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Regulatory mechanisms and support schemes towards the energy sector's transition with a focus on systems integration

Relatore: Prof. Carlo Cambini

Candidato: Sara Durante

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Abstract

The purpose of this work is to give a general overview of the main regulatory mechanisms and of the key support schemes adopted by EU Member States to sustain the transition of the energy system towards a zero-emission economy. In this work, the focus is on energy systems integration and the role of the relative technologies in the achievement of the environmental targets. We analysed the regulatory and policy context of three EU Member States: Belgium, Denmark and the Netherlands, trying to provide a general view of the main characteristics influencing the investments by network operators and by other energy players. Every country has different ways of supporting innovation and in particular systems integration. From the assessment made, it is possible to observe that not all the analysed regulatory contexts are appropriate to give reasonable incentives for investing in such topics. However, all countries are continuing to improve their mechanisms of regulation and their methods of support for boosting key energy innovation technologies.

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Introduction

The aim of the work is to examine different European contexts to understand what governments are doing to encourage investment in the integration of energy systems. In particular, the regulatory framework and the associated incentive mechanisms put in place by the National Regulatory Authority (NRA) are analysed. The objective is to examine how much regulated network operators are stimulated to invest, not only in infrastructure expansions but also in innovation. In addition to this, a broader context has also been considered, referring to both European and national energy policies and some investment support mechanisms. The aim is to investigate the paradigm of integrated energy systems because it is one of the most likely models for the future, as it allows for many benefits both in environmental and economic terms.

The energy system of all European countries is undergoing substantial changes due to stringent environmental policies. These are the main drivers of the European energy transition and are the basis of many European Directives. National governments are working hard to enact ad hoc laws to achieve the targets imposed at EU level. The integration of energy systems and the related technologies makes it easier to meet environmental goals, allowing for greater flexibility, high integration of renewable resources in multiple sectors at the same time and a full exploitation of existing synergies. The importance of this new paradigm has been widely accepted; however, there are still no clear guidelines to facilitate a change in traditional systems. That is why it is important to investigate what is happening at the level of single countries, allowing to build guidelines at European level based on the best practices observed.

The first chapter briefly described the European context, the key Directives for environmental sustainability and a brief description of the main technologies for integrating energy systems. From the first chapter, it is decided to focus also on environmental issues as they are considered fundamental in the transition of the energy system. Without environmental concerns, both governments and energy companies would not have adequate motivation to invest in innovative and risky technologies.

The second chapter described the best-known methods of regulation and financial incentives adopted by national and EU governments. In addition, an overview of the main tools, that can be incorporated into the regulatory structure to incentivize some innovative projects, was also carried out.

The last chapter looked at the framework of Belgium, Denmark and the Netherlands. The different methods of regulation and the various investment support mechanisms adopted by different governments were described. However, it was particularly difficult to understand which mechanisms led to increased investment by network operators. For this reason, we report, where possible, a list of several projects subsidized by national funding programs. These can be used as an approximation to determine how much a given context facilitates investment in innovation and in particular in energy systems integration technologies.

The search for information has in some cases been hampered, as institutions often elaborate documents only in the national language. For this reason, the data shown represent only a general view of national contexts.

1. Transformation of the European energy sector

1.1. Towards a zero emissions economy

European energy sector, over the past decade, has been the centre of multiple European directives that have led to substantial changes for the entire system, in terms of technology, organization and regulation. These transformations are largely due to climate change and pollution, as they are often part of broader strategies to improve environmental conditions, which the European Commission considers to be one of the most pressing issues.

The European Directive 2009/28/EC (Renewable Energy Directive) is part of a wider plan drawn up by the Committee to guide Member States towards 2020 (Europe 2020) and allow for a faster exit from the economic crisis of the past decade. The main goal was to achieve smart, sustainable and inclusive growth, through a path based on reaching specific goals in different areas. Several objectives had been set in relation to climate and energy[1]:

- reduce greenhouse gas emissions by at least 20% compared to 1990 levels or 30% if the conditions are right;
- increase the share of renewable energy sources in final energy consumption to 20%;
- 20% increase in energy efficiency.

Working on these purposes, Europe wants to achieve not only an improvement in environmental conditions but also economic growth that exploits resources efficiently and is disconnected from the use of energy. In this way European economy would be less dependent on non-renewable resources and on importation of energy. Achieving these aims would allow Europe and its companies to gain a competitive advantage on the international market.

In 2015 the European Commission presented the Energy Union Strategy[2], which aims to integrate, within a single plan, different sectors and initiatives, allowing for greater coordination and consistency between national policies. The central dimensions of the

[1] EUROPE 2020: A strategy for smart, sustainable and inclusive growth
[2] COM (2015) 80

strategy are security of supply, a continental integrated energy system, energy efficiency, decarbonization of the economy and research, innovation and competitiveness in the sector of low carbon technologies.

To provide an insight into the progress made, reports and studies are developed allowing us to chart the European and country paths. The Fourth State of the Energy Union Report[3] states the latest development data on 2020 targets.

In terms of greenhouse gas emissions, there was a 22% reduction between 1990 and 2017 compared with economic growth of 58% during the same period. This highlights how Europe is managing to decouple economic growth from CO2 emissions and energy consumption. The 20% target now seems to have been reached for Europe and, indeed, the projections report a possible overshoot of the target with a total reduction of 26% by 2020, maintaining only existing policies. Despite this, only 20 of the Member States will meet or exceed national targets, while for the remaining eight the existing policies are not enough to achieve them (Austria, Belgium[4], Cyprus, Finland, Germany, Ireland, Luxembourg and Malta).

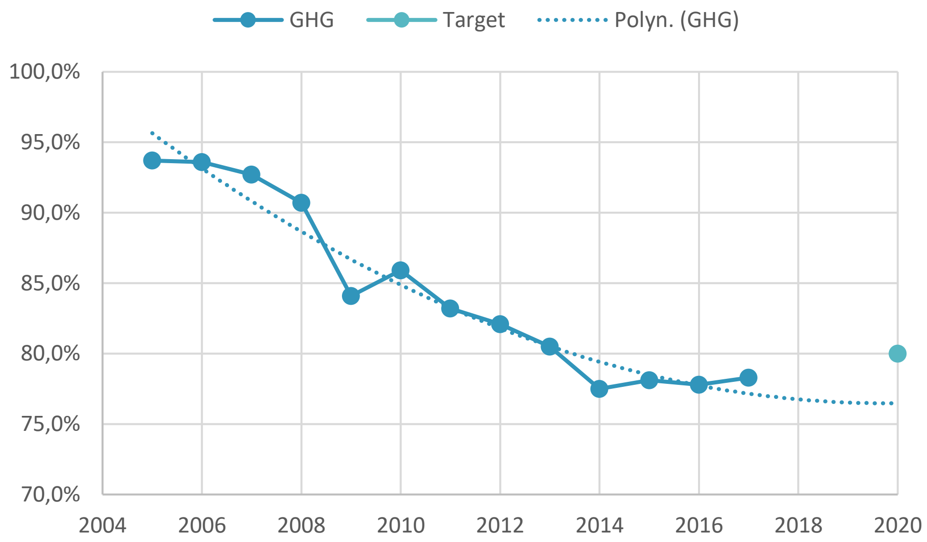

Figure 1:Greenhouse gas emissions of EU (2005/2017)[5]

[3] COM (2019) 175 final/2
[4] As it will be possible to observe in the paragraph related to Belgium, the level of investment and energy policies are not enough to meet the national targets.
[5] Source of data: Eurostat

The data for energy efficiency shows that there is not a completely positive situation at European level. After a decline in energy consumption between 2007 and 2014, which had brought levels even below the annual targets, there has been an increase in energy consumption since 2015 that has brought levels above the estimated trajectory. The 20% target is still achievable, but it requires a lot of effort, as projections predict that, with the growth rate of energy consumption recorded in 2016, Europe will not succeed in its aim. It is necessary to act at the level of nations, since the individual targets set by the Member States are less ambitious than that set at European level. In fact, the sum of the national targets, set for primary energy consumption, leads to a result of 3.3% higher than that set at EU level. In addition to this, ten of the Member States did not even reach their target in 2016, contributing to the departure from the common goal. In the figure below is reported the reduction of primary energy consumption of European Union. This indicator covers the energy consumption of end user plus the one of the energy sectors, for all the activities (production, losses, transmission, etc.).

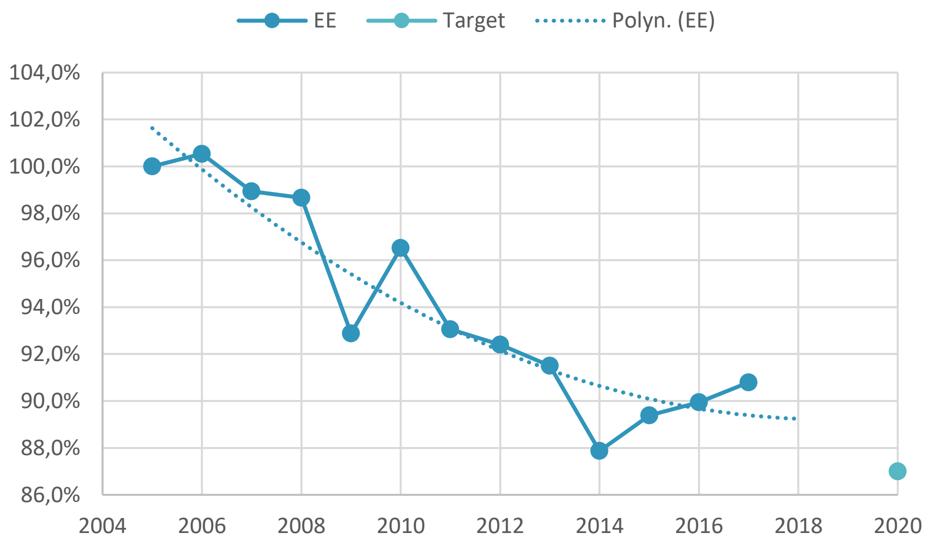

Figure 2: Primary energy consumption reduction of EU compared to 2005 levels[6]

In 2017, the share of energy from renewable sources reached 17.5%, which puts Europe in a good position to reach the 20% target. However, it should be considered that the share of renewables varies widely between different sectors, from 30.8% in energy to 7.6% in transport[7]. Under current national policies in 2020, the share of renewable energy will be

[6] Source of data: Eurostat
[7] The transport target is set at 10% by 2020.

around 1% higher than set, although the growth rate of the sector has slowed since 2014. Eleven Member States had already met their 2020 targets in 2017, while seven were below the annual targets set.

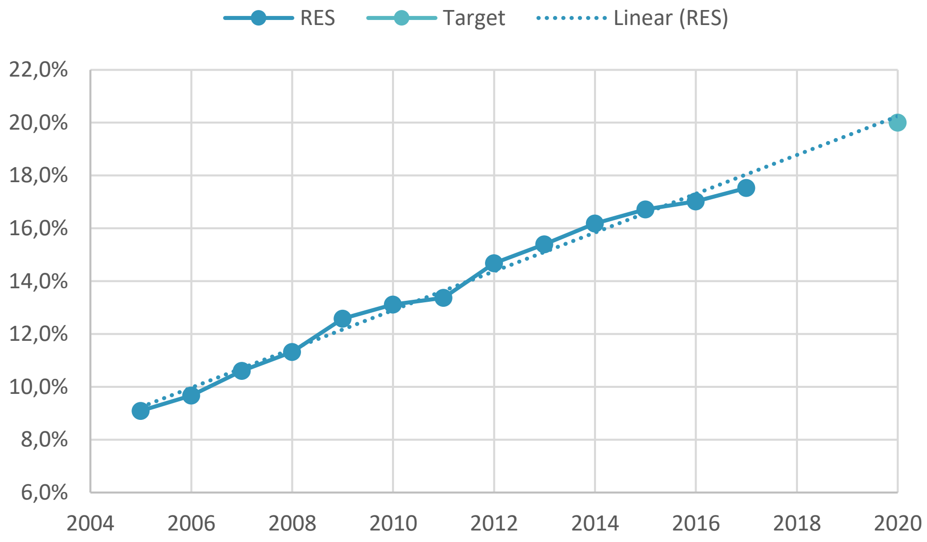

Figure 3: Share of renewable sources of EU[8]

After a brief look at the data, it is possible to see that Europe is on track to meet its 2020 energy and climate targets, but as the end of the 2010/2020-decade approaches, the European Commission has begun to work on the 2021/2030 period. The framework for 2030 was adopted in 2014, but some of the targets have been revised and raised in 2018. Current targets include:

- a reduction of at least 40% in greenhouse gas emissions compared to 1990 levels;
- 32% of renewable energy (previously set at 27%);
- an improvement of at least 32.5% in energy efficiency.

Achieving these objectives is closely linked to the commitment of both the European Commission and individual states, which must provide the right support through appropriate regulatory and incentive systems. Final national plans for 2021/2030 must be submitted by the end of 2019 and, in addition, each state will be required to develop long-term strategies consistent with what has already been planned.

[8] Source of data: Eurostat

In addition to the plan for 2030, in November 2018 Europe presented its long-term strategy for a prosperous, modern, competitive and climate-neutral economy by 2050[9]. The European Commission's communication examines several possible scenarios for reaching the zero share of greenhouse gas emissions by 2050. In all of these, the energy sector, responsible for 75% of European emissions, will have to move closer to zero through the integration between different energy systems and markets, efficient exploitation of renewable resources and new ICT tools as well as an improvement in technology and network innovation. The integration and exploitation of renewable resources play a key role in this transition to a zero-emissions economy, but to make renewable resources and related technologies efficient, both in terms of reliability and cost, facilitate the entry into the market of innovations such as conversion or storage systems is needed.

1.2. New challenges for the energy system

As explained in the previous paragraph, at the heart of many of the changes, that Europe is pursuing to achieve a sustainable economy, there are renewable resources and their relative integration into energy networks across the European Union.

The increased use and inclusion of these resources lead to different changes and challenges:

- The transition from a centralized system, where energy production is concentrated in a few large power plants connected to the transmission network, to a distributed generation system, in which production takes place in small units scattered over the territory and linked directly to the distribution network.
- More flexible system as many of the renewable energy sources are intermittent in nature, given their dependence on weather conditions.
- Greater interconnection between Member States, both in terms of market and system in order to ensure greater security, better use of renewable energy and less dependence on imports.
- Cross-sector integration to achieve an integrated energy system, harnessing renewable resources not only for electricity production but also for heating,

[9] COM (2018) 773 final

cooling and electric vehicles. Better use of ICT resources would also make cross-sector integration more efficient and cost-effective.

- Consumers are moving from a totally passive role to active, thanks to decentralized production and technological innovations that allow people to manage independently the consumption of their home. In addition to this, citizens play a primary role in the drive to find new solutions, as the growing awareness of climate change leads them to be more attentive in their choices and to demand green answers in all sectors, including energy.

1.3. Analysis of selected technologies and methods for the integration of energy systems

To solve the problems listed above and to increase the chances of achieving a zero-emission economy, the energy sector is developing new technologies and improving existing ones. Research, innovation and the exploitation of new techniques must be fostered by a regulatory context designed and modified to encourage improvement and adapt to the new challenges. Among all the energy solutions, it is important to focus on system integration, because this emerging trend could lead to substantial improvement in every aspect of energy market. The interconnections between different energy sectors, as electricity, gas, heat and transport, allow to exploit renewable energy, to improve systems flexibility and to gain maximum benefit from the existing synergies. In the next sections, we provide a description of the main technologies which enabling energy system integration.

1.3.1. Energy storage and conversion system

One of the solutions, that allows to respond effectively to different problems of the energy system and of many other sectors, is energy storage. This technology enables to store energy in times of low demand and then make it available in times of need, allowing a better match between supply and demand. In recent years, the integration of these technologies into the electrical system has become of significant importance, as they let full exploitation of variable sources, such as solar and wind, reducing the need for curtailment.

The definition provided by the European Commission for Storage Systems is:

"Energy storage in the electricity system means the deferring of an amount of the energy that was generated to the moment of use, either as final energy or converted into another energy carrier"[10,11]

The definition is directed to give clear guidelines to all Member States, as national legislations are inconsistent with each other and the concept of energy storage is confused. With this classification, the concept has expanded, introducing systems that do not reconvert energy into electricity. This allows storage facilities to be used for the integration of renewable sources not only in the energy sector but also in transport, buildings and industry, contributing to the decarbonization of them. These markets could reduce their emissions through the exploitation of energy carriers such as hydrogen, methane and heat obtained from the conversion and storage of electricity generated from renewable sources. An integrated approach, both in regulatory and market terms, is essential in order to achieve a benefit in many areas, reachable thanks to the use of appropriate mechanisms. Maximum support must be offered to tools that provide flexibility, such as storage systems, by removing market, regulatory and administrative barriers to the installation and operation of such plants.

It is necessary to underline that the European Commission has established that energy storage operators must be independent of transmission and distribution network operators (TSO and DSO), excluding clearly defined exceptions. They must also be allowed to provide services to network operators, but at the same time must be able to participate in other business activities.

Energy storage systems are also a response for citizens, equipped with an energy self-producing system, who have to cope with the variability of renewable sources. Using small localized plants, prosumers can be totally independent, or almost, from the electricity grid, managing to take full advantage of the potential of their generator.

Energy can be stored using different technologies: mechanical, thermal, chemical, electrochemistry and electrical. Each methodology has different technical characteristics in terms of capacity, power and reaction speed, making them suitable for different

[10] SWD (2017) 61

[11] The energy carrier is a form of secondary energy that can be transported (often by special networks) to the place of use.

applications. In addition to the technical features, the level of investment required, costs and efficiency must always be considered to estimate the impact of storage systems. The methods for storing energy are different, a selection of the main ones is reported:

- Mechanical technologies leverage the conversion of electricity into kinetics energy and/or potential one.
  - Among the most popular and mature methods there is the pump hydro storage (PHS) which accounts for about 97% of the storage capacity installed globally. The biggest limit for this technology is the need for appropriate locations for the installation.
  - Compressed air or liquid air technologies use electricity to compress or liquefy air that is then stored. Next, the air is expanded and passed into a turbine to generate electricity again. These techniques are recent and only two facilities are currently in operation, but it is expected that by 2030 they will reach costs and capabilities like those of PHS. Even for these types of storage, the highest barrier is the lack of adequate sites. To take full advantage of the potential, there is the need to combine these technologies with other heating and cooling applications.
- Thermal systems (Power to Heat, P2H) convert electricity into heat, stored in a specific storage material, such as gases or liquids. Stored heat can be used for heating or converted into electricity through turbines. This type of storage solutions can be used for the electrification of heat sector, combining P2H technologies with district heating or using thermal systems for residential heat.
- Chemical storage (Power to Gas, P2G) can store energy for different intervals of time depending on the choice of conversion vector. This technology is mainly based on the conversion of electricity into hydrogen and oxygen via electrolyte process. Hydrogen is the most common result of these processes and can be used pure or to produce other substances, such as synthetic natural gas (SNG), ammonia or other chemicals. Hydrogen-to-methane (SNG) processing requires carbon, often gained from the emissions of combustion plants and captured by special technologies (Carbon Capture and Storage technologies, CCS). The results of these processes can both be converted into electricity and used as raw materials in industrial processes, contributing to the decarbonization of various sectors (refineries, fertilizers and transport). An advantage

of this technology is the possibility to transfer the hydrogen or the SNG through the gas networks already existing. Economic pros should also be considered, as hydrogen storage is already characterized by low costs that make it the most convenient for long-term storage and for integration between sectors.

- Batteries are electrochemical storage solutions whose properties depend on the specific technology. These tools have short storage durations and very fast response times, making them suitable for medium or low voltage distribution networks. Emerging technologies in recent years include lithium-ion batteries, thanks to the significant research and development investments in areas such as electronics and transportation. These researches have enabled this technology to become economically competitive thanks to an increasing cost reduction. A focus should be done on the sector of electro mobility, as the electrification of transport has an impact on the energy sector both in terms of load but also in terms of flexibility. Electric vehicles (BEVs), hybrids (HEVs) and fuel cell (FCEV) have made much progress in recent years and, in addition to the decarbonization function of the transport sector, can be used as localized storage methods and as generators (Vehicle to grid, V2G).

Although many of the mechanisms described are already playing a key role in the transformation of energy systems, an improvement in efficiency and a reduction in costs are needed. The expenses are expected to decrease between 50 and 70% by 2030, based on technologies.

1.3.2. Combined heat and power (CHP) and District Heating (DH)

Energy efficiency is one of the issues at the heart of European plans, as losses in sectors such as electricity are considerable. About two-thirds of the primary energy is lost during the transformation into electricity, dissipated in the form of heat. Among the methods that can improve this condition are combined heat and power plants (CHP) and district heating (DH).

Cogeneration or CHP allows simultaneous production of electricity and heat, greatly increasing energy efficiency with conversion rates of up to 90% (while a traditional plant has a conversion efficiency of about 36%). Heat in a cogeneration plant is recovered and used for many applications such as in industrial sectors or in-home heating. This technology can be even more effective when combined with different methods of thermal storage, which allow not to reduce production even in times of low demand and to respond adequately to different capacity needs and power. A further step is to use tri-generation, with simultaneous production of electricity, heat and cooling.

There are also small systems called micro CHP that use different types of fuels and sources and allow to produce electricity and heat at domestic level. These technologies have the same function as traditional boilers but in addition produce electricity to satisfy all or part of self-consumption. Micro-cogeneration machines have total returns of between 85 and 90% (electric and thermal efficiency) and, moreover, eliminate network losses due to the transport of electricity from the power station to end users.

In addition to increasing energy efficiency, many cogeneration technologies use renewable sources (geothermal, biogas) and alternative fuels (e.g. hydrogen), further contributing to the decarbonization of the energy sector.

A good use of the heat coming from CHP plants is district heating, a technology that allows consumers to get heat directly for low and medium-temperature applications, such as spaces heating and hot water in residential and commercial buildings. The heat used in the DH plants is recovered not only from cogeneration facilities but also from renewable sources located in the territory and from industrial processes.

The benefits of combined heat and power plants and of district heating are many, including:

- Improving energy efficiency and system flexibility
- Reducing CO2 emissions
- Reducing dependence on fossil fuel imports
- Improving the stability of the power grid
- Efficient use of local, renewable and waste energy resources
- Reducing costs for end consumers.

The use of these technologies is still limited due to different economic and regulatory barriers, which the European Commission sought to eliminate under Article 14 of the 2012 European Energy Efficiency Directive. The declaration required member countries to assess the spread of district heating and cooling systems by December 2015 and an analysis of the strategies to be adopted by 2020 and 2030 to achieve the diffusion planned. A further assessment is expected by the end of December 2020.

1.3.3. Smart grid and the role of ICT technologies

For the European commission, the term smart grid means:

"an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both " in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety."[12]

The use of these technologies permits to have a network monitored continuously and able to automatically adjust energy flows, to adapt to changes in demand or supply. Moreover, it is possible to have a greater integration of renewable resources thanks to the possibility of combining demand projections with weather forecasts, so that network operators can plan and balance the flow of energy.

In addition to this, the use of smart metering systems allows operators and consumers to have a real-time view of energy consumption, bringing considerable benefits to all users of the network. End customers can decide to change their habits in terms of moment of usage and volume, taking full advantage of dynamic pricing contracts. The European Union's goal is to replace 80% of traditional meters in smart ones by 2020, as this technology allows for an annual reduction of around 9% in both domestic energy consumption and CO2 emissions.

In 2017, the Joint Research Centre (JRC), the scientific service within the European Commission, published the report "Smart grid projects outlook 2017" which describes the European situation regarding smart grid projects. In this report, research and development and demonstration projects were considered, not taking into account those technologies that are ready to enter the market, such as smart metering systems. The European projects considered are 950 with total investments of around 5 billion euros, given that for some projects the budget data are absent or incomplete. The figure below summarizes the main data of the projects analysed in the report (Figure 4).

[12] SEC (2011) 463 final

Figure 4:Summary of the 2017 database of smart grid projects[13]

It is important to note that not all Member States have the same level and pace of investment in smart grid projects, in fact there are substantial differences due to specific characteristics and circumstances as well as very diverse regulatory contexts. There are 10 Member States which present a number of projects above the European average (equal to 75 projects). The highest number of projects participation are related to Germany, United Kingdom and Denmark. These three countries present also the highest number of national projects. All these indicators can be used as evidences for the favourable national and regulatory environment. In the last chapter, we provide some further evidences about the favourable investment conditions in Denmark.

For the projects analysed, the main source of funding is private investment, which accounts for 60% of the total for research and development projects and 40% for demonstration ones. Despite this, only 15% of projects are financed entirely from private sources. National and European Union funding is key to continued innovation, enabling companies to manage and share the risk of highly innovative technologies.

In addition to direct investment sources, Europe and Member States can encourage companies to invest in innovative projects, through incentive and remuneration

[13] Source: Gangale F., Vasiljevska J., Covrig F., Mengolini A., Fulli G., Smart grid projects outlook 2017: facts, figures and trends in Europe, EUR 28614 EN, doi:10.2760/701587

mechanisms, especially for distribution network operators (DSOs). The latter are at the centre of the changes in the electricity grid and of the progressive digitization, indeed they are the ones who invest the most in innovation in order to be able to change their role at the same time as market needs.

Smart grid projects can be divided into different domains, as the innovations included in the smart grid concept are of different nature:

- Smart network management (SNM): in which are projects that aim to the flexibility of the power grid through the use of monitoring and control systems.
- Demand side management (DSM): this section includes projects that intend to reduce energy consumption and change the demand response profile. In order to do this, they try to act directly on the end consumer, guiding them to change their habits.
- Integration of distributed generation and storage (DG&S): this type of project focuses on advanced control schemes and the use of new ICT technologies to facilitate the use of the latest integration techniques, allowing to have an improved network security and reliability.
- E-mobility: this domain collects projects that focus on integrating electric and hybrid vehicles into the network.
- Integration of large-scale renewable energy sources: these projects aim to facilitate the integration of renewable resources into the transmission network or high voltage distribution.

Smart network management, demand side management and integration of DG&S are the domains that received about 80% of the total investments in 2017. The level of investment in the different domains are very diversified between Member States. For this reason, an explanatory graphic is reported, which is part of the JRC study and represent the total investments in smart grid projects for 2015. As we can see, the total investments vary very much between different countries and also the composition of the projects' domains is diversified.

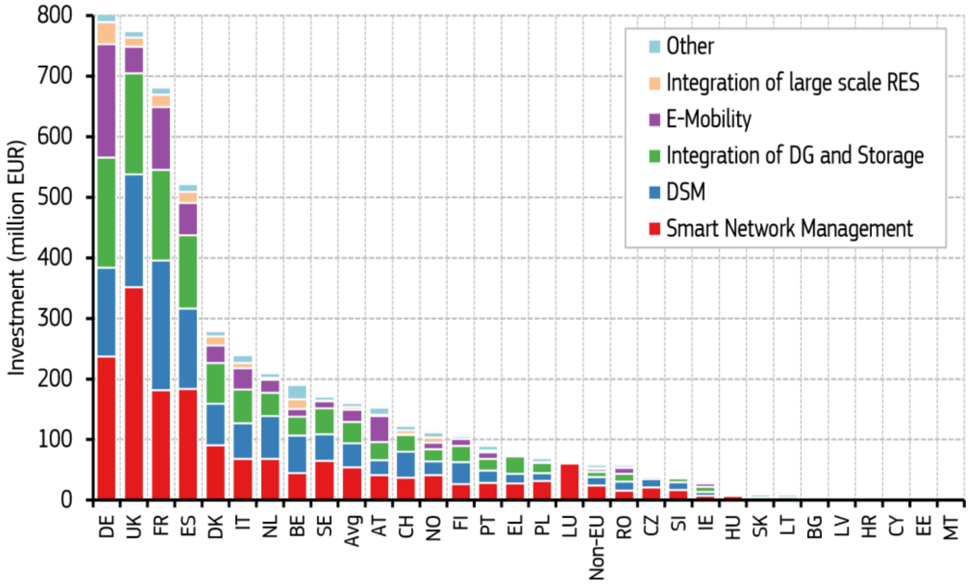

Figure 5: Distribution of investment per smart grid domain and country[14]

Although these technologies have a key role to achieve the goal of a zero-emission economy, the use of integrated ICT systems within the electricity grid leads to privacy issues and to the spreading of end-consumer personal data. That is why the European Commission has imposed norms and rules on how data should be processed and transferred to ensure both an adequate level of security and efficient data exchange.

[14] Source: Gangale F., Vasiljevska J., Covrig F., Mengolini A., Fulli G., Smart grid projects outlook 2017: facts, figures and trends in Europe, EUR 28614 EN, doi:10.2760/701587

2. Regulatory tools and financing mechanisms

The energy sector is characterised by economies of scale and externalities, especially environmental ones, that hamper the establishment of a competitive market and facilitate the emergence of a natural monopoly in many of the activities within it (such as transmission and distribution of electricity and gas). The natural monopoly is defined as a form of market in which it is cheaper to have a single company that produces the full amount of the good or service required than any other forms of market. Monopoly, despite being more efficient under certain conditions than competition, is a market failure and as such leads to inefficiencies such as higher prices and lower investments. As many public utilities (electricity, gas, telecommunications and others) are characterised by natural monopoly conditions, it is necessary to introduce supervisory and regulatory authorities to ensure an adequate service and to protect citizens interests. These institutions, in addition to controlling the work of network operators, must also establish a system of tariff regulation and a support structure to encourage investments in infrastructure improvements and innovation.

2.1. Regulatory system

2.1.1. Cost based regulation and rate of return

The methods of setting tariffs can be based on the costs incurred by the company:

- One practice is cost-plus, which defines prices as the sum of costs sustained and a certain profit margin, established by the authority.
- A way to implement a cost-plus regulation is to set a limit on the rate of return on investments that the monopoly company can achieve (Rate of Return). This method aims to cover the operating costs incurred by the company for the delivery of the service, and a default rate of return on the regulatory asset base (RAB). The difficulties consist of defining both the regulatory asset base, i.e. the calculation of the amount of capital to be paid, and the rate of return to be fixed. The rate of return is an example of an ex-post adjustment scheme as tariff recognition is based on the actual costs incurred by firms. With this method, investment choices are scrutinized and approved by the regulator or other authorities.

In addition to variable-definition difficulties, cost-based approaches lead to overinvestment problems and do not incentivize companies to minimize operating costs, because the increase of the cost base and of the investments level assures higher revenues. Monopolists subjected to these pricing methods can behave opportunistically, declaring higher costs compare to what they actually sustained, as regulators cannot access to all the necessary information inside the companies and are, therefore, subject to information asymmetry. Furthermore, the risk of investment in these cases is almost entirely reversed on end consumers, as for every investment made there is a guaranteed return obtained from an increase in the price of the service.

2.1.2. Incentive based regulation and Price Cap

In order to improve the efficiency of companies in recent years, many states have radically changed pricing methods, as seen cost-based approaches do not lead to totally appropriate solutions. Incentive-based approaches are characterised by financial rewards and penalties to drive companies to meet their productivity and investment goals. Firms are free to choose their preferred method of achieving their targets and are more incentivized to reduce operating costs, as they are allowed to maintain the extra-profits generated over a certain period of time.

The most used method that belongs to this category is the price cap, also used in the revenue cap variant, which can be considered as an indirect price cap because the revenues are the result of the price for the quantity. The price cap is an example of an ex-ante regulatory scheme as tariff recognition depends on the company's expenditure forecasts, done at the beginning of the regulatory period, and not on the costs actually incurred in the same time frame. This type of mechanism places greater freedom in the investment choices by the company, unlike ex-post schemes.

The price cap is a mechanism that constrains the rate of price growth during the regulatory period (generally between 3 and 5 years), adjusting them annually through a factor that takes into account the inflation rate (retail price index, RPI) and a productivity coefficient (X). Prices must increase along with the inflation rate to reflect input price rises, which are out of the control of the regulated company. The productivity measure is used to lower the inflation rate, so that the prices of regulated enterprises rise less than general market ones. In this way, consumers can gain the benefits deriving from the increases in efficiency and productivity and from the minimization of the firm's costs. This mechanism creates strong incentives for reducing operating costs, as prices are set taking into account the productivity coefficient set by the authority (a tariff reduction that the regulator wants to impose) and not the actual efficiency. If the latter is superior than the established value, the company generates extra profits until the next adjustment of the parameters, coinciding with the beginning of the following regulatory period. However, there are some concerns about the use of the price cap and revenue cap, in fact it must be considered that the strong incentive to minimize operating costs can lead companies to decrease the quality of service. In addition, the use of the revenue cap can lead to higher prices than optimal ones and to try to keep demand below the limit imposed by the authority, as it is not possible to derive further revenue from demand excess.

2.1.3. Efficiency Requirements

Many regulators to stimulate companies to be increasingly cost-efficient have adopted incentive-based schemes, which involve the definition of specific efficiency requirements. In general, incentive-based approaches encourage lower operating costs (OPEX), as the duration of the regulatory period promotes investment with short-term returns since in the remaining period firms can benefit from cost-cutting. Capital expenditure (CAPEX) is more difficult to incentivize as it is associated with investments with extended payback time, often even longer of the entire regulatory period. In most cases, regulators only establish the efficiency requirements on OPEX, although it is possible to use approaches that take both into account:

- A first method is the building block approach, in which CAPEX and OPEX are considered separately. This model ensures that the company earns sufficient revenue to cover the expected costs of service providing. Allowed revenue is calculated considering OPEX, CAPEX depreciation and the rate of return on capital (assessed with the cost of capital, WACC). The latter represents the opportunity cost of investing in the network rather than in other activities.
- TOTEX approach allows tariff regulation to be based on the sum of OPEX and CAPEX, referring to the total expenditure incurred by the venture rather than operating costs and investments separately. The adoption of a TOTEX approach requires that total expenditure is divided into two allowances: one that contributes

to the determination of the recognized cost in a certain year (fast money) and the other that flows into the capital invested recognized for regulatory purposes (slow money). With this method, firms are equally incentivised to make reductions in OPEX and CAPEX, choosing to use both operating costs and capital expenditures, and are less likely to make inefficient investments. This approach aims to improve the overall productivity of companies and foster innovative investment choices. The TOTEX rule has information asymmetry issues, as prices are based on costs estimated by the company at the beginning of the regulatory period. Regulators, for a successful enforcement, need to be able to adequately evaluate the spending forecasts through in-depth cost assessments and benchmarking.

Regardless of the approach chosen, the effectiveness of each method of regulation depends on several factors that vary between the different European states, such as national context, length of the regulatory period, frequency of parameters reviews, methods for the costs calculation, regulatory asset base evaluation and different procedures used for the analysis of the individual factors.

2.1.4. Overview of the regulatory schemes in the European context

In the previous paragraphs, the main systems for regulation, applied by national authorities to controlled companies, have been listed, but it is important to note that they are not all used with equal frequency. In fact, most European countries use incentive-based forms of regulation, especially in the form of revenue caps, also combined with other models. Many states use systems that mix cap regulation (price or revenue) with the rate of return model, while the cost-plus approach is only used by a few regulators.

Each Member State can use different control systems for the transmission and distribution of both electricity and gas. The table below shows the number of countries that use a certain regulatory approach divided by the different regulated activities of the energy sector.

Table 1: Analysis of regulatory schemes used in different European states (2017 data)[15]

Electricity transmission	• Pure incentive methods in 9 Member States • Combined model of incentive and cost-based methods in 11 Member States • Pure cost-based methods in 4 Member States
Electricity distribution	• Pure incentive methods in 15 Member States • Combined model of incentive and cost-based methods in 5 Member States • Rate of return regulation in 4 Member States
Gas transmission	• Pure incentive methods in 14 Member States • Combined model of incentive and cost-based methods in 8 Member States • Pure cost-based methods in 2 Member States
Gas distribution	• Pure incentive methods in 16 Member States • Combined model of incentive and cost-based methods in 6 Member States • Rate of return regulation in 2 Member States

Most national regulators require savings mostly in operating costs while only in a minority of cases efficiency requirements are also applied to capital spending or total expenditure.

The differences between the Member States are manifold, not only in the choice of regulation schemes to be applied but also in the method of calculating the different parameters to be considered. The regulatory environment of each individual country is very complex, and it is therefore difficult to compare the decisions made by national authorities.

2.1.5. Incentives and tools to drive investment and innovation

The European Union sees energy innovation as one of the key components with which it could be possible to realize the Energy Union's objectives. In the Energy Union's communication adopted on 25th February 2015, the committee devoted one of the five

[15] Sources: CEER Report on Investment Conditions in European Countries. In appendix 1, it is possible to find a list of all countries divided by regulatory schemes applied.

main points to research and innovation, to achieve European technological leadership and to accelerate the transformation of energy systems.

In markets such as energy, which are characterized by a natural monopoly condition, the incentive to innovate is low. Therefore, in the absence of competition, regulators need to implement the right tools to encourage research and innovation. In particular, DSOs play a key role in the industry transformation process and require a regulatory environment that stimulates innovative solutions that are sustainable and cost-effective for the entire system. It must be taken into account that it is not enough to foster innovation, but that it must be done efficiently, because we do not want to achieve situations of over-investment and opportunism by regulated companies. Innovation must be encouraged by using public policy concerns, such as safety and environmental conditions, as motivating factors, in order to replace the stimulus of competition with equally effective drivers.

In addition to the use of appropriate motivations to drive innovation, there are several regulatory mechanisms to support it. In particular referring to the classification made by D. Bauknecht[16] in 2011 the main ones are reported:

- Input-based mechanisms: in this type of approach R&D costs are explicitly included in the regulatory scheme. Once R&D costs have been included, it is possible that they may be treated as any other cost or may be considered separately.
  - A first system is the pass-through ones, which allows R&D costs to be transferred to end consumers, considering them as operating expenses. This method is mostly used for costs over which companies have no control and consists of including them directly in the tariffs. Including R&D costs in final prices transfers the risk of investment to users. The main drawback of this method is that investments that do not lead to any useful results are still borne by consumers. Companies have an incentive to invest in research and development but not to choose only the really useful projects, as they are still being repaid by clients. One solution to this problem may be to define an upper limit on transferable costs to customers, forcing companies to select projects to work on.

[16] D. Bauknecht, *Incentive Regulation and Network Innovations*, January 2011

    - Capitalization of research and development costs: with this approach, R&D costs are considered to be investments, are included in the regulatory asset base and are depreciated.
- Output-based mechanisms: these methodologies are based on the outputs of the research and development process and not on inputs (costs), such as previous ones. Companies in these cases benefit only from successful innovations. One of the main disadvantages is the difficulty of adequately identifying the outputs of the innovative process.
    - It is possible to include innovation targets in pricing systems by raising the cap imposed by the regulator and, therefore, allowing greater revenue for the company. The additional revenues in this case are not directly related to the costs incurred by the company, but to the savings generated by the introduction of innovation.
    - A second method is to extend the duration of the regulatory period, leaving more time to the company to benefit from the efficiency obtained by innovations. In this way companies recover research and development costs but there is a delay in transferring benefits to consumers.
    - Limited periods of time can be set up during which revenue constraints are removed, these time intervals are called regulatory holidays.

In general, many of the regulatory incentives aim to influence the risk-reward ratio resulting from the regulatory method. The incentive mechanisms described above are part of the mitigator category because they aim to lower or cancel the level of risk incurred by network operators for certain investments (transferring it to users' network). There is also a category of mechanisms that is based on increasing the allowed revenues or decreasing the cost recovery period for network operators, favouring investments against a higher reward guarantee. Within this category there are:

- WACC premiums: regulators can encourage certain types of investment by guaranteeing an increase in WACC. In this way, regulated companies will be more motivated to invest as the level of profit will be higher than in the non-investment situation. This type of scheme is normally applied only to a selection of investment projects.

- Rules for anticipatory investments: it is possible for the regulator to set well-reasoned rules on anticipatory investments. The latter refer to those investments related to infrastructures and assets that must be made before the demand appears. These investments are highly risky because the demand does not have to develop as expected. For this reason, clear rules from the regulator are useful to prevent an inadequate level of investment and to ensure the development of infrastructures.
- Adjusted depreciation periods: to better incentivise regulated companies, the regulator needs to ensure a favourable path and recovery period for investment. Depreciation represents a significant portion of the company's total costs and is, therefore, critical to ensuring high level of security related to the recovery of those costs.
- Exemption from efficiency gain requirements: some companies may be freed from achieving efficiency targets for a given period. The regulator, by exempting operators from achieving these objectives, incentivizes them to invest, as they no longer have to bear the risk of not achieving the required efficiency. In addition, this mechanism allows companies to focus more on infrastructure or strategic projects rather than investing only in solutions aimed at achieving efficiency goals.
- Sliding scale: the regulator sets out a set of specific objectives that the company must achieve, for example in terms of investments or OPEX reduction. If the company reaches the set level the benefits or costs are fully recognized by the regulator and then enter into the calculation of the tariffs. On the contrary, if the target is not reached the benefits or the costs will be divided between the companies and consumers. This mechanism punishes companies that do not meet their targets, forcing them to bear some of the costs incurred (which they cannot recover through tariffs) or to divide the level of gains obtained with consumers. Network operators subject to this type of regulation are motivated to present realistic investment plans, as the differences between current and budgeted costs are penalised by the regulator.
- Favourable debt/equity ratio in the WACC: the choice of debt-equity ratio made by the regulator has a strong impact on the return on investment granted to

regulated companies. The regulator can therefore incentivize investment by setting a debt-to-equity ratio that allows companies to receive an attractive return on investment.

A study, conducted in July 2016 by Eurelectric[17], found that countries that adopted specific mechanisms had a positive impact on investment in innovation and research and development costs, while the partial or complete absence of recognition of R&D costs can lead to barriers to innovation. In the Eurelectric report, the authors found out that mechanisms to foster innovation are still not widespread in Europe. In fact, in the study is reported that in 2016 only 9 of the Member States[18], compared to the 20 considered, had adopted specific approaches to manage research and development costs. Incentive methods have not yet been introduced in the remaining eleven countries, so R&D expenditure is treated as well as other costs.

In addition to the mechanisms to be included in regulatory schemes, governments can also use financing systems to foster innovation and R&D projects. For a general overview, we report a table summarizing the most important methods described in the International Energy Agency (IEA) report "Technology Innovation to Accelerate Energy Transitions".

[17] Eurelectric, *Innovation incentives for DSOs - a must in the new energy market development,* July 2016.
[18] Finland, France, Great Britain, Greece, Ireland, Italy, Norway, Portugal and Slovenia.

Table 2: Principle funding instruments or policies to foster innovation[19]

Funding instrument or policy	Description
100% grants	Allocate public funding to selected projects of private or public institutions, providing the total project cost.
Co-funded grants	Set a minimum limit of own investment for private projects, from a minimum of 5% to a maximum of 50% of project cost.
Research by state-owned enterprises	Governs can drive and choose innovation and research projects of state-owned company.
Loans and loan guarantees	Governs can finance companies through loans, useful for the implementation of demonstration or risky projects.
Tax incentives	Governs can incentive R&D investments exempting them from taxes. The tax exemption or reduction can be applied to all R&D expenditure or only to targeted projects.

2.1.6. RES support scheme

Since 2009, with the adoption of the European Renewable Energy Directive, the European Commission has underlined the key role that renewable energy plays in meeting its 2020 targets. The spread of renewable energy is essential to achieving a safe, sustainable and competitive energy system also with regard to the plans set for 2030 and 2050. Each Member State can introduce financial support schemes and other measures to promote technologies that exploit renewable sources and increase the share of clean energy. Among the main methods of aid there are:

- Investment support: this method provides direct support through public subsidies to increase renewable energy production.
- Feed in tariffs (FIT): is a tool that allows renewable energy producers to obtain a higher fixed price than the market one for energy produced and fed into the grid. The fee is guaranteed for extended periods of time in order to boost investments in plants and technologies and to reduce their risks. This method acts on the supply side by incentivizing producers to push green energy into the grid. It is possible

[19] International Energy Agency (IEA), *Technology Innovation to Accelerate Energy Transitions,* 2019

to set different prices based on technologies, managing to create support schemes specific to the different types of renewable sources.

- Feed in premiums (FIP): is an approach that divides the price of energy into two different dimensions, the first relating to the market price including fluctuations and the second for an additional premium that can be fixed or variable.
- Green certificates (GCs): they are equivalent to tradable goods that are released to a producer as a specific share of electricity was generated using renewable resources. Since green electricity usage quotas can be imposed on grid operators, public bodies or large consumers, it is possible to meet these requirements either by using renewable energy or by purchasing green certificates, which can be sold separately from the energy produced.
- Tax and financial measures: these are tax reductions for investments in technologies, production or consumption of renewable resources. They are among the simplest methods to stimulate the demand and supply of green energy.

The support tools considered can have variable duration depending on national decisions, generally between six and twenty years. According to the Ceer study[20], between 2016 and 2017, 16 countries, out of the 27 analysed, used FIP schemes, 17 use FIT ones (especially for small installations) and only 6 implemented GCs. However, 15 Member States adopted two or more support schemes for renewable resources, most of them combining FIT and FIP programs. Overall, renewable energy under a support scheme in 2016 amounted to 16.7% of the total energy produced, increased from 2014.

Member States can use two different approaches to finance the support schemes described above. The first is to impose taxes on all citizens, while the second is to collect contributions by including them in the electricity bills of some or all consumers. The most adopted mechanism is the second, in fact in 2017 it has been preferred by twenty-one of the Member States.

In addition to the indicated support schemes that facilitate the spread of renewable resources by incentivising either demand or supply, in order to achieve the most effective integration it is necessary for states to also consider the methods of connection and input of energy into the transmission and distribution network. With regard to physical

[20] Status Review of Renewable Support Schemes in Europe for 2016 and 2017

connection to the network, most of the countries analysed in the study (23 states out of a total of 27) in 2017 applied the same tariff regime to both conventional and RES plants, but 13 states ensured the priority of access to RES installations rather than traditional ones. In addition to the physical connection, many of the Member States have introduced certain provisions to allow renewable energy to be fed into the grid as a priority, compared to that coming from traditional plants. This ensures that the maximum amount possible of RES electricity is fed into the grid and that it is the last to be curtailed.

2.1.7. European financial instruments and funds

In addition to the regulatory and support mechanisms, Europe also uses several financial instruments to meet the 2020 targets, indeed financing funds are provided for the granting of certain projects. For the energy and the environment issues, the main funding instruments, set up and managed directly by the European Commission for 2014/2020 period, are:

- Horizon 2020 is the framework programme for innovation and research, which has been allocated a budget of 79 billion euros. For the first time, all funding for these sectors was brought together. The objectives are different, in fact the program is based on three key concepts, such as scientific excellence, industrial leadership and societal challenges between which the total budget has been divided. The program directly funds projects that fall within the guidelines defined by strategic priorities, in order to achieve the objectives of innovation, competitiveness and sustainability. Within Horizon 2020, approximately 5.9 billion euros has been allocated for energy research and innovation projects with the aim of creating and implementing green technologies that allow for greater exploitation and wider spread of renewable resources. In the following table, there are some data about the Horizon 2020 allocated funding to Smart grid projects. The source of the information is the JRC report on smart grid[21].

[21] Gangale F., Vasiljevska J., Covrig F., Mengolini A., Fulli G., Smart grid projects outlook 2017: facts, figures and trends in Europe, EUR 28614 EN, doi:10.2760/701587

Table 3: H2020 funding for R&D and demonstration activities for 2016-2017 related to smart energy in million €.

Scope of the call	Total funding 2016	Total funding 2017
For R&D projects related to technologies and services enabling smart grids, storage and energy system integration with increasing share of renewables address to distribution network (LCE-01-2016-2017)	20.0 M€	19.0 M€
For R&D projects related to tools and technologies for coordination and integration of the European energy system (LCE-05-2017)	0	30.0 M€
For Demonstration projects related to smart grid, storage and system integration technologies with increasing shares of renewables address to distribution system (LCE-02-2016, LCE-04-2017)	73.7 M€	65.3 M€
For demonstration projects related to smart cities and communities' lighthouse (SCC-1-2016-2017)	60.0 M€	69.2 M€

- Life Environment and Climate Action is the programme set up to support Member States in meeting the 2020 environmental and climate targets and getting a sustainable development. More than 3 billion euros have been allocated to be divided between environmental and climate projects. The environment package consists of three priorities, such as resource efficiency, biodiversity and administrative practices and information in the environmental sector. The climate sub-programme presents climate protection, adaptation to climate change and climate information as focal points.
- Connecting Europe Facility is a financing programme with a budget of approximately 33 billion euros divided between the transport sector (26.3 billion euros), telecommunications (1.1 billion euros) and the energy sector (5.9 billion euros). The aim is to support trans-European networks through the development and implementation of new infrastructures and the modernization of existing ones, achieving the goal of the European single market in the fields under consideration.

In addition to the programmes listed, there are many funding instruments that the European Commission, together with other EU and national authorities, has set up to subsidise projects aimed at innovation and continuous improvement of the energy sector.

3. Description and analysis of the regulatory conditions and energy system of three European states

The following chapter will describe the regulatory contexts of three different European states and provide an overview of the main policies and measures taken by national governments to make the transition of the energy system more effective. In particular, this will describe:

- The national organizational context, to have a clear view of the divisions of responsibilities within the different nations.
- The national environmental targets set following the European directives for 2020, as these are one of the strongest drivers for the transition of the energy system (without the imposition of constraints on environmental sustainability, energy innovations and transformation would be much slower).
- Regulatory systems imposed on network operators to get an overview of how much regulators incentivize different types of investments.
- Some of the energy sectors that are particularly important for the sustainability of the whole system, with a focus also on emerging sectors that allow the integration of different energy systems.
- An overview of the support schemes for renewable resources, as these are one of the key factors in achieving the long-term goals. Moreover, renewable resources require greater flexibility and so they are one of the drivers for integration systems' technologies (such as storage systems and CHP plants).
- The main research, development and demonstration programs in the energy sector, with a brief evaluation of numerical data on public investment carried out in the period from 2010 to 2018. Where possible, a list of research, development and demonstration projects related to energy system integration is provided.

The whole chapter will be aimed at understanding how much national governments are changing the political and regulatory environment to address the future challenges facing the energy sector. The information reported is often not entirely exhaustive due to the difficulty of finding appropriate documents in English, as many of the main documents are written entirely in the national language.

3.1. Belgium

3.1.1. National and organizational context

Before analysing Belgium's energy and regulatory system, some key information should be given on the country's organizational structure and in particular regarding the division of energy and environmental responsibilities.

Belgium is a federal state consisting of three regions, Flanders, Wallonia and the Brussels-capital region. There are also three language communities: French, German and Flemish. Belgium foresees institutions at the federal, regional and community levels, allowing a division of powers according to the different areas of competence assigned. In particular, with regard to energy policies, responsibilities are divided between regional and federal authorities. The latter deal with security of supply, investment plans for gas and electricity, nuclear and offshore[22] power, energy production and transmission, as well as related tariffs, and other issues of national importance. Regional authorities deal with local activities and the main responsibilities are the regulation of the gas and electricity markets, distribution and tariffs, the management of renewable sources apart from offshore wind, the recovery of waste energy, energy efficiency and R&D activities for all energy sources other than nuclear power.

Regions and the federal government must cooperate and ensure consistency between the policies and measures taken, which is why several bodies have been set up to facilitate and improve coordination and to reach a more efficient communication between the various authorities. The main ones are:

- The federal-regional co-ordination platform on energy policy ENOVER/CONCERE. This institution has been operating since 1992 and its main objectives are to ensure the exchange of information and to support all regulatory measures. This body meets once a month and has permanent working groups on some national and European priorities.
- The Co-ordination Committee for International Environmental Policy (CCIEP) established in 1995, serves to be able to define an opinion for the entire nation on

[22] Wind farms are located in Belgian territorial waters, which is why they are part of the commitments of the federal authorities.

environmental issues, necessary in international domains. The CCIEP includes several working groups on specific issues, including climate change.

- The National Climate Commission (NCC), founded in 2002, began its work in December 2003. Its tasks include monitoring the national climate plan and the compliance with EU and international obligations and assessing federal and interregional cooperation. It is a committee made up of representatives from the federal authorities and those of the three regions.

In addition to federal, regional and coordination institutions, there are four regulators. The federal regulator is the Commission for the Regulation of Electricity and Gas (CREG), while the regional ones are the Vlaamse Regulator voor Elektriciteit en Gas (VREG) for Flanders, the Commission Wallonne pour l'Ènergie (CWaPE) for Walloon region and Brugel for the Brussels one.

3.1.2. Overview of the energy sector in Belgium

This section examines the Belgian energy sector, analysing production, consumption and the main sources used. This overview offers an insight of the challenges that authorities must face to ensure an efficient transformation of the energy system.

In 2017, Belgium's total primary energy supply (TPES), the total supply of energy consumed by the nation for both final uses and transformations into industrial processes, amounted to 55.25 Mtoe (million tons of oil equivalent). 70% of this value is made up of fossil fuels, of which 38% of petroleum products, 26% of natural gas and the rest from coal. Nuclear energy accounts for 20% of the total available energy and it is the first of the country's energy sources, accounting for 73% of total production. Finally, renewables account for only 8.5% of total energy supply, while they account for 25% of Belgium's energy production. Domestic production is only 27% of the TPES, in fact the remaining share is imported. This leads to heavy dependence of Belgium's supply on other states and, consequently, it is difficult to achieve the full safety and reliability of the energy network.

The final consumer demand (total final consumption), which excludes from the calculation the energy used by the energy sector itself, in 2017 amounted to 40.73 Mtoe, corresponding to almost 74% of the total energy supply. The three sectors that contribute the most to total consumption are industrial (27%), transport (22%) and residential (20%).

The share of energy from renewable sources rose to 9.1% of the gross final energy consumption, an increase of about twice respect to 2009. This indicates that Belgium continues to increase this value and seeks to better integrate renewable resources into its energy system.

Despite the country's heavy dependence on nuclear power, a law was passed in 2003 that provides for the phasing out of nuclear plants. This raises issues relating to energy security and to the need for additional generating capacity within the country. In order to avoid incurring unsustainable situations, the Belgian authorities decided to postpone the decommissioning of two of the nuclear plants, extending their operational life until 2025.

The challenges facing the country's institutions are manifold and it is therefore necessary for them to devote themselves to create an adequate regulatory framework to incentive the network operators to invest properly and to ensure an efficient energy system transformation.

3.1.3. Overview of 2020 targets and of prospects

Belgium, with the National Renewable Action Plan of November 2010, adopted the European provisions relating to the 2009/28/EC Directive (Renewable Energy Directive) and set national targets to be met by 2020 for a progressive evolution towards low-carbon economy. As done with the European data, we analyse some key indicators to assess whether Belgium could realize its goals.

Regarding the reduction of greenhouse gas emissions, Belgium has set a target of a 15% reduction from 2005 levels, covering sectors excluded from the Emissions Trading Scheme (ETS[23]) such as transport, buildings, agriculture and some industries. The graph below shows GHG emissions data for the 2005/2017 ESD[24] (effort sharing decision) sectors, including 2020 targets for both Belgium and Europe.

[23] The EU ETS operates on the principle of limiting and exchanging emissions. A cap is set on the total amount of certain GHG that can be emitted from the plants that fall under the system. The cap is reduced over time so that total emissions decrease. (https://ec.europa.eu)
[24] The Effort Sharing Decision sets national annual binding targets for emissions not covered under the EU emission trading scheme (ETS). (https://ec.europa.eu)

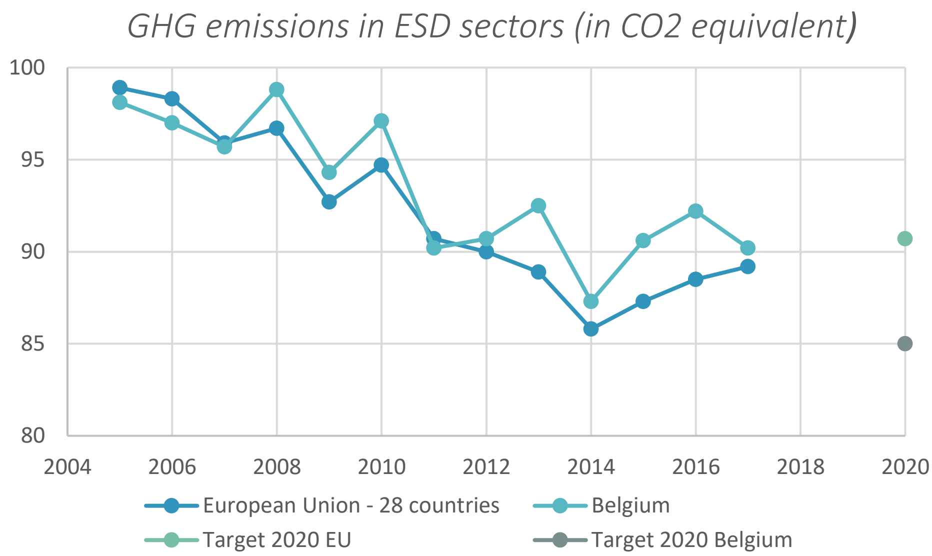

Figure 6: GHG emission in ESD sectors of Belgium from 2005 to 2017

Belgium does not seem in line to meet its emission reduction targets for ESD sectors, in fact in 2017 the estimated quota is higher than the limit set to follow the trajectory towards 2020. Despite this, the reduction in total emissions (considering both the ETS and ESD sectors) in 2017 was 20.3% compared to 1990 levels.

Belgium has determined that, by 2020, 13% of the gross final energy consumption will have to come from renewable sources. Below there is the graph of the share of renewable energy from 2005 to 2017, representing both the European and Belgian trends. The total target of 13% of the total share of renewable energy was divided between different sectors by the Belgian institutions. For the heating and cooling sector, the minimum limit of renewable energy to be reached by 2020 is 12%, the limit for the electricity sector is 21% and the limit for transport is 10%.

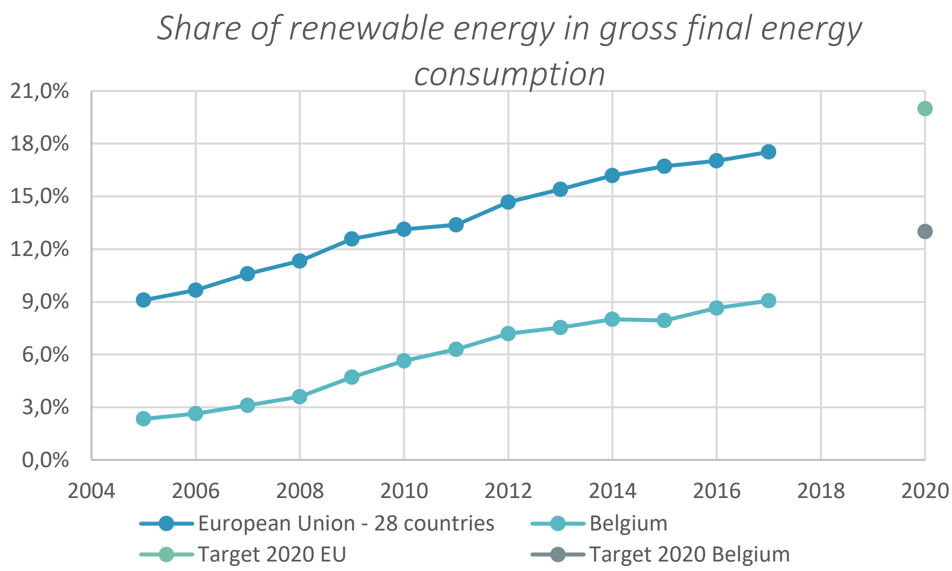

Figure 7: RES share in Belgian gross finale energy consumption from 2005 to 2017

Belgium is in line to meet its 2020 targets, in fact the value corresponding to 2017, equal to 9.1%, is on track with the expected values[25] (shown in the table below).

Table 4: RES trajectory planned by Belgian government

	2011-2012	**2013-2014**	**2015-2016**	**2017-2018**
RES minimum trajectory (%)	S2005 + 20%*(S2020-S2005)	S2005 + 30%*(S2020-S2005)	S2005 + 45%*(S2020-S2005)	S2005 + 65%*(S2020-S2005)
	4,36	5,44	7,06	9,22

Energy efficiency is a mostly regional subject, in fact local reduction targets have been set. These allowed to estimate national levels both in terms of primary energy consumption and final energy consumption. In particular, the primary energy consumption in 2020 is expected to reach 43.7 Mtoe, a saving of about 15% compared to 2005, while the limit for final energy consumption has been set at 32.5 Mtoe, corresponding to a decrease of about 11% compared to the 2005 values. The graph below shows the data recorded by Belgium for both indicators for the period 2005/2017 and their targets.

[25] BELGIUM National renewable energy action plan, 2010

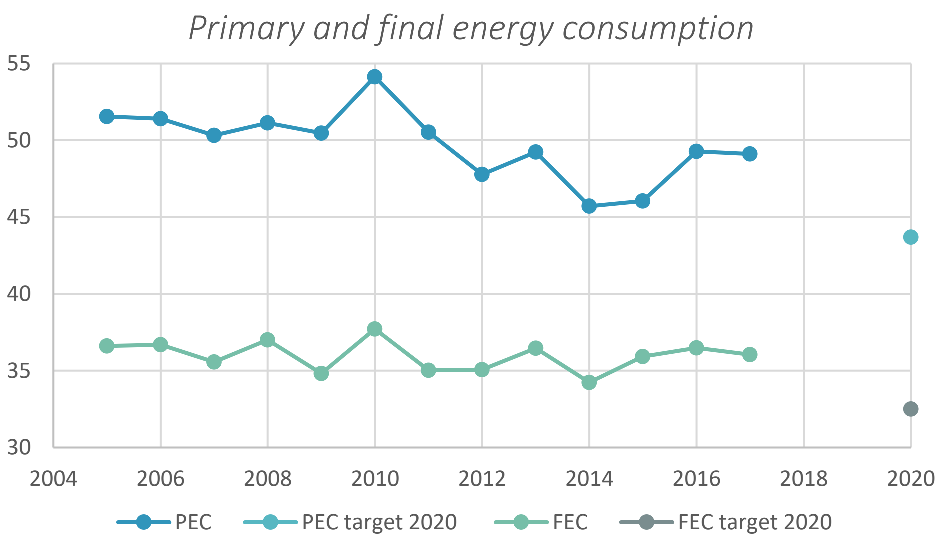

Figure 8: Belgian primary and final energy consumption from 2005 to 2017

Belgium has recorded values above the expected trajectory in the last two years (2016 and 2017), although the records in 2015 were in line with the expectation. That is why it is not certain that the energy savings set for 2020 will be achieved.

As the end of 2010/2020 approaches, the European Commission has required all member states to provide a plan for 2021/2030 by the end of 2018. In December 2018, Belgium presented the National Integrated Energy and Climate Plan, which summarizes the main points of the strategies and programmes developed by individual regions and federal authorities for the next period.

3.1.4. Belgian electricity and gas market

Electricity market

The electricity market has been liberalised since 1999, with the transposition of the European Directive. The liberalisation process was completed in 2007, when all three Belgian regions implemented the European directives.

The market structure within the electricity sector is very different depending on the activities carried out, in fact the production, transmission, distribution and sale are characterized by totally different conditions. Because of the typical properties of each business, it is not always possible to allow competition between companies. The various market structures in the Belgian territory are briefly described:

- Electricity production is dominated by two companies, Electrabel (which in 2014 had 66% of the country's generating capacity, including the entire nuclear capacity) and EDF Luminus (represented the country's second largest generation company with a 12% in 2014), which together control almost 80% of the generation plants. The production market, despite being very concentrated, enjoys a certain degree of competition due to the high import levels allowed by a well-connected electricity network with neighbouring countries (especially France and the Netherlands).
- Transmission and distribution activities must be separated from electricity generation and supply companies since 2007. The only TSO is Elia, a public company owned by 45% of Publi T, which represents Belgian municipalities and inter-communal companies, for 2.5% by Publipart while the remaining share is free float on the stock exchange market. Elia operates under a legal monopoly and therefore his activities are regulated by the state authorities. The distribution operators are manifold and are divided according to the regions in which they operate. Most of the DSOs are owned by local public authorities and their activities are regulated by the regional organizations.
- Electricity supply to end consumers are completely liberalized and are characterized by many suppliers and high switch rates. This part of the market is therefore considered competitive and dynamic, as customers are free to choose their supplier and change according to their needs. From 2011 to 2014, competition increased significantly and as a result the market concentration decreased. The levels of the rate of consumers changing suppliers are among the highest in Europe, thanks to awareness campaigns conducted by national authorities, aimed at improving citizens' knowledge of the market, and to the removal of barriers that prevented consumers from easily switching operators.

Electricity TSO’s regulatory mechanism

After this short overview of the Belgian power market structure, the regulatory aspects concerning transmission and distribution operators are investigated. As they are among the most affected players by changes in the energy system, they must be adequately supported to provide an optimal service to consumers and to facilitate the investment needed for network transformations.

The regulators, as mentioned above, are four, one federal and the other three regionals. In particular, the CREG is focused on defending the interests of citizens and ensuring that market conditions are appropriate to the national context. The CREG, among its responsibilities, must define the methodology for calculating TSO tariffs, while the methodology for DSOs is set by the various regional authorities since 2014.

Elia, as the only transmission system operator, is remunerated by access fees formulated by the company itself, according to the rules imposed by the CREG. The tariff programme must be submitted before the beginning of each regulatory period, lasting 4 years. These tariffs must be re-approved by the regulator before they can enter into force. The CREG decides the price structure, the revenue allowed and the amount of costs that can be passed through to consumers. To analyse in detail the tariff regime imposed by the CREG, we refer to the regulatory periods of 2012/2015 and 2016/2019. The pricing method adopted is a revenue cap mechanism with the addition of incentives for cost control, through which operating costs are considered, plus a cost-plus mechanism for investments. OPEX and CAPEX are considered separately (building block approach):

- OPEX are considered as costs that can be controlled by the company and for this reason a coefficient of productivity is applied. This serves to reduce operating costs during the regulatory period (for the 2012/2015 period the X-factor were 25 million euros, corresponding to 2.3% of basic controllable costs). Both the initial value of OPEX and the productivity factor are defined ex-ante by the CREG, based on the proposal made by the TSO. With this system the greater or lowest efficiency fall entirely on the TSO, allowing for greater gain or loss, respectively, and providing an incentive for reducing operating costs.
- CAPEX are calculated as uncontrollable costs of which the largest share is transferred to consumers. In order to check the efficiency of CAPEX, the CREG proceeds to approve the plan of investments ex-ante, to include a define part of it in the RAB. Moreover, the CREG carry out ex-post checks and adjustments, if the budgeted costs deviate too much compared to those sustained.

With the described method, it is not possible to achieve maximum cost reduction, because the ratio between OPEX and CAPEX cannot be optimized by the company. The risk that the TSO has to bear is very low, because of the pass-through mechanism and the ex-ante approval of investments.

With regard to capital remuneration, the regulator distinguishes between equity and debt remuneration, so the average cost of capital (WACC) is not used. Debt remuneration is guaranteed as it is covered by tariffs. The remuneration of equity (fair remuneration), on the other hand, is calculated as the product of the RAB for a fixed level of return calculated as:

$$Roe_t = OLO_t + \min\,(\beta_t \times \; Rp_t, 70bp\;)$$

Where:

- Roe_t is the return on equity allowed in the year t;
- OLO_t is the risk-free rate, corresponding to the interest rate of Belgium's ten-year government bonds in the year;
- The Beta factor is calculated based on the TSO's share price and the BEL index over a 3-year period ('t-2', 't-1' and 't'). It was equal to 0.53 in 2017.
- Rp_t is the premium market risk calculated as the average value of the Belgian stock exchange's premium market in the period 1900-2013, equal to 3.5%.

The regulator uses a fixed rate to define the share of RAB paid with the cost of capital just described. In particular, the CREG has set the value of capital gearing[26] at 67%, so only 33% of the RAB can be financed by equity. If the share is greater than the permitted value, the excess party is remunerated at the minimum possible value, equal to $Roe_t = OLO_t + \; 0.7$ [27].

Incentive mechanism and interconnection projects

The system applied to transmission operator by the CREG leads to low levels of remuneration and investment financing. For the replacement investments, the regulator has included an additional system to permit higher remuneration for this type of CAPEX. Indeed, they can be financed through a fund of 5 million euros per year.

TSO in Belgium must make all the necessary investments to perform its functions at their best. In addition to this, Elia is responsible for the development of network

[26] The gearing ratio could be defined as the proportion of assets that were funded from borrowing funds.
[27] Minimum allowed value. The regulator imposes that the product $\beta_t \times \; Rp_t$ must be at least equal to 0.7.

interconnections with other countries, onshore projects and of the modular offshore network. The return of these investments in the Belgian system can only be achieved through pricing, in fact the tariff system must ensure a fair remuneration as well as the properly network development. In particular, the tariff structure established by the CREG may include more favourable conditions for the construction of new infrastructures of national or European interest and for the extension of existing ones, in order to encourage investment. The regulator provides financial incentives to stimulate research and development projects by the TSO. In fact, it can partially recover the costs incurred up to 50% of the subsidies received in the year under consideration and no more than 1 million euros. In addition to this type of incentive, the regulator granted incentives and rewards to the TSO when certain conditions were met, such as the implementation of priority projects, compliance with user obligations, the implementation of investments with a higher risk and a demonstrable improvement in market integration. In particular, we proceed to list some important interconnection projects implemented by Elia:

- Alegro is the first interconnection project between Germany and Belgium, conducted by Elia and Amprion (German TSO), with the aim of increasing the import and export capacity between the two countries. It consists of the construction of a 90 km underground high voltage line, 49 of which are in Belgium. The transmission capacity will be 1000 MW. This project is part of Elia's investment plan and has been approved by the regulator. His costs will be subject to an ex post check. The European Commission supports Alegro through the TEN-E programme. The aims of the project are greater security for Belgian supply, greater integration of renewable resources and price convergence in the energy market.
- Brabo is the improvement of the portion of high voltage network that connects Belgium with the port of Antwerp. It can increase the transmission and import capacity of the network and, moreover, it allows the continued growth of port of Antwerp. Again, the project's cost recovery will take place in accordance with the rules imposed by the CREG, no additional incentive has been provided. It is a project divided into three main phases:

- Brabo I: for the period 2015/2016, it involved the installation of new transformers at Zandvliet and the improvement of the high voltage line between Doel and Zandvliet, increasing voltage to 380 kV.
- Brabo II: started in 2017 and with an end date scheduled for 2021, including a series of improvements to the transmission network between Lillo and Zandvliet (including upgrading up to 380 kV) and the construction of a new 380 kV line between Lillo and Liefkenshoek.
- Brabo III: the start is scheduled for 2023 and will consist of the modernization and improvement of the high voltage line between Liefkenshoek and Kruibeke.

- Modular offshore grid consists of the creation of a line to connect several offshore wind farms with each other and with the onshore network. By creating an infrastructure that functions as a hub, it is possible to maximize the transmission of energy produced by wind farms compared to the direct solution. The offshore switchyard platform is expected to be fully operational by mid-2020. In this case, the regulator allowed additional remuneration as this was considered as a risky project. So far it is the only project that has benefited from this type of incentive.
- NEMO is a project for the purpose of interconnection between Belgium and the United Kingdom. It consists of an underwater and underground line that connects conversion stations and electricity substations in each country, thus the energy can flow in both directions. This allows for greater network reliability in both states and better exploitation of renewable plants. A special tariff mechanism has been adopted for this project. It has been defined that for the first 25 years, after the commission, costs can be recovered through a tariff ranging between a cap and a "floor". This ensures that cost recovery cannot be below the minimum level set.

DSOs' regulatory mechanisms

For DSOs regulations, imposed by the regional authorities, it is not easy to find data in English, so it is reported only a table including the available information divided by region[28]:

[28] Sources of all data is the Report on Investment Conditions in European Countries conduct by Ceer and published on December 2017.

Table 5: Overview of the main characteristic of Belgian regulatory system applied to DSOs of the power grid

	Flemish region	**Walloon Region**	**Brussels-capital Region**
Regulatory system	Revenue Cap for endogenous costs with incentives for quality of service and pass through for exogenous costs.	Revenue cap	Revenue Cap and Cost plus with incentive regulation based on controllable cost
Efficiency requirement for CAPEX	The revenue cap and so the productivity factor is applied on TOTEX	No	No
X-factor on OPEX		1,5% annually	No
Risk free rates	For the cost of equity weighted rate on basis of daily Belgian and German 10-y government bonds interest rates over the last 12 months and for cost of debt VREG considers the rates over last 120 months	Public bonds (average of OLO 10 years over the last 10 years)	Public bonds on 10 years of the year itself
Market risk premium	5,01%	4,3%	4,5%
Capital gearing	60%	52,5%	40%
Equity Beta	0,76	0,65	0,7

Natural gas market analysis and regulatory mechanisms

An overview of the natural gas market is also described, as it has a regulatory system like the electrical one and is an important sector for the energetic transition. Natural gas is the country's second-largest energy source, with a share on final consumption in 2017 equal to 25.8% and on total electricity production in 2018 of 31.7%. Belgium depends solely on imports for this energy source, which leads to some supply security problems, especially about imports from the Netherlands. This is because part of the gas imported from this nation is low calorific (L-gas), coming from the Groningen site. This latter, according to the programs, should decrease exports until the complete divestment in 2029, due to some security measures imposed by the Dutch government. Belgium must therefore plan a gradual transition to high-calorie gas (H-gas) infrastructure by 2029.

In the natural gas sector, too, European directives have imposed a separation between network, supply and generation activities. The transmission operator is Fluxys Belgium since 2012 and is regulated by the CREG, while the 17 DSOs are regulated by the regional authorities. As with the electricity market, regulators are responsible for setting tariffs for access to transmission and distribution networks. The methods imposed by the regulators for the electricity and gas markets are similar, so only the main values in the table are shown.

Table 6:Overview of the main characteristic of Belgian regulatory system applied to DSOs of the gas grid

	Gas TSO	**Flemish region**	**Walloon Region**	**Brussels Region**
Regulatory system	Revenue Cap + cost control incentives	Revenue Cap for endogenous costs with incentives for quality of service and pass through for exogenous costs.	Revenue cap	Revenue Cap and Cost plus with incentive regulation based on controllable cost
Efficiency requirement for CAPEX	No	The revenue cap and so the productivity factor is applied on TOTEX	No	No
X-factor on OPEX	No		1,5% annually	No
Risk free rates	Public bonds on 10 years of the year itself	For the cost of equity weighted rate on basis of daily Belgian and German 10-y government bonds interest rates over the last 12 months and for cost of debt VREG considers the rates over last 120 months	Public bonds (average of OLO 10 years over the last 10 years)	Public bonds on 10 years of the year itself

Market risk premium	3,50%	5,01%	4,3%	4,5%
Capital gearing	67.0%	60%	52,5%	40%
Equity Beta	0.65	0,76	0,65	0,7

Regarding the gas transmission network, the incentives and pricing methods are the same as those imposed on the electricity operator, but there are some differences in approaches to innovative investments. In fact, according to a special provision, it is possible for the new large natural gas infrastructures (interconnections, LNG plants, storage installations and increased capacity of existing infrastructures), to obtain exemptions to the access policies or network fees. In practice, this would greatly encourage innovation on the network, but in order to obtain such exemptions it is necessary for the owner of the infrastructure to be independent by the network operator, which is not the case of Belgium because the TSO of the network operates under monopoly conditions. Projects concerning power to gas, new uses of gas and gas from renewable sources (both synthetic natural gas and hydrogen) are considered innovative but there are no specific mechanisms to incentivize TSO to invest in these technologies. It is likely that additional incentives will be added in the regulatory period that will begin in 2020. Fluxys' 2018/2019 investment plan provides for a total expenditure of 529 million euros for the improvement of the transmission network, of the Zeebrugge terminal (access route for the supply of liquefied natural gas) and of the Loenhout storage.

Conclusion and consideration about regulatory framework

After presenting an overview of the regulatory instruments imposed by the authorities, the context is analysed to understand whether pricing schemes encourage both network and innovation investment by operators. The main driver for investments by network operators is the high level of pass-through, as these, once approved by the regulator, are entered the regulatory asset base and remunerated through an increase in fees. However, it should be emphasized that operators are more incentivised to invest in projects that are not risky and that allow safe returns. This is also due to the efficiency targets applied to OPEX, which, if not achieved, cause uncertainty in the return of supported costs.

3.1.5. Support schemes for technologies useful for energy system integration

CHP plants

Cogeneration plants are among the technologies that allow greater integration not only between energy systems but also of variable renewable resources into the energetic mix. In Belgium, this type of structure has grown steadily in recent years, thanks to various support mechanisms imposed mostly at the regional level. By 2020, installed capacity is expected to increase by 25% compared to 2012 values, with a total generative capacity of 3203 MWe. Cogeneration plants are supported within Belgian energy policies because they are a valuable and efficient aid in achieving the environmental targets set for 2020 and a useful method to allow Belgium to be less dependent on fossil fuels. Despite this, many of Belgium's cogeneration plants are still powered by natural gas (among the first sources used), except in the Walloon region where renewable resources are the main source of CHP plants. As mentioned above, this type of technology is supported at regional and federal level through several mechanisms:

- At the federal level, the authorities provide mostly financial support in the form of tax reductions for the owners of these plants. In 2013, the deductible value was 14.5% of the total investment.
- The Brussels region offers as the main support mechanism Green Certificates, which, in addition to being released for RES plants, are also issued to electricity producers who own a cogeneration plant. This mechanism proves that the plant produces a certain saving of energy or CO_2 compared to a traditional one. In the Brussels region, the regulator imposed the release of one GC for every kg of CO_2 avoided divided by 217 (CO_2 emission coefficient of natural gas). The market for green certificates is unique, i.e. there is no difference between those issued for renewable plants and those for CHP plants (more information is provided in the next paragraph). In addition to the Green Certificates, the regional authorities in Brussels have instituted a grant mechanism to support investment in this type of plants.

- The Flemish region, unlike Brussels, has CHP certificates as its main support mechanism. Those are certificates with the same purpose as those described previously but which are traded on a separate market respect to Green Certificates. In this way, it is possible for an electricity producer, owner of a CHP plant powered by renewable sources, to obtain both CHP certificates, for the Energy Savings obtained compared to a traditional plant, and the GCs, for the MWh of green electricity produced. This system has led to more certificates than required by the quota obligation system, necessitating an increase in the mandatory quotas to be purchased by network operators. In addition to this, the Flemish authorities have some support tools for both private investment and demonstration projects, especially for micro-CHP technologies.
- The Walloon region has adopted a system similar to the one of Brussels region, namely the release of GCs for CHP plants as well as for the RES ones. In this case, the regulator has imposed as a rule that one GC represents 456 kg of CO2 saved.

Despite the various support mechanisms put in place by the Belgian regional and federal authorities, there are still several barriers to the complete development of these plants. In particular, the diversity of mechanisms adopted between the various regions plays a key role, leading to a very complex and difficult environment to manage for investors, importers and producers. In addition, the certificates distributed cannot be exchanged between the different regions but only within them.

Green hydrogen market and Power to X storage

In Belgium, the hydrogen market is among the most developed in the world, as several industries dependent on this raw material (such as refineries, fertilizer production and chemical industries) are located in Belgium and the Netherlands. Having already a developed market, Belgium is a state that can focus heavily on the decarbonisation of different sectors through the integration of green hydrogen. In particular, different organizations and public institutions started several projects, aimed at the development of different hydrogen technologies and applications. These, in the past years, were mostly focused on the transport sector (construction of fuel stations and diffusion of hydrogen-powered cars and public transport), but also in Belgium the purpose of the projects is expanding. Several projects for the integration of hydrogen into the energy sector were announced, such as:

- The plan to build a large plant for the conversion of offshore wind energy into hydrogen. It was announced in 2018 by Eoly, Fluxys and Parkwind and consists in the construction of a facility with a capacity of about 25 MW, representing one of the first plants of industrial scale in Europe.
- The Don Quichote (Demonstration of New Qualitative Innovative Concept of Hydrogen Out of wind Turbine Electricity) project started in 2012 and concluded in 2018, which aimed to demonstrate the use of hydrogen as an energy storage solution both technically and economically. The project focused on both hydrogen applications within the energy sector and transport. It was part of a European project, supported by Fuel Cells and Hydrogen Joint Undertaking funding program.
- A project was conducted from 2014 to 2016 to study the possibilities of hydrogen and Power to Gas technologies within the Flemish region. In the Power to Gas Roadmap for Flanders project, several paths were analysed such as the use of hydrogen in the industrial sector, direct injection into the gas grid, the methanation and subsequent injection of natural synthetic gas, fuel for vehicles and ultimately the use of hydrogen as a method of electricity storage.

Despite the development of several projects at national and regional level, energy regulation and policies do not fully consider this type of energy carrier. In Belgium, for example, there are no provisions regarding the level of hydrogen that can be fed into the gas network. In addition to this, there is a lack of a clear business model to apply to new operators and to their functions. At the national level, many efforts are made for the spread of hydrogen in the transport sector, in fact there are several mechanisms of support and incentive. In Flanders, on the other hand, most of the directives relate to industrial applications. There are no specific regulations on Power to Gas or Power to Power systems at national or regional level. Improvements to energy policies are therefore needed for the full deployment of these technologies:

- Clearly define the role of Power to Gas systems within regulatory, tax and legal texts at both regional and national levels. Paragraphs dedicated to these new technologies must be included in energy policies, both to regulate their use and to make the energy players aware of the environmental and economic benefits.

- Financial incentives to support Power to Gas systems, such as network tax exemptions, the introduction of a favourable tariff system (feed-in tariffs) or loans for investments in storage plants.
- Encouraging investment by network operators in both electricity and gas sectors.
- Create experimental areas in Belgium for Power to Gas technologies projects. The so-called experimental areas allow projects to be conducted under special regulatory conditions that are less stringent than those in force.

3.1.6. Belgian RES support

Belgium, as has already been described in the previous paragraphs, has progressively increased its share of renewable resources within final energy consumption. The support mechanisms are different depending on the application area, in fact there are different systems between the electrical, heating and cooling and transport sectors. This section will briefly analyse the support schemes and incentives that exist on the Belgian territory, leaving out transport schemes in order to focus on the electricity and heating sectors.

For the electricity market, the main support mechanisms are a quota obligation applied to grid operators, i.e. a minimum share of electricity from renewable sources within the entire supply, and the green certificate market. Again, each region applies a different system. The main aspects of each region's quota system are listed in the tables below.

Table 7: Summery of the main support RES support scheme in the different Belgian regions

Federal quota obligation

Eligible technologies	Offshore wind and some hydropower installations with specific conditions
Number of certificates	CREG has indicated the emission of one certificate per MWh of electricity produced
Minimum price per certificate	• Offshore wind: 107 € per MWh for electricity generated resulting from first 216 MW of installed capacity, 90 € per MWh for volume above 216 MW. • Hydropower installations: 20 € per MWh of electricity produced

	Brussels capital quota obligation
Eligible technologies	Wind, solar, geothermal, biogas, hydropower and biomass energy. The GCs will be released only if the installations are certified for a maximum of 10 years.
Number of certificates	Brugel has indicated the emission of one certificate for every 217 kg of CO_2 saved
Amount of quota	The amount of quota obligation increases every year. It started from 3,5% in 2013 and it will arrive to 14% in 2025.
Minimum price per certificate	The transmission system operator (Elia) pays a minimum price of 65 € per certificate
Penalty	If one grid operator does not meet its target, it must pay a penalty of 100 € for every missing certificate
Annual average price	The annual average price of GCs in the Brussels region is between 81 and 92 €
	Flanders quota obligation
Eligible technologies	Wind, solar, geothermal, biogas, hydropower and biomass energy. The GCs will not be released for small installations, with a capacity lower than 10 kW
Number of certificates	The GCs are issued by VREG and the number is calculated from the electricity produced and a banding factor specific for every technology.
Minimum price per certificate	For the installations with a start date from 1st January 2013 the minimum price is 93 € per certificate
Penalty	If one grid operator does not meet its target, it must pay a penalty of 100 € for every missing certificate
Annual average price	The most recent annual average price of GCs (2017/2018) is 89,03 € per certificate
	Wallonia quota obligation
Eligible technologies	Wind, solar, biogas, hydropower and biomass energy. The GCs will be released only if the installations have a certificate of origin.

Number of certificates	The number of GCs is calculated by a formula that considers 3 main factors (the net amount of electricity produced, the energy performance coefficient of the installation and the economic performance factor of the technology).
Amount of quota	The amount of quota obligation increases every year. It started from 34,03%% in 2017 and it will arrive to 37,9 % in 2024.
Minimum price per certificate	The transmission system operator (Elia) pays a minimum price of 65 € per certificate
Penalty	If one grid operator does not meet its target, it must pay a penalty of 100 € for every missing certificate

Each region transfers the costs of the quota system and green certificates to end consumers through the electricity bill. Below are reported the data on the energy produced that benefited from the above schemes and the relative level of support, calculated by technology. In this way, it is possible to understand the cost of these mechanisms and the budget that Belgium has allocated to RES support. It was decided to report the data from 2013 to 2015 in order to have a clearer view of the progress of Belgium's support mechanisms.

Table 8: Belgian data for the energy supported by national schemes and average levels of support

	Year	Bioenergy	Hydro-power	Solar	Wind - Onshore	Wind - Offshore	Total
Total renewable electricity produced that received support in MWh	2013	4.288.061	374.692	2.607.141	2.058.355	1.539.699	10.867.947
	2014	3.639.114	271.289	2.830.705	2.330.567	2.221.311	11.294.209
	2015	4.127.942	270.590	2.896.328	2.573.522	2.611.751	12.481.356
Weighted average support level by technology in €/MWh	2013	94,38	24,11	369,07	84,19	104,89	157,41
	2014	93,4	25,21	182,9	81,04	104,24	113,78
	2015	92,72	25,06	180,33	81,76	104,45	111,78

The table above shows the total MWh that received support divided by technology and its average level of support expressed in euros per MWh. In particular, it is noted that during the 3 years analysed the amount of supported energy increased by almost 15%

while the average support level decreased by almost 30%, due to the sharp decrease in the level of support for solar energy (-51%). The remaining average levels of support do not change significantly during the period observed.

In addition to the quota system, individual regions have implemented direct subsidy mechanisms to encourage investment in renewable installations. These systems allow companies to cover a variable part of the costs (depending on the region and the size of the company) sustained for investments in renewable resources. It should be noted that not all installations and technologies are eligible for subsidies, as each region has defined which technologies and plants can benefit from the funding. On the other hand, regarding network connections, all the Belgian regions have given priority of both connection and use to RES plants, in order to encourage their diffusion and to facilitate the integration of the distributed generation.

Belgium has also adopted several support measures for the heating and cooling sector, such as the possibility of deduction from taxes for some heating technologies that use renewable sources (heat pumps), some direct investment mechanisms and indirect financing programmes for research, development and demonstration projects.

3.1.7. Research, development and demonstration projects in Belgium

Public funding for research, development and demonstration projects for energy technologies in Belgium is a key tool to support national energy policies and to stimulate innovation in private companies. The data[29] on research and development investments from national and regional sources are then explored concisely. The available data, representing the sum of the budgets planned by the regional and federal authorities, for the period 2010/2017, are reported, although the 2010 data are incomplete as there are only values related to investments in Nuclear.

[29] Source Energy Technology RD&D budgets, IEA website

Table 9: Public RD&D budget distributed from 2010 to 2017 in Belgian energy sectors

Indicators in M€, 2018 prices	2010	2011	2012	2013	2014	2015	2016	2017
Energy efficiency	0	49,068	83,799	54,637	54,477	55,905	45,389	44,11
Fossil fuels	0	0	2,645	0,106	1,652	1,857	0,715	0
Renewables	0	18,736	18,831	20,334	28,422	18,424	15,621	16,506
Nuclear	62,76	76,487	87,64	110,253	70,818	79,96	91,262	73,704
Hydrogen and fuel cells	0	1,568	0,233	0	3,354	1,276	1,292	1,943
Power and storage tech.	0	16,434	29,807	18,882	13,218	9,359	12,672	20,967
Cross-cutting tech./research	0	3,195	3,853	3,146	4,353	2,034	2,231	4,167
Unallocated	0	0	0	0	0	0	4,49	0,534
Total Budget	62,76	165,487	226,811	207,359	176,294	168,814	173,672	161,931

As can be seen from the numbers, nuclear represents a dominant share of the total budget in each of the years considered, despite the fact that the gradual elimination of nuclear power from the Belgium production mix has been scheduled (by 2025 they will have to decommissioned all installations). The government wants to continue to invest part of its budget for nuclear fission research, setting up about 50% of the total for almost the entire period.

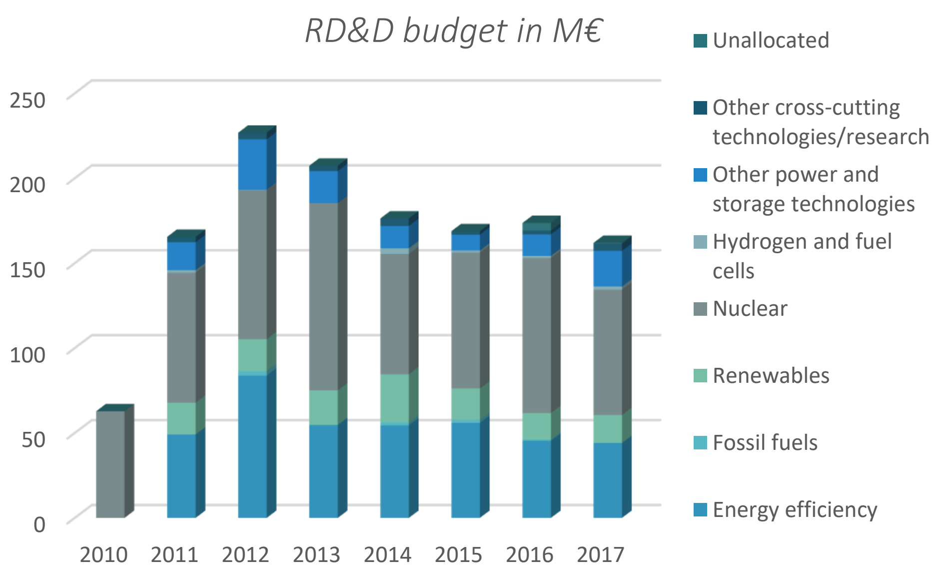

Figure 9: Belgian RD&D divided for technologies

The total investment was calculated leaving out the categories related to nuclear, fossil fuels and unallocated, so that we could get a rough idea of the level of the budget for innovative technologies that use renewable sources or that aim for better energy efficiency. Below there is an explanatory chart representing the different quota of investments allocated to other RD&D projects rather than nuclear ones. It can be noted that the category related to energy efficiency is predominant compared to other categories excluding nuclear, in fact it represents 50% in 2017 considering the total investment excluding nuclear, while in the same year equals 27.2% of the total budget.

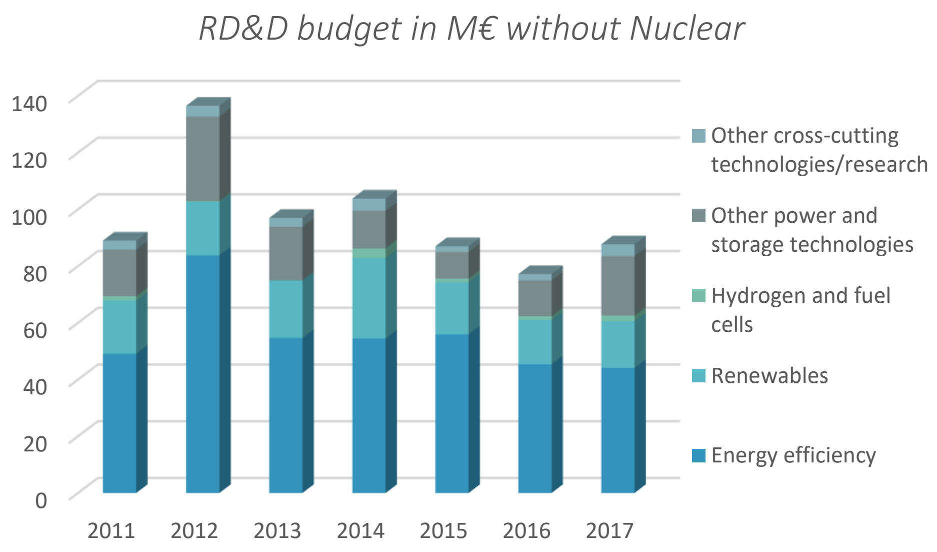

Figure 10: Distribution of RD&D budget to other technologies excluding nuclear

From the data, it is possible to observe that Belgium investments in energy system integration and related technologies, such as storage or hydrogen, are only a minimum part of the total, accounting together for 10.2% of the total allocated budget for the period 2011/2017. Moreover, these projects are only encouraged by few support mechanisms, such as tax exemption or public funding (mostly provided by European programs). Substantial changes to the regulatory framework to including and allowing for the full deployment of integrated energy systems are not yet envisaged.

In addition to direct funding for projects, federal authorities have also adopted tax measures, such as tax exemption for both public and private researchers and the possibility of deduction of patents, which serve as tools for indirect financing.

After an overview of the budgets allocated to energy by national authorities, we briefly analyse the available data on European funding, in particular for projects funded under the Horizon 2020 and Life 2014/2020 programmes. As part of the Horizon 2020 energy efficiency programme, 38.55 million euros were allocated for projects located in Belgium, of which almost 10 million were allocated to projects coordinated by Belgian companies or institutions. Of the total budget allocated, 8.4 million euros have been distributed to projects in the "innovative financing" category, which includes projects that aim to establish new financial measures in order to create favourable conditions for private investment. As regards the Life programme, 23.9 million euros has been allocated to projects located in Belgium, of which around 17 million are allocated to environmental projects and the remainder to climate ones.

The figures are only a general overview of Belgium's public and European funding, while there is no information on private investment in research and development in the energy sector due to the difficulty in finding such data. In order to be able to get a view of the investments made in the private sector, some data from a study carried out by Trinomics is describe. This report was published in 2016 and describes the Belgian context of climate finance, i.e. financing and investment climate change mitigation and adaptation actions. In this case, the information involves a greater number of projects within it, resulting in data not consistent with those previously reported (relative only to the portion of research, development and demonstration projects). In 2013, the year of reference of the study, all the investment flows identified and covered by climate finance amounted to 6.4 billion euros, of which 47% came from large companies, 34% from public and European funds and 19% from households and small and medium enterprises (SMEs). 84% of total funding was used for projects aimed at mitigating climate change, for example through renewable energy production and investment to improve energy efficiency in industrial sectors. While 15% corresponds to climate services, representatives mostly national R&D programs funded almost entirely through equity and resources within companies.

3.2. Denmark

3.2.1. National and organizational context

The Danish national energy sector context has several institutions and authorities with different responsibilities and tasks. The first of these is the Ministry of Energy, Utilities and Climate responsible for implementing all national and international policies. Under its control there is the Danish Energy Agency (DEA), which deals with the production, transmission and use of energy and all the issues related to these activities. In addition to these two main institutions, the Danish Council on Climate Change provides recommendations and suggestions for climate solutions and measures that are sustainable, not only for the environment, but also from an economic point of view. It is an independent organization made up of experts, set up to help the Danish economy in the transformation towards zero emissions. Suggestions, given from the Council, are based on independent and professional studies. In addition to advising Danish authorities and businesses, the Council is responsible for assessing the state of implementation of climate targets and assessing potential new mechanisms for climate policies.

The Danish Energy Regulatory Authority (DERA) was responsible for the electricity, gas and heating market until 1st July 2018. Among its tasks were the regulation of distribution and transmission network and market tariffs, coordination with other regulators in the Nordic states and multiple other activities. This institution was replaced in 2018 with the Danish Utility Authority (DUR), to which all the duties of the previous regulator were transferred. The aim of the DUR is to ensure the interest of citizens in all public sectors, keeping the prices level as low as possible, efficiently developing new technologies and ensuring stability and security of supply. With the introduction of a single regulator for all public services, Denmark aims to ensure greater integration between sectors by proposing consistent and interconnected policies.

3.2.2. Overview of the energy sector in Denmark

Denmark has a fairly complex energy sector as it is a point of interconnection between continental Europe and the Nordic countries. Institutions and national government are focused on achieving a zero-emissions economy by 2050, which is why they adopt many policies and measures aimed at decarbonizing all markets. Thanks to the strong attention of the state authorities to environmental and energy issues, the Danish sector is further ahead in the economy transformation than the European states' average.

TPES in 2017 was about 17 Mtoe, a decrease compared to 2005 of 10%. The total supply of energy consists of 45% of oil and coal, 16% of natural gas and 36.3% of renewable resources (biofuels, wind and solar). With regard to the value of energy production in 2017 it was 15.6 Mtoe, equal to 92% of the total supply, mostly made up of oil (44%), natural gas (28%) and renewable resources (28%). Production is almost entirely sufficient to cover the total supply needed by the country. However, Denmark has a good level of interconnection with its neighbours and has high export and import quotas, a symbol of the fact that the Danish network is also being *exploited* as a transitional hub between continental Europe and the Nordic.

Denmark's energy policy is mainly based on Energy Agreements, which are made up of national directives that are updated and amended every five years. Up to now, the Energy Agreement for the period 2012-2020 is applied, which includes several measures and initiatives in support of European climate policies. The plan estimated to spend DKK 3.5 billion on the implementation of the various planned measures. The main areas of action of the program are:

- Energy efficiency in all sectors, that can be achieved through the implementation of measures and subsidies that the Danish Government has allocated to incentivize energy companies to increase their commitment.
- The expansion of wind power and renewable sources into electricity production. The wind source is projected to account for 50% of Denmark's electricity consumption. Several initiatives have been put in place to achieve this, including the construction of offshore wind turbines with a total capacity of 1000 MW, an increase in capacity of 400 MW for wind farms near the coast and 500 MW for onshore wind farms. In addition to wind development measures, an investment of DKK 100 million has been set up to finance the development of new technologies and DKK 25 million for demonstration projects involving wave energy.
- Energy from biomass and the replacement of fossil fuels with biogas, especially substituting coal in cogeneration plants and increasing the use of biofuels within gas grids, industrial processes and transport sector.

- The integration of renewable resources in industry, transport and buildings. A ban on oil boilers in new buildings has been planned and the government has allocated DKK 42 million to fund the conversion of old boilers in existing buildings as well. For the industrial sector, an increase of DKK 500 million per year has been allocated for the period 2014-2020 for the subsidy dedicated to the promotion of renewable resources. Moreover, the government establishes a fund for industrial cogeneration plants.
- The implementation of smart grids and the creation of special strategies. A smart grid strategy has been launched that lists some key initiatives. One of these is the complete spread of smart meters, which allow time and remote controls. By installing them throughout the network and to all users, it is possible to offer dynamic pricing, which allow to drive the demand for electricity, to level the peak load and consequently to make better use of variable renewable energy. In addition, the government has partnered with energy companies to make the most of their competitive advantage in the European context. Denmark has carried out the highest number of smart grid projects over the years and this experience can be exported to other countries, allowing to gain benefits from the situation.

In addition to the Energy Agreement, the government has also realized several strategies, which are not real directives but more general guidelines. This category includes the Utilities Strategy launched in September 2016. For example, it provides for the clear separation between monopolistic and non-monopoly activities, in order to ensure competition for all activities not considered monopolies, the introduction of incentive-based mechanisms in the regulation of natural monopolies and an effective and transparent financial oversight. In general, with all the initiatives described in this strategy, the government expects to achieve efficiency levels of € 790 million per year by 2025.

3.2.3. Overview of 2020 targets and of prospects

As mentioned in the previous paragraphs, the Danish Government is very attentive to climate and environmental targets. These are among the main drivers of many of the Danish energy sector's policies, measures and initiatives. Denmark began implementing this type of policies very early, the first began in the years following the 1973 oil crisis.

This long tradition has enabled Denmark to create a solid basis for the low-carbon transition of the energy sector and the whole economy. The government's objectives have not only an environmental perspective but also one relative to economic development. In fact, thanks to the favourable policies context it has been possible to create an entire innovative sector dedicated to green technologies and smart energy, which in recent years has taken an important role in the growth of the country. In addition to this, the implementation of energy policies has allowed Denmark to become one of the most energy-efficient economies in the world. It has also managed to make its growth independent of energy consumption, managing to record economic growth of 44% between 1990 and 2015 and a simultaneous decrease in consumption.

Because of the importance of climate and environmental issues, it will be presented an overview of the progress made by Denmark in meeting its 2020 targets. The national targets set in 2010 by the Danish Government for compliance with European directives are very ambitious and, in each case, higher than those set at EU level.

The energy efficiency target set for 2020 sets a primary energy consumption level of 17.8 Mtoe (a decrease of 8.4% compared to 2005 levels). From the data recorded in 2017, the target seems already reached. The graph shows primary energy consumption and final energy consumption levels with projections for 2020.

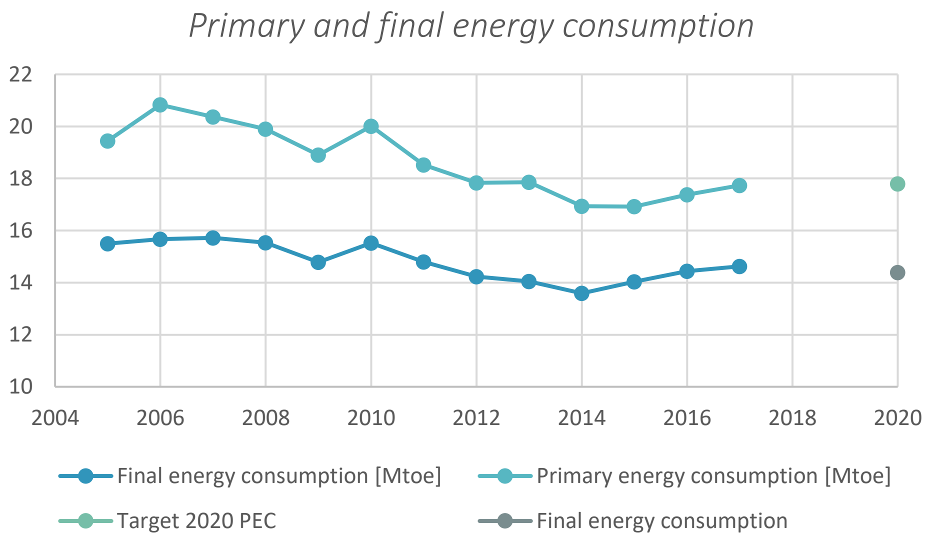

Figure 11:Danish primary and final energy consumption from 2005 to 2017

Over the years Denmark has implemented numerous initiatives aimed at improving energy efficiency, among them one of the most important and effective is the Energy Savings Obligation Scheme. It is a market-oriented measure that requires network and distribution companies in the electricity, natural gas, heating and oil sectors to reduce energy consumption annually by integrating into the network some techniques for the energy saving. Companies are free to choose which measures take even if not all initiatives are evaluated in the same way. In fact, weights have been introduced to encourage more initiatives that lead to higher and longer-term benefits, with the aim of achieving a combined savings of 1.5% per annum compared to the total energy sold to end users. Companies are allowed to save any energy carrier or resource, even those not sold directly, and to trade efficiency credits (as in the GCs market, companies that have a surplus with respect to the target can sell part of their share to others). This initiative can also increase the spread of technologies aiming at energy systems integration, thanks to the fact that every company can apply measures to save all energy carriers. The cost of this measure (approximately 0,02 DKK/kWh) can be fully included in the tariff and passed on to consumers, which offers no incentive to reduce costs and could lead distributors to overestimate their investments. Due to these possible problems, additional resources have been put in place since 2017 to ensure greater monitoring and control of companies' expenses and activities.

The spread of renewable resources in the Danish system has reached quite high levels and has made Denmark one of the global leaders in renewable energy production. In particular, the energy sector has benefited from the continued growth of wind farms, which are one of the country's leading sources of supply. The share of renewable resources within the gross final energy consumption to be reached in 2020 is 30%, a target exceeded in 2015. In 2017, the value of RES within the GFEC was almost 36%.

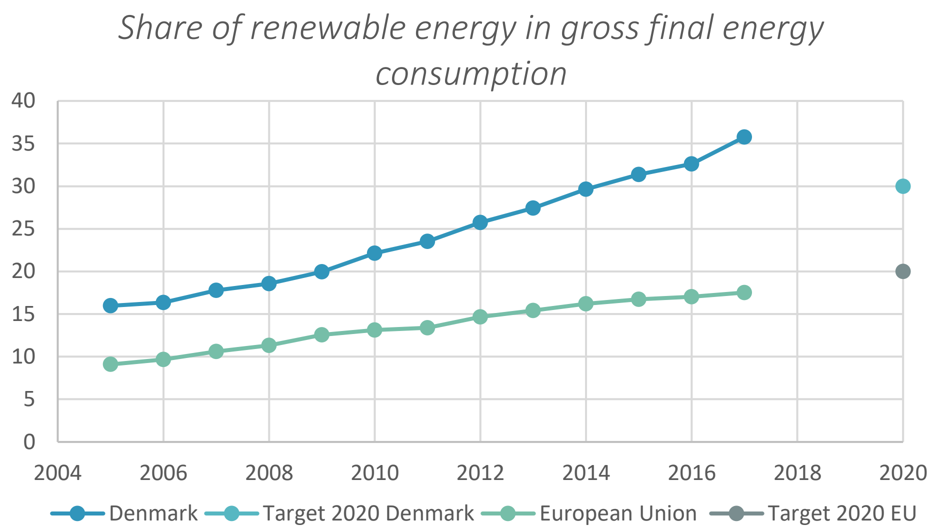

Figure 12:RES share in Danish gross finale energy consumption from 2005 to 2017

The increase in incentives and policies aimed at the spread of renewable resources in parallel with the progressive growth of fossil fuel costs and taxation has allowed renewable plants to become even more affordable compared to traditional ones. Denmark has faced several challenges to achieve high levels of renewable quotas in the energy mix, especially as the primary renewable source is wind. This resource has an intermittent nature and therefore presents several integration issues. Denmark has an advantage in the integration of variable resources because of the strong interconnection with its neighbours and, therefore, the possibility to exchange electricity with the Nordic countries (in which Denmark can freely buy and sell electricity to balance production). In addition to these factors, however, the Danish government and companies have been very committed to finding suitable solutions to integration, among the main ones there are:

- Exploitation of cogeneration plants, integrating the supply of heat and electricity. These systems allow for greater flexibility, as wind energy can be used for both electricity and heat as needed in the moment.
- The introduction of innovations to make thermal plants more flexible, allowing them to quickly reduce their capacity and to adapt to fluctuations of wind energy.
- Introducing innovative wind forecasting techniques to improve load balancing.

The measures listed act on the supply side, but for greater flexibility, the demand side must also be considered. Danish strategies include the introduction of techniques to change consumer behaviour and induce them to follow energy production (by changing the profile of energy demand).

The high spread of renewable resources has allowed Denmark to significantly reduce greenhouse gas emissions. The target for this dimension to be reached by 2020 is 20% less emissions for ESD sectors than in 2005. Denmark's efforts, in this case too, are sufficient to reach the ambitious target, in fact considering the entire GHG emissions system (both ETS and ESD sectors) the values recorded in 2017 indicate a reduction of about 30% compared to 2005 values.

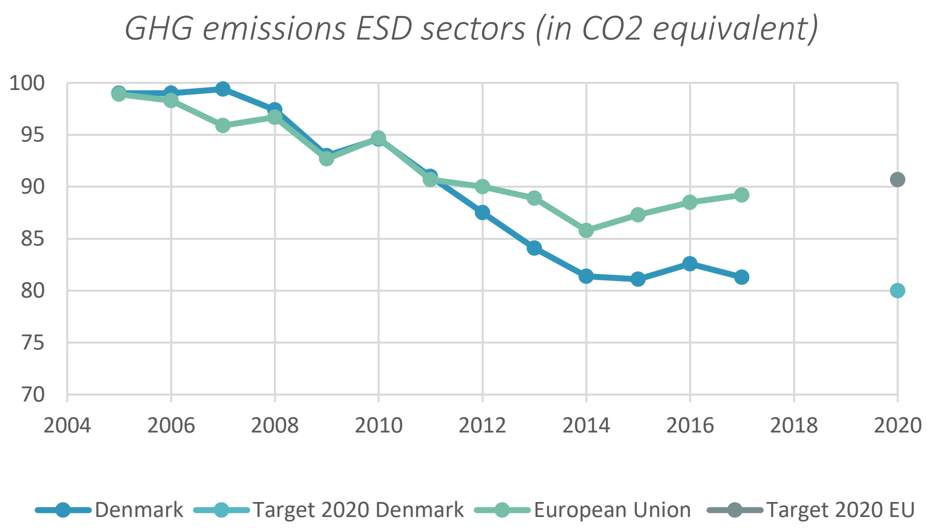

Figure 13:GHG emission in ESD sectors of Denmark from 2005 to 2017

In addition to all the measures aimed at the energy sector which also have the secondary effect of reducing emissions (renewable introduction, energy efficiency...), the Danish Government is working to try to introduce capture technologies and carbon dioxide storage within reservoirs in the North Sea. These technologies could be used in the refining of petroleum products and therefore the authorities are investigating their potential through various research and development projects.

3.2.4. Danish electricity and gas market

Electricity market

The Danish electricity sector has a market structure similar to that of Belgium. In fact, in Denmark, generation and supply activities are also competitive and network activities, such as distribution and transmission, are considered natural monopolies. In addition to the internal market, when describing the Danish system, it is necessary to consider the markets of the surrounding countries, which are a key component in the Danish electricity market. After these conditions, the main players in the sector and the most important features related to activities and infrastructures are listed:

- The producers and owners of the plants perform the function of generating electricity. Electricity in Denmark is produced through 100,000 plants (of varying size) and is made up of about two-thirds of renewable sources.
- Electricity suppliers sell electricity to consumer and they represent the first point of contact with end users. They can buy electricity either by producers or through a responsible part at the North Pool Spot. The latter is the electricity market owned by the transmission companies of Finland, Sweden, Norway, Denmark and the Baltic countries.
- The operator of the transmission network is Energinet.dk, which owns and operates the entire electricity and gas network. It is a fully state-owned company, therefore owned by the Danish government. The transmission network is divided into two main portions, the first, the Western one, which is connected to the German network and to the rest of continental Europe, while the second, or Eastern, is connected to the Swedish network. The only direct connection between the two transmission networks is the Great Belt Power Link, which is a direct line with capacity of 600 MW. In addition to managing the transmission network, Energinet.dk is responsible for directing the DataHub, a central IT system that, through standardized processes, manages interactions between the various players in the industry. It acts as a *warehouse* of all consumers data.
- Distribution network operators own and manage medium-low voltage networks. The 47 DSOs[30] serve approximately 3.3 million users and on average have a fairly small size (each DSO serves an average of 54,000 customers). They operate in a monopoly in the assigned geographical area and are regulated by the national regulator (first by DERA and now by DUR).
- There are six interconnection infrastructures (three with Sweden, two with Germany and one with Norway) and are owned by Energinet.dk and related TSOs

[30] Data for 2017

corresponding to the connecting nation. The capacity of interconnection with neighbouring states is high enough to cover the typical peaks in demand of Denmark.

Power DSOs' regulatory mechanism

The pricing mechanism applied before 2018 will be used to describe the regulatory system applied by the authorities to network operators. Nods will also be made to the pricing method adopted from 2018, although accurate data on this system are not readily available.

The model applied by DERA (before 2018) to all DSOs consists of a revenue cap with the addition of a maximum rate of return on network assets. Revenues are set annually on the basis of the regulatory price, adjusted according to inflation and the expected demand volume in terms of kWh. The regulatory price is calculated as the ratio of DSO revenues divided by sustained demand in 2004, the year taken as the basis for calculating the allowed revenues. Within the regulatory price, the necessary costs are considered, corresponding to the operating costs, depreciation and capital costs associated with efficient network management. The overall aim is to ensure that tariffs do not rise above 2004 levels.

The levels of CAPEX to be remunerated are calculated through the RAB. This is determined by investments made in past years minus the relative depreciation fee, calculated according to the straight-line method, plus the current costs incurred for the investments of the considered year. This value is then multiplied by the admitted return value of the 30-year interest rate on mortgage bonds plus 1%. Under the method applied by the Danish regulator, the allowed revenues are constrained by two limits, the 2004 DSO revenue levels and the maximum return on investment.

However, the model is adjusted annually through benchmarking mechanisms that consider cost efficiency and supply quality. These systems allow DERA to penalize companies that offer a worse service than the others. The benchmarking mechanisms applied are:

- Cost-efficiency benchmarking that is based on annual reports made by each DSO regarding the current stock of each component installed in its own portion of the network. The regulator, based on the transmitted data and on estimates of operating costs and depreciation, calculates the level of cost that, on average, a DSO should get to manage that given network tract (this value is called *Netvolumen*). This value is used to calculate the cost-index, according to the formula:

$$Cost\ index = \frac{(Operational\ cost + Depreciation\ of\ capital)}{Netvolumen}$$

This parameter is then adjusted for a factor that takes population density into account. After calculating the adjusted cost index for each DSO, the regulator proceeds to perform the benchmarking analysis. DERA sets efficiency requirements considering the top 10 DSOs and stipulates that operators, who are not among the best, must, within 5 years, at least achieve average efficiency levels of the top 10 values.

- Quality of supply benchmarking that is based on two main indices, the System Average Interruption Frequency Index (SAIFI) and the System Average Duration Frequency Index (SAIDI). In order to calculate the quality of the supply, the Danish system bases on the number of service outages and their duration. The regulator penalizes DSOs that have recorded values of SAIFI and SAIDI higher than those recorded by the aggregate operators own 80% of the network. The penalty corresponds to a 1% reduction in operating costs for each value outside the limits. The quality of supply is also assessed by an additional parameter that is used to evaluate whether DSOs neglect some type of customer. In particular, DERA penalizes DSOs if they have at least 1% of customers who experienced more outages during the year than those experienced by 99.5% of the total users during the same year.

All benchmarking mechanisms influence only a small part of the revenue allowed, as these depend mainly on other factors. In addition to revenue cap adjustments made through benchmarking mechanisms, the regulator may increase revenue allowed to incentivise certain types of investments.

There are also some systems in place to mitigate the risk incurred by DSOs, in fact if they have lower (or greater) revenues in one year than allowed, the regulator’s model provides adjustments for the next two years so that operators can recover (or return) the sustained difference.

The regulatory mechanism has been changed since 2018. The model remained a revenue cap but is no longer based on the 2004 values for calculating the allowed revenue. The aim of this scheme is to cover the costs of efficient asset management and the remuneration of invested capital. Again, the values are determined annually by the DUR, but on the basis of a 5-year regulatory period. Admitted revenues are defined through a cost limit (OPEX and depreciation) and a return limit. Subsequently, they are adjusted taking into account efficiency requirements (obtained by benchmarking), the level of supply quality, the costs of the energy savings and other secondary factors. The model also includes a change in the calculation of future return, which is measured through a market based WACC. The value of the WACC considered for the return rate is 3.66%, while the return value on equity, before taxes, is 5.63%.

Gas market

The natural gas market has been, in the past, one of the most important for the Danish energy system. In recent years, however, the share of this resource within the energy mix has decreased to make room for wind energy. The market structure of the natural gas sector includes:

- Energinet.dk which is the only TSO also in the gas network. The transmission network connects production plants in the North Sea to the distribution network. Again, Energinet.dk, together with the TSOs of neighbouring nations, owns some infrastructure of interconnection with Germany and Sweden.
- Three operators of the distribution network, all owned by public institutions. One of the characteristics of the distribution network is that, although it was designed only to transport natural gas, recently, it has also been connected to biogas plants, allowing them to be easily integrated into the country's energy supply.
- A single operator that manages the storage infrastructure, represented by an independent subsidiary of Energinet.dk. There are two storage facilities and they are used to compensate for seasonal fluctuations in demand. The total capacity in 2016 was 8.1 GWh/h. Storage facilities are not considered natural monopolies as

foreign storage installations can be accessed. However, the regulator must still supervise and ensure equal access for all customers.

- About twenty companies that supply the gas to end users. The sales market has been liberalised since 2004 and consumers are free to choose their supplier.

Gas DSOs' regulatory mechanism

The tariff system imposed by the regulator also for the gas distribution operators is a form of revenue cap with benchmarking mechanisms for operating expenses. The regulatory period lasts 4 years even if the allowed revenues are calculated annually. The revenue cap includes the operating costs, representing the level of activity and the exogenous costs, historical debt (relative to 2004), regulatory asset base and costs for energy efficiency activities. Revenues are also adjusted through operating cost efficiency requirements based on benchmarking methods. These are based on the calculation of industry-specific marginal costs for a predefined output, which are then used for the efficient estimation of OPEX for the company. The expected value is then compared to the actual OPEX. Unlike the electrical sector, the regulator does not apply any kind of incentive based on the quality of the supply.

With regard to the level of remuneration of the assets and, therefore, of the regulatory asset base, the regulator sets the value of the WACC at the beginning of the regulatory period (equal to 4.51% in 2017).

The mechanism described above has been in place since 2005 and the regulator sees achievable efficiency potential by 2025 of 112 million DKK for all DSOs. In general, the system imposed on gas grid operators is not much different from that applied to the electricity grid, although not completely equal the two mechanisms have the same purpose on the part of the regulator.

Electricity and gas TSO regulatory mechanism

Energinet.dk is the sole operator of both the electrical and gas transmission network. It is a totally state-owned company and almost all of its activities are regulated. The current regulation of transmission tariffs (valid for both sectors) provides for a break-even mechanism, i.e. it follows the "non-profit" principle. The rates are set annually to cover the costs, incurred by the company for efficient operation, and an interest rate to guarantee the real value of the capital as of 1st January 2005 (equivalent to 3.157 million DKK).

This type of adjustment is called strict cost-plus. Energinet.dk is not subjected to any efficiency requirements, but the regulator may assess the partial or total exclusion of specific costs that do not fit into efficient operation. In addition, there is no regulation that takes into account the quality of supply. The system is based on cost forecasts for the following year, so it is possible that the company's revenues are not the same as those allowed. To maintain the break-even principle, revenue differences are included in the following year's tariff calculation (both positive and negative).

In 2018, it was announced that the regulatory mechanism, to which it is subjected Energinet.dk, will be changed in the coming years. A revenue cap system with efficiency requirements will be introduced from 2021.

3.2.5. Energy research, development and demonstration in Denmark

Research, development and demonstration activities in the energy sector are very important, not only for the achievement of environmental goals, but also for the economic growth of the country. Denmark in 2014 recorded a record in the export of energy technologies, reaching a value of 10 billion euros (or 74.4 billion DKK, equivalent to 12% of the total exported goods). Thanks to investments in research and development projects, the Danish energy sector has gained a competitive advantage in multiple technologies, such as wind energy, heating, smart grids and system integration.

Public energy project financing programmes are:

- Energy Technology Development and Demonstration (EUDP) consists of an autonomous entity managed and owned by a board of directors directly elected by the Danish Ministry of Energy. From 2017 it also manages the ForskEL fund, previously financed through PSO. The total budget allocated for 2017 amounted to 40 million euros (300 million DKK), through which projects related to numerous technologies are financed. For example, projects related to energy efficiency, to hydrogen and its applications and to storage systems both of energy and of CO_2. The primary objective is to finance projects that develop exportable technologies.
- The Innovation Fund is a Danish organisation set up to allocate funding to research and development projects in all sectors, not just energy.

- ELForsk is a PSO-funded research and development program with an annual budget of 25 million DKK. The main objective of this programme is energy efficiency in sectors such as industrial, commercial and residential.
- European programmes such as Horizon 2020. Danish companies obtained about 350 million DKK in 2016 through the Horizon 2020 programme to finance energy projects. The Danish target is to receive a total of funding in 2014/2020 equal to 2.5% of the entire Horizon 2020 budget.

In addition to these programmes devoted to research, development and demonstration, Denmark has also set up an investment fund to support new energy technologies during the commercialisation phase, in order to promote their penetration into the market. The total budget allocated in 2016 amounted to DKK 58.5 million.

Energinet.dk developed its internal strategy for three-year RD&D projects. This strategy includes internal activities (ForskIN) and a programme funded through external funding (first ForskEL and then EUDP). ForskIN's activities are mostly focused on the implementation of commercial solutions and the main initiatives include electricity and infrastructure quality, flexibility and storage solutions, renewable gas and safety consumer data. While those financed externally focus more on applied research and development (early stages of the innovation process, preceded only by basic research) with main themes the integration of RES technologies and systems storage.

As done for Belgium, there is a table with the public funding values dedicated to the RD&D projects for the period 2010-2018. Last year values are just an estimate and do not match the actual data.

Table 10:Public RD&D budget distributed from 2010 to 2018 in Danish energy sectors

Indicators in M€, 2018 prices	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Energy efficiency	27,45	20,82	24,81	35,96	45,67	29,69	20,15	19,36	18,78
Fossil fuels	4,63	4,19	5,52	1,14	2,26	4,73	0,87	3,05	0,83
Renewables	88,38	82,30	67,48	86,31	57,89	72,11	47,17	28,73	42,45
Hydrogen and fuel cells	34,31	31,05	26,19	13,85	27,91	14,87	8,70	9,81	4,84
Power and storage tech.	21,56	30,10	19,46	15,50	16,03	22,49	17,49	18,21	11,97
Cross-cutting tech/research	11,14	10,64	7,74	11,13	1,28	1,18	3,45	0,12	1,43
Total Budget	190,59	180,55	156,79	166,59	153,72	151,64	100,64	85,49	100,25

As it can be seen from the data, Danish public funding fell sharply over the period, in fact between 2010 and 2017 there was a halving of the total allocated budget. However, the government has already declared its commitment to raising public funds for energy RD&D projects. In the period in point, the total amount of public funding amounts to about 1.3 billion euros, of which 45% has been allocated to renewable resources, 19% to energy efficiency technologies, 13.4% to storage and 13.3% to hydrogen and related technologies.

A graph is shown below to get a visual understanding of the weights of different technologies on the total investments made.

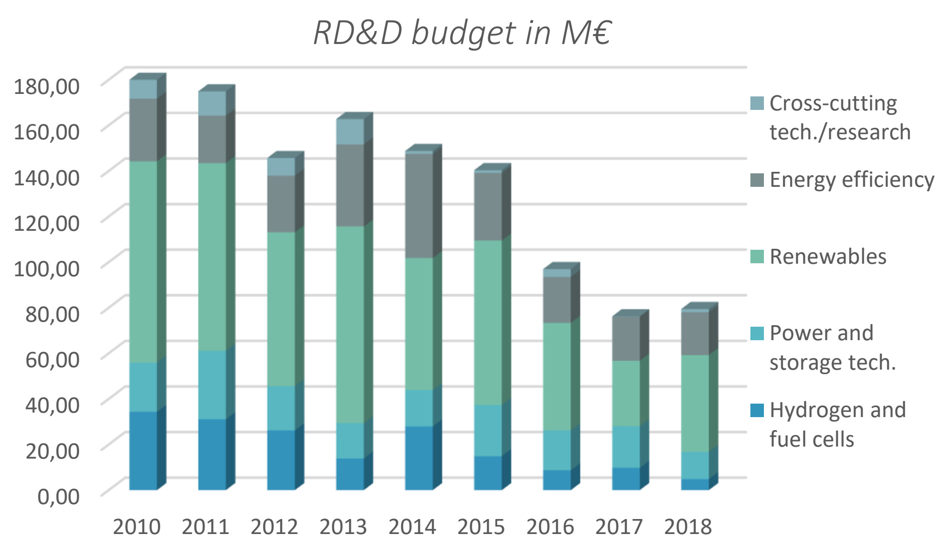

Figure 14:Distribution of RD&D budget to the main technologies

3.2.6. Regulatory context for Power to Gas projects

Denmark has several conditions that make particularly useful to introduce Power to Gas technologies within the energy system, as ideal solutions to solve some problems related to the transition to a low-carbon system. For example, the high share of wind energy within the energy mix, which leads to numerous problems of integration and optimal exploitation due to its variable nature, and the existence of an already well-developed gas network are some of the qualities that make P2G technologies particularly attractive for the Danish system. Until now, projects developed in Denmark have mostly biomethane as their final output, because, unlike hydrogen, it can be injected in the existing network without volume restrictions.

The following are some of the main characteristics of the Danish context, both which support and hinder P2G technologies:

- In Denmark there is a favourable tax environment for electrolysis processes. Under Danish legislation, electrolysis is part of an energy-use process in which an input is transformed into value-added output and can be exempted from some of the taxes on electricity and other fuels.
- Hydrogen-produced electricity enjoys exemptions from environmental taxes because hydrogen is considered a cleaner fuel than others, for example compared to natural gas.
- The methanation processes can benefit from some subsidies as Denmark has set up a subsidization scheme for the enhancement of biogas. In contrast, there are no subsidies for electrolysis processes, therefore, even if they benefit from a favourable tax environment, they are not directly supported.
- Network tariffs are considered a barrier to P2G applications.
- A well-defined business model for P2G installations has not yet been clearly identified, representing the fact that the Danish government does not yet have a certain vision on how to support these technologies.

Despite the not entirely favourable conditions, Denmark is the only Nordic country to have high capacity P2G projects (in the order of MW). The most important P2G projects are:

- HyBalance will runs for the period 2015/2020 and the goal is to demonstrate the effectiveness of hydrogen use in energy systems. The project provides the development of an electrolysis plant with a capacity of 1.2 MW, which will use wind energy for hydrogen production. This project is aimed at demonstrating the convenience of the electrolysis process that allows the storage of electricity in the form of hydrogen, which can then be used in multiple ways, for example converted back into electricity to balance the grid, as a raw material in industrial processes or, finally, in the transport sector. The total budget allocated to the project is EUR 15 million, financed in large part by European and national funds

(8 million euros from Horizon 2020 and 2.6 million euros by the Energy Technology Development and Demonstration Program).

- The BioCat Project ran from 2014 to 2017 and the overall goal of the project was to design and build a power to gas plant on a commercial scale and demonstrate its ability to provide energy storage services to the Danish energy system. The plant consists of an alkaline electrolyser with a capacity of 1 MW and a methanation system. The plant is connected to both the electrical and gas grid. It is located at the wastewater treatment plant in Avedøre in the south region of Copenhagen. In fact, they also wanted to demonstrate the possibility of recycling oxygen and heat from the process of electrolysis and methanation in the treatment of wastewater. The total budget for this project was 59.95 million DKK, 46% of which was obtained from public funding (ForskEL).
- "Biocat Roslev – Project 1" runs for the period 2018/2019 and the main purposes is the construction of a power to gas plant near Roslev. The plant will be located close to two anaerobic digesters and a biogas upgrading facility and it will include an electrolyser with a bio-methanation system with a capacity of 8 MWe. The project team will focus on the creation of a favourable regulatory context, on the development of a market model and a growth strategy for P2G in Denmark and on the technical preparation for the plant. The entire budget is equal to 10.09 million DKK, 58% of which is financed by national funding programs (EUDP).
- "P2G-Biocat 3, System control and integration" will run for the period 2017/2020 and it proposes to complete the maturation of the bio-methanation technology developed during the previous Biocat projects. The project will focus on different activities that comprise also plants' improvement to allow them to operate automatically in every condition. The total budget for the project is 9.14 million DKK, 66% of which is provided by national funding programs (EUDP).
- EP2Gas (Efficient Power2Gas Combining SOEC[31] and Biomass Gasification) will run for the period 2017/2020. The general objective is to develop a P2G solution based on the integration of SOEC electrolysis, biomass gasification, and methanation technologies. To achieve the purpose, it is necessary to further develop the newest technology, namely the SOEC electrolysis, and to investigate

[31] Solid Oxide Electrolyser Cell

the existing synergies between the three processes. The whole budget is 17.96 million DKK, 84% of which is financed by national programs (EUDP).

- BEEST (Boosting Economic Electricity Storage) will operate for the period 2017/2020 and it aims to further develop the alkaline electrolysers technology to increase efficiency and to reduce cost. The main objective is to obtain a stable technology to use for the achievement of a flexible and highly integrated energy system relying 100% on renewable energy. The entire budget is equal to 9.97 million DKK, 82% of which is allocated from public funding (EUDP).

Although we reported only some of the major projects relating to Power to Gas technologies and their integration within the energy system, it is possible to note that the Danish Government is very committed to the development of these systems. In fact, for all the projects listed a considerable proportion of the total budget comes from national funding programs (previously described). This is a symbol of the fact that P2G systems are not negligible for the development of the future Danish energy system.

To conclude, a summary table is exhibited to represent the different situations relating to P2G technologies and the gas sector in general. It provides an overview of the factors of influence, the type of regulation and the existing barriers. The table is taken from Deliverable 6 of the Future Gas project[32].

[32] https://orbit.dtu.dk/ws/files/163241950/FutureGas_WP6_Deliverable_report_6.1.1._Tariffs_v3.pdf

Table 11: Danish conditions relating to P2G technologies and to the gas sector in general

	Grid interaction	Regulation	Influencing market factors	Barriers
Injecting hydrogen to the gas distribution grid	Power-gas	In progress	Power price, power tariff, taxes	Gas quality, capacity tariffs, no subsidy for hydrogen
Biogas Upgrading[33]	Gas distribution	Subsidy for biogas upgrading	Gas price, Gas tariff	None
Bio natural gases for the transport sector	Gas-Transport	Green energy in transport	Gas price, Gas tariff, LNG price	Competition in international LNG markets, electricity price
Gas-Electrical Hybrid Heat Pumps[34]	Power-Gas-Heat	In progress	Gas price, Gas tariff, Power price, power tariff, taxes	Investment cost of heat pumps, electricity price
SNG Upgrading[35]	Gas	None	Gas price, Gas tariff, Biomass price, taxes	Investment cost, lack of economic incentives

3.2.7. District heating market and integration with the electricity sector

District heating is the Denmark's largest source of domestic heating, accounting for almost half of heat consumption and 18% of total final consumption (2015). It also offers many opportunities for integration between different energy sectors, particularly between the heat and electrical sectors. For this reason, a general overview is proposed, to identify the Danish Government's position on sectors integration and related policies.

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[33] Upgrading of biogas and syngas transforms them in gases with the same quality as natural gas and then they can be injected into the gas infrastructure.

[34] Electric Heat pumps are devices that absorb and transfer thermal energy from a low-grade source to a heating element with a higher temperature.

Denmark built the first infrastructure related to heating in the 1920s to take advantage of the waste heat of electricity generation. Over the years, district heating has become more widespread and was mostly based on coal or oil cogeneration plants. Natural gas was later introduced. In recent years, many of the cogeneration plants have used biofuels, as they are supported by favourable tax regimes. For this reason, many of the coal-fired plants have been converted to use biomass or biofuels as a resource. In addition, Denmark is also becoming a world leader in photovoltaic heat production plants. These are often combined with thermal storage installations, as the peak production is in summer while the peak demand is in winter. The introduction of storage systems allows to retain some of the production for periods when demand is high. Although CHP plants account for about two-thirds of production in the heating sector, their share has fallen due to low energy prices which make combined production less profitable than the only generation of heat. To promote CHP plants, the government has adopted some subsidies and methods of regulation, such as the "basic amount" subsidy, which guarantees a minimum level of revenue from the sale of electricity. This type of measure was introduced mostly in order to take advantage of the generation capacity already existing in the country, but from 2018 some of the subsidies have been eliminated. In 2019, only biofuel plants can receive financial support and can benefit from a premium over the market price (feed in premium).

The Danish DH market is very varied, in fact there are approximately 600 suppliers of different proprietary structures and sizes. Both production and network activities are considered natural monopolies and are subject to regulation. In particular, cogeneration plants with a heating output greater than 25 MW are regulated both from the point of view of the electrical and heat markets. Companies operating in the heating sector are currently regulated by a break-even mechanism, i.e. the price imposed on consumers must cover the costs of production. However, this mechanism will be replaced in the coming years with an incentive-based system that will allow companies to create a surplus to invest in DH activities. Costs will be calculated through a benchmarking mechanism (as in the electricity and gas sectors). In addition, the possibility of temporarily increasing fees to cover investment costs will be eliminated, as the investments will have to be financed through bank loans, equity or undistributed profits. The new mechanism will allow companies to invest according to their interests, encouraging the development of a more market-based sector.

The potential for integration between the electricity and heat sectors is manifold, mainly due to the ease of heat storage compared to electricity. Key roles in the integration of these two sectors are represented by thermal storage technologies, the building sector (which may be short-term storage) and the industrial sector (as the surplus heat generated by industrial processes can be either entered into the heating network or used for electricity generation). In order to optimise synergies between the various sectors considered, the Danish Government must adopt policies that include the whole energy system. Denmark has already included some technologies in the system that are useful for integration between energy sectors, for example thermal storage facilities are quite common as they allow the balance of electricity and heat production and demand in cogeneration plants. The thermal storage systems used in Denmark are either with short or seasonal capacity (such as those used to store the heat generated by photovoltaic systems).

Among the main barriers to integration between the electricity and heating sectors is the high level of taxation on the use of electricity in heat generation. This measure was imposed to discourage the excessive and inefficient use of electricity, but in this way, it also hinders new technologies that, without high taxation, would be efficient. To try to remedy to this problem, the Danish Government has taken some measures, especially to promote the spread of heat pumps. In particular, in 2015 investments in this technology within the heating sector were promoted thanks to contributions of 26.7 million DKK allocated to a total of 10 projects. In 2017-2018, 53 million DKK were allocated for the same purpose.

In Denmark there are many ongoing projects related, not only to heat pumps, but also to other innovative technologies for the integration between heat and electricity or gas sectors. Among the main projects there are:

- "Experimental development of electric heat pumps in the Greater Copenhagen DH system - Phase 2" operates for the period 2016/2021 and it is the second part of a bigger project, made of three phases. The main activity of this phase is the development of two electric heat pumps with capacity of 5 MW, one based on geothermal heat and the other on sea water. The project's aim is to accelerate the use of large heat pumps for DH, addressing the main barriers that hamper the use of heat pumps for systems integration. The ultimate goal is to obtain a mature technology that will allow for an economically efficient system and with potential for scaling up concepts to 50-100 MW. The allocated budget is 110 million DKK, with a public funding rate equal to 20% (EUDP).

- FLEX-TES will run from 2018 to 2022 and it aims to demonstrate a new function for the pit heat thermal storage (PTES) technology. The project consists on the construction of a PTES system with a 70000 m^3 capacity. This facility will be used for the storage of excess electricity and heat produced by CHP plants connected with district heating systems. The storage plant will be connected to Høje Taastrup Fjernvarmes distribution system and to the VEKS´ transmission network as part of the integrated District Heating in Greater Copenhagen, making possible for many CHP plants to exploit the storage capacity. The main purpose for the project is to demonstrate the value of this type of storage for the heat sector. The total budget is equal to 83.82 million DKK, 16% of which is provided by national funding (EUDP) while 82% of the budget is sustained by VEKS (DH's transmission company).
- HEAT 4.0 (Digitally supported Smart District Heating) began in 2018 and it will end in 2021. The objective of this project is to develop an integrate flexible product platform that allow DH companies to match demand and production in an affordable way. The goal is the digitalization of district heating systems through data intelligence, artificial intelligence and other technologies. To this project, partners companies allocate 37.27 million DKK, with 68% funded by public funds (Innovation Fund).
- "Local Heating Concepts for Power Balancing" was conducted from 2017 to 2019 and it had as central focus the optimization of energy systems' synergies. The project aims at creating a new model for the exploitation of district heating technologies to balance power grids. The project team wants to demonstrate that both systems can benefit from the interactions with one-another. The total budget was 12.39 million DKK, with a public funding rate of 77% (EUDP).

- o SMARTCE2H (Smart citizen-centred local electricity to heat systems) started in 2019 and it will end by 2021. The main purpose of the project is to demonstrate the technical and economic value of the installation of smart heat pumps in residential communities and in the district heating network. This will be verified through test and demonstration activities on integrating electricity and heat system in Skive Municipality. Among the project's activities, there will be also a complete analysis, to assess how regional grids can be optimized to form a local integrated community energy system. The whole budget is 7.66 million DKK, 66% of which is allocated by a funding national program (EUDP).
- o Denmark participates to IEA DHC Annex TS3 (Hybrid Energy Networks) an international project that wants to assess the role of district heating and cooling in an integrate energy system context. The project will run for the period 2019/2022 and it will focus on the district heating and cooling system (DHC) as an effective technology for the implementation of hybrid energy networks (HEN). The project budget is 3.59 million DKK, 66% of which is provided by national funding (EUDP).

As in the previous paragraph, we listed only some of the projects carried out by Danish institutions. Reporting a short list of projects, we want to underline Denmark's commitment also in the integration of the electricity and heating sectors. The Danish government uses mostly public subsidies to encourage this type of project, which are directly financed through national funding programs. In the coming years, the integration of energy systems can be further encouraged through the introduction of the incentive regulatory mechanism for district heating operators.

3.2.8. Smart grids and energy system integration in Denmark

Denmark was one of the first nations to introduce the concept of smart grids into the national electricity system, in fact as early as 2010 the Danish Minister for Climate and Energy had set 35 recommendations to promote the diffusion of smart technologies. In addition to the concept of smart grid, in the same years, Denmark adopted the concept of smart cities, which means cities that adopt digital solutions and organizational structures with the aim of improving the liveability, sustainability and prosperity of citizens. Within this definition, both digital technologies and all those solutions that allow integration between different energy systems have a key role. In particular, the Danish holistic approach stems from the construction of cogeneration plants since the 1980s, which makes the energy sector suitable for the integration of energy systems both from an infrastructure and organizational point of view.

As evidence to Denmark's strong commitment to this area (smart grid and energy system integration), the main results of a 2015 study by Aalborg University[36] are analysed. In this study, the authors examined smart energy projects for the period 2005/2015 in Denmark, Europe and Nordic countries. Within this study, 225 Danish projects were considered, selected among those on the online database *Energiforskning.dk*. At the time of the study, in the database there were more than 2400 projects divided into different technological areas. The projects referred to the three main energy sectors in Denmark, namely electricity, gas and heating. Studying the 225 selected projects, it was found that in the 10 years considered the level of public funds allocated to the smart energy category has grown significantly, from negligible to a cumulative total of 1.5 billion DKK in 2015 (compared to a total budget of 2.6 billion DKK). The analysis found that Denmark had already achieved a better level of smart energy and related technologies than the other countries considered. By reporting some data in detail, it is interesting to note that public funding in multi-sector research, namely those which include two or more energy sectors, had grown significantly over the period under consideration, although 124, of the 225 projects considered, were related to a single energy sector (of which 76 related to the electricity sector only). Despite this, multi-sector projects achieved a higher level of funding, amounting to 738 million DKK, compared to 686 million DKK reached by single-sector projects. These data are useful to understand how much Denmark is committed to encouraging investment in smart energy, including possible projects related to the integration of energy systems.

After this brief description of the main results of the study conducted on smart energy projects, we list some of the projects, considered most useful for the purpose of the work, currently active among those reported within the Energiforskning.dk database. In particular, the focus is on projects related to the integration of energy systems and those

[36] Mathiesen, B. V., Drysdale, D., Chozas, J. F., Ridjan, I., Connolly, D., & Lund, H. (2015). A Review of Smart Energy Projects & Smart Energy State-of-the-Art. Department of Development and Planning, Aalborg University (Mathiesen, 2015)

related to technologies supporting this new energy paradigm. Below is a brief description of the selected projects:

- "EnergyLab Nordhavn - New Urban Energy Infrastructure", running for the period 2015/2019, aims to foster and develop new solutions for multi-carrier energy systems (electricity/thermal/transport). The project utilizes the harbour area of Nordhavn as a laboratory to test future smart energy technologies and related business models. The main purpose of the project is to create a coherent flexible energy system through the use of innovative methods, like storage technologies or digital solutions. The project main characteristic is the possibility to test new solutions in a "real-life" laboratory, which allows a greater examination of all the related aspects (it is possible to analyse also the societal and economic impacts and not only the technical ones). The entire budget is equal to 128.95 million DKK, with a public funding rate of 60% (EUDP).
- Ecogrid 2.0, going for the period 2016/2019, focuses on the demonstration of the value of demand response mechanisms. The project team wants to examine the support of these technologies to operational services in power system, in the view of the new challenges related to the integration of RES and to the electrification of both heating and transport sectors. The project objective is to develop and demonstrate demand response products, useful either for DSOs, TSOs and customers. The allocated budget is 97.58 million DKK, 50% of which is financed by national programs (EUDP).
- CITIES (Centre for IT-Intelligent Energy Systems in Cities) lasted from 2014 to 2019. It is a holistic research project that aims at developing a fully integrated urban energy system. It contains all the energy system aspects (electricity, gas, district heating and cooling and biomass) and it focuses on ICT methods for control, forecasting and optimisation of the interaction between sectors. The CITIES project develops new tools for the integrated energy system solutions at every level, both for the appliance and the total system. In addition to the technical and commercial objectives, the project aims to educate the new generation of academics, engineers and entrepreneurs at how valuable can be considering the energy system as a whole. The project has a budget of 70.67 million DKK, funding at 62% by national programs (Innovation Fund).

- FED (Flexible Energy Denmark) will last from 2019 to 2023. The project will focus on the demonstration of digital technologies enabling energy system integration and flexibility. The solutions provided will be based on data analytics and IoT devices. FED will support industrial partners in the creation of new products, testing them in living labs, through the new data platform, Uni-Lab.dk. The product test will significantly decrease the time-to market for the innovative solutions. Moreover, the FED project will create new competences on energy flexibility, exploitable both at policy and product level. The total budget is 43.67 million DKK, with 69% provided by national funding (Innovation Fund).
- MultiCon (Multi Storage Converter for Wind Energy) was launched in 2018 and it will end in 2021. The project furthers innovative storage solution based on Power Management System for wind energy. The new model will allow monitoring and control of batteries, generating important benefits in terms of functionality, stability, and cost efficiency. The budget is 17.55 million DKK, with a public funding rate of 57% (Innovation Fund).
- CORE (Coordinated Operation of Integrated Energy System) runs for the period 2017/2020 and the main focus is the development of a stable integrated energy system based on renewable sources at 100%. In order to achieve an optimal solution, the project team will analyse in detail different energy storage technologies (Power to Heat and Power to Gas), the flexibility requirements related to the integration of heat, gas, transport and electricity and innovative business models. After examining every aspect of the integrated energy system, the suitable solutions will be tested in PowerLabDK[37]. The total budget is 12.53 million DKK, 83% of which provided by national funding (EUDP).
- SEMI (Sustainable Energy Market Integration), active for the period 2017/2020, will focus on the energy system integration from a market perspective. The main deliverables will be the Danish energy market models of the future. They investigate the potential synergies between energy sectors and the possible business models, which allow to have optimal investments to reach the most

[37] PowerLabDK is a national green lab under the control of Danish Energy Agency (DEA). It was established as an experimental platform for technology development, test, demonstration and training.

coordinated energy system integration. The allocated budget is 7.74 million DKK, with a funding rate equal to 82% (EUDP).

- EPIMES (Enhancing wind Power Integration through optimal use of cross-sectoral flexibility in an integrated Multi-Energy System) was launched in 2016 and it will end in 2019. EPIMES is an international project, in fact it has been carried out thanks to a partnership between Danish and Chinese institutions. The main purpose of the project is to address the challenges related to wind integration on power system. In particular, the research groups will utilize a multi-disciplinary approach to provide an optimal solution. They want to focus on the potential of cross-sectoral flexibility in an electricity-heat-gas system from an integrated energy system perspective. The project is organized in different phases with specific target. The ultimate step will be the test of selected solutions of cross sectoral flexibility both in Denmark and China. The total budget allocated for the project is 7 million DKK, financing at 90% by national funding programs (Innovation Fund).

3.2.9. Danish RES support

Renewable resources in Denmark within the electricity sector are mostly supported by mechanisms such as feed-in premium, net-metering and local initiatives. Below there is a brief description of the main support scheme:

- Feed in premium: Renewable energy producers receive a variable premium in addition to the market price of electricity. The sum of the two, in some cases, may not exceed a certain limit that depends on the date of connection of the plant to the network and on the resources used. There are two types of mechanisms, the first, defined as maximum bonus, provides a variable premium and a maximum limit and the second, guaranteed bonus, provides a fixed guaranteed premium and no maximum limit. The resources eligible for this type support are wind (both onshore and offshore), solar, biogas, hydro and biomass.
- Net-Metering regulation: Some manufacturers are exempt from the full or partial payment of the Public Service Obligation (PSO). The PSO is a tax added to the price of electricity to fund support mechanisms for renewable resources, but it will be phased out in 2017/2021. In the future, support mechanisms will be

financed directly by the state through a general increase in taxation. From 2021, therefore, no one will have to pay the share for the PSO.

As far as the connection to the grid is concerned, renewable systems do not have any priority connections but can benefit from the priority in the use of the network. In cases of grid capacity shortages, energy from renewable plants take precedence over traditional produced one.

Renewable resources are also supported in the heating sector, for example through exemption from contributions on the use of fossil fuels or through a bonus per giga joule of biogas used for heating purposes.

As for Belgium, data from 2015 to 2017 show supported renewable energy and the average level of support for each technology.

Table 12: Danish data for the energy supported by national schemes and average levels of support

	Year	Bioenergy	Solar	Wind Onshore	Wind Offshore	Others	Total
Total renewable electricity produced that received support in MWh	2015	3.045.650	128.053	4.911.959	9.138.155	3.084.000	20.307.817
	2016	3.836.315	239.799	7.389.216	4.361.913	3.498.548	19.325.791
	2017	5.004.648	348.557	8.798.048	4.808.052	3.511.470	22.470.775
Weighted average support level by technology in €/MWh	2015	42,75	77,57	47,6	40,12	101,06	51,81
	2016	36,04	147,57	27,44	67,67	79,05	49,06
	2017	35,74	94,97	26,06	65,33	70,89	44,69

The energy that received the most support (in terms of volume) over the years was wind energy, counting for more than 60% of the total supported energy. The average level of support decreased by almost 14% between 2015 and 2017 while supported energy increased by 10% in the same years.

3.3. The Netherlands

3.3.1. National organizational context

The Dutch Government has distributed climate and energy policy responsibilities to several institutions which must operate both individually and collectively for the effective and coherent implementation of their measures. All policies relating to the energy sector, including those for the spreading of renewable resources and for support of research, development and demonstration activities, are the responsibility of the Ministry of Economic Affairs. The Ministry of Infrastructure and the Environment is responsible for all environmental and climate issues, as well as those relating to the transport, water and public works sectors. Energy efficiency, on the other hand, is the responsibility of three different ministries according to the areas of application, the Ministry of Economic Affairs deals with the general context, the Ministry of Infrastructure and the Environment of efficiency applied to the transport sector and the Ministry of the Interior and Kingdom Relations of the residential and buildings sector.

Regulatory activities are entrusted to the Consumer and Markets Authority (ACM), an institution established in 2013 that represents the union of three other organizations, the Netherlands Consumer Authority, the Netherlands Competition Authority and the Netherlands Independent Post and Telecommunication Authority. ACM is responsible for overseeing and regulating electricity, gas and heat markets. Again, as in Denmark, the regulator is unique to all public services, so as to ensure a more complete and coherent view of the entire energy system and beyond.

Other institutions that perform support, monitoring and research functions are the Energy Research Centre of the Netherlands (ECN), the Environmental Assessment Agency (PBL) and the Netherlands Enterprise Agency.

3.3.2. Overview of the energy sector in the Netherlands

The Netherlands is strategically located as it is an important transition hub for several energy carriers, such as gas, coal, oil and electricity. It is therefore necessary to be able to have a high level of cooperation with neighbouring states in order to ensure the full efficiency of the sector. In addition, it is particularly suitable, due to its geographical conditions, for the location of energy-intensive industries (coastal localization allows access to ports and to a large amount of water, while the connection with the surrounding states allow access to infrastructure with high transport capacity), in fact in the Netherlands the industrial sector is the first for energy consumption (corresponding in 2017 to 24% of total consumption).

The TPES in the Netherlands for 2017 was 74.2 Mtoe and the TFC was 58.8 Mtoe. Both have fallen by about 7% compared to their respective 2005 levels, which is an important signal for the independence of economic growth from energy exploitation. The incidence of fossil fuels for both indicators is still very high, in fact they still count for 91.5% of the total supply and for about 78% considering the total consumption. The quotas for renewable resources are still very low, corresponding to less than 7% in TPES and 2.3% in TFC. Considering Dutch production, in 2017 this was 41.8 Mtoe, of which 80% related to natural gas production as there are important gas fields on both onshore and offshore Dutch territory.

The Dutch energy policies are mostly based on European directives and almost all have as ultimate goal the reduction of GHG emissions, so as to achieve a zero emissions economy by 2050. The main Dutch policies are:

- The National Energy Agreement for Sustainable Growth, adopted in 2013, aims to ensure a balance between environmental sustainability and the competitiveness of the economy by providing an overview of measures and initiatives to be implemented by 2023. It is based on ten key dimensions, such as energy efficiency, the spread of renewable energy, the increase in capacity, the support of local generation, the dismission of coal-fired power plants and the implementation of Carbon Capture and Storage (CCS) solutions. The main commitment of the plan is to drive financings in order to reach a level of investment between 13 and 18 billion euros in the period 2016/2020.
- Energy Report and Energy Agenda which consist of documents drawn up every 4 years by the Dutch government to set the main long-term energy and climate initiatives (2050) both in terms of objectives and in terms of implementation.

3.3.3. Overview of 2020 targets and of prospects

The Dutch government pays close attention to reducing greenhouse gas emissions, placing it as the primary objective of the country's internal energy policy. This is due to the fact that the sharp reduction in GHG emissions is the most cost-effective and sustainable way to contain climate change below the threshold imposed by the Paris Agreement. The Netherlands has been very committed to reducing emissions in the sectors of the Effort Sharing Decision (ESD), in fact, compared with a reduction target of 16%, the Netherlands achieved a reduction of almost 21% in 2017 compared to 1990 values.

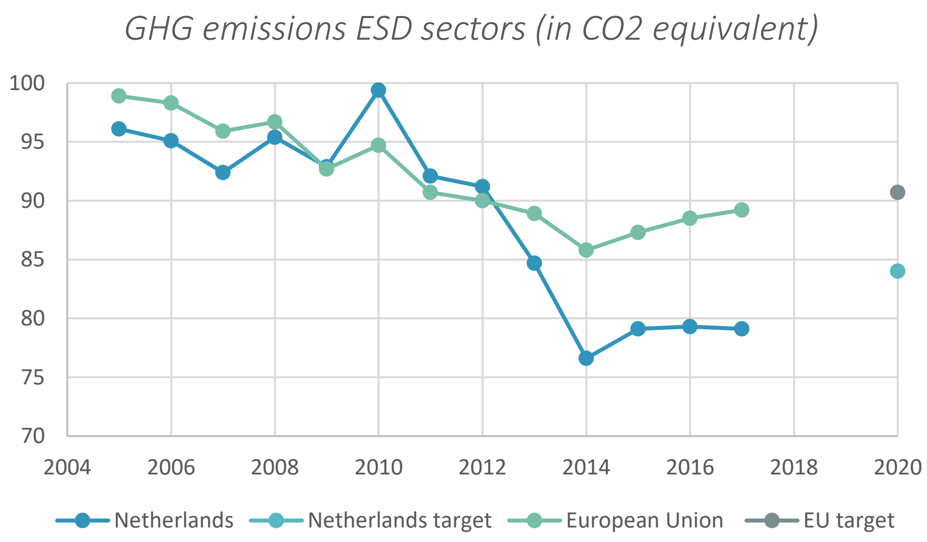

Figure 15: GHG emission in ESD sectors of the Netherlands from 2005 to 2017

From the graph it is possible to see that between 2012 and 2014 there was a sharp reduction that brought the values of the Netherlands well below those established at European level. With regard to the total emissions target, the Netherlands is still a long way from the target of 23% of reduction compared to 1990 values to be reached by 2020. In fact, in 2017 the total emissions had fallen by about 10%. The target is closely linked to the energy sector, which is the country's largest source of emissions with a share of more than 60% compared to the total (considering all energy sources and the transport sector). The government needs to reduce emissions through energy-saving policies and renewable resource integration ones. However, this process is subject to a lot of uncertainty due to both controllable and exogenous variables, such as climate and foreign policies. These are the reason why the total target is not likely to be reached by 2020. To continue its commitment to GHG reductions, the Dutch government published the Energy Report in 2016 representing the long-term vision and in this there are also focuses on CO2 capture, storage and reuse systems. The Netherlands, therefore, in addition to focusing on technologies aimed at reducing CO2 creation, wants to implement and integrate technologies that act downstream of the CO2 creation process, collecting emissions from industrial activities and storing or reusing them (CCS and CCU).

The use of renewable sources within the energy mix reduces the share of fossil fuels and thus reduces GHG emissions. Despite this, the share of renewable resources in the Netherlands is still very low. The 2010 National Climate Action Plan set a target of 14% renewables compared to gross final energy consumption, subsequently improved to 16%. The share in 2017 was only 6.6% of the total. However, the achievable share for 2020 is expected to be 12.4% and in 2023 16.7%, as the growth rate of renewable resources is expected to increase despite this not being very high in past years.

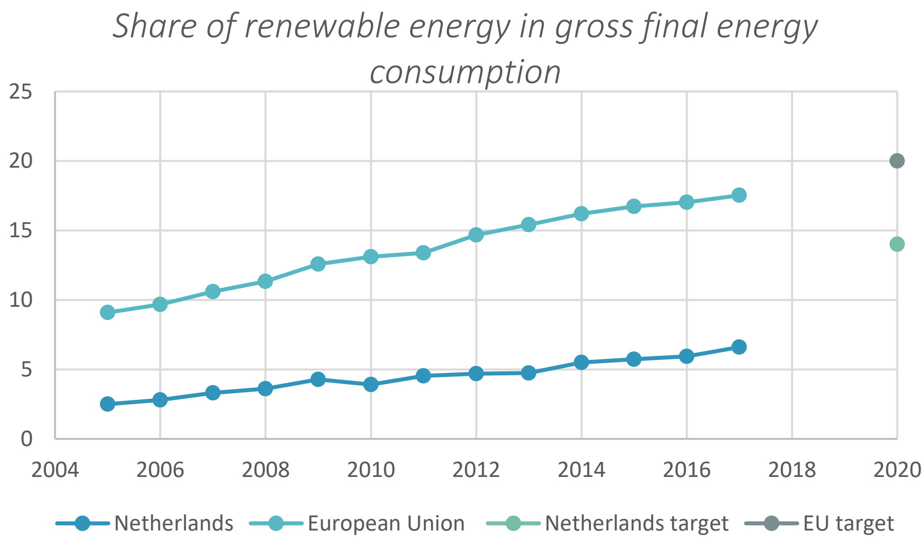

Figure 16:RES share in Dutch gross finale energy consumption from 2005 to 2017

Wind power is growing at a lower rate than planned also due to public opposition to the installation of turbines in onshore parks, while solar energy has been subject to higher growth than in the initial projections. Further efforts will be made to develop the capacity of offshore wind farms, especially for electricity generation, and for better exploitation of geothermal energy and biomass, for heating production.

The energy saving rate that the Netherlands has planned to achieve for 2013/2020 is 1.7% per annum. This can be realized thanks to the policies developed in the Energy Agreement of 2013 and the strengthening of the same imposed by the Dutch government. It should be noted that the efficiency rate also depends very much on extremely volatile market conditions, which is why the expected degree is not insured. In general, considering the targets set in terms of Primary and Final energy consumption, the Netherlands is in line with the projections made for 2020.

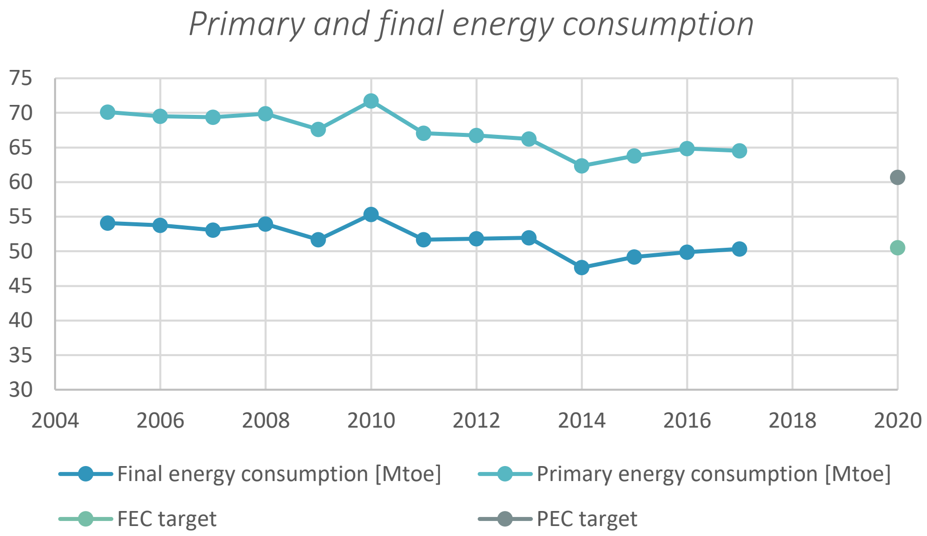

Figure 17:Dutch primary and final energy consumption from 2005 to 2017

The Dutch government offers multiple tax incentives for companies and citizens who take energy efficiency measures through various financing programs or exemption policies (Voluntary Agreements, Energy Investment Allowance, Green Funds Scheme and others). In all the programs, the total funding for energy efficiency is around EUR 250 million.

3.3.4. Dutch electricity and gas market

Electricity market

The Dutch electricity market has been legally liberalized since the 1990s, but it was not until the early 2000s that the first consequences of European and government directives were observed. In 2002, the industrial market was liberalized and in 2004 the residential one. Since 2007, a ban has been introduced for network operators to be part of a production or supply group. The government has therefore decided to privatize production and supply and to keep network activities under direct control of the state. The privatization of the electricity generation sector has led to a consolidation of electricity and a moderately concentrated market. The main players in the electricity market are:

- Electricity producers, four of whom are dominant in the rest of the market, owning a large part of the country's generating capacity (in 2013 the share held was 55%).
- TenneT is the sole operator of the transmission network and is owned and controlled by the national government, in particular by the Ministry of Finance. Again, the TSO is regulated by the national authority ACM which is responsible for overseeing and regulating TenneT's activities, but some responsibilities are in the hands of the Ministry of Economic Affairs (e.g. final approval of the structuring terms of access to the network and the final investment decision).
- There are 7 distribution operators, they are mostly owned by public and local institutions and operate through concession agreements.
- Electricity suppliers, whose market is highly concentrated as the three main suppliers account[38] for more than 80% of the total market. Despite this, the rate of consumers who have changed their supplier has been quite high since 2004 (it is estimated that about 65% of users changed their contract or supplier from 2004 to 2012).

In the analysis of the electricity market, it should be considered that the Netherlands is strongly interconnected with adjacent states (especially Belgium, Germany and France) both at market and network level. The integration of different international markets leads to increased competition in the market and lower prices. In addition to the so-called countries belonging to the central and western European area, the Dutch government is also focusing on integration with the British and Nordic markets (through interconnection with Norway).

Gas market

Natural gas is one of the primary energy sources for the Netherlands, especially because the territory is rich of gas fields. In 2016, gas accounted for more than 40% of total energy supply, but this share is set to decline more and more. In the Netherlands the gas network is divided into two distinct sections because the gas injected inside is of two different qualities, one is the so-called Low-calorific and the other is the High-calorific. These gases are generally used for different purposes, the former is mostly used for residential and commercial functions, while the second is more widely used in the industrial sector

[38] https://www.statista.com/

or for exports. The Netherlands has always been a net exporter of natural gas, but with the policies of recent years it is preparing for a transition, as, with the decrease in extraction and the closure of some fields, soon the country will become an importer of this resource. The main cause of this transition is the decision to phase out the Groningen field. This choice was dictated by safety problems arising from the intensive extraction activity carried out since the 1960s in that area that led to the occurrence of frequent earthquakes. The final closure of the activities was planned for 2030, but in the short term several strategies have been developed to minimize production and allow for a smooth transition for both Dutch and EU-dependent nations from exports of this site. The peculiarity of this field is the production of low-calorific gas, extracted only at this site. This situation is related to some important issues that need to be solved before the close of the site. Several measures have been taken in this regard, such as:

- The construction of additional nitrogen plants that can be used for the conversion of high-calorific gas into Low-calorific, so that it is possible to continue to enter L-gas even without intensive extraction activity at the Groningen site.
- The conversion of industrial plants using L-gas to another energy source (electricity, H-gas, renewables).
- Decrease in L-gas exports and agreements with importing nations.
- Progressive elimination of the use of natural gas in residential and horticulture sectors, for example by prohibiting the connection to the gas network for newly constructed buildings.

Despite the gradual decline in production, gas and its infrastructure still play a key role and can be used in the future for the integration of renewable variable energy. The Dutch government plans to increase the injection of synthetic gas and biogas into the existing network, as well as the use of P2G storage systems.

The market structure of the gas sector is rather complex and composite, below are the main roles and the most important companies:

- NAM (Nederlandse Aardolie Maatschappij) is the largest Dutch producer, 50% owned by Royal Dutch Shell and Exxon Mobil. It produces gas from the Groningen field (which accounts for about two-thirds of production) and about half of the other smaller fields. The Groningen site is also controlled by EBN

(Energie Beheer Nederland) a Dutch exploration, production, storage and trade company owned by the Ministry of Economic Affairs. The production market is completely liberalized and so there are also other smaller producers operating in the market. They can sell their gas directly or sell it to GasTerra.

- GasTerra is one of the wholesale gases companies. It is 50% owned by the state (through 40% through EBN and 10% with direct shares), 25% by Exxon Mobile and the remains of Royal Dutch Shell.
- Gasunie Transport Services B.V. (GTS) is the only operator of the transmission network. It is owned by Gasunie which also operates storage sites, the interconnection network with the UK and the LNG terminal in Rotterdam. It is fully owned by the Dutch state through the Ministry of Finance and is controlled and regulated by the ACM.
- There is a total of 8 DSOs which manage the low-pressure distribution network and are owned by local public authorities.
- The supply market to end customers is totally liberalized and is dominated by 3 large companies (Eneco, RWE-Essent and Vattenfall-Nuon). Users are free to choose their own supplier.

There are also unbundling guidelines for this sector, because network operators cannot be part of a vertically integrated company that also carries out the supply and production activities. Both the TSO and the DSOs operate under monopoly conditions and are regulated by the ACM. However, the latter does not have all the responsibilities, as some of the investments must be approved in advance by the Ministry of Economic Affairs. The state in this case occupies both a regulatory and owner position creating possible conflicts of interest.

TSOs' and DSOs' regulatory mechanism

The tariff regulations applied to different network companies, both in the electricity and gas sectors, are based on the same methodology and assumptions. For this reason, a description of the individual methodology is not carried out, but a general description of the price structure applied to all companies (TSO and DSO) will be included.

Since 2002, the Dutch regulator has been applying an incentive-based pricing scheme, particularly in the form of either revenue or price cap. The ACM at the beginning of the regulatory period (which can last 3 or 5 years) defines the pricing method for GTS, TenneT and DSOs. Decisions regarding productivity factors and RAB are then published, with the addition of a quality of service factor for only DSOs of the electricity network (q-factor). In addition to the decisions taken at the beginning of the period, ACM can make annual changes and adjustments to the tariffs.

The duration of the regulatory period is decided by ACM based on the incentives it wants to give to the companies. The current period began in 2017 and will end in 2021, with a total duration of 5 years. By choosing the longest duration possible, the regulator wants to allow operators to earn more money from their efficiency initiatives, encouraging more investment in cost-cutting. Longer durations allow regulated companies and users to have greater security and stability.

The pricing mechanism is a revenue/price cap based on both operating and capital costs. The regulator enforces a TOTEX system, calculating the allowed revenue against the sum of OPEX and CAPEX and does not consider them separately. The productivity factor is applied to them, which is used to incentivize operators to reduce their costs. Applying the TOTEX method leaves the decision of what is the optimal ratio between OPEX and CAPEX to companies. Operating and capital costs are determined on the basis of data provided by network companies, and the latter also include return on investment and depreciation.

The permitted revenues are defined at the beginning of the regulatory period (ex-ante regulation) based on different parameters, such as the costs incurred in previous years, the level of inflation and some measures of static and dynamic efficiency. Using these factors, the ACM estimates future cost trends and determines the level of revenue at the end of the period. The productivity factor, which takes into account the different efficiency measures, represents the decrease in the annual costs that the regulator wants to impose on companies. In order to determine static efficiency factors, ACM makes comparisons between companies. In particular, cost-benchmarking is carried out for TSOs compared to European transmission operators (setting the efficiency level equal to the average of the three best) while for DSOs the yardstick competition between national operators is used. With regard to dynamic efficiency measures, the ACM sets productivity boundaries taking into account the overall technological progress of the entire sector and economic trends for TSOs. While for DSOs these measures are calculated as the average differences in the ratio of costs to output. Both of these measures are subsequently adjusted through comparison mechanisms. In addition to the factors listed, the ACM adds a quality factor to the power grid DSOs, so that they are incentivized to maintain an optimal level of service. The q-factor, added to the productivity one, can be positive or negative by allowing extra revenue or removing part of them, based on the service offered by the DSO.

The ACM scheme allows operators to recover costs incurred and earn an appropriate return on their investments. The return is the same for all investments as the regulation applied is neutral with respect to investment technology (the choice on how and what to invest is not driven by the regulator but is left to individual companies). The return on investment is based on the WACC method, taking into account both the cost of debt and equity. The regulator wants to ensure a return similar to what the companies would have in a competitive market. For this is calculated a WACC (real, pre-tax) considering a group of reference companies, valid for all the network operators. The calculated WACC in 2016 was equal to 4.3%. With regard to investments for network expansion, the WACC is reduced as it is not necessary to take into account the embedded debt and therefore it was equal to 3.6% in 2016. Most investments are approved ex-post by the regulator, so operators must first bear the costs and only at the investment concluded can recover the expenses and an appropriate return. Only a few extraordinary or large investments are approved ex-ante ensuring less risk for operators. For example, some of the nationally important investments that must be supported by transmission operators must be approved by the government and can then be included directly in the calculation of the pricing method. Investments related to network expansion, on the other hand, are included in the RAB after an ex post assessment where it verifies its efficiency, utility and need.

Finally, we report a summary table of the main value used for the calculation of the tariffs of grid operators. The values referrer to mainly to 2016.

Table 13: Summary table of the main value applied to regulated companies by ACM

	Electricity TSO	**Gas TSO**	**Electricity DSOs**	**Gas DSOs**
Regulatory system	Revenue Cap	Revenue cap	Price cap	Price cap
Efficiency requirement for CAPEX	Yes			
X-factor on OPEX	Efficiency requirements is applied on TOTEX			
Risk free rates	Dutch and German government bonds			
Debt premium	1.08% for 2016 and 0.96% for 2021. ACM uses the average of the debt premium over a period of ten years that was demanded on bonds of European utility companies with a single A-rating.			
Market risk premium	5.05% for 2016. ACM uses the average of the geometric and the arithmetic mean of the Eurozone level of market risk during the period 1900- 2015.			
Capital gearing	50%			
Equity Beta	0.74			

The pricing mechanism imposed by the ACM on network operators offers strong incentives to reduce costs and to increase efficiency, due to the ex post inclusion of the costs incurred for investments and, at the same time, offers a low remuneration of the latter. Because of the regulatory method, the risk that operators have to bear is quite high, which leads to a low level of incentive for investment compared to other European nations.

3.3.5. Main conditions for district heating, CHP plants and storage systems

The heat market is often less considered than gas and electricity, but despite this it can bring non-secondary benefits in the transition of the energy system. In the Netherlands, the main heating resource for domestic and commercial users is natural gas, that as explained in the previous paragraphs will have to be replaced. In fact, new buildings cannot be connected to the gas grid at present, but they have to use other heating resources, such as district heating, heat pumps or other solutions under development.

Implementation of this measure is quite difficult due to the high costs of alternative resources compared to natural gas.

Heat in the Netherlands can be recovered from industrial processes, geothermal energy or biofuels. This market offers multiple possibilities for integration between sectors, not only within the energy system but also externally. One of the most relevant possibilities for the Dutch state is to make more use of the residual heat from industrial processes (even considering the high number of energy-intensive industries in the territory), either incentivizing the capture of heat by the company itself and transferring it to the surrounding residential buildings via the heating network. The exploitation of residual heat in the Netherlands is not yet at an optimal level, especially due to the limited public network. The share of DH within the Dutch heating sector is extremely low due to the full spread of natural gas, which has resulted in limited development of heat transport infrastructure. Another possibility is to take advantage of geothermal heat pumps that obtain heat from the Earth's subsurface and then transfer it to utilities.

In addition to these solutions, CHP plants are often used on the Dutch territory even though they mostly work via natural gas. Due to the progressive decrease in gas use, many of the cogeneration plants will be decommissioned and will need to be replaced by new, more efficient and renewable resources-fuelled systems (such as biofuels). Cogeneration has always been supported by the Dutch government through investment premiums and tax exemptions, but since 2011 only plants that are more efficient than average and use renewable resources can benefit from support. Due to the lack of specific aid, CHP systems and their generative capacity are expected to decrease. This type of plant in the Netherlands is regarded as a mature technology as it has been widely used for the production of electricity via natural gas, but the current regulatory environment is ineffective in incentivizing operators to a development towards a most sustainable and greener sector. In addition, the proposed energy efficiency targets to be achieved by 2020 mostly relate to final energy consumption, which does not allow the energy savings resulting from the use of cogeneration plants to be taken into account. In addition to the context of national regulatory policies, companies also have no incentive to invest in cogeneration plants, as investments related to the core business are preferred. All these reasons are very strong barriers to the development of new CHP plants. These would allow to efficiently replace old ones that have been built for operation with the base load and are not able to modify their production. The old plants therefore cannot be used, such as new ones, either to change the production of electricity and heat according to demand or for the integration of variable resources within the energy sector. The Dutch Government needs to resolve at least some of these problems in order to be able to convert the situation and to encourage the development of new plants.

The implementation of new plants can lead to the integration of thermal storage technologies that can make the energy system even more flexible. Others to so-called power to heat systems, the Netherlands has some positive features for the introduction of technologies such as compressed air storage systems. These plants need special sites for their installation as abandoned gas reserves or salt caves, sites that can easily be found on the Dutch territory. This technology is therefore considered by the government to be a possibility for energy storage, but due to the high costs and current efficiency levels it is valued for a not too close future (at least 2030).

3.3.6. Green and blue hydrogen market

The role of hydrogen in the transition to a zero-emission economy is becoming increasingly apparent, especially for the northern region of the Netherlands. In this region there is a common commitment between the government and companies to the development of an entire economic sector based on zero-emission hydrogen. Zero-emission hydrogen refers to green hydrogen, produced by converting wind or biomass energy via electrolysis, and blue hydrogen, which identifies hydrogen produced through the combination of natural gas and CO2, previously captured and stored. In particular, local companies and institutions have established an investment agenda for the development of the entire system, including production, infrastructure and marketing.

The northern Dutch region is particularly well-suited to developing this new hydrogen-based system for several reasons:

- It is a region that has suffered greatly from the intensive exploitation of local resources, in fact in recent years it has been subject to numerous earthquakes due to gas extraction activities. It is, therefore, a region particularly inclined to commit itself to achieving a fully sustainable economy.

- The natural gas industry is mostly located in this region, which would allow the use of existing infrastructure by converting them and making them suitable for hydrogen.
- The presence of salt caves allows to store hydrogen, saving the construction of special storage sites.
- It is a region that is home to many companies, especially those in the chemical, electrical and logistics sectors. This type of industry makes it possible to take the higher advantage of hydrogen and of all the by-products resulting from its processes.
- There are already several sites and laboratories for research and development that can then also develop hydrogen technologies and applications.
- The presence of ports can provide an additional method of transport for the hydrogen produced or to import it from other nations without the necessity of introduce too much additional infrastructure.
- Eemshaven is a hub for the country's electricity grid, in fact there are several power plants, interconnection networks with offshore wind farms. It is also well connected to the rest of the nation by the high voltage transmission network. The proximity of these infrastructures to those related to hydrogen makes it possible to fully exploit the energy produced through wind farms and to produce electricity from hydrogen if necessary.

All these conditions make the northern region the ideal site for developing a hydrogen-based economy, which is why several projects subsidized by companies, the government and the European funds are in place to create the entire value chain. The New Energy Coalition (NEC) has also been created between local companies and institutions, which allows cooperation and coordination between them. The New Energy Coalition was established on 1st January 2018 after the merger of three other institutions, namely Energy Valley, Energy Academy Europe and Energy Delta Institute. The main purpose of the NEC is supporting the development of a future sustainable energy system. NEC activities focus on innovation, mainly through R&D projects and business development, and on education, via the New Energy Coalition business school and other initiatives. NEC investigates five principle themes, i.e. North Sea Energy, Hydrogen, Greening of the gas system, Industrial transformation and Local energy system. Even if the New Energy

Coalition has been in place for less than 2 years, it already participated in many projects and activities to pursue its goals.

One of the main projects is HEAVENN (H2 Energy Applications in Valley Environments for Northern Netherlands) led by a part of the New Energy Coalition. This project won European funding from the European Commission against many others who applied. The commission, through the Fuel Cells and Hydrogen Joint Undertaking (FCH JU, part of the Horizon 2020 program), has allocated a budget of € 20 million to subsidize HEAVENN. In addition to these, local public authorities and private companies have allocated a budget of 70 million euros for the project.

Moreover, the companies and governments of the Northern Netherlands region presented in early 2019 the first investment plan to turn the region in a "hydrogen valley" (Investment agenda hydrogen Northern Netherlands). The plan includes projects and initiatives for 2.8 billion euros. The program includes large-scale production facilities, storage, transport and distribution infrastructure, as well as the implementation of innovative applications in the industrial, residential and mobility sectors. The plan includes 33 concrete projects, conducted by private company, such as Shell, or by public operators, as Gasunie (a scheme of projects started or planned in shown in appendix 2). All projects will lead this region to a leadership position in this area and will be an inspiration to the rest of Europe's regions. However, the implementation of this project depends not only on public and European investment but also on the measures put in place by the central government to support its success. In particular, the coalition responsible for the development of the project called for the adoption of several tools, such as:

- The inclusion of hydrogen production in the SDE+ scheme, which provides subsidies for renewable energy production. This makes it possible for companies to increase the scale of hydrogen production without incurring in too high costs. At this stage, government support is needed to meet the operational costs of production and distribution.
- The consideration of the entire value chain in the granting of aid, and not individual parts of it.
- The clarification of the different functions of hydrogen, so as to have clear and unambiguous certifications.

- The introduction of mechanisms to stimulate the demand for hydrogen, for example by stimulating different applications through incentives and tax benefits.

The Dutch government has to develop a regulatory framework suitable for full implementation of ambitious projects. At present, Dutch energy policies are not entirely in favour of hydrogen, as this has only been included through hints in some amendments made in recent years. However, it should be pointed out that some steps have been taken in the right direction, such as the introduction of P2G technologies in the regulatory context for the construction and operation of offshore wind farms, the adoption of a motion to eliminate the double tax on electricity consumption (taxes on electricity consumption were previously paid by both the storage operator and consumers, increasing the price of energy and making storage technologies more expensive). In addition to these, some of the energy measures adopted by the Dutch Government (such as the prohibition on the connection of new buildings to the gas grid) can indirectly benefit storage systems as well, and therefore also for those related to hydrogen.

3.3.7. Energy system integration in Netherlands

The Dutch government is leading investment in innovation through the Top Sector program (explained in more detail in paragraph 4.3.9). In particular, the energy program focuses on several main issues, including the integration of energy systems. This is also considered a key issue by the Dutch Government in achieving a flexible energy system based mostly on renewable resources. The Dutch Research Council (NWO) in collaboration with the Top Sector Energy programme has organised several rounds of investments in systems integration projects. At the beginning of 2018, the NWO allocated EUR 3.85 million to finance six projects in the "Energy system Integration & Big Data" category. For the third call to the investment program (April 2019), the NWO has allocated a total of 4.9 million euros. Subsequently, some of the projects, financed within the Top Sector Energy program in recent years, have been reported. The projects described are selected from those on the projecten.topsectorenergie.nl website which are listed in the section on the integration of energy systems. It was decided to select the projects completed after 2017 and with a grant share of more than 200,000 euros. It should be noted that the names of the projects and their information have been translated from

Dutch, which leads to some uncertainties in the transposition (See Table 14 for project details).

In addition to the top sector projects, there are also other organisations working to implement an integrated energy system for the future Dutch energy sector. To provide some examples of this, we present a selection of projects for which appropriate information could be found:

- "Integrated Energy System Analysis" is a project monitored by the New Energy Coalition and conducted by University of Groningen, TNO[39], Gasunie and other partners of NEC. It runs for a period of 4 years, from 2018 to 2022, and it aims to provide a deep analysis of the linkages and the interaction between the energy sectors. This will help to understand the suitable models for the future integrated energy system. The total project costs will be € 1.83 million, 73% of which is provided by national funding.
- SIDE (Smart Integrated Decentralised Energy Systems) is a study commissioned by the Dutch Ministry of Economic Affairs and the Netherlands Enterprise Agency. The objective is monitoring 4 microgrid projects to evaluate all the societal and economic aspects. A SIDE network is composed by a set of integrated components (like solar panel, heat pumps, electric vehicle and a local management system), which allow local communities to self-manage supply and demand. In the study, the author analysed the potential impact of diverse technologies on the 4 base cases, utilizing both real data and design criteria to create 9 different scenarios. The examined scenarios describe a favourable situation for the SIDE approach, with the emerge of several best practises for the future. The author of the study found out that the SIDE model is cheaper in the long run compared to the conventional energy system. Indeed, according to projections, a SIDE system has a payback time equal to 8.5 years while a conventional gas-based system of 11.6 years. The implementation of SIDE systems among Dutch cities could significantly help the Netherlands in the achievement of a sustainable energy system. The SIDE study received approximately 46 thousand euros through state subsidies.

[39] The Netherlands Organisation for Applied Scientific Research

Table 14: Top Sector Energy projects related to energy system integration

Project	**Period**	**Subsidy**	**Description**
Serially switched storage of wind energy with imbalance control	2016/2019	€ 752.598,00	The main objective is the demonstration of a 1 MW lithium-ion battery connected to the wind farm of Giessenwind. The battery has a function of balancing the energy networks.
Flexible energy infrastructure through cost effective and efficient PEM electrolysis and Sorption	2015/2017	€ 500.000,00	The project result was a new model for the implementation of a flexible P2G technology. The project included a complete platform for the electrolyses process and a market analysis for the integration of P2G in the energy system.
Evaluating lifetime of electrolysers managing fluctuating supply of renewable energy	2016/2018	€ 446.441,00	The project aimed at evaluating the different factors and processes that speed up the decline in performance for the electrolyses plants.
FlexNode	2016/2018	€ 368.833,00	The aim of the project is to investigate the potential of reversible fuel cells. These can be decentralized and integrated into the existing energy infrastructure to increase the flexibility.
Supply and demand for flexibility in a sustainable, integrated energy system in the Netherlands	2015/2017	€ 260.723,00	The project aimed at investigating the demand and supply of flexibility in the Dutch power sector toward 2050. The team examined both the reasons under the need of flexibility and the possible solutions.
FlexiGrow	2015/2018	€ 242.122,00	The purpose was the demonstration of how Micro-CHP and residential heat pumps could be exploited in neighbourhoods integrated energy systems.
FlexiForFuture	2015/2018	€ 231.100,00	The aim of the project was to develop a conceptual framework that allows for the linking and quantification of various forms of flexibility. A model of services has been developed which allows to obtain energy flexibility in an effective and economic way.

3.3.8. Dutch RES support

Renewable resources, including in the Netherlands, are supported through various subsidy or tax-free mechanisms for both the electricity and heating sectors. In particular, the main[40] support schemes are:

- SDE+ scheme: it is a mechanism that guarantees a premium in addition to the market price for producers of renewable electricity for up to 15 years. The premium varies and depends on the market price of electricity and certain correction factors. All renewable resources can receive this type of subsidy even if the value differs for each technology. The scheme supports renewable energy producers using a "first come, first serve" method, and since the total budget is predefined it is not said that everyone who can receive the subsidies actually benefits. The scheme for 2018 was divided into two stage, in fact it was possible to carry out the application procedure both in March and October, allowing the financing of more plants. The total budget for the 2018 autumn period was 6 billion euros fully supported by the state.
- Tax-exempt mechanisms: these are tools that allow certain individuals to benefit from tax incentives. For example, renewable electricity producers may be exempted from power taxes if they use the electricity, they produce themselves (self-consumption clause). Another type of exemption is that of companies that invest in renewable resources, some of which can be deducted from taxes. Only solar panels and biomass are still covered by this type of exemption.
- Loans: It is a tax incentive mechanism aimed at encouraging citizens to invest in green energy. It consists in the possibility for banks to offer a lower interest rate to customers who invest in projects aimed at improving environmental conditions. In practice, support consists of a 1% reduction in the interest rate for projects with a minimum cost of € 25,000. The costs of this measure are supported by the state through lower tax revenue.

[40] The systems listed refer to the electricity sector but are roughly the same for the heating sector

With regard to the electricity grid, the Netherlands has adopted a non-discrimination system, which is why renewable resources do not enjoy any kind of priority either for the physical connection or for the use of the grid.

For the Netherlands, too, there are data on the total renewable energy that has received support and its average level. The data refer to the two-year period 2016-2017.

Table 15: Dutch data for the energy supported by national schemes and average levels of support

	Year	Bioenergy	Geothermal	Solar	Wind-Onshore	Wind-Offshore	Total
Total renewable electricity produced that received support in MWh	2016	5.905.000	790.000	287.000	3.575.000	2.200.000	12.757.000
	2017	5.633.000	196.000	487.000	3.805.000	3.386.000	13.507.000
Weighted average support level by technology in €/MWh	2016	22,29	-10,93	68,51	26,09	107,1	36,96
	2017	18,64	-11,18	63,92	15,16	66,15	30,77

In both years the largest share of energy that has received some kind of support is bioenergy, in fact it counts for more than 40%. The other significant share is onshore and offshore wind, which in 2016 accounted together for more than 45% of the total, while in 2017 it was more than 53%. Its average support levels remained largely unchanged, except for offshore wind, which fell by almost 40%.

3.3.9. Research, development and demonstration projects in the Netherlands

All decisions relating to RD&D's energy policies are the responsibility of the Ministry of Economic Affairs. This, together with other institutions, is responsible for guiding the choice of the necessary projects and the implementation of funding programs. Research institutions include the Netherlands Enterprise Agency (RVO), the National Organization for Scientific Research (NWO) and the Technology Foundation (STW). In addition to these, the Netherlands has a dedicated research centre (the Energy Research Centre of the Netherlands, ECN) that is responsible for researching some of the key subjects for the development of a sustainable energy system and which also collaborates with international partners as well as with Dutch public institutions.

Since 2011, Dutch RD&D policies have been reformulated in a "Top sectors" approach, whereby the government has selected 9 priority economic areas on which to act in a targeted manner. These sectors were chosen on the basis of several characteristics, including the possible contribution to environmental sustainability, participation in the country's GDP and the achievable competitive advantage. The energy sector has been selected to be part of this program as it is fundamental to the country's continued development. This program is the main driver for industry innovations focusing not only on environmental sustainability but also on economic goals. In addition to the main program team, consortia have been set up to deal with RD&D strategies in some specific areas to provide dedicated support. The approach includes long-term investment plans, in fact it lasts between 2011 and 2025.

For completeness, public funding data for RD&D projects carried out between 2010 and 2018 are shown. The 2018 figures represent only estimates and not actual data.

Table 16:Public RD&D budget distributed from 2010 to 2018 in Dutch energy sectors

Indicators in M€, 2018 prices	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Energy efficiency	156,23	51,36	50,11	53,37	38,92	45,56	68,79	50,90	65,92
Fossil fuels	33,79	9,89	14,40	12,95	3,85	17,28	4,80	11,41	21,21
Renewables	149,55	57,55	97,49	93,89	66,80	110,10	65,66	62,37	96,69
Nuclear	19,38	14,62	11,02	8,52	8,52	7,42	6,51	6,39	6,49
Hydrogen and fuel cells	4,80	0,00	0,00	1,57	0,03	0,79	0,30	3,39	11,47
Power and storage tech.	4,06	18,65	20,11	16,33	19,23	11,55	6,41	14,79	13,13
Cross-cutting tech. /research	10,60	10,42	16,31	8,04	22,75	4,65	2,61	4,10	8,48
Total Budget	378,41	162,50	209,43	194,68	160,09	197,34	155,21	153,99	225,32

In total, the Netherlands has invested approximately € 1.8 billion over the years under consideration, with a peak reached in 2010, when 21% of the total sum was invested. From the data it can be seen that the Dutch priorities were renewable resource projects, which received 44% of the total funds, and in second place those related to energy savings, with a share of 32%. A minority share was attributed to energy storage and hydrogen projects, which together contributed only 8% to the total.

As done for the previous paragraphs, a graph is reported representing the quotas for different technologies on the total investment.

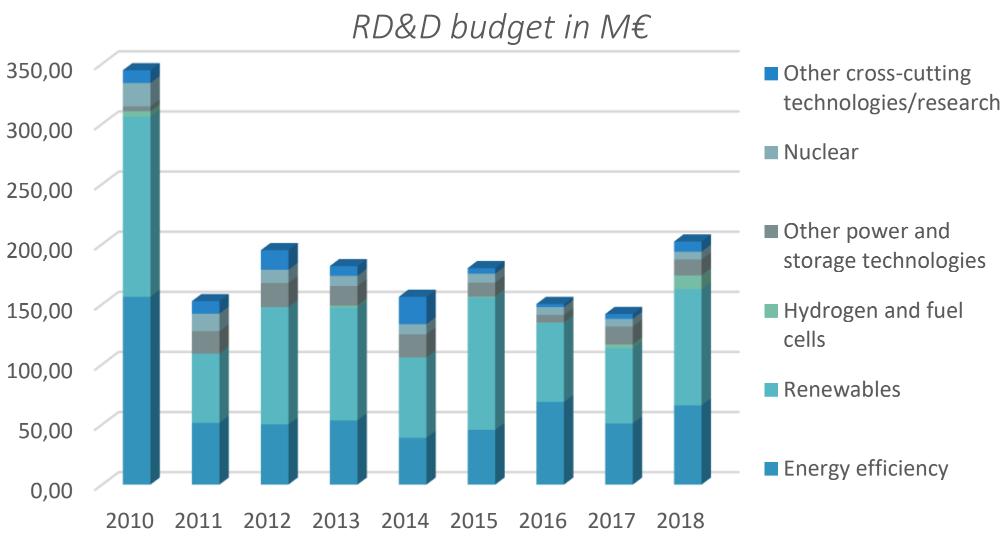

Figure 18: Distribution of RD&D budget to the main technologies

Conclusion

The different investment conditions in Belgium, Denmark and the Netherlands were presented in this work. As far as possible, an attempt has been made to give a vision to analyse how these contexts favour investment in innovation and in integration of energy systems. From the information provided, some conclusions can now be drawn, and a general comparison of the states analysed can be made.

After presenting the different pricing methods imposed by national regulators to network companies, it can be seen that no regulator applies incentive mechanisms to encourage investments in innovation. In fact, in none of the countries considered it was possible to identify a particular incentive method, such as premiums on the WACC or increases in the revenue allowed in the case of certain investments. Some incentive mechanisms were found, such as those on the quality of service imposed on Danish DSOs or some incentives allowed to the Belgian TSO, but in no way, they were related to investments in innovative technologies or ESI. It is, therefore, possible that in order to further encourage this type of investment, governments and regulators in these countries will introduce incentive mechanisms within the pricing structures in the future.

Despite this situation, an attempt was also made to analyse a broader policy environment, to examine all possible elements on which a government can act to support energy innovation. To do this, information was sought on national energy policies to understand how investments in innovation and integration between energy systems were taken into account. In addition, an attempt was made to examine the government's commitment to invest directly or indirectly in such projects. In particular, it was found that the Danish Government, through its financing programs, invests in multiple projects concerning both energy system integration and related technologies. To give an evidence of this, we report a, not exhaustive, list of projects financed directly through the national programs (EUDP, Innovation Fund and ForskEL). Investments made by companies and by the Danish government are driven both by environmental reasons and by the fact that Denmark has made the smart energy sector one of its core markets, both within the country and in terms of exports. Searches for the other two countries were not as significant. For the Netherlands, it was only possible to report some evidence of investments in the integration of energy systems. Despite this, the Dutch commitment to these issues is not negligible, demonstrated both by the growing budget allocated to ESI projects and by the fact that an entire category of the Top Sector program is dedicated solely to integration between energy systems. For Belgium, however, although much research has been carried out, it has not been possible to report significant information on active ESI-related projects. This lack of data could mean that the Belgian Government is not yet fully exploiting all possible incentive mechanisms. In the future, both regional and federal authorities need to increase their efforts to encourage investment in these issues.

In conclusion, it can be said that only for Denmark there is strong evidence of the favourable regulatory environment. Whereas for the remaining two countries these are scarce or absent. It is not possible to know whether these shortages are due to a real lack of commitment on the part of national governments or incomplete information.

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Appendix 1[41]

Electricity transmission

Pure Incentive methods	Czech Republic, Finland, Greece, Iceland, Luxembourg, Netherlands, Romania, Slovenia, Sweden
Combined model of incentive and cost-based methods	Belgium, Germany, France, Great Britain, Hungary, Ireland, Italy, Lithuania, Norway, Poland, Portugal
Pure cost-based methods	Austria, Estonia, Latvia, Spain

Electricity distribution

Pure Incentive methods	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Poland, Slovenia, Sweden
Combined model of incentive and cost-based methods	Great Britain, Hungary, Italy, Lithuania, Portugal
Pure cost-based methods	Estonia, Greece, Latvia, Spain

Gas transmission

Pure Incentive methods	Belgium, Croatia, Czech Republic, Finland, France, Germany, Lithuania, Luxembourg, Latvia, Netherlands, Romania, Slovenia, Sweden
Combined model of incentive and cost-based methods	Austria, Spain, Great Britain, Hungary. Ireland, Italy, Poland, Portugal
Pure cost-based methods	Estonia, Greece

Gas distribution

Pure Incentive methods	Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Lithuania, Luxembourg, Netherlands, Poland, Romania, Slovenia, Spain, Sweden
Combined model of incentive and cost-based methods	Great Britain, Greece, Hungary, Ireland, Italy, Portugal
Pure cost-based methods	Estonia, Latvia

[41] Source: CEER, Report on Investment Conditions in European Countries, 2017

Appendix 2[42]

PRODUCTION/CONVERSION

Lead company	Plan/Project	Location	Year of completion
1. Equinor/Gasunie	Blue hydrogen produced from an ATR (H2M)	Eemshaven	2025/2026
2. Gasunie/HyStock	1 MW electrolyser	Zuidwending	2018
3. Nouryon/Gasunie	20 MW electrolyser	Delfzijl	2020/2021
4. Engie/Gasunie	100 MW electrolyser	Eemshaven	2022
5. Lagerwey	2-3 MW hydrogen wind turbine	Eemshaven/Delfzijl	2020
6. Lagerwey	4 hydrogen wind turbines	Eemshaven/Delfzijl	2020/2022
7. Emmen partnership	2-5 MW electrolyser	Emmen	2020
8. Nouryon	200 MW electrolyser	Delfzijl	2025
9. Shell & Partners	Blue hydrogen	to be determined (part of larger chain)	after 2024
10. Engie	Scaling up 100MW --> 850MW --> 1GW electrolyser	Eemshaven	2026-2030
11. To be announced shortly	40 MW electrolyser	n.t.b.	2020
12. Nuon/Proton Ventures/ BASF/Yara/Orsted/TU Delft	Battolyser (15 kW testinstallation)	Eemshaven	2019
13. SCW/Gasunie	300 MW Supercritical water gasification	Eemshaven	n.t.b.

INFRASTRUCTURE

Lead company	Plan/Project	Location	Year of completion
14. Gasunie	Pipeline Eemshaven-Delfzijl-Zuidwending-Emmen	Eemshaven-Delfzijl-Emmen	2022/2023
15. GSP	Hydrogen Distribution Network Chemical Park Delfzijl	Delfzijl	2019
16. Gasunie/EnergyStock	Hydrogen cavern	Zuidwending	2023
17. Gasunie/EnergyStock	Hydrogen cavern	Zuidwending	2025/2026
18. Shell, NAM & Partners	CO_2 infrastructure, offloading, shipping and (offshore) storage	to be determined	after 2025
19. NAM & Partners	Small chain: Reusing infrastructure and energy locations to connect renewable energy sources	Emmen and other clusters in the Northern Netherlands	to be determined

USE

Lead company	Plan/Project	Location	Year of completion
20. Emmtec and customers	High temperature proces heat and power from hydrogen	Emmen	2020
21. Public transport Groningen/ Emmen	Hydrogen-electric buses	Groningen/Emmen	2020
22. Nedmag	Conversion of burners and furnaces	Veendam	2023
23. Holthausen/Green Planet/ Pitpoint	8 hydrogen refueling stations	Provinces Groningen, Drenthe, Fryslân	2019-2022
24. Hydrogreenn	Newly build residential area; space heating on hydrogen	Hoogeveen	early 20ies
25. Gemeente Groningen	Street sweepers and garbage trucks on hydrogen	Groningen	2018
26. Shell & Partners	050Buurtwarmte Paddepoel - small-scale district heating	Groningen	to be determined
27. Shell & Partners	Multiple hydrogen refueling stations	Provinces Groningen, Drenthe, Fryslân	to be determined
28. Holthausen	Fuel cell component factory	Hoogezand	2020 up to 2025
29. Nuon	Magnum power plant partially converted to hydrogen use	Eemshaven	2025/2026
30. Holthausen	Conversion of 5000 cars into fuel cell electric cars	Hoogezand	2020 up to 2025
31. BioMCN	Production of biomethanol from CO_2 free hydrogen	Delfzijl	2021
32. Teijin Aramid	Development of enhanced synthetic pipematerial for hydrogen	Emmen	2018
33. ISPT & Partners	HydroHub: Testing and development centre on EnTranCe	Groningen	2019

[42] Source: Investment agenda hydrogen Northern Netherlands, February 2019