This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 884157

FLExibilize combined cycle power plant through power-to-X solutions using non-CONventional Fuels

D1.4 – "Electrical market assessment for enhanced FLEXnCONFU concept in CC"

Organisation name of lead contractor: RINA-C

Project Contractual Details

Project Title	FLExibilize combined cycle power plant through power-to-X solutions using non-CONventional Fuels
Project Acronym	FLEXnCONFU
Grant Agreement No.	884157
Project Start Date	01-04-2020
Project End Date	31-03-2024
Duration	48 months
Website	www.flexnconfu.eu

Deliverables Details

Number	D1.4		
Title	Electrical market assessment for enhanced FLEXnCONFU concept in CC		
Work Package	**WP1**		
Dissemination level[1]	PU		
Due date (M)	24	Submission date (M)	24
Deliverable responsible	RINA-C (Federico Sanguineri)		
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Reviewer(s)	KTH, CNET, NPT, TP, ENLAB		
Final review and quality approval	28-03-2022		

Document History

Date	Version	Name	Changes
23/03/2022	1.0	FLEXnCONFU D1.4 First Version for Review	First Version to be reviewed
28/03/2022	2.0	FLEXnCONFU D1.4 Reviewed Version	Second Version Reviewed by Partners containing feedbacks and comments
31/03/2022	3.0	FLEXnCONFU D1.4 Final Version	Final Version for submission, modified according to the Partners Review

[1] PU = Public
CO = Confidential, only for members of the consortium (including Commission Services)

Executive Summary

The objective of the document: D1.4 "Electrical market assessment for enhanced FLEXnCONFU concept in CC", is to identify the most suitable European Member States for the application of the FLEXnCONFU project solution.

To achieve this goal, the document was structured as follows.

First of all, the functioning of the electricity market at European level was described, considering the electricity supply chain, the main players involved, the main types of market (long-term, spot, balancing and re-dispatching markets), and their functioning also considering the zonal subdivision that characterizes Europe. Moreover, the electricity sector of the three representative Member States (Portugal, Belgium, Italy: where FLEXnCONFU demo will be demonstrated), has been examined individually, detailing for each Country, the relevant information regarding generation, transmission, distribution, and retail of electricity.
The operation of the supply chain is very similar in the three Countries. They all present national monopolies for electricity transmission, zonal monopolies for distribution, and liberalized generation and retail activities. An important aspect in the context of the FLEXnCONFU project is the **share of electricity generation through natural gas**, which is one of the main sources of production (in Italy and Portugal is the first source by production shares) in all three representative States.

Secondly, the ancillary services market at European level has been analysed, defining the main type of services provided, their functioning and the actors involved. In addition, some of the current trends (decarbonisation, electrification of consumption, urbanisation) have been described, as they involve significant effects on the functioning of the grid, in terms of balance, stability and security. These aspects determine the increasing relevance of ancillary services. In addition, the functioning of the ancillary services market was analysed across the three representative EU Countries. Here, again, the functioning of the markets is similar, and the three types of reserves (primary, secondary and tertiary) play a fundamental role.

Thirdly, the methodology used to define the most suitable European States to apply the FLEXnCONFU solution was identified and described. First of all, a series of KPIs were identified, and approved by the Partners. Such KPIs allow to consider several relevant aspects of the market features and of the electricity supply chain of each State. Following the research for all the needed data, these indicators were normalized in order to assume a value between 0 and 1. Before defining the overall score per Country, for each indicator it was assigned a weight (which was again validated by the Partners) based on its relevance on the applicability of the solution. Finally, the various normalized and weighted KPIs were summed for each Country. The result is a ranking that allows to identify the most suitable Countries for the implementation of the FLEXnCONFU solution and shows the relative total scores. An interesting aspect is that the top 5 positions in the ranking include the three representative EU States: Italy (1st), Belgium (4th) and Portugal (5th).

Table 1: Top five EU Countries

Country	Sum of TOTAL
Italy	5.0197
Spain	4.9932
Germany	4.5556
Belgium	4.3542
Portugal	4.3114

Finally, for each representative EU State a relevant Partner has analysed the grid code of its Country considering a specific set of areas: the market for ancillary services, electrolyser installations, emission limits, hydrogen blending and storage of hydrogen and ammonia.

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Abbreviations	
Acronym	Definition
AAT	Very High Voltage
ACER	Agency for the Cooperation of Energy Regulators
AIA	Integrated Environmental Authorization
ARERA	Regulatory Authority for Energy, Networks and Environment
BSP	Balancing Service Providers
CA	Consortium Agreement
CBA	Cost Benefit Analysis
DMP	Data Management Plan
DSO	Distribution System Operators
ECB	European Central Bank
ENTSO-E	European Network of Transmission System Operators
ERSE	Energy Services Regulatory Authority
EU	European
FRNP	Non-programmable Renewable Sources
GA	Grant Agreement
GME	Gestore dei Mercati Energetici – Energy Market Manager
HV	High Voltage
IMF	International Monetary Fund
IPQ	Portuguese Quality Institute
LV	Low Voltage
MGP	Day ahead market
MI	Intraday Market
MIBEL	Iberian Electricity Market
MSD	Ancillary Services market
MV	Medium Voltage
NoBo	Notified Body
PE	Pressure Equipment
PS	Permissible pressure
REN	Redes Energéticas Nacionais – National Energy Grids
RIB	Recognized Inspection Body
SOGL	System Operation Guidelines
TIDE	Integrated Text of Electricity Dispatching
TIUC	Integrated Text of Accounting Unblinding
TIUF	Integrated Text of Functional Unblinding
TSO	Transmission System Operator

1. Introduction

This deliverable was prepared within the framework of Work Package 1 "Scenario analysis and requirements definition" and refers to activities carried out by RINA-C within Task 1.4 "Most promising EU electrical market for FLEXnCONFU enhanced CC and related technical/grid requirements".
The purpose of this document is to identify the European countries where the FLEXnCONFU solution is most suitable. To achieve such result, the document provides:

- ✓ a description of the electricity market both at European level and at single representative Country level (representative Countries are Italy, Belgium and Portugal)
- ✓ an analysis of the ancillary services market both at European level and at single representative Country level
- ✓ analysis of network codes and regulations for each country
- ✓ an identification through a defined and explained methodological approach, of the Countries where the application of the FLEXnCONFU solution appear most suitable.

The structure of the document is in line with the four performed activities just listed.

2. Task planning

2.1. Dependencies on other tasks

Main interdependencies of Task 1.4 with other Tasks and Deliverables have been highlighted in Table 2 below.

Table 2: Interdependencies with other tasks and related deliverables

Outputs to	
Tasks	Deliverables
T3.2: Dynamic modelling of the integrated systems (P2H/P2A)	D3.2: P2A/P2H dynamic model of FLEXnCONFU integrated system
T6.2: Feasibility study of the FLEXnCONFU concept	D6.4: Pre-feasibility studies of P2A and P2H solutions in real application
T6.5: Regulatory and non-technical framework	D6.7: Regulatory and nontechnical assessment of FLEXnCONFU solutions

2.2. Contribution from partners

The collaboration of the Partners was requested to carry out two sections.

First, considering the methodological approach used, approval was requested (from KTH, CNET, NPT, TP, ENLAB) for the correct identification of the KPIs. Once identified, support was also requested for the correct assignment of the weight of these KPIs in the calculation of the overall score.

Secondly, an analysis of grid regulation specifically for Portugal, Belgium, and Italy was requested by CNET, ENLAB, and TP respectively.

3. EU Electrical Market

In this paragraph the European electricity market will be analysed considering its general structure and evaluating the future potential developments. The aim of this introduction is to define the basic information that will be used to understand which EU electrical markets, have the greatest potential to promote FLEXnCONFU concept.

First of all, it is appropriate to describe the main stakeholders involved in the European electricity supply chain:

- ✓ **Generators:** are electricity production plants, rated by their generation capacity, that is the maximum power they can produce. They are divided into Firm-capacity generators, that can be switched on or off on demand, and Variable-capacity generators whose production depends on factors like wind or sunshine, so they are only able to generate certain amounts at certain times depending on weather conditions. Generators also differ based on the flexibility that they can provide to the system. Some generation technologies are well-suited for producing a stable amount of electricity over longer periods, while others can change production more rapidly to adapt to fluctuations in electricity demand.

- ✓ **Transmission System Operator (TSO)**: are responsible for the transmission of electricity from generation plants to regional or local electricity distribution operators (DSOs) by way of a high voltage electrical grid. Since TSOs are usually a natural monopoly, they are subject to state regulation. TSOs are responsible for operating, maintaining and planning the transmission network. Their primary activity is to ensure the balancing of the grid, i.e., the balance between demand (energy consumption) and supply (generation), in order to avoid the risk of overloading, fluctuations in frequency, interruptions in supply and even grid failure. In this way, the TSO guarantees the supply of electricity to all consumers. With the increase in the share of renewable generation, maintaining grid balancing is more complex as the production pattern does not coincide with the consumption trend. TSOs provide grid access to the electricity market players (i.e., generating companies, traders, suppliers, distributors and directly connected customers) according to non-discriminatory and transparent rules. At European level, these are organized in the European Network of Transmission System Operators (ENTSO-E), which draws up 10-year network development plans and participates in the development of network codes.

- ✓ **Distribution System Operators (DSO):** are entities that enable the supply of electricity to end customers. While long-distance transport (transmission) is carried out at high voltage, energy distribution is carried out at medium or low voltage. Energy is taken from the transmission grid and supplied to each end-user. Like the TSO, the distribution operator has to maintain the balance of its grid and has to guarantee the supply of electricity to all consumers in its area.

- ✓ **Electricity Retailer**: re entities (usually companies) that supplies electricity to end-users in order to obtain economic revenues. They purchase energy in the wholesale market and then resell it to consumers at a higher price. The goal of the Retailers is to reach many customers and to maximize their profits. The Retailer is also responsible for getting customers connected to the grid and for customer billing. Relationships with consumers are determined by contractual agreements, where the supply period, the price of energy and any clauses are determined.

✓ **Consumers**: are end-users of electricity. They pay suppliers through bills for the electricity that they receive. Electricity prices vary based on type of consumer. In fact, industrial consumers can usually obtain more competitive prices than household's users, thanks to their high level of consumption and consequently high negotiating power. Electricity suppliers and Consumers represent the electricity Retail market.

✓ **Regulators**: are entities that set regulations and oversee the functioning of the market. The rules for the operation of electricity markets are set by independent national regulators. At EU level, the Agency for the Cooperation of Energy Regulators (ACER) defines the guidelines for transnational electricity networks and markets, the so-called Network Codes. These are then further developed by ENTSO-E (the European association for the cooperation of transmission system operators for electricity) and approved by Member States' representatives through the comitology procedure. (Erbach, 2016)[14]

The Figure 1 shows the electricity supply chain and the different players involved in its functioning.

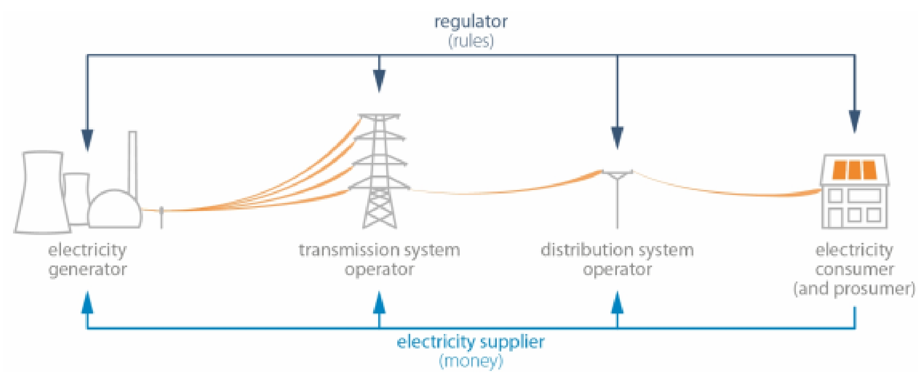

Figure 1: Schematic overview of the electricity supply chain
Source: (EPRS, 2016)[13]

According to the European University Institute, the electricity markets can be represented in four main clusters:

- **Long-term markets**, that includes Forward Energy Markets, Forward Transmission Markets and Capacity Mechanism
- **Wholesales or Spot Markets**, that includes Day-ahead and Intraday Markets.
- **Balancing Markets**, that includes Balancing Energy Markets and Balancing Capacity Markets.
- **Transmission-redispatch Markets**, that includes Re-dispatching markets and reservation for redispatch.

This concept is highlighted in Figure 2.

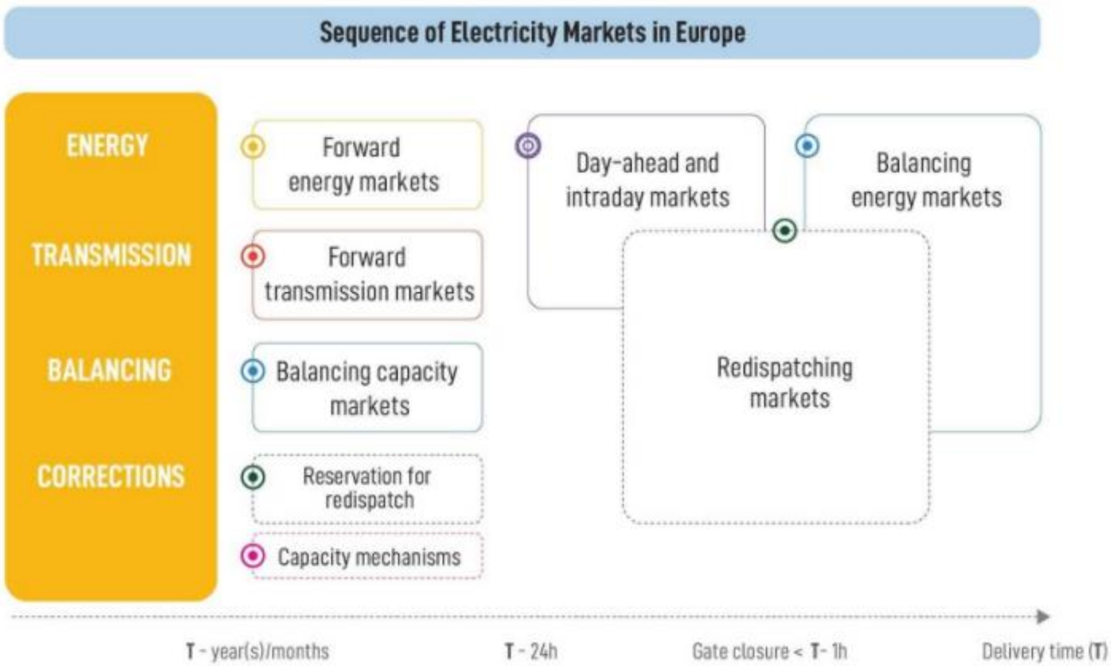

Figure 2: Schematic overview of the typical sequence of existing electricity markets in the EU
Source: (EUI, 2020)[16]

Long-term markets

Forward Electricity and Transmission Markets entail transactions involving future exchanges of electricity whose delivery may range from one month to four years ahead. In these financial markets both standardized products, and bilateral contracts among parties (OTC) can be concluded. Electricity prices vary according to the bidding zone, and energy exchanges follows the prices in according to the zone considered. The Figure 3 shows the current configuration of bidding zones in Europe.

Figure 3: Bidding zone configuration in Europe, 2014
Source: (Ofgem, 2014)[28]

In addition to the forward energy and transmission markets, considering the long-term time horizon, Member States may decide to establish a capacity mechanism if it is considered necessary, with the aim to ensure the stability of the electrical system in case of demand peaks. Capacity mechanisms are usually organized by the TSO and involves payments to electricity generators to keep generation capacity in reserve. Capacity supply occurs from one to about four years before delivery. (EUI, 2020)[16]

Wholesale or Spot Markets

The participants in the wholesale electricity market are generators, electricity suppliers and large industrial consumers. The main purpose of the spot market is to adjust long-term position closer to delivery by market participants. The volumes traded in the wholesale electricity markets are frequently a fraction of the total volume of generated electricity. The wholesale electricity prices act as price reference for long-term contracts.

The wholesale energy market is divided into the **Day-Ahead Market** and the **Intra-day Market**. The Day-Ahead Market consists of an auction that takes place at midday and covers the next day's 24 hours. All accepted bids are paid at the marginal offer price as the Figure 4 shows. Trading is organized by one or several power exchanges per Member State.

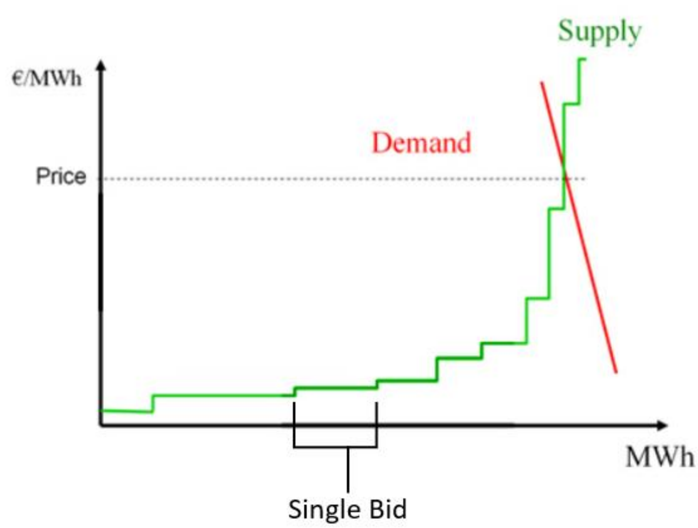

Figure 4: Price definition in the day-ahead market

After the day-ahead market is executed, the intraday market starts. The intraday market is an important element that allow to adjust the quantity of energy exchanged in the day-ahead market, according to expected needs in real-time from the market agents. Currently, intraday markets differ by countries: in some countries they are structured via continuous trading, while in others via auctions. Once operations in this market are completed, the results are sent to system operators to allow the scheduling of the balancing processes. (EUI, 2020)[16]

Balancing markets

Considering balancing, the electricity supply must be always equal to the electricity demand, otherwise the system risks breaking down. Traditionally, non-flexible generators are used for serving the base load, while flexible generators are used for meeting peaks in demand. The increased share of variable capacity, such as wind and solar, means that more flexible generation capacity is needed to satisfy demand when production from variable generators is low. To ensure security of electricity supply, enough generation capacity must be available to always meet demand.

In this context, once the exchanges in the spot market are defined the balancing mechanism takes place to ensure that electricity supply equals demand in real-time. Balancing activities include all actions and processes through which each TSO ensure the correct frequency of the system and the guarantee the required quality of the grid in each control area. The balancing process consists of three main steps: TSOs size their need for balancing reserves, purchase the required balancing capacity, and purchase the energy to maintain the grid in balance. (Entsoe, 2018)[12]

In balancing capacity markets, contracted Balancing Service Providers (BSPs) are paid based on the availability of provided energy. BSPs contracted in the balancing capacity market then offer their balancing energy in the balancing energy markets. The volume of exchanged energy is based on real-time imbalances (EUI, 2020)[16]. Balancing supply and demand in the short term is carried out with the use of primary reserves (activated within seconds), that it must be provided by the generators and the remuneration for this production variation is usually optional. Secondary reserves (activated within a few minutes) and tertiary reserves (activated within 15 minutes) are activated through the request (automatic or not) of the TSO in the balancing energy market and the energy is paid at offered price (Pay-as-bid).

Transmission re-dispatch markets

The term redispatch in the European Union Internal Electricity Market refers to a measure implemented by one or various system operators by changing the pattern of generation and/or load in order to change physical flows in the transmission system with the aim to resolve a physical congestion or to ensure system security. Such action is required when generation or consumption led to a potential violation of operational limits (e.g., thermal limits, voltage ranges, etc.) of a certain network element within a bidding zone. This situation occurs regularly. In most of EU member states, generators are legally obliged to participate in redispatch and prices are regulated. (Statnett et al., 2020)[36]

3.1. Belgium Electrical Market

Since the beginning of the 21st century, the Belgian electricity market has been fully liberalized for the generation and supply of electricity. In accordance with EU electricity regulation, the objective is to:

- ✓ Improve competition in electricity market.
- ✓ Enable final customers to select their energy providers
- ✓ Achieve a higher quality of service standards
- ✓ Ensure security of supply and sustainability.

In contrary, transmission and distribution activities are subject to a monopoly, either national (TSO) or zonal (DSO).

3.1.1 Belgian Generation

The largest electricity producer in Belgium is Engie Electrabel that has an installed capacity of 9,077MW. Other generators are:

- ✓ EDF Luminus (the second largest producer)
- ✓ Eneco
- ✓ Lampiris
- ✓ Ecopower

The remaining shares of electricity generation are produced by small independent producers.
As Figure 5 shows, in Belgium nuclear generation accounts for about 38,9% of total generation. The use of renewable sources has been growing in recent years, while as regards fossil sources, coal has recorded a significant reduction while natural gas has increased.

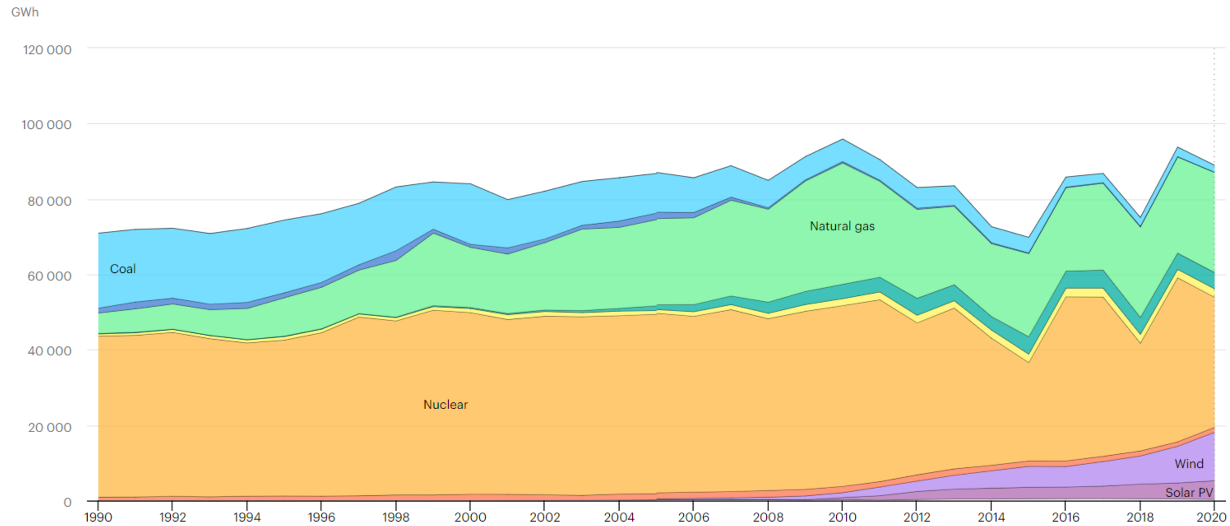

Figure 5: Belgian electricity generation by source (GWh)
(IEA, 2020)[22]

3.1.2 Belgian Transmission

The Belgian transmission and distribution are regulated through national or local geographic monopolies. "Elia" is the national transmission system operator (TSO), who transmits electricity through high voltage lines from generators to industrial consumers or to the regional distribution system operators (DSOs). The Article 8 of the Belgian Electricity Law define the management of the transmission system that must be carried out by Elia.
Elia has responsibility to:

- ✓ Guarantee security of supply of the transmission grid (management, development, and maintenance)
- ✓ Guarantee safety, balancing, and efficiency of the grid
- ✓ Ensure an equal treatment between users
- ✓ Set tariffs and measures applied to Balancing Responsible Parties to ensure grid balancing
- ✓ Providing information to end-users for their efficient access to the grid.

3.1.3 Belgian Distribution

DSOs convert the electricity into low voltage and supply electricity to end-users through their electricity line grids. The DSOs are owned by public local municipal entities and must respect EU unbundling requirements. The various DSOs have legal monopolies related to defined geographical areas:

- ✓ **Flanders**: Fluvius
- ✓ **Wallonia:** ORES and RESA
- ✓ **Brussels**: Sibelga

These DSOs are management corporations that include smaller operators that are responsible for specific sections of the region.
The DSOs are responsible for:

- Ensure the electricity needs of customers
- Resolving interruptions and problems in the supply of electricity to their network
- Guarantee network access
- Management and maintenance of the grid assuring security, balancing and efficiency.

3.1.4 Belgian Retail

Retailers are responsible for supplying electricity to end users. A supplier must obtain a supply license before being able to deliver electricity in Belgium through the transmission or distribution grid.
The main Belgian suppliers are listed below, highlighting the distinction based on the geographical areas considered (Flanders, Wallonia, and Brussels). In addition, Figure 6 Figure 7 Figure 8 show the market share of the main Retailers in each region. As can be seen, Engie is the market leader with **over** 39% of market share in all three regions.

Flanders:

- Engie Electrabel
- Luminus
- Eneco
- Lampiris
- Mega
- Elegant

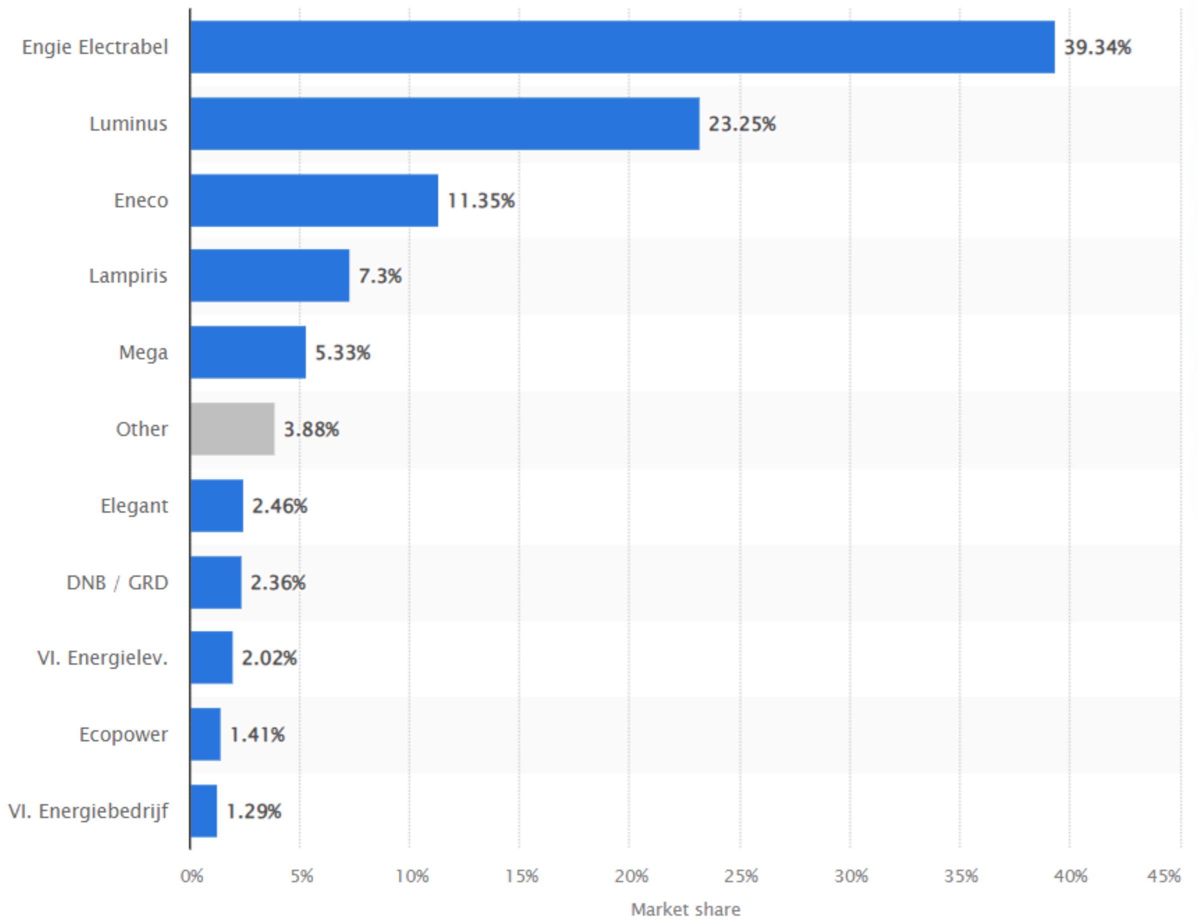

Figure 6: Biggest electricity suppliers in Flanders (Belgium) 2021, by market share (Statista, 2021)[32]

✓ **Wallonia:**

- Engie Electrabel
- Luminus
- Lampiris
- Mega
- Eneco

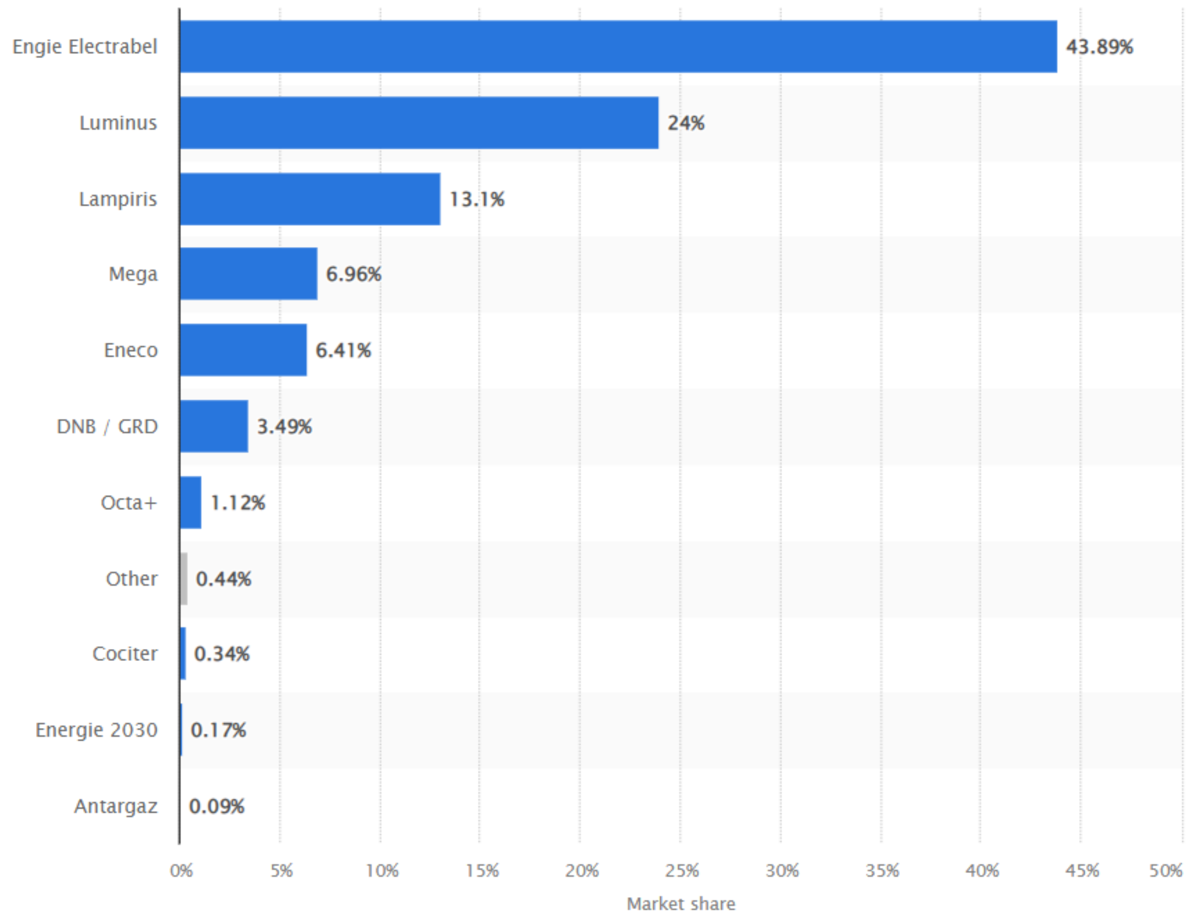

Figure 7: Biggest electricity suppliers in Wallonia (Belgium) 2021, by market share
(Statista, 2021)[33]

✓ **Brussels:**
- Engie Electrabel
- Lampiris
- Luminus
- Mega
- Octa+
- Eneco

(Thomson Reuters, 2021)[41]

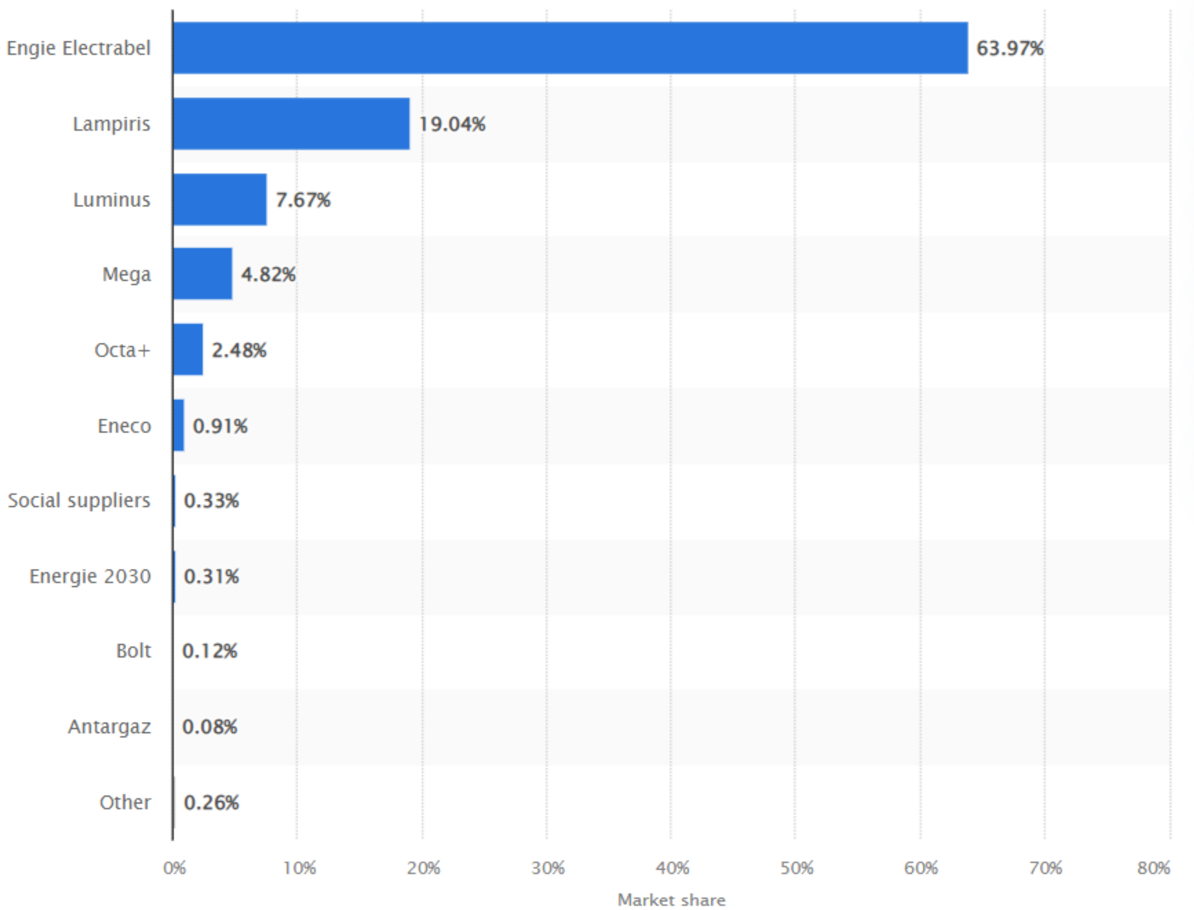

Figure 8: Leading electricity suppliers in the Brussels-Capital Region (Belgium) in 2021, by market share (Statista, 2021)[34]

3.2. Portugal electrical Market

The energy sector in Portugal has been almost completely liberalized as a result of the application of European directives (Electricity Directive 2009/72/EC) and of the privatization process which was stimulated by the financial assistance plan imposed by the International Monetary Fund (IMF), European Central Bank (ECB) and European Commission. To date, anyone who has obtained a license can become a generator or a supplier of electricity. In fact, generation, distribution, and supply must be unbundled in terms of legal and accountability separation while transmission must also have an unbundled ownership. Regarding transmission and distribution, they are allocated through service concession agreements signed with the Portuguese government, granting concessionaires the exclusive right to manage the networks for periods of 50 and 35 years, respectively.

3.2.1 Portuguese Generation

Two generation regimes can be considered. Ordinary regime that includes thermoelectric generation and special regime which includes renewable generation, cogeneration, small production plants, and other regimes (such as individual generation for self-consumption).

As a result of government incentive policies, renewable production in Portugal has increased significantly in recent years as Figure 9 shows.

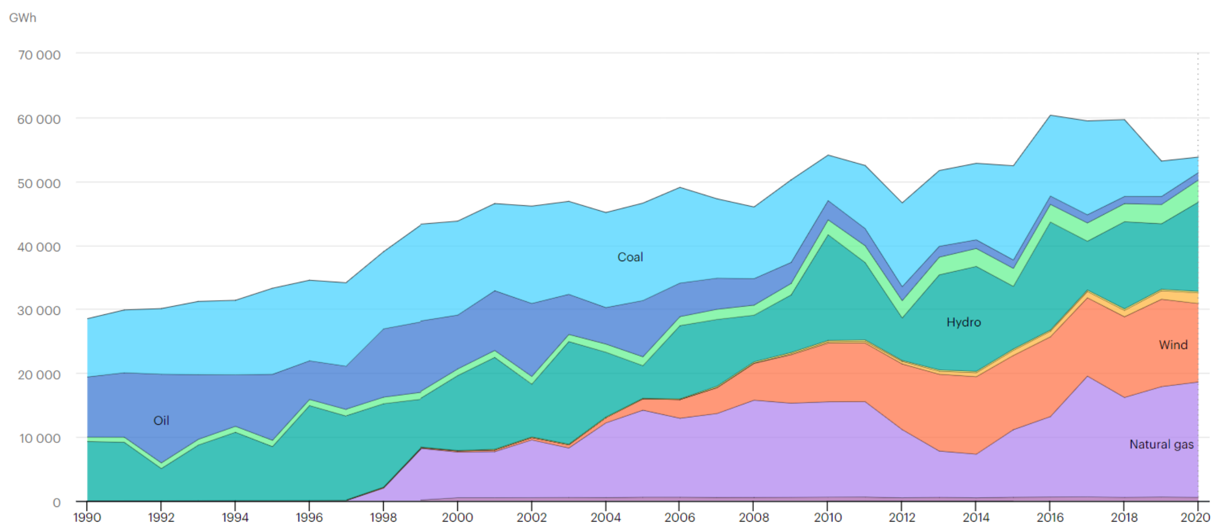

Figure 9: Portugal electricity generation by source (GWh)
(IEA, 2020)[22]

Considering the ordinary regime, the largest company is EDP Gestão da Produção de Energia SA, followed by:

- ✓ Elecgas and Tejo Energia (owned by Endesa and Trustenergy, a joint venture of Engie and Marubeni)
- ✓ Turbogás (owned by Trustenergy)

Considering the special regime, the main companies are:

- ✓ EDP Renováveis
- ✓ Acciona Energia Portugal
- ✓ EDF EN
- ✓ Finerge
- ✓ GENERG
- ✓ Iberwind
- ✓ Truswind

3.2.2 Portuguese Transmission

"Redes Energéticas Nacionais" (REN) is the Portuguese TSO and exclusively owns, manages, and maintains the electricity transmission system in accordance with an exclusive public service concession contracted with the government until 2057. As other European TSO, REN must connect all entities (generators, distributors, industrial consumers) in a non-discriminatory way. The TSO is compensated for the use of its infrastructures as set out in the tariff regulations approved by the Energy Services Regulatory Authority (ERSE).

3.2.3 Portuguese Distribution

In mainland E-REDES is the only DSO for high and medium voltage distribution systems. It also operates the low-voltage distribution for 278 of Portugal's 308 municipalities, which represent 99.5% of the low-voltage grid connected consumers. Ten other smaller DSOs supply 0.5% of the low voltage connected consumers. (IEA, 2021) [24]
In Azores and Madeira, the DSOs are Electricidade dos Açores and Empresa de Electricidade da Madeira. Like the TSO, in order to use the distribution grid, it is necessary a government concession for the use of infrastructure and an approval on pricing scheme by ERSE.

3.2.4 Portuguese Retail

Considering the wholesale market, Portugal and Spain have a single integrated Iberian electricity market (MIBEL) since 2007. They have a common spot and forward market operator. The MIBEL wholesale market is based on standardized trading methods.

Considering supply, some customers (about 15%) are supplied by the Supplier of last resort, where the supplier must provide universal supply to defined consumers at regulated rates (set annually by ERSE), while most customers (85%, representing 94% of electricity consumption) have moved to the free-market regime where supply is carried out by providers on freely negotiated terms (ERSE, 2022)[15]. The main Supply companies are:

- ✓ EDP
- ✓ Galp
- ✓ Endesa
- ✓ Iberdrola

As Figure 10 shows, EDP is the main supplier with 73,8% of consumers and 42% of total supply. Although there are 29 retailers active in Portugal, the market is highly concentrated, with the top four companies (EDP, Endesa, Iberdrola and Galp) holding 93,6% of consumers and 81,8% of total supply, in January 2022.

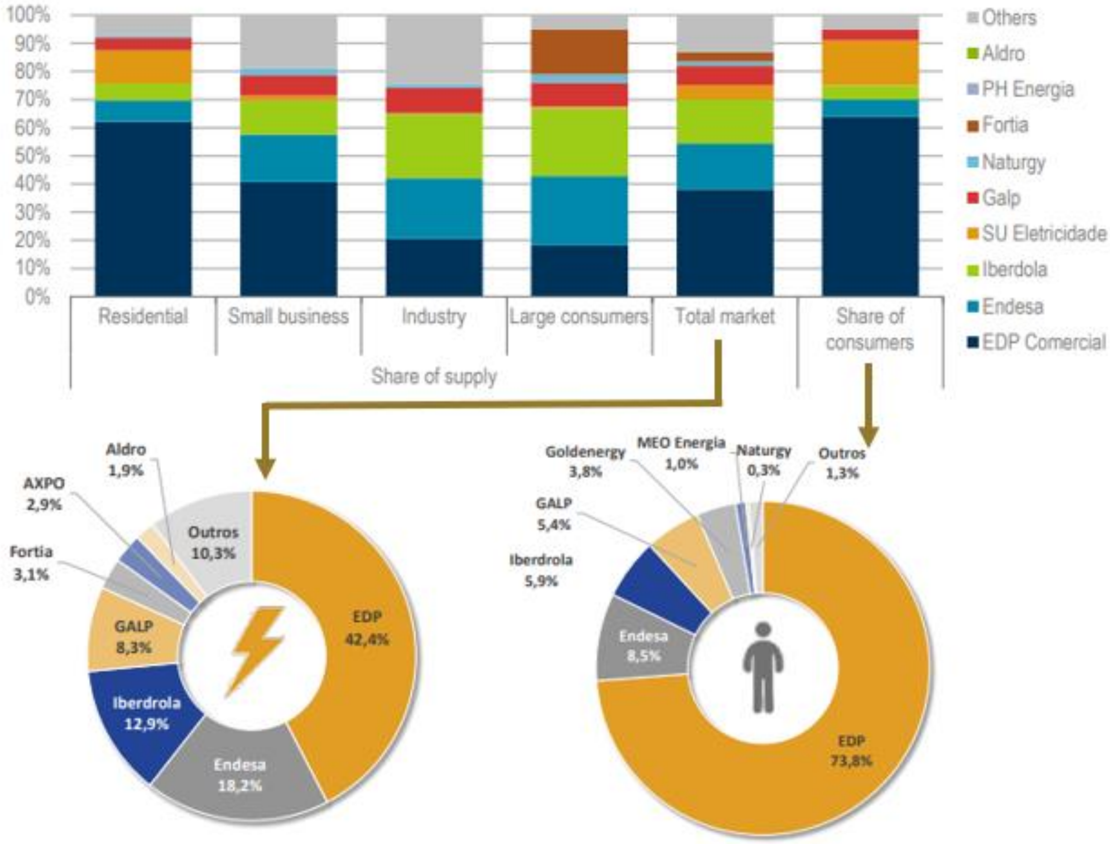

Figure 10: Electricity suppliers in Portugal, by type of consumer, 2022
(IEA, 2021)[24] (ERSE, 2022)[15]

Considering the supply of last resort, the main supplier is EDP Serviço Universal, that supplies continental Portugal while in the Azores and Madeira, the suppliers of last resort are Electricidade dos Açores and Empresa de Electricidade da Madeira. (Thomson Reuters, 2020)[40]

3.3. Italian Electrical Market

The Italian government has promoted the liberalization of electricity markets (both wholesale and retail) in order to increase their efficiency and the level of competition. The wholesale market was established as a result of the Bersani Decree (1999) which launched the liberalization of the electricity market. This decree was implemented following the EU directives concerning the creation of an internal integrated electricity market. The Italian electricity market is managed by the Gestore dei Mercati Energetici (GME). This market was established to promote competition (in generation, sale, and purchase) ensuring transparency and neutrality, and to ensure the availability of ancillary services. Concerning transmission and distribution activities, these are carried out under a national or zonal monopoly. In particular, the activity of electricity transmission is the exclusive responsibility of the transmission system operator, that is Terna. (Ministero dello Sviluppo Economico, 2022)[27]

As defined by ARERA (Regulatory Authority for Energy, Networks and Environment) through the TIUC and TIUF (concerning, respectively, accounting unbundling and functional unbundling), companies or groups of companies that operate in the infrastructure sectors (e.g., transmission) of electricity and in the liberal sectors (e.g., sale) are required to meet the obligations of functional unbundling. Considering accounting unbundling, the activities impacted are production, transmission, distribution, and sales. (Arera, 2016)[2] (Arera, 2015)[1]

3.3.1 Italian Generation

The main Italian generation companies have been listed by share contribution to national generation in Figure 11:

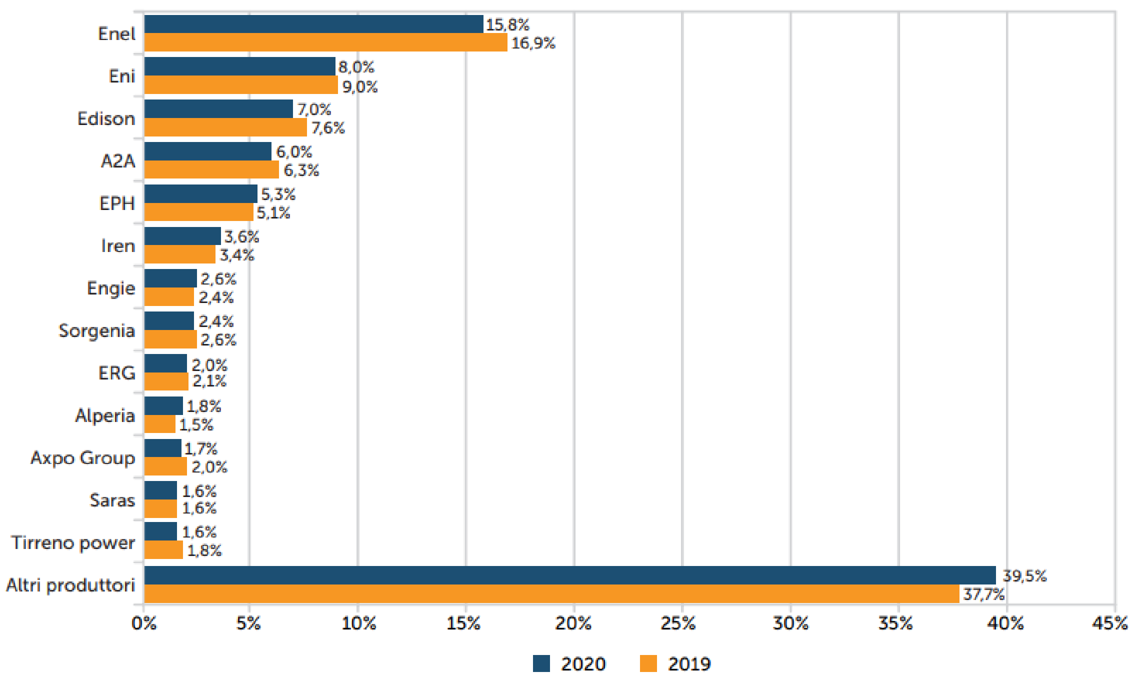

Figure 11: Italian electricity generation companies, by contribution to gross generation

Source: (Arera, 2020)[4]

As of 2020, the main electricity generators in Italy are Enel with 15,80% of the market value, Eni with 8% of market value, Edison with 7% and A2A with 6%. The others player in the market have less than 6% share contribution.

In 2020, as Figure 12 shows, the Italian electricity generation was 281.487 GWh. 42,77% derived from renewable sources (Wind, Solar, Hydro, Geothermal, Biofuels and Waste) while the remaining 57% derived from thermal sources. Since there is no energy from nuclear sources, the most common energy source is gas (48,9%), which is mostly imported from Russia and Algeria. Other fossil sources include oil (3,47%) and carbon (4,64%).

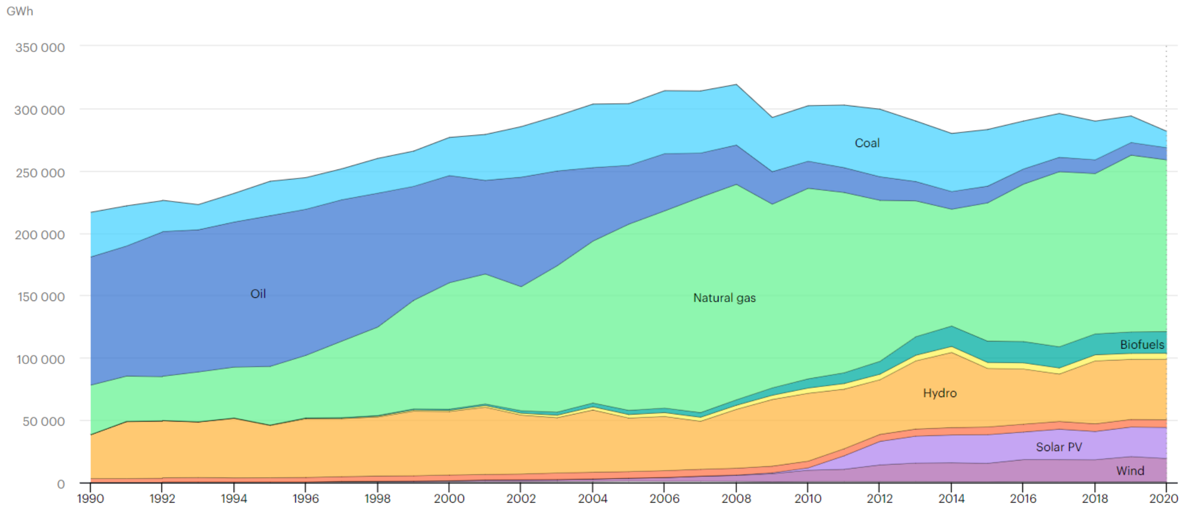

Figure 12: Italian generation by source (GWh), 2020
(IEA, 2020)[22]

3.3.2 Italian Transmission

In Italy electricity transmission (maintenance of electric infrastructures, realization, and development of the national electric grid) and dispatching (ensure that the energy needed by consumers is always in balance with the energy produced) is carried out by Terna. For electricity transmission and dispatching services, Terna is remunerated based on a tariff system established by the "Autorità di Regolazione per Energia Reti e Ambiente" (ARERA). (Terna, 2022)[39]

3.3.3 Italian Distribution

The main distribution companies in Italy are E-distribuzione, Unareti, Areti, Ireti. The Figure 13 shows the related market shares:

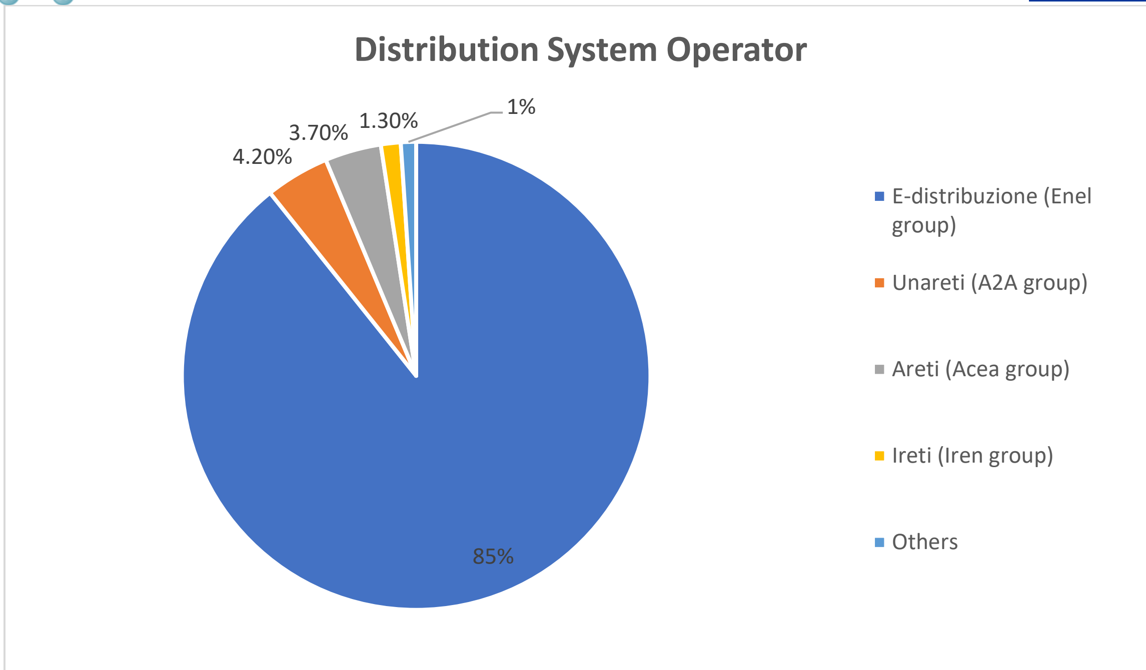

Figure 13: DSO Companies, by market share
Source: (Arera, 2021)[7]

E-distribuzione subsidiary of Enel Group is the major player as DSO with 85% of volume of energy distributed.

3.3.4 Italian Retail

The Retail companies active on Italian free power market are 638. The Figure 14 shows the shares of energy supplied in 2020 by the main corporate groups that sales electricity to domestic customers in the free market:

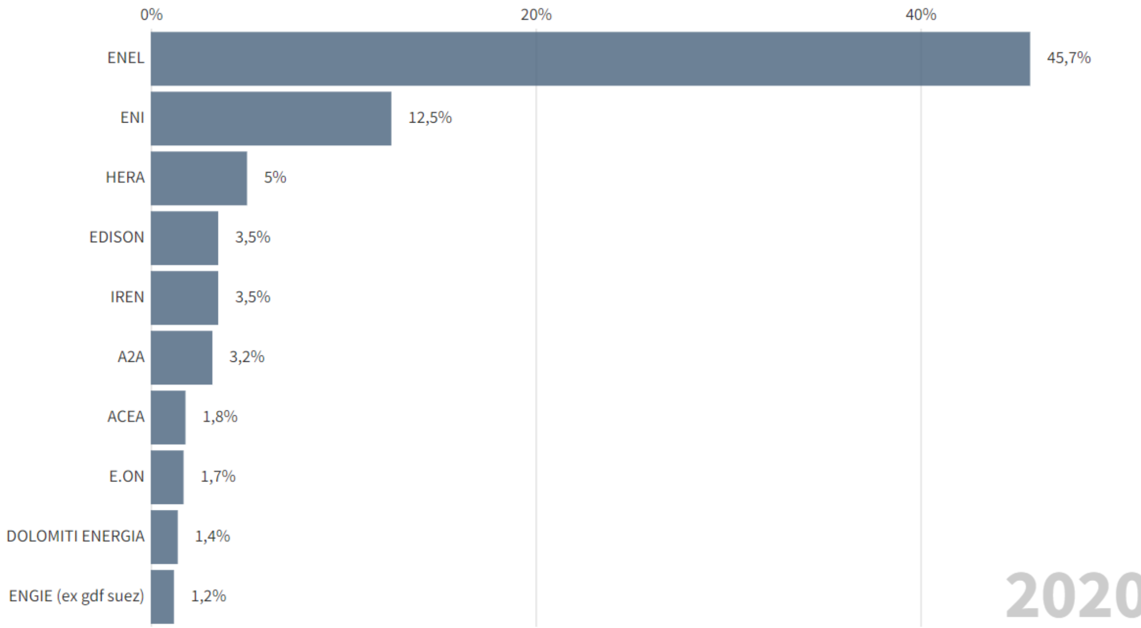

Figure 14: Retail free market, sales share by company
(Arera, 2020)[4]

Again, Enel is the market leader with over 45% of the market share.

3.4 Future of EU electricity market

As regard the future of the electricity market, the European Community objective is to create an integrated market in which the same regulations are applied, and where networks that enable connection between Countries allow to maintain a certain level of competition and to guarantee security of supply to all European customers. On the generation side, the share of renewable generation is expected to grow from about 35% to 50% by 2030, according to European targets (IEA, 2020) [23]. Therefore, energy markets must adapt to this growth, encouraging and favouring the development of systems (e.g., storage) and services (e.g., Ancillary Services) that allow the balancing, stability, and security of the grid. (European Commission, 2020) [18]

In addition, other trends would probably characterize the European electricity market. First of all, the electrification of consumption and the expected economic growth will lead to an increase in electricity consumption, which will, however, be limited by a higher level of energy efficiency. Secondly, as already stated, generation from renewable sources (which is extremely variable as it depends on weather conditions) is expected to increase significantly over the next few years in line with European targets for 2030. As a result, generation will be significantly more variable and less programmable. Third point concerns the decrease in generation from fossil sources, especially coal and oil, which, due to the rising costs of CO_2, is decreasing significantly. The same decrease is characterizing the nuclear production, in which different states have already announced the shutdown of production plants by defined dates. These concepts are shown in Figure 15. Consequently, natural gas plants and storage systems will become increasingly important to ensure the flexibility, the balancing, and the stability of the electric network. This topic will be explored more in detail in paragraph 4.2.

Considering this information, the European targets, and the EU regulations, it is reasonable to conclude that in the next few years the European electricity market will be more integrated among the various Nations, therefore more connected and more competitive, and at the same time, it will have to adapt to the rise in generation volatility by implementing specific measures and incentives.

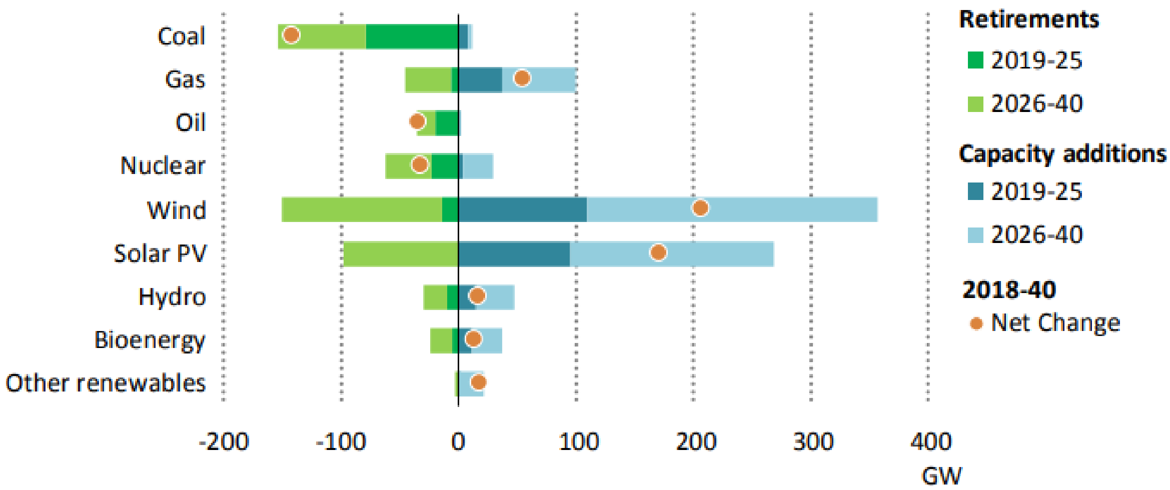

Figure 15: Forecasted generation changes at 2025 and 2040, Europe
(IEA, 2020)[23]

4. Ancillary Services Market

4.1 Introduction to the Ancillary Services Market

Ancillary Services are a set of processes that provide stability, efficiency and security to the electric transmission and distribution grids. The first aspect to highlight is that power generation must be controlled to ensure the proper balance between generation and consumption. Secondly, other elements such as frequency and voltage must be managed so that the electricity transported can be used in a safe and reliable way. In this context Ancillary Services enable the power system to operate in a stable, efficient, and safe way.

Thermoelectric plants thanks to their flexibility of generation can provide ancillary services to the system by modifying their production when necessary. There are different types of Ancillary Services that can be offered by a combined cycle thermoelectric power plant, all of which are focused on ensuring stability of the electrical system. The main ones are listed below:

- ✓ **Frequency control**: electrical systems are characterized by a certain frequency (in hertz) and must maintain that level of frequency to remain stable. Turbines and generators automatically adjust the speed at which they run to increase or decrease power based on demand and ensure that the system is kept stable.
- ✓ **Voltage control:** transmissions and distribution systems must maintain determined voltage level (in kilovolts). Voltage is a local quantity and varies according to the grid typology. Lack of voltage is controlled with reactive power injections and, conversely, excess is resolved by absorbing it. In this context power plants are fundamental for keeping the overall system reliable.
- ✓ **Inertia:** the utilization of turbines allows the electric system to better manage sudden changes in the frequency of the grid, providing stability. Adjustment provided in fractions of a second, in the first instants after an inefficiency.
- ✓ **Reserve:** fundamental factor is the availability of reserve energy that can be produced and used in case of unexpected events (e.g., unforeseen changes in generation or demand). Reserve power is not delivered as rapidly as frequency response but involve a greater volume of electricity pushed into the system. (Drax, 2020)[10]
- ✓ **Peak Shaving:** the process is to store energy when demand is low and release it when demand is high. The objective is to remove peaks and flatten the load curve.
- ✓ **Black start capacity:** In the event of a general black-out, the procedure for restarting the electrical system requires the availability of autonomous restarting plants, i.e., plants (hydroelectric, thermoelectric) capable of starting autonomously in the absence of power from the grid (black-start capability).

The ancillary services regarding the frequency control can be provided by generation plants through the supply of three types of energy reserves: primary, secondary and tertiary reserve.

The purpose of the primary reserve is to automatically correct instantaneous imbalances between total production and total demand of the entire interconnected European electrical system, through the intervention of the speed controllers of the turbines of the generators, in response to frequency variations. The primary reserve is the most flexible resource in the electrical system and must be provided by all generation plants.

Considering the secondary reserve its objective is to compensate the energy differences between the consumption and the production of the national system, and consequently contributing to the re-establishment of the European frequency (50 Hertz). The secondary reserve is configured as the most valuable resource as it is activated automatically with response times in the order of seconds. Secondary reserve must be provided within about 5 minutes (200 seconds) after request for a minimum of two hours of continuity.
The tertiary reserve consists in the plant capacity of increasing (or decreasing) production that can be introduced (withdrawn) into (from) the grid within 15 minutes after the request of the Grid Manager, potentially without duration limitations. The plant is qualified to provide this service if it can vary in increase (decrease) its own input with a rate of at least 50 MW/min. The tertiary reserve is usually "cold", i.e., it consists of shutdown plants that, thanks to a good flexibility, are able to activate and provide energy in a short time (usually they are thermoelectric or combined cycle power plants fueled by natural gas). (Dataenergia, 2014)[9]

Therefore, the electricity grid is based on the fundamental principle of balance between production and demand. In the case of imbalances, ancillary services are the intervention method and are purchased in **the balancing market**. The System Operator compensates the ancillary service provider through a direct payment within the balancing market. Following, the EU market of ancillary services is descripted, then the balancing markets in different European countries are analyzed.

4.2 Ancillary services market potential and forecasts at EU level

Forecasts regarding the evolution of European ancillary services market can be defined by analysing several ongoing trends.

1. **Decarbonization:** according to 2015 Paris UN Climate Conference, the objective is to limit the rise in the planet's surface temperature to +2 °C. This objective implies a shift towards an increasing share of electricity production from renewable energy sources. This shift led to **balancing problems** in the power grid due to the impossibility of scheduling generation patterns and due to production variability based on weather conditions.
2. **Urbanization:** Almost three-quarters of the EU's total population already lives in urban areas. The resulting increase in traffic, industrial activity and infrastructure amplify environmental challenges. Considering the Environmental objectives, EU cities are becoming laboratories for low-carbon lifestyles and for electrification.
3. **Electrification of consumptions:** According to the IEA (International Energy Agency), European electricity consumption has increased by 452Twh over the period 2000-2019. Despite in 2020, due to the Coronavirus pandemic, such consumption has recorded a decrease, the trend is rising again. According to the IEA's World Energy Outlook, this is a global trend, and the main reasons are the environmental impact, the level of efficiency and the level of digitalization.

Moreover, considering the strong correlation between energy consumption and GDP, the forecasted growth of European GDP is an element that suggests a likely increase in electricity consumption. (European Parliament, 2020)[19]. However, factors such as the increase in energy efficiency and the demographic decrease (Statista, 2021)[35] that characterizes the European continent (as opposed to the global trend), will probably slow down the increase in electricity consumption.

Therefore, the ongoing trends will probably involve an increase in the level of electricity consumption and certainly an increase in the use of renewable energy sources which, as already stated, involve significant problems regarding grid management. The Figure 16 shows the historical data regarding the EU electricity generation by source and the **forecasts to 2040**.

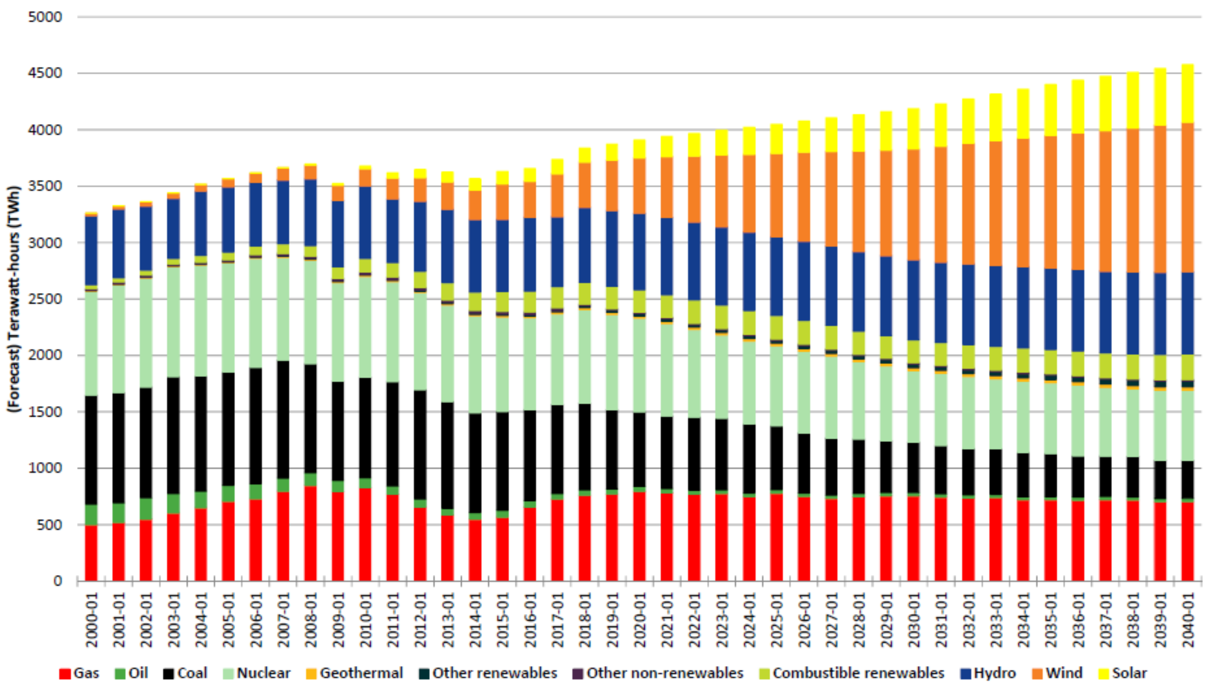

Figure 16: European Union (EU-28), Net Generation, 2000-2040
Source: (IHS, 2018)[25]

Due to the continued changes of Europe's electricity systems, and due to Europe's 2030 targets, an increase of the share of renewable electricity generation is required. Consequently, the demand for ancillary services is expected to follow the same trend. The shift from large power plants to a greater variety of different electricity sources, as well as the changes in the way Countries uses electricity, means that there is a greater need for flexibility to keep the grid stable. These ancillary services are usually provided by thermal power plants, but new innovations are enabling wind turbines to provide inertial response and overcome frequency changes, and batteries to store reserve energy that can then be supplied to the electrical system to ensure balance.

Considering frequency, a 50 Hertz frequency must be maintained throughout the whole European transmission grid. The control centres monitor the grid 24 hours a day, ensuring that this balance is always guaranteed. In the event of an imbalance between production and consumption, reserve energy is injected into the grid. So, in the event of unexpected fluctuations, the power plants can increase or reduce their output within a short period of time and thus compensate for the missing or excess electricity. In the European interconnected grid, the balance between production and consumption is achieved through a three-stage process: in the first stage, the primary control energy is switched on. The turbines in power plants across Europe automatically react to frequency fluctuations by increasing or decreasing their output. After a few minutes, the secondary control replaces the primary control, and National Grid Operators send an automatic signal. After a quarter of an hour, the Operators use the tertiary control energy manually by indicating to individual power plants in each Country to feed more or less energy into the grid. These concepts are shown in Figure 17. (Swissgrid, 2020)[37]

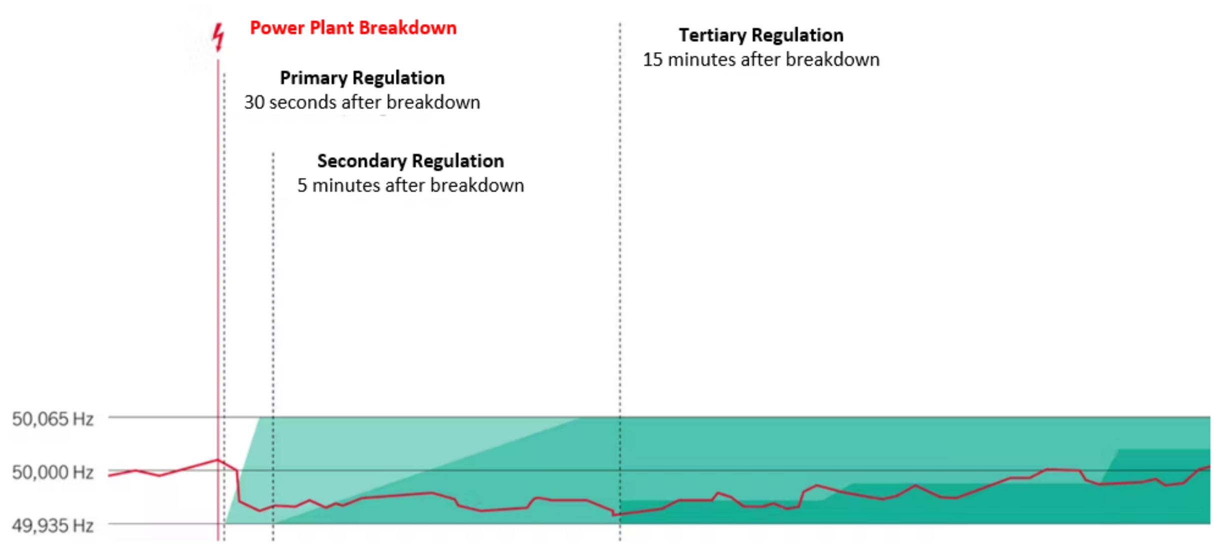

Figure 17: Time of reserves application following a breakdown
(Swissgrid, 2020)[37]

The European ancillary services market, due to the variability and uncertainty of increasing renewable generation, need to be adapted to increase system flexibility, incentivizing fast response, and ramping ability, and remunerating each of the services accordingly. In this context, in addition to being open to conventional generation units, the EU ancillary service market is probably going to be open to new participants, such as large-scale renewable generators, battery storage, and providers of DERs, including demand response, small-scale battery storage and distributed VRE generation. Table 3 describes the main types of ancillary services that are still being provided in Europe, highlighting the traditional players and the possible new players who could provide these services.

Table 3: European main ancillary services

Ancillary service	Product	Description	Response time
Frequency regulation	Primary regulation	**Traditional:** Frequency regulation automatically activated by generating plants through turbines speed	Sub-seconds to seconds

		regulators (usually thermal power plants)	
		Innovations: • Batteries are great providers of fast frequency response • Wind turbines can provide inertial response through power electronic converters. • Photovoltaic (PV) installations, direct current systems and batteries can also provide synthetic inertial response if the inverter is programmed to do so. • If regulation allows, DERs can provide this service	
	Secondary regulation	Traditional: The National Energy Management sends automatic signals from the control centre to certain generators to re-establish the nominal frequency value	5–15 minutes
		Innovation: If regulation allows, DERs can provide this service	
	Tertiary regulation	Traditional: The manual National regulation provided by generating units and controlled by the system operator.	>15 minutes
Non-frequency regulation	Voltage support	Traditional: The injection of reactive power to maintain system voltage within a prescribed range	Seconds
		Innovations: • Voltage control through reactive power provided by resources connected to the power system through inverters, such as solar photovoltaic and battery storage. • If regulation allows, DERs can provide this service.	
	Black start	Traditional:	Minutes

		The ability to restart a grid after a blackout. Generations plants (hydroelectric, turbogas) capable of starting autonomously in the absence of power from the grid.	

Source: (IRENA, 2019)[26]

As can be seen in the Table 3, gas-powered generating plants appear to be the most comprehensive provider of different types of ancillary services.

4.3 Focus on Italian Ancillary Services Market

In Italy, the transmission system operator (TSO) is Terna and is the entity responsible of dispatching activities, which consist in the procurement and subsequent supply of services necessary to ensure the security and balancing of the national electricity system. The resources Terna needs for ancillary services can be obtained from the Balancing Service Providers (BSP) through:

- ✓ impositions (that could also consist in unpaid obligations)
- ✓ the Dispatching Service Market - MSD (preferable solution where there is competition). On the MSD products through which the TSO obtains the necessary resources for the supply of ancillary services are negotiated. The TSO selects the cheapest bids from the BSPs. Currently, BSPs are programmable generating units (i.e., large thermoelectric and hydroelectric facilities) and can submit bids on MSD. These large generation plants are the BSP and are the only units currently classified as eligible. Accepted bids are remunerated at the price submitted (pay-as-bid).
- ✓ contracts signed with certain producers or customers selected through a competitive basis.

The main ancillary services, the supply and remuneration method are described in the Table 4.

Table 4: Italian main ancillary services

Ancillary Service	Product	Eligible Units	Supply Method	Remuneration
Frequency Control	Primary Reserve	Relevant units obligatorily qualified	Obligatory	Optional
	Secondary Reserve	Relevant units obligatorily qualified	MSD	Pay-as-bid (€/MWh)
	Tertiary Reserve	Relevant units obligatorily qualified	MSD	Pay-as-bid (€/MWh)
Voltage Control (50 Hertz)	Primary and Secondary settings	Relevant units obligatorily qualified	Obligatory	None

Black Start	Re-powering of electrical system	Relevant units obligatorily qualified	Obligatory	None

Source: (Arera, 2020)[5]

In June 2006, the Electricity and Gas Authority passed Resolution 111/06 requiring energy producers to provide advance projections about the quantity of electricity they would inject into the grid to create a predictable supply and assist Terna to balance supply and demand.

4.4 Focus on Portugal Ancillary Services Market

The ancillary services in Portugal are mainly provided through primary, secondary, and tertiary reserves. As the Italian case, primary reserve in Portugal represents a mandatory and non-remunerated service provided by the running generators with the objective of automatically compensating the instantaneous imbalances between electricity production and demand. It is provided by varying the generators' current production in an immediate and autonomous manner by actuating on the turbines' speed regulators as a response to variations in frequency. In Portugal, it is formally equivalent to the new FCR (Frequency Containment Reserve) service defined in EU Regulation 2017/1485 (SOGL).

All production units directly connected to the national transport grid must have primary regulation, in the case where primary regulation is technically impossible, this service must be contracted to other units that can provide it. Generator groups must allow a primary regulation of at least 5% of the nominal power from every stable operation point, together with an adjustable speed droop characteristic between 4% to 6%. The maximum activation time is 15 seconds for changes in frequency under 100 mHz and linearly between 15 and 30 seconds for changes in frequency between 100 and 200 mHz. The frequency response insensitivity must be under 10 mHz with a dead band of 0 mHz. Maximum value for the initial delay for power-generating modules without inertia is 500 ms.

The secondary reserve assures: the control of power and frequency within normal ranges, the control of the deviation from the interconnection with Spain compared to the scheduled operation, the cooperation in the maintenance of the joint frequency with Spain, or in the case of island operation, the control of the frequency. It is formally equivalent to the aFRR (automatic Frequency Restoration Reserve), described in EU Regulation 2017/1485.
All power generating units with the ability to participate in the secondary reserve must place bids with the respective band (in MW) and the band's unitary price (in €/MW). These bids are then part of an internal market to determine which units are selected. Participants are obliged to comply with the following requirements:

- ✓ Activation should be concluded in less than 5 minutes.
- ✓ Thermal groups shall be capable of continuously varying their power within a band corresponding to at least 10% of their rated power, within their operating power range and beyond the band available for primary control.
- ✓ This secondary control band shall be at least 30% of the rated power for hydro power generators

- ✓ The system operator determines a ratio between upward and downward reserves, (which is usually 2/3 in the upward direction and 1/3 in the downward direction) and with a tolerance of 5%.

The tertiary reserve, also known as regulating reserve is an active power reserve that ensures the balance between supply and demand when incidents that exhaust the primary and secondary reserves occur. Despite not being a mandatory service, physical units are obliged to bid if they take part in the wholesale market (and if qualified to participate in the system services market).
The participants must offer, for balancing areas of either production installations or consumption installations for pumping storage, all their feasible reserve regulation, both to increase and decrease, in MW with the energy price in €/MWh.

4.5 Focus on Belgium Ancillary Services Market

The Belgian TSO is Elia and is responsible for maintaining the balance between production and consumption of its transmission grid which covers the entire country.
Since Elia has no production plants, it assigns responsibility of ensuring the balance to the Balance Responsible Parties (BRPs). A BRP is a legal entity that supervises the balance of one or more grid connection points. The purpose of the BRP is to create a balanced portfolio through a combination of injection, withdrawals, and exchange with other BRPs. Each generator and purchaser in the network must have a signed contract with a BRP. Elia imposes a penalty on all BRPs that are in imbalance, to encourage BRPs to keep their portfolio in balance. On the other hand, if BRPs reduce the net system imbalance they will be rewarded.
Elia also buys capacity reserves to maintain the stability of the grid. The different types of reserves are used when different imbalance events happen. These include: primary reserve for frequency containment, that reacts within 500 milliseconds when a tension on the grid occurs; secondary reserve that is a bigger automatic frequency restoration reserves; and tertiary reserve that is a manual frequency restoration reserves, and is useful for larger and long-lasting imbalances.
Furthermore, it should be pointed out that Belgium participates in the International Frequency Containment Reserve co-operation: is a common market for the procurement and exchange of balancing capacity and involves ten TSOs of seven countries: Austria (APG), Belgium (Elia), Denmark (Energinet), France (RTE), Germany (50Hertz, Amprion, TenneT DE, TransnetBW), the Netherlands (TenneT NL) and Switzerland (Swissgrid).

5. Benchmark of the most promising EU Member state electrical market

5.1 Methodology & Approach

To extract the most promising EU member states electrical market where to promote the FLEXnCONFU project, a method based on statistics has been specifically tailored. In particular, a benchmarking approach allows to rank countries based on specific characteristics hereafter recognized as KPIs. The selected KPIs are the results of an analysis carried out in collaboration with the project partners CNET and ENGIE.

The methodology is divided in 4 main steps:

- ✓ KPI's list definition
- ✓ Data research for KPIs estimation
- ✓ Definition of a scoring method based on statistics
- ✓ Ranking and comparison of the results

5.1.1 KPI's list definition

The first point mainly consists in the identification of KPIs. The cluster of KPIs shown in Table 5, emerged from analyses carried out and from different meetings and confrontations with project partners, and allows to define a shortlist of selected countries qualified as the most promising.

RES penetration has been included since, as the share of renewable generation increases, ancillary services become more and more important to ensure production flexibility and grid balancing.

Transmission costs have been considered since such costs largely derive from the TSO's expenses for the purchase of ancillary services, and so, the proposed solution could lead to a decrease in the costs of such services.

Highest **electricity prices** for end users have been considered because they are also affected by the costs of ancillary services.

The **costs of Natural Gas** are included as the solution would guarantee significant savings in the use of this energy source.

The **number of CC plants** is included as these plants are the generation typology that allows the implementation of the solution, therefore if the solution was implemented in a high number of plants, it would guarantee a significant level of flexibility.

Hydrogen production is considered as this element is fundamental for the injection of clean gases into the production cycle.

Finally, the **percentage of electricity produced by gas** is considered, as this solution can only be applied to gas-fired generation plants, and therefore as the electricity produced by gas-fired plants increases, the potential share of energy produced through the proposed solution would increase as well.

Table 5: Market analysis KPIs

KPIs	***Measurement***
RES penetration with respect to total consumption 2019	% RES over Total Consumption
% Network transmission cost in energy price for household 2019	% Of Total Cost

Network transmission cost in energy price for household 2019	€/MWh
% Network transmission cost in energy price for non- household 2019	% Of Total Cost
Network transmission cost in energy price for non- household 2019	€/MWh
High Price of electricity non - household 2019	€/MWh
High Price of electricity for household 2019	€/MWh
NG costs 2019	€/MWh
Number of CC power plant	Number
Number of CC power plant per person	Number
Country Gas power plant capacity	MW
Country Gas power plant capacity per person	MW/100k inhabitants
Hydrogen Production	Thousand tons/year
% Electricity produced from gas	% Of total generation

5.1.2 Data research for KPIs estimation

Based on the KPIs list defined int the previous subchapter a common based dataset served to fulfil KPIs estimation. The dataset widely used for the analysis is Eurostat with except for few KPIs where it have been specifically declared the data source. 27 European countries were analysed using this methodology, and for each country the data necessary for the construction of the KPI was researched and applied. Figure 18 represent a part of the data that have been identified for the construction of the KPI per each Country.

	country	RES penetration with respect to total consumption	RES penetration with respect to total consumption	% Network trasmission cost in energy price for household 2020	Network trasmission cost in energy price for household 2019	% Network trasmission cost in energy price for non-household 2020	Network trasmission cost in energy price for non-household 2020	% distribution cost in energy price for household 2020	distribution cost in energy price for household 2020	% distribution cost in energy price for non-household 2020	% distribution cost in energy price for non-household 2020	High Price of electricity non household 2020	High Price of electricity for non-household 2020	High Price of electricity household 2020	High Price of electricity for household 2020	NG costs 2020 (consumption over 200 GJ, Eurostat)	NG costs 2020 (consumption over 200 GJ, Eurostat)	number of Gas power plant	number of Gas power plant per person
		% RES over TC	% RES over TC	%	€/MWh	%	€/MWh	%	€/MWh	%	€/MWh	€/MWh	€/kWh	€/MWh	€/kWh	€/MWh	€/MWh	Number	Gas Power Plant/ 100k inhabitants
	Austria	33,63	33,63%	15,3%	31,4262	15,3%	12,38535	84,70%	173,9738	84,7%	68,56465	80,95	0,08095	205,4	0,2054	39,95	0,03995	19	0,213071248
	Belgium	9,92	9,92%	12,3%	35,04885	57,6%	46,3392	87,70%	249,90115	42,4%	34,1108	80,45	0,08045	284,95	0,28495	33,3	0,0333	41	0,354794138
	Bulgaria	21,56	21,56%	20,0%	19,55	33,9%	29,37355	80,00%	78,2	66,1%	57,37645	86,75	0,08675	97,75	0,09775	30,75	0,03075	5	0,072178319
	Croatia	28,47	28,47%	26,5%	35,0914795	33,0%	29,5906845	73,47%	97,1585205	67,0%	60,1093155	89,7	0,0897	132,25	0,13225	28,9	0,0289	3	0,074125321
	Cyprus	13,80	13,80%	30,0%	66,487342	37,6%	52,1229515	70,04%	155,462658	62,4%	86,3770485	138,5	0,1385	221,95	0,22195	#N/A	#N/A	#N/A	#N/A
	Czechia	16,24	16,24%	12,0%	21,108	#VALUE!	#VALUE!	88,00%	154,792	#VALUE!	#VALUE!	65,35	0,06535	175,9	0,1759	42,85	0,04285	39	0,364523592
	Denmark	37,20	37,20%	25,0%	73,85	48,0%	30,048	75,00%	221,55	52,0%	32,552	62,6	0,0626	295,4	0,2954	26,85	0,02685	26	0,445861751
	Estonia	31,89	31,89%	25,0%	34,6	35,0%	26,845	#VALUE!	#VALUE!	65,0%	49,855	76,7	0,0767	138,4	0,1384	29,8	0,0298	5	0,375641314
	Finland	43,08	43,08%	10,0%	17,585	20,0%	12,9	90,00%	158,265	80,0%	51,6	64,5	0,0645	175,85	0,17585	#N/A	#N/A	16	0,289293309
	France	17,22	17,22%	20,7%	38,1579271	38,6%	29,8754081	79,32%	146,3920729	61,4%	47,5745919	77,45	0,07745	184,55	0,18455	38,95	0,03895	77	0,114257594
	Germany	17,35	17,35%	23,4%	69,77237	23,4%	18,396235	76,61%	228,52763	76,6%	60,253765	78,65	0,07865	298,3	0,2983	39,3	0,0393	256	0,30754251
	Greece	19,68	19,68%	20,0%	31,52292	41,7%	33,88125	79,96%	125,77708	58,3%	47,36875	81,25	0,08125	157,3	0,1573	44,45	0,04445	19	0,177312427
	Hungary	12,61	12,61%	22,7%	25,2079551	22,7%	19,5228051	77,26%	85,6420449	77,3%	66,3271949	85,85	0,08585	110,85	0,11085	24,7	0,0247	33	0,338469766
Country	Ireland	11,98	11,98%	20,8%	51,6910163	41,0%	52,58075945	79,19%	196,7592322	59,0%	75,76924055	128,35	0,12835	248,45	0,24845	51,4	0,0514	13	0,260274642
	Italy	18,18	18,18%	16,7%	38,7741618	54,3%	51,054896	83,29%	193,3258382	45,7%	43,045104	94,1	0,0941	232,1	0,2321	36,7	0,0367	201	0,337508685
	Latvia	40,98	40,98%	22,8%	37,2476398	31,8%	26,912265	77,21%	126,2023602	68,2%	57,637735	84,55	0,08455	163,45	0,16345	22,65	0,02265	4	0,210354932
	Lithuania	25,46	25,46%	29,6%	37,1703332	42,2%	35,5466967	70,37%	88,2796668	57,8%	48,7533033	84,3	0,0843	125,45	0,12545	22,9	0,0229	7	0,250474112
	Luxembourg	7,05	7,05%	0,0%	0	9,0%	7,36281	100,00%	179,85	91,0%	74,53719	81,9	0,0819	179,85	0,17985	33,8	0,0338	3	0,474477087
	Malta	8,49	8,49%	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	133,5	0,1335	129,7	0,1297	#N/A	#N/A	2	0,38074569
	Netherlands	8,77	8,77%	18,0%	37,098	18,0%	12,267	82,00%	169,002	82,0%	55,883	68,15	0,06815	206,1	0,2061	#DIV/0!	#DIV/0!	52	0,298145666
	Poland	12,16	12,16%	14,4%	19,5727215	14,4%	10,2578625	85,60%	116,3772785	85,6%	60,9921375	71,25	0,07125	135,95	0,13595	35,8	0,0358	33	0,086954684
	Portugal	30,62	30,62%	13,4%	29,0177	27,1%	23,42795	86,60%	187,5323	72,9%	63,02205	86,45	0,08645	216,55	0,21655	52,35	0,05235	98	0,950942617
	Romania	24,29	24,29%	15,1%	21,02494135	27,7%	23,2259967	84,87%	117,9250587	72,3%	60,4740033	83,7	0,0837	138,95	0,13895	25,7	0,0257	19	0,098516431
	Slovakia	16,89	16,89%	8,2%	12,9642	17,0%	15,9205	91,80%	145,1358	83,0%	77,7295	93,65	0,09365	158,1	0,1581	37,75	0,03775	10	0,183189539
	Slovenia	21,97	21,97%	23,6%	38,94	26,5%	20,89525	76,40%	126,06	73,5%	57,95475	78,85	0,07885	165	0,165	34,9	0,0349	3	0,142848572
	Spain	18,36	18,36%	20,2%	48,47296545	20,2%	18,1078912	79,79%	191,3770346	79,8%	71,4921088	89,6	0,0896	239,85	0,23985	45,4	0,0454	608	1,284012417
	Sweden	56,39	56,39%	12,2%	25,23807	12,2%	8,47374	87,79%	181,46193	87,8%	60,92626	69,4	0,0694	206,7	0,2067	60,15	0,06015	10	0,096586237

Figure 18: Part of the data researched and used for the definition of KPIs by country

5.1.3 Definition of a scoring method based on statistics

The scoring methodology adopted in this project supports the definition of a synthetic indicator useful to compare all the KPIs estimated. Each KPI of Table 5 produced a series of value $\hat{x}$ for each EU Member state country. Those values x_i passed through a normalization process, each value of the series is normalized to the maximum value of the series $\hat{x}$, by generating a new sequence of values from 0 to 1, hereafter $\bar{x}$.

$$Normalized\ Value\ \bar{x}_i = \frac{x_i}{Max\ \hat{x}}$$

This last aspect is crucial for the scoring method adopted; it enables the possibility to design a common function that brings as output a weighted sum of all the KPIs with a consistent approach.

$$Syntetic\ Indicator = \sum_{i=1}^{n} (\bar{x}_i * k_i)$$

where n is equal to the number of KPIs.

The k parameter represents the weight attributed to the specific normalized KPI $\bar{x}$. This last feature allows a certain level of flexibility to the methodology. Indeed, not all of the KPIs considered have the same weight according to CNET and ENGIE experts. For this reason, following dedicated meetings with these partners, it was decided to assign different weights to each KPI, also excluding some indicators considered irrelevant. Based on the opinions of Partners expert in the area of interest (combined cycle gas-fired generating plants and supply of ancillary services) on the incisiveness of each KPI for the implementation of the proposed solution, specific weights were assigned to each indicator.
Therefore, the Table 6 below shows the weights assigned to each KPI.

Table 6: KPIs weights in the model

KPIs	*WEIGHT*
RES penetration with respect to total consumption 2019	100%
% Network transmission cost in energy price for household 2019	0%
Network transmission cost in energy price for household 2019	0%
% Network transmission cost in energy price for non- household 2019	100%
Network transmission cost in energy price for non- household 2019	100%
High Price of electricity non - household 2019	100%
High Price of electricity for household 2019	0%
NG costs 2019	100%
Number of CC power plant	50%
Number of CC power plant per person	50%
Country Gas power plant capacity	50%
Country Gas power plant capacity per person	50%
Hydrogen Production	100%
% Electricity produced from gas	100%

5.1.4 Ranking and comparison of the results

Once the data for each indicator and each country had been collected and normalized according to the method described above, a ranking was constructed for each KPI (Figure 19) based on the scores of each country on the specific indicator. As already stated, for each KPI each country registers a score between 0 and 1, where 1 represents the score of the country with the highest value (Table 7 and Table 8).

Row Labels	Sum of RES penetration with respect to total consumption 2	
Sweden	56,4%	1
Finland	43,1%	0,76397
Latvia	41,0%	0,72662
Denmark	37,2%	0,65975
Austria	33,6%	0,5963
Estonia	31,9%	0,5655
Portugal	30,6%	0,54298
Croatia	28,5%	0,5048
Lithuania	25,5%	0,45151
Romania	24,3%	0,43074
Slovenia	22,0%	0,38967
Bulgaria	21,6%	0,3824
Greece	19,7%	0,34894
Spain	18,4%	0,32551
Italy	18,2%	0,32241
Germany	17,4%	0,30774
France	17,2%	0,3053
Slovakia	16,9%	0,29959
Czechia	16,2%	0,28806
Cyprus	13,8%	0,24472
Hungary	12,6%	0,22369
Poland	12,2%	0,21571
Ireland	12,0%	0,21252
Belgium	9,9%	0,17599
Netherlands	8,8%	0,15549
Malta	8,5%	0,15052
Luxembourg	7,0%	0,12497
Grand Total	**6,04251**	

Row Labels	Sum of NG costs 2020 (consumption over 200 GJ, Eurostat)	
Sweden	60,15 €	1,0000000
Portugal	52,35 €	0,8703242
Ireland	51,40 €	0,8545303
Spain	45,40 €	0,7547797
Greece	44,45 €	0,7389859
Czechia	42,85 €	0,7123857
Austria	39,95 €	0,6641729
Germany	39,30 €	0,6533666
France	38,95 €	0,6475478
Slovakia	37,75 €	0,6275977
Italy	36,70 €	0,6101413
Poland	35,80 €	0,5951787
Slovenia	34,90 €	0,5802161
Luxembourg	33,80 €	0,5619285
Belgium	33,30 €	0,5536160
Bulgaria	30,75 €	0,5112219
Estonia	29,80 €	0,4954281
Croatia	28,90 €	0,4804655
Denmark	26,85 €	0,4463840
Romania	25,70 €	0,4272652
Hungary	24,70 €	0,4106401
Lithuania	22,90 €	0,3807149
Latvia	22,65 €	0,3765586
Netherlands	#DIV/0!	0,0000000
Finland	#N/A	0,0000000
Malta	#N/A	0,0000000
Cyprus	#N/A	0,0000000
Grand Total	**#DIV/0!**	

Row Labels	Sum of High Price of electricity household 2020	
Germany	298,30	1
Denmark	295,40	0,99028
Belgium	284,95	0,95525
Ireland	248,45	0,83289
Spain	239,85	0,80406
Italy	232,10	0,77808
Cyprus	221,95	0,74405
Portugal	216,55	0,72595
Sweden	206,70	0,69293
Netherlands	206,10	0,69092
Austria	205,40	0,68857
France	184,55	0,61867
Luxembourg	179,85	0,60292
Czechia	175,90	0,58967
Finland	175,85	0,58951
Slovenia	165,00	0,55313
Latvia	163,45	0,54794
Slovakia	158,10	0,53
Greece	157,30	0,52732
Romania	138,95	0,46581
Estonia	138,40	0,46396
Poland	135,95	0,45575
Croatia	132,25	0,44335
Malta	129,70	0,4348
Lithuania	125,45	0,42055
Hungary	110,85	0,37161
Bulgaria	97,75	0,32769
Grand Total	**5.025,05 €**	

Row Labels	Sum of High Price of electricity non household 2020	
Cyprus	138,50 €	1,03745
Malta	133,50 €	1
Ireland	128,35 €	0,96142
Italy	94,10 €	0,70487
Slovakia	93,65 €	0,7015
Croatia	89,70 €	0,67191
Spain	89,60 €	0,67116
Bulgaria	86,75 €	0,64981
Portugal	86,45 €	0,64757
Hungary	85,85 €	0,64307
Latvia	84,55 €	0,63333
Lithuania	84,30 €	0,63146
Romania	83,70 €	0,62697
Luxembourg	81,90 €	0,61348
Greece	81,25 €	0,60861
Austria	80,95 €	0,60637
Belgium	80,45 €	0,60262
Slovenia	78,85 €	0,59064
Germany	78,65 €	0,58914
France	77,45 €	0,58015
Estonia	76,70 €	0,57453
Poland	71,25 €	0,53371
Sweden	69,40 €	0,51985
Netherlands	68,15 €	0,51049
Czechia	65,35 €	0,48951
Finland	64,50 €	0,48315
Denmark	62,60 €	0,46891
Grand Total	**2.316,45 €**	

Row Labels	Sum of Hydrogen Production ('000 tons/y)	
Germany	2400	1
Netherlands	1500	0,625
Poland	1250	0,52083333
Italy	750	0,3125
France	730	0,30416667
Spain	720	0,3
Belgium	600	0,25
Romania	375	0,15625
Czechia	280	0,11666667
Lithuania	250	0,10416667
Bulgaria	245	0,10208333
Austria	240	0,1
Hungary	235	0,09791667
Slovakia	230	0,09583333
Finland	200	0,08333333
Sweden	190	0,07916667
Croatia	180	0,075
Greece	160	0,06666667
Portugal	100	0,04166667
Estonia	25	0,01041667
Denmark	15	0,00625
Slovenia	5	0,00208333
Ireland	4	0,00166667
Malta	0	0
Luxembourg	0	0
Latvia	0	0
Cyprus	0	0
Grand Total	**10684**	

Figure 19: Part of Country rankings for each KPI

Table 7: Country rankings based on KPI 1: RES penetration

Row Labels	Sum of RES penetration with respect to total consumption	Score
Sweden	56,4%	1
Finland	43,1%	0,763969
Latvia	41,0%	0,726623
Denmark	37,2%	0,659751
Austria	33,6%	0,596301
Estonia	31,9%	0,565498
Portugal	30,6%	0,542977
Croatia	28,5%	0,504797
Lithuania	25,5%	0,451508
Romania	24,3%	0,430742
Slovenia	22,0%	0,389672
Bulgaria	21,6%	0,382401
Greece	19,7%	0,348939
Spain	18,4%	0,325513
Italy	18,2%	0,32241

Germany	17,4%	**0,307744**
France	17,2%	**0,305297**
Slovakia	16,9%	**0,299587**
Czechia	16,2%	**0,28806**
Cyprus	13,8%	**0,24472**
Hungary	12,6%	**0,223688**
Poland	12,2%	**0,215708**
Ireland	12,0%	**0,212516**
Belgium	9,9%	**0,175986**
Netherlands	8,8%	**0,155486**
Malta	8,5%	**0,15052**
Luxembourg	7,0%	**0,124967**
Grand Total	**6,04251**	

Table 8: Country rankings based on KPI 11: Country Gas power plant capacity

Row Labels	**Sum of Country Gas power plant capacity**	
Italy	40.377,52	1
Germany	29.371,57	0,727424
Spain	26.095,36	0,646284
Netherlands	13.674,74	0,338672
France	8.040,77	0,19914
Greece	6.052,74	0,149904
Belgium	6.042,60	0,149653
Portugal	4.847,77	0,120061
Hungary	3.908,47	0,096798
Romania	3.736,85	0,092548
Austria	3.665,36	0,090777
Ireland	3.078,13	0,076234
Poland	3.040,89	0,075311
Finland	1.849,60	0,045808
Czechia	1.262,02	0,031255
Lithuania	1.125,60	0,027877
Sweden	1.087,70	0,026938
Latvia	942,00	0,02333
Bulgaria	824,90	0,02043
Denmark	679,10	0,016819
Slovakia	635,10	0,015729
Estonia	567,00	0,014042
Slovenia	449,00	0,01112
Croatia	416,80	0,010323
Malta	370,30	0,009171
Luxembourg	6,15	0,000152

Cyprus	#N/A	0
Grand Total	**#N/A**	0

The final ranking is given by the sum of the scores recorded by the countries for each KPI (appropriately weighted). In the Table 9 the results are represented. The ranking shows the most adapted Countries where the FLEXnCONFU project can be implemented. It is useful to highlight that the three representative State (Italy, Portugal and Belgium) are positioned into the top five countries of the ranking.

Table 9: Ranking of European Countries

Country	Sum of TOTAL
Italy	5.0197
Spain	4.9932
Germany	4.5556
Belgium	4.3542
Portugal	4.3114
Ireland	4.1138
Greece	3.7912
Malta	3.7459
Latvia	3.6719
Croatia	3.6411
Sweden	3.5107
France	3.4314
Netherlands	3.3319
Austria	3.2573
Hungary	3.1949
Lithuania	3.0660
Poland	3.0121
Estonia	2.9910
Denmark	2.7732
Luxembourg	2.7350
Romania	2.6785
Slovenia	2.6315
Bulgaria	2.5468
Czechia	2.4590
Finland	2.4480
Slovakia	2.3040
Cyprus	2.1306
Grand Total	90.7000147

Considering **the top 5 Countries**:

1. Italy achieved the highest score, compared to the other Members State primarily as a result of: a **high number of combined cycle plants** (both total and per person), the **high production capacity** of thermoelectric power plants, the very **high amount of electricity produced** through Gas and also the high amount of **hydrogen** produced.
2. Spain recorded the second highest score mainly for: **the high cost of natural gas,** the **number of CC plants**, which is the highest in the EU
3. Germany ranked third in the list mainly due **to high generation capacity of thermal power plants**, and **hydrogen production** that is the highest in EU
4. Belgium reported a high score mainly due to: **high electricity transmission costs** (as a % of energy cost) especially for non-household customers, and the **high capacity of Gas plants** per person
5. Portugal recorded a high score mainly due to: a **high percentage of renewable energy** consumed compared to the total consumption, a **high cost of Natural Gas** and a high number of Gas production plants per person

6. Grid code requirements and regulatory aspects

In this paragraph, the Partners TP, CNET, and ENLAB have analysed the main characteristics of the Grid Codes of the three representatives EU countries (Italy, Portugal and Belgium). In particular, the regulatory aspects concerning ancillary services, installation of electrolysers, emission limits, hydrogen injections and storage of hydrogen and ammonia were analysed.

6.1 Italian Grid code requirements and regulatory aspects

ARERA, in July 2019, published a Consultation Document for the reform of the Integrated Text of Electricity Dispatching (TIDE). (Arera, 2019)[3]. The document has two objectives:

1) Making the dispatching activity suitable for efficiently guaranteeing the safety of the electricity system, that is characterized by a rapid and continuous evolution (due to the increase of non-programmable renewable sources and distributed generation, as well as the reduction of number of programmable plants).

2) Continue with the integration of the Italian wholesale market with other European Countries, in particular taking into account the intraday market model based on continuous trading and the obligation of cross-border exchange of balancing resources through specific European balancing platforms.

The first objective requires a reform of the methods of procurement and remuneration of dispatching resources. The aim is to eliminate barriers that prevent the use of all available resources, and to adjust imbalances through energy considering its value in real time, to avoid inefficient wholesale market outcomes.
The second objective also requires taking into account the main innovations introduced by the new Directive and the new Regulation on the internal electricity market referred to in the Clean Energy Package. (European Commission, 2019)[17]
Main topics of the reform are:

- ✓ separation between commercial negotiations and physical planning for production and consumption units
- ✓ review of the classification of ancillary services
- ✓ measures for the introduction of negative prices on national markets (limited to MGP and MI)
- ✓ review of the mechanism for imbalances calculation (Arera, 2021)[8]
- ✓ coordination between the Italian MSD (ancillary services market) and the European balancing platforms

6.1.1 Ancillary services enhanced by FLEXnCONFU

In recent years there has been a rapid increase in domestic production from non-programmable renewable sources (FRNP) and decrease in the consumption of electricity (from 339 TWh in 2006 to 295,9 TWh in 2020 (IEA, 2020)[22]. This trend affects the safety of the system as it determines both the reduction of system stability and the reduction of frequency and voltage regulators capacity. To address these issues, "traditional" production units are enabled to supply ancillary services. As regards the reduction of stability, the typical static generation of the photovoltaic source could replace the rotating generation of "traditional" production units by decreasing the inertia of the system. These problems are common to many other European Countries.

Considering frequency, **Terna has adopted Annex A.70 to the Grid Code "Technical regulation of system requirements of distributed generation**" which defines requirements for production plants connected to MV and LV networks. The Authority's Deliberation 84/2012/R/ eel, in approving Annex A.70, defined the timing for its implementation, distinguishing between newly built plants and older existing plants (with a power of over 50 kW connected to medium voltage) where a "retrofit" program is expected.

As regards the voltage regulation, the reduced incidence of generation units (voltage regulators) in the transmission grids enhances high voltage regimes, especially during low-load periods, causing stress to generation plants and problems for grid users, as well as uncontrollable evolutions in case of accidental loss of generation.

As for congestion phenomena, it should be pointed out that the increasing penetration of FRNP production plants, often involve phenomena of energy rising from the distribution towards the transmission grid, especially in periods of high production and low local demand. As a first consequence, these phenomena determine a possible increase in local congestion, especially on the sections of the HV network characterized by high density of distributed production compared to the local electrical load and by poor network meshing. There was also a progressive increase in congestions on the primary transport system in the AAT, more critical in the central-southern area of the country where most of the installations of FRNP systems are concentrated and where the grid has a lower level of mesh and a more limited transport capacity.

Finally, considering balancing, FRNP production is characterized by the impossibility of remodelling (only reduction actions can be activated). Moreover, the production profile determines a greater uncertainty than the production from traditional systems and, as regard the photovoltaic systems, is only concentrated during the day. Firstly, this implies an increase of resources and measures that have to be prepared and used for balancing purposes; secondly this implies a reduction of the availability on the network of the production units available to supply the required frequency regulation margins.

In the thermoelectric sector, gas is replacing other fossil fuels that emit higher carbon and pollutants emissions. The period 2000-2010 was characterized by the triggering of about 35 GW of combined cycle plants which they have almost completely replaced the oil generation. In the first months of 2019, thanks to the drop in natural gas prices and to the increase of the cost of CO_2, the process of coal replacement with gas experienced an acceleration, determining a decline in coal generation by a further 30%. By 2025, an increase of 3.2 GW of flexible gas power is planned by TP, functional to total drop out from coal.
Thanks to their programmability characteristics, **gas combined cycle plants are indispensable** for providing efficiency and flexibility. They are strategic plants for the energy transition thanks to their capacity to compensate for the intermittence of renewable sources, and to replace the supply from coal plants that will be shut down in the coming years.

The CCGT can provide ancillary services necessary to guarantee the safety of the whole electricity system. They are related to the management of a transmission or distribution network. As highlighted in paragraph 4.3, the main ancillary services in the Italian context are:

- static reserve
- frequency regulation
- voltage regulation
- restart of the grid.

6.1.2 Electrolyser installation requirements regulations

On 15 December 2021, the **EU Commission published the "Hydrogen and Decarbonized Gas"** Package composed of a Regulation and a Directive proposal. This is aimed at being complementary to the "Fit for 55" Package.

Although the package recognizes the transitional role of fossil natural gas, it encourages member states to ensure that their planning is aimed to decarbonization goal and to the European Climate Act achievements by ensuring a gradual phase-out of fossil natural gas wherever electrification or switching to renewable or low-carbon gas is possible. In order to avoid lock-in of natural gas, **is set a cap on long-term gas contracts**, that are not allowed to extend beyond 2049.

Aiming to eliminate an entry barrier for renewable and low-carbon gas into the system, the Commission proposes to provide 75 percent discounts on entry tariffs. The Commission also proposes to remove border tariffs for renewable and low-carbon gas to facilitate cross-border sales in the European market and take advantage of the most promising generation sites. In a similar way, no cross-border tariffs will be applied to the dedicated hydrogen pipeline network in the future, promoting competition, accessibility, and security of supply. The Commission also proposes to introduce renewable and low-carbon gases into the existing gas network, including smaller plants to be connected to the distribution network.

The Package is intended to create a hydrogen market with appropriate infrastructure and a cross-border coordination, that includes interconnectors, where hydrogen can be conveniently transported from production areas to industrial end-users. Existing natural gas pipeline networks can be in some case reused to transport hydrogen, representing significant savings compared to constructing new infrastructure. The Package suggests regulations on the management and financing of hydrogen systems, on transparency of gas quality parameters, on hydrogen blending, on unbundling and on non-discriminatory access to the network. To ensure optimal development and management of the EU hydrogen network and to promote hydrogen trade and supply across borders, a European Network of Hydrogen Network Operators (ENNOH) will be implemented.

Hydrogen is expected to register an increase in the energy mix foreseen to reach 13-14% by 2050, with an underlying electrolysis capacity of 500 GW. Member states are now adopting the EU's strategic vision: some of them (such as France, Germany, Portugal, Spain and the Netherlands) have already set targets for 2030 or 2050 and have identified key use cases within the relevant sectors, such as industry and transport. To date, Italy has defined its climate strategy inside the **National Energy Strategy (SEN) (2017)** and the **National Integrated Energy and Climate Plan (PNIEC, 2019)**, in accordance with the EU Clean Energy Package and the European Green Deal.

In order to achieve hydrogen production that meets 2% of energy demand by 2030 (corresponding to approximately a 0.7 Mton/yr production increase), favourable conditions must be identified to ensure production feasibility. In general, there are three theoretical production/transport models that can be identified:

- On site production: renewable electricity generation plant and the electrolysers are located next to the point of consumption with the aim to minimize transport costs
- On-site generation with electricity transmission: renewable electricity is generated in areas with high availability of natural resources, then it is transported through the grid to the consumption location where it is converted to hydrogen by electrolysis
- Centralized production with hydrogen transport: renewable power generation and electrolysis capacity are located in areas with good conditions for renewable production. The hydrogen produced is then transported to the consumption site through a dedicated pipeline that could take advantage of the existing gas pipeline or through other transportation methods (e.g., trucks).

The advantages and disadvantages of these different supply models should be analysed especially with a long-term view, looking at the cost-benefit ratio not only for a single project but for a system creation, exploiting the concentration of consumption and production that could result from the development of "hydrogen valleys".

6.1.3 Emission limit directives

Partial or total use of NH_3 or H_2 would produce benefits in terms of reduced CO and CO_2 emissions. In the first case (CO) would help to reduce the environmental technical minimum, in the second (CO_2) would impact the cost of production at all production stages.
A lower environmental technical minimum would allow operation at very low load levels and could encourage TSO to maintain the plant in operation, increasing its possible participation to the markets. The preference that Transmission System Operator (TSO) could give to the dispatching of the plant is due to the faster response to load variations than the same plant in start-up phase.
From an economic point of view, low loads correspond to low revenues and therefore high production costs, so reducing production to the level of the technical minimum would increase the cost of production.
However, the reduction of CO_2 emissions, would reduce production costs in addition to other environmental benefits.

The emission limits in force for gas-fired electricity production plants in Italy are **established in the national AIA, as defined by Legislative Decree 152/2006 and subsequent modifications**. Limit values are aligned in the range of the BAT (best available technologies) Conclusion for Large Plants of Combustion (COMMISSION IMPLEMENTING DECISION (EU) 2021/2326 of 30 November 2021).

6.1.4 Hydrogen injection regulations

To date, in the gas transport and distribution network of Italy every year circulate over 70 billion cubic meters of natural gas, with dioxide emissions of carbon up to ~ 160 Mton. Hydrogen blending can represent an effective method for achieve the decarbonisation objectives and stimulate the hydrogen market. In the case of green hydrogen, the overgeneration from renewable sources can be exploited to produce the hydrogen to be mixed a lower cost.

Several European Member States are thinking to use hydrogen by mixing it with gas in the network to achieve the decarbonisation of the sector.

Over 10 EU countries have already set thresholds for mixing hydrogen. Although **in Italy an official technical limit is still in defining phase**, it is plausible to think that by 2030 an average of up to 2% of natural gas distributed may be replaced with hydrogen.

Considering the experimentations already carried out, Snam, in April 2019, was the first in Europe to test the introduction of a mixture of 5% hydrogen into its natural gas transportation network. The testing took place in Contursi Terme, near Salerno, and involved the supply, for about a month, of H2NG (hydrogen-gas mixture) to two industrial companies, a pasta factory and a mineral water bottling company. The Contursi experiment was replicated in December 2019, doubling the percentage of hydrogen to 10%. Assuming an application of 10% of hydrogen to the total gas transported annually by Snam, 7 billion cubic meters of hydrogen would be injected into the network resulting in a reduction of CO_2 eq emissions of 5 million tons.

Moreover, Snam planned to install the first "hybrid" hydrogen turbine in the world designed for a natural gas transportation infrastructure and fuelled up to 10% by hydrogen. The company is now verifying the compatibility of its infrastructures with increasing quantities of hydrogen blended with natural gas. Currently about 70% of SRG's pipelines are compatible with hydrogen.

6.1.5 H2/NH3 storage regulations

Through **Legislative Decree n. 257 of 16 December 2016,** the Italian government implemented the European directive 2014/94 / EU for the creation of an infrastructure for alternative fuels, where hydrogen is included. In Italy currently, there are 4 refuelling stations for hydrogen built with private or state funds. The most advanced station is in Bolzano, with a potential production of 180 Nm3 / h of hydrogen, enough to refuel 15 buses and 700 cars per day.

6.2 Portugal Grid code requirements and regulatory aspects

6.2.1 Ancillary services enhanced by FLEXnCONFU

The topic of ancillary services in Portugal was addressed in paragraph 4.4, where the three types of reserves (primary, secondary and tertiary) that are provided to keep the network stable and secure, in line with EU Regulation 2017/1485 (SOGL), were considered. Summarizing what has already been stated, all production units must allow a primary regulation of at least 5% of the nominal power. The maximum activation time is 15 seconds for changes in frequency under 100 mHz and linearly between 15 and 30 seconds for changes in frequency between 100 and 200 mHz. The frequency response insensitivity must be under 10 mHz with a dead band of 0 mHz. Maximum value for the initial delay for power-generating modules without inertia is 500 ms. Considering secondary reserve, all power generating units must place bids with the respective band (in MW) and the band's unitary price (in €/MW). These bids are then part of an internal market to determine which units are selected. Participants are obliged to comply with several requirements: activation in less than 5 minutes, capacity of vary the power within a band corresponding to at least 10% of the rated power, and ratio between upward and downward reserves is usually 2/3 in the upward direction and 1/3 in the downward direction with a tolerance of 5%. Finally, considering the tertiary reserve, physical units are obliged to bid if they take part in the wholesale market and if qualified to participate in the system services market. The participants must offer, for balancing areas of either production installations or consumption installations for pumping storage, all their feasible reserve regulation, both to increase and decrease, in MW with the energy price in €/MWh.

In terms of added flexibility to the CC power plant, the FLEXnCONFU concept can provide faster ramp up/down rates and a lower minimum environmental load. The faster ramp up/down rates increase the available power band for all of the ancillary services (even though this might not enhance the plant's ability to act on the ancillary services market in every situation). This effect is most present on the primary and secondary reserves as they have strict time requirements on the activation of these reserves.

The increased minimum environmental load not only allows the plant to operate at a lower load in the day ahead and intraday markets, but also increases the ramp down band of the power plant when operating at a relatively low load.

6.2.2 Electrolyser installation requirements regulations

The Portuguese Government has published reviewed regulation for the gas sector - **Decree Law nº. 62/2020 (August 28th)** - that sets the legal framework for gas in Portugal, incorporating renewable and low carbon gases. The permitting and licensing process for the production activity of renewable and low carbon gases is also defined in this regulation.

The activity of producing gases of renewable origin is subject to prior registration with the General Directorate of Energy and Geology (DGEG), which can take up to 30 days to get approved. APA (Agência Portuguesa do Ambiente) is the Portuguese environmental agency responsible for the environmental impact studies, required to be performed for any new power plant. If FLEXnCONFU is to be retrofitted to existing power plants, the following circumstances will be subjected to an assessment (AIA) on a case-by-case examination (according to **Decree-Law no. 151-B/2013 of October 31st**):

- ✓ Any change in or extension of projects listed in Annex I or Annex II, previously subjected to AIA and were approved, currently in execution or already executed
- ✓ Any project that is exclusively or essentially designed to develop and test new methods or products that is not operated for over two years considered, based on the case-by-case analysis, as susceptible to cause significant impact on the environment.

Other required permitting processes include a water use license, complying with the Seveso directive and with Safety against fires in buildings, where:

- ✓ Law no. 123/2019 identifies all the uses and risk categories subjected to the control for fire protection and prevention and regulates the verification of firefighting systems condition that is to be conducted by ANEPC (Autoridade Nacional de Emergência e Proteção Civil) or an entity accredited by ANEPC.
- ✓ Installations that produce and store hydrogen are classified as Type XII. Type XII uses corresponds to buildings, parts of buildings or open-air spaces, not usually receiving public,

destined for the exercise of industrial activities or for the storage of materials, substances, products or equipment, workshops repair services and all auxiliary or complementary services for these activities.

- ✓ Depending on the specific characteristics of the areas, it will be classified in one of four categories [A, B, C, C+ (aggravated risk), D, E or F] for all the applicable uses. For each category, there are different requirements to be met, in terms of documentation to submit to ANEPC in permitting phase.
- ✓ The SCIE Project must consist of written and drawn parts, in accordance with Annex IV of the Law no. 123/2019.
- ✓ During the detail engineering phase, the SCIE Project of the P2H2P demo plant shall be submitted to ANEPC, the competent authority to ensure compliance with the fire safety regime in buildings, in full compliance with the Law no. 123/2019 requirements.

6.2.3 Emission limit directives

The following Table 10, obtained in Decree-Law No. 39/2018, contains the emission limits for a CC power plant in mg for each Nm^3 of natural gas burned.

Table 10: Portugal CC power plant emission limits

	CO	NO_x	NMVOCs
Limit [mg/Nm^3]	100	50	110

6.2.4 Hydrogen injection regulations

In order to inject hydrogen into the national natural gas grid, the project must be registered as a location that produces gas from renewable sources (according to **decree-law No. 62/2020, article 69**). Afterwards, the gas grid operator declares if the technical requirements to connect to the grid exist and the General Directorate of Energy and Geology (DGEG) either approves or refuses the connection.

The regulation for the cost of the infrastructure connecting the production of gas from renewable sources (in FLEXnCONFU's case is the electrolyser and storage tanks) to the natural gas grid is described in **article 72 of decree-law 62/2020**. To summarize:

- ✓ The connecting infrastructure must be paid for by the producer. If other users will also use the infrastructure, the cost is to be divided among all users. The same is applicable for future users, where they will reimburse the producer that supported the cost for the infrastructure.
- ✓ The natural gas grid operator can propose to over-size the connecting infrastructure in order to obtain a more economical solution, where the operator will support part of the costs.
- ✓ The costs are estimated/determined by the Energy Services Regulatory Authority (ERSE).

The real time monitoring and control of the flow of injection of other gases (such as H2) in the natural gas grid and the adjustment according to the consumption downstream of the injection site is the responsibility of the grid operator (article 31 of decree-law 62/2020).

The grid operator cannot refuse the installation of a hydrogen injection point into the natural gas grid based on an eventual future constraint in the grid's available capacity or additional costs regarding the required increase in grid capacity (article 142 of decree-law 62/2020).

6.2.5 H2/NH3 storage regulations

Decree-Law No. 111-D/2017, of 31 of august 2017, transposing to the Portuguese legislation the Pressure Equipment **Directive 2014/68/EU, of 15 May 2014** on the harmonization of the laws of the Member States relating to the making available on the market of pressure equipment. This decree-law applies to the design, manufacture and conformity assessment of pressure equipment and assemblies subject to a maximum permissible pressure (PS) greater than 0.5 bar.

During equipment construction phase the Notified Body (NoBo) entity is hired, in order to ensure compliance with Decree Law nº. 111-D/2017 in the fabrication of pressure vessels (as defined in the PED Directive nº. 2014/68/EU) for CE marking. CE marking process has to be concluded before sending the equipment to the site, or otherwise it will not be accepted. The Issuing Authority is the NoBo.

Decree Law nº. 131/2019 ensures that a RIB (Recognized inspection body) entity is hired, in order to ensure compliance with Decree Law nº. 131/2019 for the installation of pressure vessels on time for commissioning and start up. The Issuing Authority is the RIB.

The Pressure equipment (PE) are subject to validation of operation, allowing the start of operation as long as the PE has been inspected, to be carried out by an NoBo qualified by the IPQ, with a favourable result.

6.3 Belgium Grid code requirements and regulatory aspects

6.3.1 Ancillary services enhanced by FlexnConfu

Regarding the use of the CCGT, it is expected that the FlexnConfu concept keeps the same flexibility as state-of-the-art CCGTs burning natural gas. On the other hand, when the power to X processes are in operation, further flexibility can be introduced, playing on the settings of the electrolysers for example, to deliver certain grid services to the grid (e.g. frequency control down – reducing load of the electrolysers whenever the grid is saturated or in power shortage). Load shedding, reduced load operation etc. are possible.

6.3.2 Electrolyser installation requirements regulations

Electrolysers are standard equipment in the chemical industry and should be seen as commonly used equipment. On the other hand, they will be considered as any process equipment (pressure vessel regulations are under pressure, ATEX, machine directive).

6.3.3 Emission limit directives

The current emission limits are technology related, and thus are the same as in the case of 100% natural gas combustion (typically 50 mg/Nm³ @ 15% O2, dry). However, the limits might differ from installation to installation, but always lower or equal to the European directives.

As ammonia and nitrogen deposits are an important issue in Belgium, further restrictions might apply, and for new installations, a denox catalyst is most of the times required (also in case of natural gas combustion).

6.3.4 Hydrogen injection regulations

The owner and operator of the natural gas transport network has plans to further decouple the gas transport infrastructure, and to make 3 different transport grids, one for methane, one for hydrogen and one for CO_2. In the industrial clusters, it will have access to all three. This concept is shown in

From this scenario, the FlexnConfu concept might evolve to a system in which hydrogen production and storage will not be done on site, but at a different location (e.g., landing of the electricity cables of off-shore wind parks).

However according to IEA, as of 2018, no hydrogen blending is allowed in the Natural Gas network (IEA, 2020)[22].

6.3.5 H2/NH3 storage regulations

Hydrogen storage and (pure) ammonia storage might be subject to all SEVESO regulation in place and will require much higher safety precautions compared to our current CCGT sites. This might be a huge barrier to the retrofit of existing sites to the FlexnConfu concept.

7. Conclusions

The objective of the deliverable D1.4 "Electrical market assessment for enhanced FLEXnCONFU concept in CC", is to identify the most suitable European Member States for the application of the FLEXnCONFU project solution.
To achieve this goal, the document has been divided into different sections:

- ✓ analysis of the European electricity market and focus on the national electricity markets of Italy, Portugal, and Belgium.
- ✓ analysis of types, functioning and forecasts regarding ancillary services and focus on the ancillary markets both in Europe and at national level (again considering the three representative states mentioned above)
- ✓ description of the methodological approach used to identify the Countries in which the FLEXnCONFU solution is most applicable, implementation of the analysis and presentation of the results.
- ✓ analysis of the national regulations (Italy, Portugal, Belgium) considering a specific set of areas: the market for ancillary services, electrolyser installations, emission limits, hydrogen blending and storage of hydrogen and ammonia.

Considering the **electricity markets**, the analysis highlights the European intention to create an integrated market among the various member States and covered by the same regulations. In addition, at the national level, the operation of the supply chain is very similar in the three Countries analysed. They all present national monopolies for electricity transmission, zonal monopolies for distribution, and liberalized generation and retail activities. Other important aspect in the context of the FLEXnCONFU project is the share of electricity generation through natural gas, which is one of the main sources of production (in Italy and Portugal is the first source by production shares) in all three representative States.

As regard the **ancillary service markets**, it has been highlighted that some trends like decarbonisation (and the consequent increase in the use of renewable sources), electrification of consumption and urbanisation, have a significant impact on the status of the electricity system and therefore they make ancillary services increasingly essential to ensure the proper functioning of the grid. Then, the main services provided at European and national level have been analysed and it has emerged that the functioning of the markets is similar, where the three types of reserves (primary, secondary, and tertiary) play a fundamental role.

The **identification of the Countries in which the FLEXnCONFU solution appear most applicable** follows a methodological approach composed by different steps:

1) Identification of the relevant KPI
2) Data research
3) Normalization of KPI in order to assume a value between 0 and 1
4) Sum of normalized and weighted KPIs

5) Ranking of the EU States

Based on the identification of the KPIs and on the assignment of the relative weight, it is possible to state that **the most suitable countries for the applicability of the solution** are the ones with:

- ✓ high share of generation from renewable sources
- ✓ high electricity costs for non-household end-users
- ✓ high natural gas costs
- ✓ high share of generation from gas-fired plants
- ✓ high production of hydrogen.

As the Table 11 shows, in the top 5 positions in the ranking include the three representative EU States: Italy (1st), Belgium (4th) and Portugal (5th).

Table 11: Top five EU Countries

Country	Sum of TOTAL
Italy	5.0197
Spain	4.9932
Germany	4.5556
Belgium	4.3542
Portugal	4.3114

Finally, considering the regulations over the three representative EU States each Partner has analysed the grid code highlighting key national and EU regulations for each topic and the existing limitations applied in its Country. A specific set of topics were considered: the market for ancillary services, electrolyser installations, emission limits, hydrogen blending and storage of hydrogen and ammonia; Highlighting key national and EU regulations for each topic and the existing limitations.

References

[1] Arera. (2015). *TIUF.* Retrieved from https://www.arera.it/allegati/docs/15/296-15tiuf.pdf

[2] Arera. (2016). *TIUC.* Retrieved from https://www.arera.it/allegati/docs/16/137-16all_ti.pdf

[3] Arera. (2019). *TESTO INTEGRATO DEL DISPACCIAMENTO ELETTRICO.* Retrieved from https://www.arera.it/allegati/docs/19/322-19.pdf

[4] Arera. (2020). *Dati statistici.* Retrieved from https://www.arera.it/it/dati/elenco_dati.htm

[5] Arera. (2020). *Evoluzione delle modalità di approvvigionamento delle risorse necessarie per i servizi ancillari.* Retrieved from http://www.tpg.unige.it/TPG/wp-content/uploads/2020/12/Seminario-Ing-Galliani-17-novembre-2020.pdf

[6] Arera. (2020). *Relazione Annuale.* Retrieved from https://www.arera.it/allegati/relaz_ann/21/RA21_volume_1.pdf

[7] Arera. (2021). *Distribuzione di energia elettrica per società di distribuzione.* Retrieved from https://www.arera.it/it/dati/eem51.htm

[8] Arera. (2021). *RIFORMA DELLA DISCIPLINA DEGLI SBILANCIAMENTI, IN ATTUAZIONE DEL QUADRO REGOLATORIO EUROPEO.* Retrieved from https://www.arera.it/allegati/docs/21/523-21.pdf

[9] Dataenergia. (2014). *Le diverse funzioni dei sistemi di accumulo nella gestione delle rinnovabili intermittenti.* Retrieved from http://dataenergia.altervista.org/portale/?q=diverse_funzioni_sistemi_accumulo_gestione_rinnovabili_intermittenti

[10] Drax. (2020). *What are ancillary services?* Retrieved from https://www.drax.com/power-generation/what-are-ancillary-services/

[11] Enel. (2020). *POWER AND GAS PRICE LEVEL.*

[12] Entsoe. (2018, November). *entsoe.eu.* Retrieved from https://eepublicdownloads.entsoe.eu/clean-documents/Network%20codes%20documents/NC%20EB/entso-e_balancing_in%20_europe_report_Nov2018_web.pdf

[13] EPRS. (2016). *Understanding electricity markets in the EU.* Retrieved from https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/593519/EPRS_BRI(2016)593519_EN.pdf

[14] Erbach, G. (2016, November). *Understanding electricity markets.* Retrieved from http://www.easyres-project.eu/: http://www.easyres-project.eu/wp-content/uploads/2019/02/understanding-elecricity-markets-in-the-eu.pdf

[15] ERSE. (2022). *Síntese Mensal Janeiro|2022.* Retrieved from https://www.erse.pt/media/noscljyt/202201_ele_rel_ml.pdf

[16] EUI. (2020). *The evolution of electricity markets in Europe.* Retrieved from https://cadmus.eui.eu/handle/1814/69266;jsessionid=D86C6562259997610090AAABEB9D351E

[17] European Commission. (2019). *Clean energy for all Europeans package.* Retrieved from https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

[18] European Commission. (2020). *Electricity market design.* Retrieved from https://energy.ec.europa.eu/topics/markets-and-consumers/market-legislation/electricity-market-design_en

[19] European Parliament. (2020). *EU economic developments and projections.* Retrieved from https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/645716/IPOL_BRI(2020)645716_EN.pdf

[20] GME. (2021). Retrieved from https://www.mercatoelettrico.org/it/

[21] GME. (2021). *https://www.mercatoelettrico.org/*. Retrieved from Gestore mercati energetici: https://www.mercatoelettrico.org/En/Mercati/MercatoElettrico/IlMercatoElettrico.aspx

[22] IEA. (2020). *Data and statistics.* Retrieved from https://www.iea.org/data-and-statistics/data-browser?country=PORTUGAL&fuel=Energy%20supply&indicator=TESbySource

[23] IEA. (2020). *European Union 2020.* Retrieved from https://iea.blob.core.windows.net/assets/ec7cc7e5-f638-431b-ab6e-86f62aa5752b/European_Union_2020_Energy_Policy_Review.pdf

[24] IEA. (2021). *Portugal 2021 - Energy Policy Review.* Retrieved from https://iea.blob.core.windows.net/assets/a58d6151-f75f-4cd7-891e-6b06540ce01f/Portugal2021EnergyPolicyReview.pdf

[25] IHS. (2018).

[26] IRENA. (2019). *Innovative Ancillary Services.* Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Feb/IRENA_Innovative_ancillary_services_2019.pdf?la=en&hash=F3D83E86922DEED7AA3DE3091F3E49460C9EC1A0markets)., (. 2. (n.d.).

[27] Ministero dello Sviluppo Economico. (2022). *Mercato elettrico.* Retrieved from https://www.mise.gov.it/index.php/it/energia/energia-elettrica/mercato-elettrico

[28] Ofgem. (2014). *Bidding Zones Literature Review.* Retrieved from https://www.ofgem.gov.uk/sites/default/files/docs/2014/10/fta_bidding_zone_configuration_literature_review_1.pdf

[29] Omie. (2021). Retrieved from omie.es: https://www.omie.es/en/mercado-de-electricidad

[30] Practical Law. (2021). *uk.practicallaw*. Retrieved from Electricity regulation in Italy: overview: https://uk.practicallaw.thomsonreuters.com/4-525-4301?transitionType=Default&contextData=(sc.Default)&firstPage=true#co_anchor_a373764

[31] Statista. (2017). *Market share of electricity Distribution System Operators (DSOs) in Wallonia (Belgium) as of December 2017.* Retrieved from https://www.statista.com/statistics/878525/electricity-dso-market-share-in-wallonia-belgium/

[32] Statista. (2021). *Biggest electricity suppliers in Flanders (Belgium) 2021, by market share.* Retrieved from https://www.statista.com/statistics/752955/leading-electricity-suppliers-in-flanders-belgium-by-market-share/

[33] Statista. (2021). *Biggest electricity suppliers in Wallonia (Belgium) 2021, by market share.* Retrieved from https://www.statista.com/statistics/752968/leading-electricity-suppliers-in-wallonia-belgium-by-market-share/

[34] Statista. (2021). *Leading electricity suppliers in the Brussels-Capital Region (Belgium) in 2021, by market share.* Retrieved from https://www.statista.com/statistics/752974/leading-electricity-suppliers-in-brussels-belgium-by-market-share/

[35] Statista. (2021). *Projected population of Europe from 2022 to 2100.* Retrieved from https://www.statista.com/statistics/875955/population-of-europe-forecast/

[36] Statnett et al. (2020). *Explanatory document to the coordinated redispatching and countertrading methodology for Capacity Calculation Region Hansa in accordance with Article 35 of the Commission Regulation (EU) 2015/1222 of 24 July 2015 establishing a Guideline on Capacity Alloc.* Retrieved from https://consultations.entsoe.eu/markets/coordinated-rdct-hansa/supporting_documents/20201203_CCR%20Hansa_RD%20CT_explanatory%20note.pdf

[37] Swissgrid. (2020). *Stabilità della rete.* Retrieved from https://www.swissgrid.ch/it/home/operation/regulation/grid-stability.html

[38] Terna. (2021, September). *Terna.it*. Retrieved from https://www.terna.it/en/electric-system/electricity-market

[39] Terna. (2022). *LA RETE ELETTRICA ITALIANA.* Retrieved from https://www.terna.it/it/chi-siamo/attivita/rete-elettrica-italiana

[40] Thomson Reuters. (2020). *Electricity regulation in Portugal: overview.* Retrieved from https://ca.practicallaw.thomsonreuters.com/6-564-1565?transitionType=Default&contextData=(sc.Default)&firstPage=true

[41] Thomson Reuters. (2021). *Electricity regulation in Belgium: overview.* Retrieved from https://uk.practicallaw.thomsonreuters.com/w-030-3627?contextData=(sc.Default)%2f)&transitionType=Default&firstPage=true

[42] Valerie Reif, T. S. (2020, September). *Florence School of Regulation.* Retrieved from fsr.eui.eu: https://fsr.eui.eu/electricity-markets-in-the-eu/