.

In 2016 the ***"Trans-European Replacement Reserves Exchange"*** (TERRE) project was formed as a target model for the EU balancing market integration allowing the exchange and the optimized activation of balancing reserves through an RR platform.

In 2017 the mFRR platform, ***"Manually Activated Reserves Initiative"*** (MARI), was activated and lastly the aFRR platform, ***"Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation"*** (PICASSO). (ENTSO-E 2020)

Figure 22: International Grid Control Cooperation, Trans-European Replacement Reserves Exchange, Manually Activated Reserves Initiative & Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation



Source: ENTSO-E 2020

Chapter 4: ”Methodology and Results”

4.1 Literary review

The electricity market framework has been drastically reshaped in the last 10-20 years, the main differences have been introduced with the liberalization of the market, the introduction of VER generation and the integration of the markets at the European level.
The rapid development of renewable energy sources power plants has led to changes in the market structure with important repercussions on resource adequacy and the MOE. These aspects result in a change in the level of day-ahead prices due to the new supply and demand equilibriums that determine the spot price.

There is a long and heterogeneous tradition of quantifying the market effects of VER with respect to methodology and focus for different countries.
A large number of studies have been conducted to assess the wholesale price effect of VER deployment, including model simulations and empirical historical price data analyses.
In addition, literature is emerging that starting from the study of VER on MOE, using similar models, investigates the impact that cross-border transits may have on prices.
In both cases, the literature is divided into two main areas: on the one hand, the simulation-based approach uses past or hypothetical data to simulate alternative scenarios, and on the other hand, the empirical method uses historical data to develop econometric models.

Simulation-based studies focus on the welfare evaluation of renewable and integration enhancing policies, from an economic and technical perspective, by comparing prices and efficient cost solutions in different hypothetical scenarios. While regression analysis is used to estimate the MOE with a focus on the price and distributional effects.
Both models present limitations, in particular, using an electricity market simulation analysis requires comprehensive assumptions and plausible counterfactual scenarios, otherwise, the results would be inconsistent with reality. The regression analysis has the benefit of being based on real data, but at the same time is able to evaluate only partially the short-term merit order effects, based on the current electricity market and power generation structure.

4.2 Simulation Based studies

The simulation-based approach has been used and applied to numerous countries and regions to explain the effects of renewables on electricity prices.

Starting from Sensfuß, Ragwitz, and Genoese (2008) that run simulations over a model of the electricity market for different scenarios with and without renewable production in Germany. The main findings are that the average electricity price for Germany was reduced by 1.7 to 7.8 €/MWh due to the electricity production of renewables in 2006.
In a follow up analysis, Sensfuß in 2011, uses the same technique showing that the 2010 effect is found to be at least between 5 and 6 €/MWh.

Weigt (2009), uses a model of the German energy market, between January 2006 and June 2008, to assess the replacement of traditional fossil-fuel capacity with wind power. The estimated electricity prices for scenarios with and without wind generation conclude that the first one has cheaper pricing with an average price spread of around 10 €/MWh.

Linares, Santos, and Ventosa (2008), use a simulation model of the electricity market in Spain to obtain results for different scenarios with and without a European carbon emission scheme and with or without additional national renewable support. Using the actual scenario of EU ETS implementation as a counterfactual for the alternative situation where additional renewable capacity is introduced in 2020, found an effect on electricity prices of minus 1.74 €/MWh.

To quantify the impact of wind power on market prices, Holttinen in 2004, conduct a simulation analysis for the Nordic electricity market. In a 2010 prediction scenario, the model yields spot price reductions of 2 €/MWh, using wind data from 1961 to 1990 to calibrate the model.

Fürsch (2013), models the international cross-border flows to optimize the growth of renewable presence in the mix. The results are forecasts for different scenarios assessing the effects on the German energy market using as counterfactual the renewable capacity at 2010 levels.

Schlachtberger (2017), develop a scenario analysis to assess the economic benefits of the cooperation between European markets by exploiting different mixes of RES and computing scenarios in relation to the optimal investment level in the transmission network.

Cartea (2022), develop a model of cross-border intraday trading for trades of electricity in different countries in the European power network. The study shows that the transmission of electricity across borders has a direct effect on the prices caused by the demand and supply changes.

4.3 Empirical studies

Different econometric approaches and techniques have been used to analyze the growing availability of ex-post data on electricity prices and renewable capacity for different countries. Würzburg, Labandeira, and Linares (2013), investigated the MOE of RES, between 2010 and 2012, using a multivariate regression model and daily average data on electricity prices. The results highlighted that RES lowered the electricity spot price on average by 7.6 €/MWh.

Cludius (2014), used hourly data on the spot market prices, load, and RES generation to conduct a time-series regression analysis. The results suggested that power from wind and solar energy sources reduced the day-ahead spot electricity price, of German/Austrian bidding zone, by 6 €/MWh to 10 €/MWh in the period between 2010 and 2012.

Analyzing the Spanish spot market price data between 2005 and 2010, Gelabert, Labandeira, and Linares in 2011, developed an ordinary least squares estimation. The findings revealed that a marginal increase of 1 GWh of energy from RES is related to a wholesale price reduction of 1.9 €/MWh.

Nieuwenhout and Brand (2011), use wind and weather data from the Netherlands to establish the effect of wind production dividing the sample into groups that correspond to different wind production intervals. Their results were in line with the previous literature finding that average day-ahead prices were 5% higher during the no-wind intervals with respect to the average of the entire sample for the analyzed period.

Woo (2011), study the period between 2007-2010 with a multivariate regression analysis, that includes different generation technologies, system load, price of gas, and a set of time dummies as additional explanatory variables. Finds that a 1 GWh increase in wind generation decreased Texas electricity prices between 3,9 and 15,3 US$/MWh depending on the different zones considered.

Following the work done by Woo, Clò in 2015, performed a time-series regression analysis focusing on the impact of wind and solar generation on the Italian spot market price, to assess the impact of RES enhancing policies. The period taken into account was from 2005 to 2013 and the results show that wind and solar generation reduced the wholesale electricity prices on average from 2.3 €/MWh to 4.2 €/MWh.

Gianfreda, Parisio, and Pelagatti in 2018 focus on the effect of VER integration on balancing markets, that differently from the negative effect of increased VER production on day-ahead prices, results in ambiguous effects on balancing market prices.
The authors compare the evidence of balancing price increases in particular market conditions in the Italian market with decreasing balancing prices of the German market, assessing the difference as a result of different market designs.

Another study by Quint and Dahlke (2019) investigated the effects of wind generation on the SMP using as a reference the Midcontinent Independent System Operator, the largest wholesale electricity market by geographical area worldwide. The results highlight that for 1 GWh of additional wind generation the wholesale price is reduced by \$1.4/MWh to \$3.4/MWh.

Hosseini (2021), studies the impact of increasing shares of RES in the generation mixes of the Italian Zonal market price from 2015 to 2019. The results show a negative effect of the increased share of RES on the day-ahead market prices, computed through a multivariate regression analysis, taking into consideration the cross-zonal transits.

The reported literature is only a small part of the vast research that tries to study the effect of different exogenous variables on electricity spot prices.
This work will start from the existing literature adapting the models on the effect of the RES deployment on the spot prices to study the effect of cross border transits, adding the net cross border flows as an independent variable to the multivariate regression model specification.
In the following section, the dataset and the methodology are described.

4.4 Data and Methodology

The approach used in this research builds up from a consolidated methodology started by Woo and continued by Clo and Husseini, enlarging and focusing the analysis on the effect of the cross-border flows on the SMP in the Day-ahead wholesale market.
This approach is used to perorate the cause in favor of higher integration in the electricity markets, showing the effects on prices of increasing cross-border transits.
The analysis is limited to the effect of the cross-border transits on the prices of the net importing country and not the effects on the net exporting countries, making it impossible to compute the net benefits for the whole system.

The study is conducted by carrying out an ex-post empirical analysis on a times series considering a period starting from 12-02-2015, Italy's entry into the European market coupling, to the end of 2020.
The year 2021 is left out of the study because characterized by specific phenomena due to social changes induced by the pandemic which could influence the results.
The data used have an hour granularity for a total of 51625 hourly observations included in the initial dataset, solving the problem of the summer-winter hour change considering only the summertime set.

The analysis is constructed to estimate the impact of the variation in the net cross-border transits on the Italy North bidding zone (North) price considering the flows from the neighboring countries (France, Switzerland, Austria, Slovenia) and also from the contiguous Central-Northern Italy bidding zone (CNorth) as a control variable.
The data have been retrieved and elaborated from the GME platform[42], ENTSO-E platform[43] and Thomson Reuters databases[44].

[42] https://www.mercatoelettrico.org/En/default.aspx
[43] https://transparency.entsoe.eu/dashboard/show
[44] https://www.thomsonreuters.com/en.html

4.5 Variables description

The dependent variable is the hourly price in the Day-ahead wholesale market in the Italy North bidding zone (NORD_PRICE).
The independent variables list starts with the demand for electricity computed as the load in the North zone, the consumption of electricity is largely inelastic to the price changes and therefore exogenous (NORD_LOAD).
The second variable considered is the hourly production of electricity from VER, in particular the sum between the electricity produced through solar power plants and eolic turbines. The characteristics of non-programmability of these sources, that depend on the weather conditions, make it an exogenous variable (VER_TOT).

Two dependent variables are considered when introducing the transits between zones.
The first one groups all hourly measured flows passing across national borders, in particular between the North zone and Slovenia, Austria, Switzerland, and France.
This variable is constructed as the absolute sum of incoming and outgoing transits including all flows, both from historical contracts and market coupling (NET_TRANSFERS_T).
The second, considers the net transits between the North zone and the CNorth zone, to control for possible effects from the cross-border trades to the national flows between zones (NET_TRANSFERS_CNOR).

To account for the influence of the commodities prices on the costs of the traditional power plants, the price of Natural Gas is inserted into the model as an independent variable (GAS_MGP).
In particular, considering the daily prices of the Day-Ahead market organized by GME on an auction-based mechanism. This market is limited by the low level of liquidity and the number of exchanges conducted but can be considered reliable in the determination of the gas price as the possibility of arbitrage is limited and prices are aligned with the main European hubs.

The independent variable representing the cost of the CO2 in the framework of the European Emission Allowances System Phase 3, has initially been considered in the model to see the effects of the CO2 certificates on the price of electricity (EUA). The variable reports the daily price determined by the auction based mechanisms of CO2 certificates. The auction runs only during the weekdays, meaning that the prices for Saturday and Sunday are considered the same as Friday.

A dummy variable is added to the model taking value one if the marginal power plant, the one that determines the SMP, exploits Natural Gas as a primary resource (GAS_PLANT).
A number of dummy variables are added to the model to account for daily, seasonal, and yearly effects, in particular a year dummy for each year in the 2015-2020 period, a month dummy for the twelve months of the year, and a day dummy for the number of days in a month, (Year-Month-Day).
In Table 1, is reported a summary with the variable descriptions, the unit of measure and the source.

Table 1: Data description

NAME	TYPE	DESCRIPTION	UNIT	SOURCE
NORD_PRICE	Dependent Variable	Hourly price DA Norden Italy	€/MWh	GME
NORD_LOAD	Independent Variable	Hourly load in the North zone	MWh	GME
NET_TRANSFERS_T	Independent Variable	Hourly Net cross border transits	MWh	GME
VER_TOT	Independent Variable	Hourly VER production: Solar+Wind	MWh	ENTSO-E
NET_TRANSFERS_CNOR	Independent Variable	Hourly net transits North-CNorth zone	MWh	GME
GAS_MGP	Independent Variable	Price of natural gas	€/MWh	GME
EUA	Independent Variable	Price of Emission Allowances	€/ton CO2	Thomson Reuters
GAS_PLANT	Dummy Variable	Dummy indicating if the marginal power plant exploits gas	0-1	GME
Year, Month, Day	Dummy Variable	Time variables dummy	2015-2020 1-12 1-24	-

In Tables 2 are reported the descriptive statistics of the complete dataset, Tables 7 and 8 in the Appendix present the descriptive statistics yearly.
The variable NORD_PRICE, has a mean of 49,90 €/MWh with a variation of the average from 37.79 €/MWh in 2020 to 60.71 €/MWh in 2018.

The maximum value is reached at 206.12 €/MWh and the minimum value is at 0.00 €/MWh, considering that the Italian market does not allow for negative prices.
The variable NORD_LOAD, peaks at 29379 MWh and never falls below the minimum value of 8167 MWh.
The average stands at 18026 MWh for the entire period, with an upward trend until 2019 and a drop in 2020, where we can assume it is due to the sanitary containment measures put in place.
The cross-border transits, NET_TRANSFERS_T, have an average value that stands at 4814 MWh, with a variation of the average from a value of 5433.24 MWh in 2015 that remains mostly stable until 2020 when it falls to 4176.53 MWh, in general therefore there is a greater propensity towards incoming flows than outgoing flows.
Taking into account the construction of the variable, we can observe how the minimum value is equal to -3765 MWh while the maximum value reaches the extraordinary amount of 9098 MWh.

With regard to the values observed in internal transits, NET_TRANSFERS_CNOR, the situation is almost the opposite. We can observe an average of -904.9 MWh over the entire period, with a progressive increase in absolute value from the value of -154.96 MWh in 2015 to the value of -1653.06 MWh in 2020, signaling a preponderance of outflows from the North zone.
The minimum value reached is equivalent to an outflow from the North zone of -4000.0 MWh and a maximum value of 2500 inflow.

The production of electricity from VER, VER_TOT, stands at an average value for the period of 793.7 MWh, which remains substantially constant over the entire period observed, signaling a lack of new installed capacity.
The minimum value is at 0 MWh while the maximum value is at 4842.0 MWh, observed at peak solar irradiation hours and optimal temperature conditions.

The price of natural gas, GAS_MGP, experiences a considerable range from a minimum value of 4.883 €/MWh to a maximum value of 58.128 €/MWh.
The average for the entire period stands at 18.638 €/MWh with a variation between 25.11 €/MWh in 2015 and 10.48 €/MWh in 2020.
It should be noted that in almost all variables the year 2020 exhibits different characteristics from previous years.

Table 2: Descriptive statistics

N=51624	Mean	SD	Min	Max
1) NORD_PRICE	*49,90*	*17,05*	*0,00*	*206,12*
2)NORD_LOAD	*18026*	*4417,07*	*8167*	*29379*
3) NET_TRANSFERS_T	*4814*	*2026,04*	*-3765*	*9098*
4)VER_TOT	*793,7*	*1172,30*	*0,0*	*4842,0*
5) NET_TRANSFERS_CNOR	*-904,9*	*1610,75*	*-4000,0*	*2500,0*
6) GAS_MGP	*18,638*	*5,83*	*4,883*	*58,128*
7) EUA	*14,20*	*8,77*	*3,91*	*33,28*

To reduce the complexity and avoid possible confounding factors the datasets have been divided into 24 subsets for every hour and following the methodology proposed by Gianfreda, Parisio, and Pelagatti in 2016 only the 4th, 13th, and 19th hours of each day have been considered.

The choice of these specific timeframes accounts for different configurations of demand and supply conditions representing situations of interest, in particular, the lowest load (H4), mid-day peak (H13) and late afternoon peak (H19).

In addition, this choice allows us to analyze periods in which the impact of RES on the model is different, particularly with regard to solar radiation, which is not available at H4 and peaks at H13.

Table 3: Descriptive statistics, H4

	H4			
N=2151	Mean	SD	Min	Max
1) NORD_PRICE	*38.45*	*11.80*	*1.02*	*95.91*
2)NORD_LOAD	*13371.68*	*1740.65*	*8166.99*	*18517.42*
3) NET_TRANSFERS_T	*4876.05*	*1617.48*	*-1016.28*	*8416.00*
4)VER_TOT	*10.08*	*10.43*	*0.00*	*81.00*
5) NET_TRANSFERS_CNOR	*-1405.96*	*1573.10*	*-3700*	*2500*
6) GAS_MGP	*18.64*	*5.83*	*4.88*	*58.13*
7) EUA	*14.20*	*8.77*	*3.91*	*33.28*

Table 4: Descriptive statistics, H13

	H13			
N=2151	*Mean*	*SD*	*Min*	*Max*
1) NORD_PRICE	*47.63*	*16.30*	*0.00*	*150.00*
2)NORD_LOAD	*19629.18*	*3945.49*	*8833.35*	*28599.24*
3) NET_TRANSFERS_T	*3903.41*	*2230.22*	*-3149.60*	*8426.00*
4)VER_TOT	*2656.36*	*1147.87*	*150.00*	*4842.00*
5) NET_TRANSFERS_CNOR	*420.31*	*1252.65*	*-3625.16*	*2500.00*
6) GAS_MGP	*18.64*	*5.83*	*4.88*	*58.13*
7) EUA	*14.20*	*8.77*	*3.91*	*33.28*

Table 5: Descriptive statistics, H19

	H19			
N=2151	*Mean*	*SD*	*Min*	*Max*
1) NORD_PRICE	*61.71*	*19.24*	*19.77*	*175.75*
2)NORD_LOAD	*20491.49*	*3482.34*	*10702.08*	*27226.99*
3) NET_TRANSFERS_T	*5289.07*	*1988.01*	*-3765.00*	*9035.00*
4)VER_TOT	*103.32*	*121.54*	*1.00*	*589.00*
5) NET_TRANSFERS_CNOR	*-1789.65*	*1244.10*	*-4000.00*	*2052.55*
6) GAS_MGP	*18.64*	*5.83*	*4.88*	*58.13*
7) EUA	*14.20*	*8.77*	*3.91*	*33.28*

Having a look at the descriptive statistics, in the previous tables, for the three models we can observe some differences.

In particular, as can be expected, the average price, NORD_PRICE, tends to be higher in the time slots with higher demand, reaching a value of 61.71 €/MWh in H19.

The average of the variable NORD_LOAD almost doubles from the value of 13371.68 MWh in H4 to values of 19629.18 MWh in H13 and 20491.49 MWh in H19. The maximum and minimum values show a considerable fluctuation in consumption.

The averages of the variable on cross border transits, NET_TRANSFERS_T, remain positive in the three intervals with a variation ranging from 3903.41 MWh in H13 to 5289.07 MWh in H19, with negative minimum values recorded, indicating a net export of the northern area to neighboring countries in limited periods of time, and maximum values approaching the physical limits of the interconnections.

Regarding the variable representing the transits between the North zone and the CNorth zone, NET_TRANSFERS_CNOR, the average is negative in the intervals H4 and H19, while in the interval of highest production from renewable sources H13 we have an inflow to the North zone averaging 420.31 MWh.

The variable VER_TOT is characterized by very limited average values in H4 and H19 due to the absence of solar irradiation and the very limited installed wind capacity. The average in H13 stands at 2656.36 MWh, with minimum values of 150.00 MWh and maximum values of 4842.00 MWh.

The variables GAS_MGP and EUA are measured daily and therefore do not differ from what has been described above.

4.6 Unit Roots Tests

The first step before proceeding with the regression analysis is to test the three time series for unit roots using two different tests.

First, the Augmented Dickey-Fuller test (ADF) is conducted to test the null hypothesis that the series have a unit root against the alternative hypothesis that the series are stationary. (Dickey and Fuller 1979)

In order to define the number of lags to be included in the test, is used the Akaike's information criterion (AIC). Several versions of the test have been run to incorporate the different specificity of each time series, in particular, the presence of a drift or a trend, indeed different critical values are considered. (Gelabert et al. 2011; Würzburg et al. 2013)

In addition, the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) is conducted to test for the stationarity of the series, using the specification and the number of lags identified in the previous test. (Kwiatkowski et al. 1992)

A trend in the specification of the model is added in those cases where it is significant (*).

ADF critical values for the models with drift are -2.57 for 10% confidence level, -2.86 for 5% confidence level, and -3.43 for 1% confidence level; for models that include a trend the critical values are -3.12 for 10% confidence level, -3.41 for 5% confidence level, -3.96 for 1% confidence level. (Mackinnon 1996)

KPSS critical values for the models with drift are 0.347 for 10% confidence level, 0.463 for 5% confidence level, and 0.739 for 1% confidence level; for models that include a trend the critical values are 0.119 for 10% confidence level, 0.146 for 5% confidence level, 0.216 for 1% confidence level. (Kwiatkowski et al. 1992)

The results, reported in Appendix in Tables 10-11-12, show discordant outcomes between the two tests, in particular, the ADF test rejects the null hypothesis suggesting that the series is stationary for all the variables in the three time intervals considered besides the EUA variable. In contrast, the KPSS rejects the null hypothesis of stationarity indicating the presence of a deterministic trend. We are thus led to use the variables in first difference to estimate the model. The two tests are then repeated on the differenced variables to check the stationarity of the new time series.

An investigation of the correlation matrix of the first differenced variables is then conducted to test for possible problems of pairwise multicollinearity, the values obtained are below the reference value of 0.8, allowing us to continue with the estimation of the model. (Verbeek 2019) Results reported in the Appendix, in Tables 13-14-15.

4.7 Empirical Model

A set of controls for seasonal effects is added by introducing a vector of time dummies (D) which includes six dummies indicating the days of the week; eleven dummies indicating the month and five annual dummies indicating the year. (Wooldridge 2012)

In addition, the variable ΔGAS_MGP is interacted with the dummy variable GAS_PLANT so that the gas price variable is only activated when the variable dummy is equal to 1, indicating that the marginal plant in the determination of the SPM uses gas as a resource.
The model is then presented and conducted on the three different datasets:

$$\begin{aligned}\Delta\text{NORD\_PRICE}_t = {} & \beta_0 + \beta_1 \Delta\text{NORD\_LOAD}_t + \beta_2 \Delta\text{NET\_TRANSFERS\_T} + \beta_3 \Delta\text{VER\_TOT} \\ & + \beta_4 \Delta\text{NET\_TRANSFERS\_CNOR}_t + \beta_5\ (\text{GAS\_PLANT} \times \Delta\text{GAS\_MGP}_t) + \beta_6 \Delta\text{EUA}_t + \gamma D_t + \varepsilon_t\end{aligned}$$

Next, the Ljung Box Test on the residuals and squared residuals of the regressions is conducted to test for the presence of serial autocorrelation; if the null hypothesis is rejected, the model exhibits serial autocorrelation. (Ljung and Box 1978)
After conducting the test, as the results reported in Table 16 in the Appendix show, the null hypothesis is rejected and a robust estimator must be used. The regressions are then re-estimated using the Newey West estimator. (Newey and West 1987)

4.8 Results

As explained in the previous section, the model is estimated for the three subsets representing the time intervals H4, H13 and H19. The following table contains the results of the three regressions for the entire period 2015-2020:

Table 6: Regression results, H4-H13-H19

	Model H4		Model H13		Model H19	
Dependent variable: ***ΔNORD_PRICE***	Coefficient (SE)	p-value	Coefficient (SE)	p-value	Coefficient (SE)	p-value
ΔNORD_LOAD	*0.00353**** *(0.00014)*	*≃ 0*	*0.00253**** *(0,00009)*	*≃ 0*	0.00260*** 0.00012	*≃ 0*
ΔNET_TRANSFERS_T	*-0.00327**** *(0.00022)*	*≃ 0*	*-0,00234**** *(0,00027)*	*≃ 0*	-0.00374*** 0.00027	*≃ 0*
ΔVER_TOT	*-0.05732**** *(0.01111)*	*≃ 0*	*-0,00246**** *(0,00027)*	*≃ 0*	-0.00287 0.00353	0.41
ΔNET_TRANSFERS_CNOR	*-0.00361**** *(0.00022)*	*≃ 0*	*-0.00243**** *(0,00031)*	*≃ 0*	-0.00238*** 0.00028	*≃ 0*
*GAS_PLANT * ΔGAS_MGP*	*0.33379*** *(0.10752)*	*0.001*	*1.3785**** *(0.22154)*	*≃ 0*	1.6088* 0.76492	0.03
ΔEUA	*0.18539* *(0.24641)*	*0.45*	*0.23412* *(0,28652)*	*0.41*	0.44467 0.51862	0.39
Constant	*0.03988* *(0.56429)*	*0.94*	*-0.56213* *(0.8398)*	*0.50*	0.78279 1.03117	0.44
DMY dummy	*Yes*		*Yes*		*Yes*	
Observations	*2150*		*2150*		2150	
Multiple R-squared	*0.4105*		*0.5389*		0.3802	
Adj. R-squared	*0.3959*		*0.5275*		0.3648	

*Note: *** p-value<0.001, ** p-value<0.01, * p-value < 0.05, ° p-value<0.1*

Standard errors in parenthesis are robust to heteroskedasticity and serial correlation (Newey West)

The first model, H4, estimated by including the time dummy variables, on a sample of 2150 observations, presents an adjusted R-squared of 0.3959.

The coefficient of the first independent variable, ΔNORD_LOAD, is positive and significant, as expected a marginal increase in electricity demand has a positive effect on the wholesale price.

The second independent variable, ΔNET_TRANSFERS_T, is significant and has a negative sign, implying that an increase in cross-border inflows leads to a reduction in the wholesale price in the area under consideration. In particular, an increase of 1000 MWh of incoming flows in the time interval considered leads to a price decrease of 3.27 €/MWh, a variation of 8.5 % considering the average price of 38.45 €/MWh.

The coefficient of ΔVER_TOT is negative, indicating that the marginal increase in the supply of energy from non-programmable renewables leads to a decrease in the wholesale price. This result confirms the merit order effect of renewables widely described in the literature.
The magnitude of the effect, however, is somewhat surprising, an increase of 1000 MWh of energy produced from renewable sources would have a negative effect on the price of 57.32 €/MWh, more than 10 times larger than the effect described in the literature.
The most plausible explanation comes by putting into perspective the magnitude of the supply increase with the average hourly production from VER of 10 MWh, in fact North zone has mainly solar renewable energy production that is unavailable at night and very limited wind power capacity, causing a disruptive effect on the SMP.

Looking at the effect of intra-state transits, ΔNET_TRANSFERS_CNOR, we can see that the coefficient is significant and negative, with a similar magnitude to the coefficient for cross-border transits. An increase of 1000 MWh of transits from the CNorth zone to the North zone would result in a reduction of the North zone price by 3.61 €/MWh. Indeed, as the average of the net flows is negative indicating a preponderance of flows from the North zone to the CNorth zone, it is suggested that in this timeframe the interconnection between the bidding zones would lead to an increase in the North zone price compared to an autarkic situation.

The iterative variable, GAS_PLANT * ΔGAS_MGP, is significant and positive, its effect describes a situation in which 1€/MWh increase in the gas price is only partially manifested in the wholesale price with an increase of 0.33 €/MWh. This situation can be attributed to several complementary causes.
Firstly, the low demand that leads to greater competition in the merit order dispatching is aggravated by the need for the traditional power plants to participate in auctions in order to recover investments made when no renewables are present, which due to the MOE can bid at lower level and be chosen first in the merit order. Another reason could be the need for these traditional plants to have warm up periods and continuous production for medium to long periods, these constraints can make it less profitable to switch off the plant with a price increase that does not absorb the increase in the commodity price and thus limits the possible mark up.

The last variable taken into account, ΔEUA, has a positive sign as expected, but as it is not significant, it is not possible to comment on this outcome in full.

The second model, H13, estimated by including the time dummy variables, on a sample of 2150 observations, presents an adjusted R-squared higher with respect to the first model in particular a value of 0.5275, the highest of the three models considered.
The coefficient of the first independent variable, ΔNORD_LOAD, is again positive and significant, as expected, meaning that a marginal increase in electricity demand has a positive effect on the wholesale price.
The second independent variable, ΔNET_TRANSFERS_T, is significant and has a negative sign, as before an increase in cross-border inflows leads to a reduction in the wholesale price in the area under consideration. In particular, the effects are slightly lower compared to the previous one and an increase of 1000 MWh of incoming flows in the time interval considered leads to a price decrease of 2.34 €/MWh, a variation of 4.9 % considering the average price of 47.63 €/MWh.

The coefficient of ΔVER_TOT is significant and negative, indicating that the marginal increase in the supply of energy from non-programmable renewables leads to a decrease in the wholesale price confirming the MOE of renewables widely described in the literature.
The magnitude of the effect is more in line with the previous studies, in particular, an increase of 1000 MWh of energy produced from renewable sources would have a negative effect on the price of 2.46 €/MWh.
This difference is mainly explained by the already high presence of renewable in the generation mix, meaning that this increase is going to affect less the prices in this time frame.

The effect of intra-state transits, ΔNET_TRANSFERS_CNOR, is significant and negative, with a similar magnitude to the coefficient for cross-border transits. An increase of 1000 MWh of transits from the central north zone to the northern zone would result in a reduction of the northern zone price by 2.43 €/MWh. The average of the net flows is positive indicating a preponderance of flows from the CNorth zone to the North zone, suggesting that the intra-state transits in this timeframe generally contribute to the decrease of the wholesale price.

The iterative variable, GAS_PLANT * ΔGAS_MGP, is significant and positive, its effect describes a situation in which the 1€/MWh increase in the gas price increases the wholesale price of 1.37 €/MWh. A possible explanation is that, given the high demand, traditional power

plants, exploiting gas as a main resource, have to be included in the merit order dispatching and, benefiting from a less competitive environment, can increase the price more than one on one and still be called into production.
Same as before the variable representing the cost of carbon certificates, ΔEUA, is not significant, making it not possible to comment on this outcome in full.

The third model, H19, estimated by including the time dummy variables, on a sample of 2150 observations, presents an adjusted R-squared of 0.3648.
The coefficient of the first independent variable, ΔNORD_LOAD, is positive and significant, as in the previous cases, a marginal increase in electricity demand has a positive effect on the wholesale price.
The second independent variable, ΔNET_TRANSFERS_T, is significant and has a negative sign with the highest effect recorded so far, but with a comparable order of magnitude. In particular, an increase of 1000 MWh of incoming flows in the time interval considered leads to a price decrease of 3.74 €/MWh, a variation of 6 % considering the average price of 61.71€/MWh.

The coefficient of ΔVER_TOT is negative, indicating that the marginal increase in the supply of energy from non-programmable renewables leads to a decrease in the wholesale price.
However, the coefficient is not significant, making it impossible to comment on the result accurately.

Looking at the effect of intra-state transits, ΔNET_TRANSFERS_CNOR, we can see that the coefficient is significant and negative, with a similar magnitude to the coefficient for cross-border transits, although appreciably lower in this particular case. An increase of 1000 MWh of transits from the central north zone to the northern zone would result in a reduction of the northern zone price by 2.38 €/MWh.

The iterative variable, GAS_PLANT * ΔGAS_MGP, is significant and positive, its effect describes a situation in which the 1€/MWh increase in the gas price increases the wholesale price of 1.60 €/MWh. A possible explanation, as in the previous case, is that given the high demand traditional power plants, exploiting natural gas as a main resource, have to be included in the merit order dispatching and, benefiting from a less competitive environment, can increase the price more than one on one and still be called into production. In this context, in addition,

the lower level of renewable energy sources puts even more market power to the traditional power plants.
Lastly, the variable ΔEUA still has a positive sign but is again not significant, making it not possible to comment on this outcome in full.

Looking at the results as a whole, it is possible to state that the variables taken into consideration have diverse effects in the time intervals considered.
These distinctions are the result of varying supply and demand conditions in the market, different energy mixes, in particular, the presence of solar renewable sources. Moreover, different competitive dynamics in the determination of merit order dispatching which, thanks to the opening of national borders, needs to be considered from a transnational perspective. In addition to these factors, there are possible technical limitations to which these systems are constrained.

Taking ΔNORD_LOAD coefficients into consideration, the highest value is observed in the H4 range, followed by a variation of approximately 30% in the subsequent ranges.
The variable of interest ΔNET_TRANSFERS_T shows a similar value in the intervals H4 and H19, and a lower value in the interval H13, in particular, the results of the three models are comparable to the values already observed in the existing literature.
Particular inhomogeneity is observed in the coefficients of the variable ΔVER_TOT, firstly, the coefficient of H19 is not significant and therefore not comparable, secondly, the highest value, observed in H4, is more than 20 times higher than the value observed in H13.
The internal transits variable, ΔNET_TRANSFERS_CNOR, sees a higher value in the H4, which decreases in the following time slots.
The iterative variable, GAS_PLANT * ΔGAS_MGP, for the reasons listed previously, settles at values below unity in the first interval, followed by a fourfold increase first and a sixfold increase thereafter.

In the following, the regressions coefficients will be reassessed by disaggregating the models and re-estimating them on a yearly basis to capture possible trends and special features, Tables 17-18-19 reported in the Appendix.
Starting from the H4 model is possible to point out that the effects seem to remain constant more or less during the years with some positive or negative variation being absorbed over time.
An exception is the variable ΔVER_TOT, which seems to have a downward trend, going from a coefficient of -0.10875 in 2015 to a coefficient of -0.05451 in 2020.

Some concern is given by the significant and negative value that the coefficient of the variable GAS_PLANT * ΔGAS_MGP, presents in the year 2015, which hardly has an economic explanation.
Particularly interesting is the coefficient of the variable ΔEUA, which is significant and positive in the year 2018.
Even more markedly, the coefficients of the second model H13 show no particular trends or outliers, with the exception of the coefficient of the variable ΔEUA, which is negative and weakly significant in the year 2016.
Finally, the H19 model has no outliers, but unlike the previous models, we can observe a slightly increasing trend in the magnitude of the coefficients of the ΔNET_TRANSFERS_T variables, while the other variables remain more or less constant.

Conclusions

This work originated from the desire to analyze the main changes and challenges that are reshaping the electricity market.
In particular, the necessary acceleration in the process towards carbon neutrality by integrating renewable generation sources characterized by intermittency and almost zero variable costs have led to changes in the structure and functioning of the market.
The process is enabled by the development and implementation of new technologies and increased interaction between different actors.
The progress in the integration of the European electricity market is analyzed examining the benefits and the price dynamics related to the integration of renewable sources generation and social welfare gains.
The analysis remains restricted to the effect of the cross-border transits on the prices of the net importing country and not the effects on the net exporting countries, making it impossible to compute the net benefits for the whole system considered.

To detect the impact of cross border trades on electricity prices an ex-post empirical analysis is developed for the Northern Italy bidding zone and the relation with the adjacent zones for a period starting from 12-02-2015 to the end of 2020.
A multivariate regression model is conducted dividing the sample by hourly time bands taking into consideration those of greatest interest and including several explanatory variables in the model specification.

The main findings show that the coefficients of the variable representing the demand remain positive and significant for all three intervals considered.
The variable representing generation from intermittent renewables sources when significant is negative, as described in the literature, confirming the “Merit order Effects of Renewables”. In addition, the effect strongly depends on the penetration of renewable generation in the generation mix.
The variable included to account for the fluctuation in the price of commodities is significant and positive, its effect strongly depends on the merit order dispatching, possible competition with other sources of production, technical constraints or the possibility to exercise market power from traditional power plants.

The variable accounting for cross-border transits is significant and has a negative sign, implying that an increase in cross-border inflows leads to a reduction in the wholesale price in the area under consideration as expected. In particular, an increase of 1000 MWh of incoming flows leads to a price decrease of 3.27 €/MWh in H4, 2.34 €/MWh in H13, 3.74 €/MWh in H19.

Similar results come from the analysis of the flows between the North and CNorth zones. The variable is significant and negative, indicating that an increase in the inflows leads to a decrease in wholesale prices. However, the average of the net flows is negative indicating a preponderance of flows from the North zone to the CNorth zone, suggesting that the intra-state transits generally contribute to the increase of the wholesale price.

The time partition adopted allows us to appreciate the different effects that the variables under consideration have in the respective intervals. These distinctions are the result of varying supply and demand conditions in the market, different energy mixes and different competitive dynamics in the determination of merit order dispatching, which, thanks to the opening of national borders, needs to be considered from a transnational perspective.

Further research could be conducted considering these results and proceeding to the analyses of the price dynamics of the net exporting countries to define the overall social welfare. In order to measure the total benefits that can be measured with the price dynamics it would be necessary to consider all the electricity trade relations between all the countries in the system, modelling the entire European market.

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Appendix

Table 7: Descriptive statistics, years 2015-2017

	2015 N=7776		2016 N=8784		2017 N=8760	
	Mean	SD	Mean	SD	Mean	SD
1) NORD_PRICE	*52.94*	*14.48*	*42.67*	*15.03*	*54.41*	*18.44*
2)NORD_LOAD	*17831.71*	*4521.55*	*17683.28*	*4564.66*	*18177.73*	*4407.46*
3) NET_TRANSFERS_T	*5433.24*	*1941.36*	*4695.07*	*2267.07*	*4644.40*	*1961.12*
4)VER_TOT	*850.28*	*1203.55*	*728.39*	*1068.81*	*818.57*	*1201.08*
5) NET_TRANSFERS_CNOR	*-154.96*	*1541.88*	*-592.66*	*1785.04*	*-508.76*	*1577.35*
6) GAS_MGP	*25.11*	*1.34*	*16.96*	*2.06*	*19.57*	*2.72*
7) EUA	*7.76*	*0.56*	*5.37*	*0.80*	*5.84*	*1.12*

Table 8: Descriptive statistics, years 2018-2020

	2018 N=8760		2019 N=8760		2020 N=8760	
	Mean	SD	Mean	SD	Mean	SD
1) NORD_PRICE	*60.71*	*15.41*	*51.25*	*12.91*	*37.79*	*14.45*
2)NORD_LOAD	*18780.64*	*4290.58*	*18499.95*	*4320.38*	*17163.02*	*4205.23*
3) NET_TRANSFERS_T	*5139.07*	*1733.97*	*4864.76*	*1479.26*	*4176.53*	*2395.35*
4)VER_TOT	*731.78*	*1114.34*	*813.35*	*1209.35*	*826.49*	*1226.52*
5) NET_TRANSFERS_CNOR	*-1079.49*	*1481.72*	*-1354.75*	*1390.34*	*-1653.06*	*1347.61*
6) GAS_MGP	*24.35*	*3.91*	*16.11*	*3.78*	*10.48*	*3.29*
7) EUA	*15.92*	*4.56*	*24.86*	*2.13*	*24.73*	*3.63*

Table 9: Correlation matrix, Total

	NORD_ PRICE	NORD_ LOAD	NET_TRANSFERS_ T	VER_ TOT	NET_TRANSFERS_ CNOR	GAS_ MGP	EUA
1)	*1,00*	*0,60*	*0,12*	*-0,07*	*0,22*	*0,55*	*-0,03*
2)	*0,60*	*1,00*	*0,35*	*0,31*	*0,29*	*0,13*	*0,01*
3)	*0,12*	*0,35*	*1,00*	*-0,21*	*-0,23*	*0,19*	*-0,09*
4)	*-0,07*	*0,31*	*-0,21*	*1,00*	*0.36*	*-0,07*	*0,00*
5)	*0,22*	*0,29*	*-0,23*	*0,36*	*-1,00*	*0,30*	*-0,29*
6)	*0,55*	*0,13*	*0,19*	*-0,07*	*0,30*	*1,00*	*-0,41*
7)	*-0,03*	*0,01*	*-0,09*	*0,00*	*-0,29*	*-0,41*	*1,00*

Table 10: ADF test-KPSS test, H4

H=4	ADF	KPSS	ADF-1st DIFF	KPSS-1st DIFF
1) **NORD_PRICE**	*-10.4079*	*8.3429*	*-45.360*	*0.0022*
2) **NORD_LOAD**	*-23.173*	*2.6371*	*-47.5447*	*0.0013*
3) NET_TRANSFERS_T*	*-16.6551*	*0.6402*	*-43.9651*	*0.0017*
4) **VER_TOT**	*-20.1052*	*3.9455*	*-48.185*	*0.0037*
5) NET_TRANSFERS_CNOR*	*-13.7664*	*0.6395*	*-45.364*	*0.0025*
6) GAS_MGP*	*-4.302*	*9.7552*	*-39.7543*	*0.015*
7) EUA*	*-2.2842*	*14.2332*	*-32.25*	*0.042*

Table 11: ADF test-KPSS test, H13

H=13	ADF	KPSS	ADF-1st DIFF	KPSS-1st DIFF
1) **NORD_PRICE**	*-13.7943*	*5.4466*	*-45.9352*	*0.0016*
2) **NORD_LOAD**	*-30.5177*	*0.772*	*-49.4223*	*0.0006*
3) NET_TRANSFERS_T*	*-19.0357*	*1.1093*	*-48.983*	*0.001*
4) **VER_TOT**	*-15.198*	*0.6476*	*-48.603*	*0.0012*
5) NET_TRANSFERS_CNOR*	*-20.6639*	*0.3231*	*-48.8344*	*0.001*
6) GAS_MGP*	*-4.302*	*9.7552*	*-39.7543*	*0.015*
7) EUA*	*-2.2842*	*14.2332*	*-32.25*	*0.042*

Table 12: ADF test-KPSS test, H19

H=19	ADF	KPSS	ADF-1st DIFF	KPSS-1st DIFF
1) **NORD_PRICE**	*-12.9487*	*4.6571*	*-42.5812*	*0.0021*
2) **NORD_LOAD**	*-25.1555*	*1.3064*	*-48.7715*	*0.0009*
3) NET_TRANSFERS_T*	*-15.2954*	*0.8996*	*-45.311*	*0.0011*
4) **VER_TOT**	*-4.7085*	*1.925*	*-53.186*	*0.0116*
5) NET_TRANSFERS_CNOR*	*-16.6515*	*1.1662*	*-47.4063*	*0.001*
6) GAS_MGP*	*-4.302*	*9.7552*	*-39.7543*	*0.015*
7) EUA*	*-2.284*	*14.2332*	*-32.25*	*0.042*

Table 13: Correlation matrix, H4

	ΔNORD _PRICE	ΔNORD _LOAD	ΔNET_TRANSFERS _T	ΔVER_ TOT	ΔNET_TRANSFERS _CNOR	ΔGAS _MGP	ΔEUA
1)	*1.00*	*0.34*	*-0.05*	*-0.17*	*-0.20*	*0.10*	*0.04*
2)	*0.34*	*1.00*	*0.38*	*0.00*	*0.14*	*0.11*	*0.01*
3)	*-0.05*	*0.38*	*1.00*	*-0.06*	*-0.50*	*0.05*	*0.03*
4)	*-0.17*	*0.00*	*-0.06*	*1.00*	*0.21*	*-0.00*	*-0.03*
5)	*-0.20*	*0.14*	*-0.50*	*0.21*	*1.00*	*-0.02*	*-0.07*
6)	*0.10*	*0.11*	*0.05*	*-0.00*	*-0.02*	*1.00*	*-0.01*
7)	*0.04*	*0.01*	*0.03*	*-0.03*	*-0.07*	*-0.01*	*1.00*

Table 14: Correlation matrix, H13

	ΔNORD _PRICE	ΔNORD _LOAD	ΔNET_TRANSFERS _T	ΔVER _TOT	ΔNET_TRANSFERS _CNOR	ΔGAS _MGP	ΔEUA
1)	*1.00*	*0.64*	*0.23*	*-0.17*	*0.07*	*0.23*	*0.01*
2)	*0.64*	*1.00*	*0.59*	*-0.03*	*0.17*	*0.19*	*0.02*
3)	*0.23*	*0.59*	*1.00*	*-0.13*	*0.33*	*0.12*	*0.02*
4)	*-0.17*	*-0.03*	*-0.13*	*1.00*	*-0.03*	*0.02*	*-0.00*
5)	*0.07*	*0.17*	*-0.33*	*-0.03*	*1.00*	*0.02*	*-0.00*
6)	*0.23*	*0.19*	*0.12*	*0.02*	*0.02*	*1.00*	*0.01*
7)	*0.01*	*0.02*	*0.02*	*-0.00*	*-0.00*	*-0.01*	*1.00*

Table 15: Correlation matrix, H19

	ΔNORD _PRICE	ΔNORD _LOAD	ΔNET_TRANSFERS _T	ΔVER_ TOT	ΔNET_TRANSFERS _CNOR	ΔGAS _MGP	ΔEUA
1)	*1.00*	*0.47*	*-0.12*	*-0.00*	*0.10*	*0.23*	*0.02*
2)	*0.47*	*1.00*	*0.37*	*0.00*	*0.12*	*0.20*	*0.01*
3)	*-0.12*	*0.37*	*1.00*	*0.00*	*-0.46*	*0.09*	*-0.00*
4)	*-0.00*	*0.00*	*0.00*	*1.00*	*0.01*	*0.00*	*0.01*
5)	*0.10*	*0.12*	*-0.46*	*0.01*	*1.00*	*0.04*	*-0.00*
6)	*0.23*	*0.20*	*0.09*	*0.00*	*0.04*	*1.00*	*0.01*
7)	*0.02*	*0.01*	*-0.00*	*0.01*	*-0.00*	*-0.01*	*1.00*

Table 16: Ljung-Box Test

	H4	H13	H19
Residuals	*p value ≃ 0*	*p value ≃ 0*	*p value ≃ 0*
Squared residuals	*p value ≃ 0*	*p value ≃ 0*	*p value ≃ 0*

Table 17: Regression results, H4 yearly period 2015-2020

	Model H4					
Dependent variable: ***ΔNORD_PRICE***	2015	2016	2017	2018	2019	2020
ΔNORD_LOAD	*0.00403****	*0.00280****	*0.00308****	*0.00356****	0.00405***	0.00306***
	(0.00030)	*(0.00024)*	*(0.00030)*	*(0.00030)*	(0.00020)	(0.00023)
ΔNET_TRANSFERS_T	*-0.00460****	*-0.00305****	*-0.00267****	*-0.00273****	-0.00377***	-0.00250***
	(0.00043)	*(0.00023)*	*(0.00039)*	*(0.00078)*	(0.00030)	(0.00022)
ΔVER_TOT	*-0.10875****	*-0.05556°*	*-0.02779*	*-0.06629*	-0.04763*	-0.05451**
	(0.02664)	*(0.02868)*	*(0.02740)*	*(0.05376)*	(0.02243)	(0.01864)
ΔNET_TRANSFERS_CNOR	*-0.00356****	*-0.00245****	*-0.00207****	*-0.00425****	-0.00424***	-0.00348***
	(0.00050)	*(0.00031)*	*(0.00044)*	*(0.00054)*	(0.00034)	(0.00029)
*GAS_PLANT * ΔGAS_MGP*	*-1.4364***	*0.11374*	*0.62816****	*-0.69627*	-0.36841	0.57311
	(0.50499)	*(0.28031)*	*(0.10006)*	*(0.69136)*	(0.35111)	(0.76600)
ΔEUA	*-1.1547*	*0.24100*	*-0.98540*	*1.3290**	-0.44998	-0.04441
	(3.5586)	*(1.3196)*	*(2.2006)*	*(0.53133)*	(0.51349)	(0.31631)
Constant	*-0.36698*	*0.91996*	*2.2041*	*0.36037*	0.91486	-2.9049**
	(1.0484)	*(1.1492)*	*(1.4617)*	*(1.7594)*	(1.1254)	(0.97829)
DM dummy	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*323*	*366*	*365*	*365*	*365*	*366*
Multiple R-squared	*0.4535*	*0.4814*	*0.3521*	*0.4069*	0.6251	0.5519
Adj. R-squared	*0.3624*	*0.4048*	*0.2561*	*0.3189*	0.5695	0.4856

*Note: *** p-value<0.001, ** p-value<0.01, * p-value < 0.05, ° p-value<0.1*

Standard errors in parenthesis are robust to heteroskedasticity and serial correlation (Newey West)

Table 18: Regression results, H13 yearly period 2015-2020

	Model H13					
Dependent variable: Δ***NORD_PRICE***	2015	2016	2017	2018	2019	2020
Δ*NORD_LOAD*	*0.00296****	*0.00217****	*0.00279****	*0.00257****	0.00223***	0.00259***
	(0.00019)	*(0.00012)*	*(0.00018)*	*(0.00038)*	(0.00018)	(0.00013)
Δ*NET_TRANSFERS_T*	*-0.00286****	*-0.00199****	*-0.00227****	*-0.00258°*	-0.00214***	-0.00238***
	(0.00043)	*(0.00022)*	*(0.00035)*	*(0.00150)*	(0.00030)	(0.00028)
Δ*VER_TOT*	*-0.00228****	*-0.00223****	*-0.00172****	*-0.00368****	-0.00254***	-0.00259***
	(0.00050)	*(0.00029)*	*(0.00049)*	*(0.00109)*	(0.02243)	(0.00037)
Δ*NET_TRANSFERS_CNOR*	*-0.00275****	*-0.00125***	*-0.00209****	*-0.00279*	-0.00184***	-0.00283***
	(0.00074)	*(0.00040)*	*(0.00051)*	*(0.00175)*	(0.00050)	(0.00034)
GAS_PLANT * Δ*GAS_MGP*	*0.71129*	*0.14866*	*1.7823****	*1.4492****	0.48867	0.99186
	(0.99251)	*(0.50857)*	*(0.24625)*	*(0.15962)*	(0.82736)	(0.97690)
Δ*EUA*	*2.9193*	*-3.0815°*	*0.71491*	*0.51931*	0.07421	0.28788
	(5.0132)	*(1.6350)*	*(2.6113)*	*(1.0182)*	(0.58946)	(0.42196)
Constant	*-0.75213*	*1.0272*	*3.1270*	*-1.8524*	-1.9011	-2.6382
	(2.1014)	*(1.2608)*	*(2.6405)*	*(2.6154)*	(1.5112)	(1.9285)
DM dummy	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*323*	*366*	*365*	*365*	*365*	*366*
Multiple R-squared	*0.5685*	*0.7079*	*0.5707*	*0.4609*	0.6392	0.7118
Adj. R-squared	*0.4966*	*0.6647*	*0.507*	*0.3809*	0.5857	0.6692

Table 18: Regression results, H13 yearly period 2015-2020

*Note: *** p-value<0.001, ** p-value<0.01, * p-value < 0.05, ° p-value<0.1*

Standard errors in parenthesis are robust to heteroskedasticity and serial correlation (Newey West)

Table 19: Regression results, H19 yearly period 2015-2020

	Model H19					
Dependent variable: Δ***NORD_PRICE***	2015	2016	2017	2018	2019	2020
Δ*NORD_LOAD*	*0.00232****	*0.00223****	*0.00332****	*0.00248****	0.00215***	0.00311***
	(0.00023)	*(0.00019)*	*(0.00035)*	*(0.00025)*	(0.00015)	(0.00019)
Δ*NET_TRANSFERS_T*	*-0.00281****	*-0.00265****	*-0.00460****	*-0.00431****	-0.00358***	-0.00407***
	(0.00047)	*(0.00044)*	*(0.00054)*	*(0.00063)*	(0.00045)	(0.00042)
Δ*VER_TOT*	*0.00871*	*-0.01459*	*-0.00438*	*0.00202*	-0.01097	-0.00879
	(0.00718)	*(0.00135)*	*(0.01290)*	*(0.01194)*	(0.00761)	(0.00887)
Δ*NET_TRANSFERS_CNOR*	*-0.00106*	*-0.00150°*	*-0.00349****	*-0.00220***	-0.00217***	-0.00234***
	(0.00077)	*(0.00082)*	*(0.00076)*	*(0.00071)*	(0.00053)	(0.00041)
GAS_PLANT * Δ*GAS_MGP*	*0.38632*	*-0.87422*	*3.9132****	*1.0667****	1.0549	0.47417
	(1.2834)	*(1.2180)*	*(0.60361)*	*(0.20977)*	(0.87081)	(0.97690)
Δ*EUA*	*-0.97043*	*0.59377*	*4.5419*	*1.8698*	-0.42335	0.31990
	(4.0602)	*(3.6144)*	*(4.1303)*	*(1.2618)*	(0.55022)	(1.3919)
Constant	*-0.13267*	*1.9429*	*4.7030°*	*-2.1261*	1.1599	-0.73042
	(1.9109)	*(3.4307)*	*(2.7526)*	*(1.8193)*	(1.5906)	(1.4814)
DM dummy	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	*323*	*366*	*365*	*365*	*365*	*366*
Multiple R-squared	*0.4528*	*0.4066*	*0.3927*	*0.4315*	0.5609	0.5618
Adj. R-squared	*0.3616*	*0.3189*	*0.3026*	*0.3472*	0.4958	0.4971

*Note: *** p-value<0.001, ** p-value<0.01, * p-value < 0.05, ° p-value<0.1*

Standard errors in parenthesis are robust to heteroskedasticity and serial correlation (Newey West)

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