

Louvain School of Management

**Definition of the current regulations,
investments and efficiency of TSOs in Europe
to assess the causes and impacts of the
network expansion**

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Introduction

1.1. Wording of the problem

The biggest challenge faced by humanity as a whole is climate change. It is the consequence of decades of highly carbonized energy consumption. We have released billions of tons of CO₂ in the atmosphere in order to promote development, technology, evolution and global welfare. However, we cannot emit countlessly if we wish to live in a habitable world in 10, 20 or 50 years. Therefore, since the early 2000s we have seen the rise of new energy forms. These are supposedly cleaner than the old generation of power plants. Renewable energy exists in many forms; from geothermal to hydroelectric, to solar and wind power. Renewable energy is at the forefront of climate change mitigation. Although some might debate that it is not as environmentally friendly as they appear, these energy sources don't emit CO₂ while in use. Despite this substantial advantage, every solution comes with its drawbacks and renewable energy also has many.

In the past, fossil fuel power plants had an incredible advantage. One plant produced a vast amount of energy at a continuous flow. An average coal fire power plant is extremely efficient and reliable. The issue with renewable energy is that you need hundreds of windmills to replace a coal fire plant, and it will never be as reliable, due to the uneven source of wind. Therefore, next generation plants will be smaller and more decentralized. Furthermore, power plants were located close to consumption nodes and it was relatively inexpensive to connect them to one another due to the short distances between them. Today, with a shift towards green energy production, power plants are located in remote areas, far from demand centers, where resources like sun or wind can be found more consistently. This new generation particularity linked with green energy requires investment in long distance transmission power lines. Other reasons, such as an increase in electricity consumption also led to the expansion of the network.

Electric power transmission is the backbone of our entire electricity system. It carries electricity from power plants to consumption centers across long distances. Today, this transmission is facing a deep reconstruction. Parts of the electric infrastructure need repairment and we are encountering a huge need for new infrastructure expansion. These

development needs are very complex for various reasons that we will explain in this document. The first one is the immense cost associated with the activity of TSOs. High voltage lines are very expensive to build and maintain. As TSOs are monopolies, their revenue stream and their ability to invest in new infrastructure is highly controlled by national regulators, which makes it hard to conduct aggressive network expansion campaigns.

Electric ‘highways’ are supported and built by transmission system operators. They operate mostly inside a national context and are responsible for the maintenance and expansion of their transmission network. Even though energy is a question of national sovereignty, the challenges often transcend borders because countries have trade agreements and it’s often economically more efficient to balance energy flow across countries. All national networks being linked to one another, energy transmission becomes a question of supranational coordination. As Europe has more TSOs than countries, it makes coordination very difficult. Very often, a national optimal solution is not an optimal solution at EU level, and this can create inefficiencies in the network. This can create loopholes in regional distortion of energy prices.

Aside the enormous cost linked to project development, we have exposed the urgency of coordination. There is a massive need for market integration and coordination to ease the deployment of such infrastructure (Lumbreras, 2016). Each TSO is regulated by its national regulator. These regulators dictate terms from pricing and cost control to equity return of TSOs. Europe has its own supranational regulator, the ENTSO-e. This supranational regulator eases coordination between TSOs in order to adopt EU-level optimal solutions. By publishing guidelines, targets and best practices they are trying to enhance TSO’s coordination in their response to today’s challenges.

The aim of this paper is to analyze regulations and data to find solutions to investment needs and challenges for the development of so-called electrical highways as well as cross-border electric power lines in different European countries. We will first introduce the subject by explaining the basics of regulations, investments and efficiency for European TSOs. Furthermore, we will analyze the case for a few European countries in

order to observe how their regulation, investment and efficiency adapt to the need of infrastructure expansion.

1.2. Liberalization of the Energy Sector

During the past 50 years, the landscape of energy companies in Europe has completely changed. State members have always played a large role in the regulation and coordination of the energy market, but it has dramatically shifted, as the sector has gone through major waves of liberalization of its activities. In the 1960's, most of the energy sector's businesses, from energy generation to transmission and distribution, were led by one vertically integrated company in each country. At that time, each monopoly mainly operated in one country with a core objective to provide energy to the consumers of this State (Langsdorf, 2011).

This started to change with the oil crisis in 1973-74, forcing Member States to cooperate and set common energy goals for 1985. They quickly realized the potential added value of enhanced coordination and therefore set guidelines to secure energy supplies in Europe. However, it wasn't until 1996 that we could see the first wave of liberalization in the sector, thanks to the first liberalization directive (also called the First Energy Package). The aim of this scheme was to provide better and cheaper energy by increasing competition and furthermore enhancing energy security.

The second package was enacted in 2003 with regulations to harmonize trade and transport across national borders. The other crucial point was the empowerment of the consumers, with industrial and domestic consumers now being able to choose between different electricity providers and thus drive down the prices.

In 2009, a Third Energy Package entered into force. It completely changed the face of the energy sector by unbundling the energy companies, separating the generation business from the transmission and supply businesses. The goal of this evolution was again to liberalize the market, to put the consumer's interests first and to ensure security of supply to as many people as possible by encouraging new players to enter the business. It brought about more rights for the consumer, better protection for the energy poor and

empowered the national regulators. Moreover, the Agency for Cooperation of energy Regulators (ACER) was created along with the third package, with the goal of strengthening coordination between regulatory agencies (ACER, 2019).

In the last decade, directives have been passed to further liberalize the market and empower consumers. Consumer rights now range from the ability to request a free smart electricity meter, to obtaining access to at least one comparison tool, in order to assess which, offer suits one's needs the most. The consumer will also be able to request dynamic electricity pricing contracts or operate as an active consumer, putting electricity back on the grid without being penalized. Other sets of rules have been put in place to meet targets for the integration of renewable energy and to promote green investments. More recently, the European Commission decided to adopt new regulations to reform ACER. Their goal was to increase the competency held by the organization and strengthen its coordinating role to take the lead in areas where there is a risk of national or regional fragmentation. The EU wants ACER to prevent free riders in order to act as a common internal market. This is also the reason that they gave ACER more responsibilities regarding market supervision, for example, by notifying them to elaborate new network codes and review processes (ACER, 2020).

Other organizations play a crucial role in the stabilization and coordination of the electricity market in Europe. These organizations were created and given legal mandates by the Third Energy Package. One of the most important organizations regarding this study is the ENTSO-e, European Network for Transmission System Operators for electricity. It is a not for profit international organization representing 43 transmission system operators from 35 countries across Europe. It was established in 2009 along with the third energy package. The ENTSO-e objectives, shared by its members are as follows:

'ENTSO-e members share the objective of setting up the internal energy market and ensuring its optimal functioning, and of supporting the ambitious European energy and climate agenda. One of the important issues on today's agenda is the integration of a high degree of renewables in Europe's energy

system, the development of consecutive flexibility, and a much more customer centric approach than in the past.¹

ENTSO-e contribute to the realization of these objectives by ensuring TSO's cooperation, coordinating operators' responses with today's challenges, drafting long-term network plans and by setting guidelines for coordinating R&D plans. This occurs with the ultimate aim of achieving an internal European energy market. (Who is ENTSO-E, 2020)

Another organization worth mentioning is the Trans-European Network for Energy (TEN-E). Their main objective is to link energy infrastructure between European member states. They help countries with the development of energy corridors that are fundamental for a better connection of isolated parts of the grid and to strengthen cross-border interconnections. (Trans-European, 2020)

¹ Who is ENTSO-E? (2020, November 15). Entso-e. <https://www.entsoe.eu/about/inside-entsoe/objectives/#entso-e-objectives>

Literature Review

2.1. The unbundled energy system

Introduction

The electricity market has been going through massive structural changes for the past 20 years. As mentioned above, it went through a deep unbundling of its activities, splitting the current electricity sector into 4 main activities: generation, transmission, distribution and retail. This was done in response to three key goals set by the European Union: increase renewable energy, ensure the security of supply and assure competitive pricing for consumers.

The unbundling took place in four steps. The first was focused on regulation, creating a regulatory body independent from political authority that hold utilities companies accountable for their performance. Secondly, the restructuring phase came with the actual unbundling of vertically integrated energy monopolies, into generation, transmission supply and retail. The third step was the entrance of private actors into the market. Those private players would bring the efficiency and knowledge of private management to the service of the energy market by improving investments and operational management. The fourth stage of the dismantling, enhancing competition, came along with the third one. By opening the generation market to private actors, competition will increase and then logically empower consumers to negotiate their tariffs (Foster and Rana, 2020).

Generation

Electricity generation is difficult as production should always meet the demand, at any time. We can store small quantities of energy, but large-scale energy storage is either too expensive or requires a massive amount of space to be significant. Therefore, generators are constantly required to extend their capacity as demand is growing along with economic and demographic growth. They are also at the forefront of the fight against climate change and with new types of business and technology making their way into the market, they are going through deep changes in order to achieve these goals.

There are a couple of variables that can help characterize different types of electricity generation plants and assess their strengths and weaknesses. Firstly, power plants often have a steady or variable generation, the two different groups here are divided by the origin of the fuel they are using; with one group relying on fossil fuels and the other one on renewable sources, such as sun and wind. As we are moving away from fossil fuels and investing massively in renewables, variability of the power output is a huge challenge. Another key element is the flexibility of the response. How quickly can a power plant react to demand increase? Renewable technologies have flaws as they have no means to react to the increase in demand, while, fossil fuel power plants, except for nuclear, can react almost instantly to these demand peaks. However, one counter example when we look at renewables is hydropower. It is one of the most flexible power sources with only seconds needed to turn the plant on or off and with a very steady flow of energy production. Finally, considering CO₂ emissions, natural gas and coal fire power plants are emission intensive, while nuclear and renewables are considered clean energy sources (Erbach, 2016). Here you can find a table with an overview of the main forms of energies we are consuming today with their respective characteristics.

Table 1: Characteristics of the main energy-generation technology²

Type	firm / variable	type of fuel	flexibility	low-carbon	CO ₂ emissions ⁵ (kg per kWh)
coal	firm	fossil	medium	no	0.95
natural gas	firm	fossil	high	no	0.55
biomass	firm	renewable	medium	yes; regrowth of biomass compensates emissions	
nuclear	firm	nuclear	low	considered as zero-emission energy sources	
hydro with dam	firm	renewable	very high		
solar	variable	renewable	very low		
wind	variable	renewable	very low		
geothermal	firm	renewable	high		

² Erbach, G. (2016). *Understanding electricity markets in the EU*.

[https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/593519/EPRS_BRI\(2016\)593519_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/BRIE/2016/593519/EPRS_BRI(2016)593519_EN.pdf)

Moreover, the shift from fossil fuels to renewable energy has been driven by the development of new technology. The cost of this technology has been falling dramatically for the past 20 years allowing for small-scale generation units to develop. Nowadays, energy production is no longer reserved to big producers; consumers have become prosumers by producing their own electricity and feeding the grid with their excess production. A series of tariffs and incentives have been put in place by different governments to push towards a greater integration of solar PV by prosumers (Internal Energy Market, 2020).

Transmission

Transmission networks are made up of high-voltage power lines running long distances to bind generation units with consumption centers. A high voltage is used for transmission as it reduces transmission losses. In the past, alternative current (AC) was preferred, but we are seeing a shift toward high voltage direct current (HVDC) as a new less costly and more energy-dense alternative. Lines are mainly overhead, but there are also many underground and sea cables. The European transmission grid is made up of 300 000km of high voltage power lines with 355 cross-border sections (Erbach, 2016). The connections between countries are key to balance supply and demand between national grids, which helps to secure a reliable energy supply across Europe and, by exchanging energy across borders, drives energy prices down.

Transmission system operators operate under the supervision of their national regulator. At the European level, the ENTSO-E is the supra-national regulator in charge of cooperation between national regulators. They ensure proper coordination of investment policy and actions towards common goals. They draft development plans and write network codes.

Furthermore, transmission system operators play a critical role in creating a real competitive power market by ensuring a fair access to infrastructure for third parties.

Distribution

Distribution network operators are the operating managers of the distribution network. High voltage electricity is transported through the transmission grid to cities, then it is

transformed into lower voltages for distribution to final consumers through the distribution grid. They also have to handle electricity from prosumers and small renewable generators, which directly feed the distribution grid, without going through transmission lines.

Retailers

Retailers are the final link in the energy chain, these are the companies from which you buy your electricity. Before the liberalization of markets, energy utilities would sell energy through an administrative branch of the company, giving incentives to use electricity when there was an excess and to save it when supply was short. Nowadays, energy suppliers have become risk managers who buy energy on the spot market and charge fixed or variable prices to consumers and industries. This evolution largely benefitted the customers. They are now able to compare and choose between different menu of pricing as well as choosing to be supplied by renewable energy sources etc.

Conclusion

Only thirty years ago, our energy sector was highly concentrated with a few giants. Today we face an unbundled system with distinctive activities ensuring more competition, which is directly reflected by the more affordable prices, better security of supply and making it easier to tackle energy challenges.

Now that we have clarified the present organization of energy sector on the European continent and how we have achieved this, we can focus on the transmission business. We will now focus on the forces that actually drive and set limits for TSOs.

2.2. Regulations

The need for new infrastructure investments in the EU is immense. It is the case for transmission system operators, but also for generators and distribution grid operators. The desire of the EU Commission to build an internal electricity market pushes national and supra-national authorities to agree on common policies and regulatory regimes that would help build a broader and more efficient internal electricity market. However, we will see in this chapter that this task turns out to be very challenging considering all the forces at stake and the different incentive regulations that can be put in place. While rate of return schemes were mainly used during the 20th century, the unbundling of the energy sector triggered a wave of cost reduction, which was ensured by well thought out incentive regulations. Today, as we are facing growth of renewables and the electrification of energy, regulatory schemes have to ensure cost effective services along with a correct balance between under- and overinvestments.

Definition

Sappington and Weisman give a broad definition of incentive regulation, as implementing rules to guide a firm to achieve a desired goal while giving them some discretion on how to do it. Vogelsang introduces more details in his definition by saying that it gives some delegation of pricing to the utility and that the firm will conduct a cost reduction policy to capture more profit. The mechanism works with ex-ante or ex-post modifications so that the companies have some time to capture the rent from cost reduction before the regulators update the cost structure. The scheduled revising of the cost structure prevents entities from capturing too much profit and focusing on the non-socially optimal topics. Therefore, the benefits from these efficiency gains can also profit other stakeholders (Agrell, 2015).

Regulatory agencies

At a national level, each country has its own regulatory agency to control and monitor the TSO(s) operating in the state, which is also accountable for setting a regulatory framework for the entire energy businesses in the country. Their role is to ensure transparency and fair competition in electricity (often also gas) market. They ensure that

markets are oriented towards general interests and are in line with global energy policies; while always taking into account the interests of consumers (A propos de la CREG, 2020).

At a regional level, regional security coordinators (RSC) are companies mandated by TSOs from a certain region of Europe. They perform different kinds of services for the TSOs such as, providing a regional model of the grid, advising TSOs. However, they are not permitted to take direct action. This aspect is essential for the RSCs to remain agile, independent and give the best advice on regulatory harmonization. By ensuring this, they provide economies of scale that benefit European customers (for example by guiding TSO to use the same IT systems). Currently there are 3 RSCs in Europe, TSC based in Munich, SCC in Belgrade and Coreso located in Brussels (Regional Security Coordinators, 2019).

Finally, we come to the two most essential entities, the ENTSO-e and ACER. First, the European network for transmission system operators for electricity (entso-e) promotes the cooperation of national TSOs in order to support European energy policies and help to carry out energy and climate objectives. The organization represents 43 TSOs from 35 countries; its range is not limited to the EU. The main objective of the association, today, is to set guidelines and coordinate TSOs response in order to achieve climate targets as efficiently as possible, while ensuring energy security and public interests.

On the other hand, the agency for the cooperation of energy regulators (ACER) is a European agency operating under the jurisdiction of the European Union. Unlike the entso-e, which represents TSO's interests and helps them improve coordination, ACER is mandated by the EU and has the power to take individual decisions. The main tasks of the agency are to supplement and coordinate national regulators' work, take an active role in the creation of network codes and rules, as well as take individual decisions on cross-border infrastructure development and give advice on energy related issues (Regulation (EC), 2009).

Framework

J-M Glachant has analyzed four aspects of regulatory regimes that have helped bring together the key issues to be addressed by effective regimes.

The first aspect is investment needs. Investment needs are directly linked to the ability of the TSO to finance itself and the risk it bears. TSOs have different levels of investment needs depending on their past investments and on what they plan to do in the short and medium term. The current situation means that TSOs with ambitious investment plans involving the introduction of new technologies will find it more difficult to access sources of funding. The common landscape for TSOs today in Europe is composed of TSOs with aggressive investment plans, with some countries bearing more risks than others.

Secondly, the cost of capital, which companies face when they call upon financial markets. This parameter also plays a role in setting a level of financeability and risks borne by the operator. However, it is partially controlled by the regulators. Indeed, if there is a great need for new infrastructure in a country, regulators should lower the cost of capital to facilitate the access of the company to the capital. They can do so by making specific regulatory choices. If the regulator is not in line with the market needs, it will create distortion and the cost of capital will likely increase.

Moreover, enhanced efficiency and cost-reduction goals often follow a period of high-level expenses for ambitious investment plans. On the other hand, if there is little opportunity of efficiency gains, there will be no incentives for cost reduction. However, it is important to note that efficiency opportunities are not always easy to spot for the regulators and that small efficiency gains might take a while to materialize.

Finally, the regulatory regimes can impact tariffs. What will be the impact of the regulator choices on consumer bills? To lower the final bill, regulators must fight for cost reduction and transfer of efficiency gains towards consumers. Nonetheless, this might contradict the need for new investments that might reduce electricity bills in the long term. We also have to note that transmission tariffs only play a minor role in consumer bills.

In conclusion, many different regulatory regimes adapted to different countries, because there are different attitudes regarding investment, risks and costs reduction.

Main regulatory regimes

There are many different regulatory regimes, but we are going to focus on the most popular ones used in Europe.

Cost plus

The cost-plus regulation allows the network operator to recover their expenses as well as a margin calculated in advance based on these costs, which corresponds to the return on investment. TSOs are incentivized to declare their true costs which allows to overcome certain problems such as monopoly rent. The problem with the cost-plus method is that companies are not incentivized to improve efficiency in their activities, which is equal to reducing their costs. Indeed, as the margin is guaranteed, there is no incentive whatsoever to reduce the costs of doing business. This solution reduces the risk borne by the operator drastically, transferring it to the customers, however the remuneration of the network only compensates for costs.

Revenue cap

This regulation is based on fixed prices set by the regulator before the period of exercise. Therefore, the company is incentivized to reduce its costs and increase its efficiency in order to capture a larger part of the profit. This method is often used to increase cost reduction when regulators think it is wise to aim for greater efficiencies. However, it does not provide any information on costs to the regulators.

Sliding scale

A performance-based regulation, also called sliding scale, this is a combination of revenue cap and cost-plus mechanism. The regulator uses a mechanism that defines a rule for sharing efficiency gains. Costs are calculated by compiling actual incurred costs with anticipated costs.

Menu of contracts

For the menu of contracts, instead of proposing a unique revenue scheme, regulators put in place a series of different schemes from which the operator can choose. The different contract corresponds to different levels of cost. Here the choice for the TSO is between disclosing of its own cost and the level of incentive regulation they want.

Yardstick or Benchmarking

Finally, the national regulators can use the yardstick method. This regulation incentive can only be used when there are different TSOs doing business in the same country, because it compares different monopolies operating in similar businesses. By comparing cost levels and efficiency opportunities of each monopoly, regulators will set the company's revenues on the average of all the companies. This will incentivize operators to increase efficiency in order to increase profits if they are better than the average.

Tradeoff

Each one of these has their own benefits and drawbacks regarding economic properties. They have the ability to drive operators in certain wanted directions, but there are always tradeoffs. There is mainly tradeoff seen in these regulations. The most obvious one is the tradeoff between cost reduction and risk management borne by the operator. The second tradeoff is between costs and the transfer of efficiency gains towards end consumers. The two regulatory regimes that have opposite and extreme effects on these characteristics are price cap and cost-plus mechanism.

- Let's first analyze the first tradeoff between **cost** and **risk**:

Price cap mechanism dissociates the remuneration scheme with the costs implied to the operator. This policy drives TSOs to reduce their costs in order to capture a higher share of profit. With regard to the disadvantages, we note an increase in the risk borne by TSOs. Indeed, as revenue stream and costs are separated, any external, unattended effects on the costs can reduce the profits of the operator. The operator is thus bearing all the risk in this situation.

On the other hand, the cost-plus mechanism has the opposite consequence. As revenue is linked to the costs of the company, any change in the cost function will be passed on to the consumer. However, the operator will be less keen to reduce its costs.

- Secondly, the tradeoff between **cost** and **transfer of efficiency gains to the consumer**:

As said previously, the revenue cap incentive regulation will drive costs down because revenue is not linked to costs. So even with a lower cost level, the price for the consumer will stay the same, as the operator will seize all the efficiency gains.

However, when we look at the cost-plus regulation, revenue is directly tied to the cost function. Therefore, there is no cost reduction incentives and efficiency gains will be directly transferred to the final customers.

In the middle, we find the yardstick regulation as well as the menu of contracts. The yardstick mechanism based the revenue scheme on exogenously assessed costs. Therefore, it makes the objectives to reduce the costs and to transfer efficiency gains compatible, as the revenue is set in between the level of cost-plus and revenue cap. Nevertheless, it does not tackle the first tradeoff mentioned above between cost and risks. We face a similar situation with the price cap regulation considering the setting of the revenue.

The menu of contracts can also balance cost and efficiency gains toward customers. If the operators want to make huge profits, it will choose a contract with large incentives for cost reduction. By doing so, it gives the regulator precious information about its cost function and in the longer term, regulators might be able to change regulations to distribute more efficiency gains to the end users.

In conclusion there is no best solution but a series of opportunities that can be taken and adjusted over time to drive the operators towards a desired result.

Current situation

Prior to incentive regulations appearing in the energy business, state regulatory commissions set a different kind of framework to control energy monopolies. Their main objective was to set a permitted rate of return for a certain period of time on the capital invested by the firm, in order to oversee utility's rate structure. This would lead utilities

to reduce their costs in order to extend their profit margin. However, before setting these rates, authorities were allowed to disregard certain costs if they thought they were unnecessary or imprudent (Joskow and Schmalensee, 1986). Moreover, they established other conditions such as extension requirements, certain levels of quality service, new power plant installation, billing requirements, etc.

At the end of the 20th century, with the liberalization of the electricity industry, regulators were willing to improve utilities performance. In regard to this new objective, they decided to choose an incentive regulation approach guided by benchmarking (Poudineh and Jamasb, 2015). This achieved positive results in efficiency improvements, especially through the reduction of operating expenses. However, new challenges emerged with an increasing need for investments. With the expansion of renewables and the generally accepted fact that further electrification of energy is necessary for a sustainable future along with more efficient use of energy, investment need has been a growing concern in the past decade. These challenges can only be tackled by significant capital investments.

The current challenge is to correctly implement a regulatory scheme capable of providing the right stimulus for cost effective services while ensuring a correct balance between over- and under-investment. However, with regulated monopolies, this task requires great caution as a low power regulation often means a poor efficiency incentive, while a rate of return higher than the cost of capital often results in over-investments. At the same time, uncertainties or a weak penalty/reward mechanism leads to strong cost reductions and a degradation of the service quality (Burns and Riechmann, 2004).

Firstly, the profit motives of regulated entities involve an assessment of the costs and benefits of any new investment by examining the changes in their revenues resulting from the efficiency effect of that investment in benchmarking costs. Today, through different regulatory designs, transmission companies are obliged to meet investment targets for economic reasons, but also to meet obligations stated in the Energy Act (for example they have to connect new generation sources and consumers). To force them maintain a certain level of service quality, cost of losses and energy are not supplied and are integrated in the model. Taking them into account for the benchmarking model prevents systemic underinvestment. Another way is to adopt quality performance targets. These

solutions would prevent utilities underinvesting, with a direct consequence of erosion of their efficiency and thus their margin. However, the substantial issue with underinvestment is that in the short term it can lead to efficiency gains as deterioration of the quality service only occurs over a longer time period (Poudineh and Jamasb, 2015). On the contrary, investment can lead to a loss of efficiency in the short term as it will increase the total cost of the utility. Moreover, partial disallowance of capital expenditures stated in the regulatory schemes often lead to more efficient investment.

Poudineh introduces 'Investment and efficiency under incentive regulation' in his paper and the notion of 'no impact efficiency'. He states that some companies will improve their efficiency by investing in new network infrastructure and some will see their efficiency deteriorate compared to a state of no impact efficiency. The proportion of improvement to deterioration is twice as high, therefore utilities are encouraged to invest more. Thus, firms with efficiency losses should reduce their investment and those with positive effects of investments compared to the 'no impact' situation should continue investing in order to capture more gains linked to their efficiency level. The investment might increase until the utility efficiency declines to the 'no impact' situation, where a form of efficiency is achieved.

The discussion above explains that benchmarking produces reliable results. However, this assumption is not always correct. Indeed, in benchmarking terms, efficiency is a relative concept. An entity is only efficient compared to the others. Therefore, efficiency can increase when other companies do not perform well. At the same time, we can observe static efficiency while the industry as a whole is under performing or the opposite, static inefficiencies because everyone is performing well. Benchmarking also embraces other assumptions such as the fact that all companies are at the same state of their investment cycle. The risk of under and over investment will go undetected and may lead to continued deterioration in the reliability of the system over the long term (Poudineh and Jamasb, 2015).

Conclusion

To conclude this regulation section, regulators should shift their focus from cost reduction towards incentives for greater investments. Indeed, economic and social losses from poor infrastructure due to a lack of investments can harm far more than the potential gain from cost reduction. The effectiveness of regulations is sometimes vulnerable to certain tendencies such as harmonized over- or under investment. Although ex-post regulatory mechanisms bring more risks for investments, consumers are more likely to benefit from the efficiency improvement of this system than with an ex-ante system. To sum up, there has always been a tradeoff in risk sharing between utilities and the consumers.

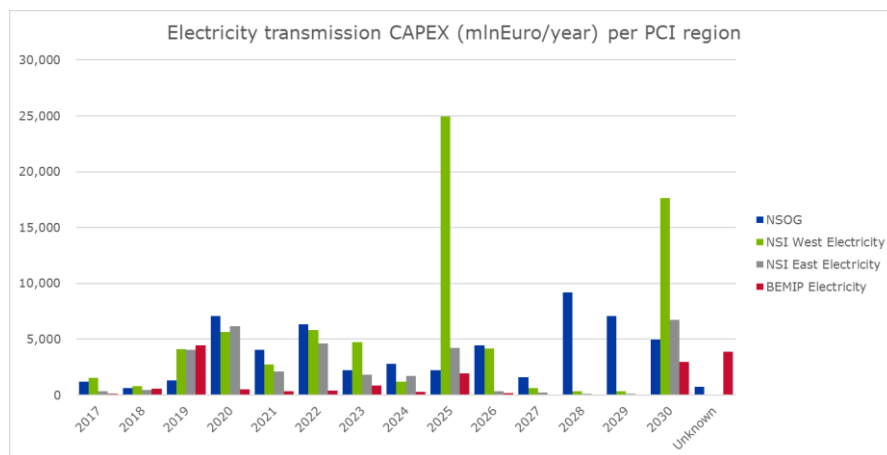
2.3. Investment

Sufficient and appropriate cross border electricity transmission infrastructure is key for an EU internal electricity market. However, more than 2 decades later, we have still not been able to achieve this goal. After the unbundling of the energy sector in Europe, regulators have set their priorities to improve TSOs efficiency for the benefit of electricity consumers. With revenue cap regulation where risk has shifted from customers to investors, national grids remain somewhat isolated from each other and many states experience congested lines due to a lack of investment. In this section we will be analyzing the scale of investment needed for new infrastructure and clarifying the way that operators and private actors can finance these developments. We will look into the risks that affect these investments and how TSOs can mitigate them and try to point out regulatory instruments, which might drive investments in the right direction.

Energy global investment need for TSOs

Transmission system operators are responsible for keeping the balance between supply and demand of electrical energy. Therefore, they need to plan the deployment of new transmission lines connecting future power plants as well as renew old existing infrastructure and increase interconnections between countries to follow EU directives. This task appears to be extremely costly. The reported total expenditure for the upcoming decade, only in transmission expansions, amounts to from 139 billion to 152 billion Euros. When we look at the following chart we can see when and where the money will be spent.

Figure 1: Transmission investments in the four electricity TEN-E corridors³



NSOG = North Sea Offshore Grid

NSI West Electricity = North-South Interconnection for Western Europe

NSI East Electricity = North-South Interconnection for Eastern Europe

BEMIP = Baltic energy market interconnection plan in electricity

The graph shows many investments planned for North and West regions with spikes in expenses in 2025 as well as in 2030. Despite noticeable divergence of investments shown on this graph, it is not as heterogeneous as it might look. NSOG planned expenses are very high because their network expansion will mainly be high-cost undersea cables. The Baltic infrastructure is rather small-scale compared to this, which could explain the lower investment level here. Regarding NS east and West corridors, the actual disparity will be smaller than what appears on the graph. Indeed, NSE East investments usually have a shorter time span than those from the West. The spread will thus likely reduce over time as more network development plans are released (Haesen *et al.*, 2017).

Costs

Transmission line development costs are very high due to different variables. First, there is obviously the cost linked to the length of the line. It is one of the first measures to estimate the global price of a project. Usually, an estimation of the total length is done, then we add 30%. This increment is intended to simulate the costs of routing constraints that can only be determined later during the project (MISO, 2018).

³ Haesen, E., Vingerhoets, P., Koper, M., Georgiev, I., Glenting, C., Goes, M. & Hussy, C. (2017). *Investments needs in Trans-European Energy Infrastructure up to 2030 and beyond*. http://publications.europa.eu/resource/cellar/431bc842-437c-11e8-a9f4-01aa75ed71a1.0001.01/DOC_1

Next comes the cost of the land and what is called in the industry ‘right-of-way’. This cost depends on the total land the TSO needs to acquire and the cost of preparation of this land. Cost of the land will vary according to the type of terrain (forest, mountains, wetland, etc) and the area it is located in (distance from cities). Regarding overhead lines, the land is not purchased, but the TSO acquires rights through leases, fee purchases or easements. Other cost structures are used for underground lines and are usually more expensive. The third component of the price comes from the structure installation itself. As said previously, underground lines are more expensive than overhead lines, ranging from 4 to 14 times more expensive (Alonso and Greenwell, 2013). Subsea cable development plans are also very costly. Finally, a large component of the price comes from the maximum capacity of the cables.

Based on all the costs quoted above, the overall price per kilometer of high voltage transmission lines can go up to several million euros. Here is a table with the total cost per kilometer of 380 kV lines. We should note that most existing lines in Europe have a lower voltage, ranging between 150kV and 200kV.

Table 2: Unit Costs of constructing new transmission lines at 380kV in different EU countries⁴

	380kV double circuit Euro ‘000/km
Base case	402
Austria	720
Belgium	469
Denmark	394
Finland	270
France	600
Germany	595
Greece	224
Ireland	n/a
Italy	464
Luxembourg	n/a
Netherlands	475
Norway	400

⁴ ICF Consulting. (2002). *Overview of the Potential for Undergrounding the Electricity Networks in Europe*.
https://ec.europa.eu/energy/sites/ener/files/documents/2003_02_underground_cables_icf.pdf

Portugal	274
Spain (REE)	332
Sweden	190
Switzerland	772
UK (E&W)	781

Risk borne by TSOs

Investment needs are a critical issue when regulators make decisions. The financeability of the project is carried by the TSO as well as the risk linked to the project. With a new project being extremely expensive, regulators must be very careful with their measures to correctly incentivize TSOs to expand the current power lines. In fact, if the access to financing is difficult and the project is high risk, the TSO will likely never invest. On the contrary, if regulators ensure a correct financeability and successfully minimize the risk borne by the operator, then investments will flourish (Glachant *et al.*, 2013).

For the past decade, three main factors have driven investment plans up in the EU: the integration of renewable energy, replacing old infrastructure and following the EU's directive for an integrated internal market. Despite a common need for investments, some TSOs are more impacted than others by new investments plans. Depending on the current asset base of the TSOs, some of them will see their total infrastructure double in the coming years. The amount they are provisioning from the depreciation of the current asset base is far lower than the amount they will spend on new investments, creating a massive need for financing new projects (Glachant *et al.*, 2013).

Moreover, risk is inherent to every project and even more in sectors with high upfront costs. Another key element driving costs upwards is technology; as technology is constantly evolving, operators need to carefully consider which technology to invest in, in order to be sure to invest in the correct technology. New technology, such as extra high voltage cables or offshore HVDC represents risk for the TSO. If transmission operators choose to follow one technology, they will have to go along with the development of this technology and potentially realize years later the incompatibility with other infrastructure. Other issues such as high costs of maintenance can also be discovered only after the installation of dozens of kilometers of new lines (Glachant *et al.*, 2013). For all of these reasons and others, the risks borne by TSOs are quite substantial. Accelerating

investments plans would require legislators to shift some of these risks on to another stakeholder.

This shows that regulators should bear in mind the investment constraints of TSOs and try to mitigate the riskiness of the projects while setting optimal regulations plans to support the shift we are experiencing.

Funding sources

All of the new projects concerning expansions of existing transmission lines or creation of new routes are endorsed either by the TSO itself or by private entities. Although private entities can invest in new infrastructure, most of the development witnessed today comes from TSO's initiatives. In order to promote new infrastructure, operators need funding access. In this section we are going to cite and analyze the different methods for TSOs and private entities to finance their projects.

Firstly, we will look at the regulated revenue coming from the price that TSOs charge to consumers for transmission tariffs. National regulators directly regulate the prices charged. Private investors rely mainly on the congestion rent, depending on whether there is a congestion rent mechanism in the country where they want to operate. Congestion rents are compensations to cover redistribution costs when the availability of an allocated interconnection is at stake or to increase the interconnection capacity in a social optimal way and not in an economical optimal way (European Commission, 2017).

Utility companies can finance new projects with equity, offering a rate of return fixed by the regulators. The national regulator authority sets a weighted average cost of capital at which the operator can raise money for expansion. An important risk here is the changes in schemes between regulatory periods. Lack of consistency in regulations leads to instability which drives investments downward. Other forces lack of willingness from investors to invest, non-mature projects or a need to balance debt and equity can also penalize development plans. As a reference, between 20 and 50 percent of a project is financed through equity (Haesen *et al.*, 2017).

Thirdly, is debt. A lot of TSOs (40-60%) rely heavily on debt for infrastructure expansion funding. The obstacles observed here are risks entailed by the TSO itself, like technological risks, risk of regulation changes towards a less favorable remuneration scheme, etc. which might raise the cost of debt. However, structures such as the European Investment Bank and the European Bank for Construction and Development have played a positive role in helping TSOs in their quest to raise debt (Haesen *et al.*, 2017).

Finally, utilities can also count on organizations such as the CEF, the Connecting Europe Facility. It is a key funding instrument, available to all European members to fund new infrastructure projects. The CEF's main objective is to promote infrastructure development in the EU to enable easier transfer of energy and people, through enhanced transportation systems and digital information, with investments in telecommunication (European Commission, 2020).

Investment Barriers

Some obstacles have already been mentioned above, such as the frenetic technological evolution which complicates decision making, or the scarcity of funding sources. These can be found in almost every sector, but others are very specific to utilities. In the case of the interconnection capacity, prices and regulations often differ in the 2 states, which can create distortions. Another issue is that local incentives might not be aligned with a wider regional perspective. As there is no supra-national organization to indicate the location of EU-optimal corridors to next invest in, some infrastructure development projects might be non-optimal. The lack of coordination between NRAs can lead to project failures. Cross border connection is highly sensitive to regulatory changes as they have a major control on the remuneration scheme applied to their network. Investments also face uncertainty regarding electricity generation expansion decisions. The conclusion is a clear lack of supra-national responsibility (Kapff and Pelkmans, 2010).

Investment Incentives

The regulatory framework applicable in European countries today mostly allows the same return for every transmission investment. An option to boost investment across a region could increase returns on the investments to reduce the risks associated with high CAPEX projects. However, this solution often appears to be too costly for the regulators.

Another solution, already used in the US and in Italy for more than a decade, is the use of dedicated regulatory incentives. In short, this offers special terms for strategically important investments.

In reaction to a mighty blackout in 2003, the Italian national regulatory authority decided to promote important expansions of the transmission network with the goal to reduce blackouts risks, improve market integration and enhance market competition. A framework was first set up in the 2004-2007 Italian regulatory period and it took 2 more periods to fine-tune this. It was a rather simple scheme, highlighting key projects and giving them dedicated incentives. To access the dedicated incentive, projects had to be interconnected or assessed as a transmission line that would reduce internal congestion (Keyaerts and Meeus, 2017).

What appears today, after periods of improvements, is a three branched dedicated incentive scheme. First, there is a specific remuneration scheme for work in progress. Each year, the development of the project must reach a certain threshold (set on a case to case basis), in order for the utility to be credited at a premium. On the other hand, if the work in progress is below a certain level, the project developer must pay a penalty to the authority, calculated on the total invested capital and on the numbers of months it is late. However, each project eligible for a dedicated incentive scheme can choose whether or not to take part in the reward/penalty scheme for the work in progress phase. When the project is completed, a key part of the scheme occurs; a certain increase in return is granted to the project for a period as long as 3 to 4 regulatory periods (Keyaerts and Meeus, 2017). This combination of methods helped drive up investment in Italy for the past decade, building a key transmission corridor inside the country as well as with neighboring countries.

The success of this application in Italy does not mean that it is a perfect solution to enhance investment. The strength of the Italian scheme is the simplicity of making it cheap to run, but it is far from perfect regarding the individual assessment of which can benefit the scheme. Other countries such as the US use the same methodology, but their system is more advanced. At a European level, such a regulation would be possible only with the participation of a supra national agency to assess the development plans. For

instance, with ACER performing case by case assessments we would be able to extract economies of scale.

Lastly, even though we are seeing more and more European countries opting for this solution, it remains controversial. The success met in Italy and the US does not imply an easy implementation elsewhere. Drawbacks such as the cost of running such assessments can appear to be extremely high, which drastically reduces the benefits. (Keyaerts and Meeus, 2017).

Conclusion

To conclude this section, there are different forces in action when it comes to investment capability. The capability of financing the TSO's investments and thus ensuring its finance ability is key for TSOs as their activities are highly capital intensive. A high finance ability will result in high investment and vice versa. Another key criterion is the capability of the regulatory regime to reduce the risk borne by TSOs. Risks need to be mitigated at all costs by the regulators if they seek investment plan growth.

2.4. Efficiency

Efficiency comes at a cost in a monopolistic landscape. NRAs have been enhancing efficiency among utilities for the past 2 decades in most parts of Europe. After the unbundling, NRAs shifted risk from customers to investors. By imposing ex-ante revenue caps, TSOs would drive their costs down to capture bigger benefits. It worked, with efficiency gains seen in many European countries. However, after a long period of time these policies have driven down investment all over Europe, having a much bigger impact on the global efficiency of the European network. Issues come from a lack of coordination between member states, would it be about prices, energy flow or regulations, but it also comes from a lack of interconnected infrastructure. While it is exactly the large availability of interconnections that could enable price convergence and will greatly improve efficiency, TSOs and NRAs have not yet been able to agree on a common rule to decide on where to build new infrastructure. There is a lack of European-level system of governance of EU planning tools with enough legitimacy and power to put these plans into action.

ITC mechanism inefficiency

One of the biggest challenges faced today in order to achieve an internal energy market is inherited from the historical fragmentation of the EU. Every state is an individual market with very few links between each other. However, there are other problems, coming from non-harmonized legislation across member states and from the inherent difficulty of electricity trading. The EU is stuck with NRAs struggling to align their policies. In 2011, after the third energy package, the ITC (Inter-Transmission system operator Compensation) scheme was created to drive cooperation mechanism and compensation tools.

The existing European Inter-Transmission system operator Compensation (ITC) works as follows:

“[...] when networks controlled by a number of different operators are mutually interconnected, due to physical laws of energy flow, it does not follow exactly contracted, intended, ‘routes’. Therefore, there are always unintended flows of energy that pass

through 'someone else's' network. Therefore, the ITC system was designed with the idea that:

- TSO's operating power systems that are either big net exporters or big net importers should be net payers to the ITC fund;
- TSO's operating transmission networks in which transits dominate over net exports or imports should be net receivers from the ITC fund.”⁵

Essentially, the ITC mechanism is designed as a compensation tool for TSOs for the cost of hosting unwanted transit flow on their networks. However, the mechanism is flawed due to various reasons, from a wrongly posed algorithm to policy limitations of the EU regulatory framework (Sabolic, 2017). Some TSOs have started to use special elements, called phase shifters, to reject unwanted electric flow from their network. It is unequivocally the proof of an inappropriate system.

Change has to come from technical features as the algorithm needs to be improved. For example, estimation of losses caused by unwanted transit need to be handled through a better method according to experts. Improvements also need to arise from regulatory modifications. Even if the ITC algorithm were to be enhanced, it would still not reach an economical efficiency because the European regulatory framework does not allow an economic value to be assigned to transmission capacity. This forces players to offer all available cross-border flow, while ensuring that the national TSO will continue increasing the capacity in the long term. However, it also enables TSO's who are less controlled, to avoid investment decisions about their internal network by using cross border transmission lines to create loopholes and thus delay their investment plan (Sabolic, 2017).

Using an ITC system is a good scheme for extremely mature regions where there is a low need for new infrastructure development. But it is not well suited to the EU, which is trying to build an internal electricity market. Indeed, it does not integrate any kind of

⁵ Sabolic, D. (2017). *On economic inefficiency of European Inter-TSO compensation mechanism*. Energy Policy. 110, pp. 548-558.

cost/benefit analysis based on future investments. Therefore, ITC should be improved with an accurate and updated cost-benefit analysis or completely replaced. In any case, the key would be the integration of externalities caused by interconnections (Glachant and Khalfallah, 2011).

Along with ITC schemes, is congestion rent, which is a mechanism used to promote interconnection capacity or guarantee the availability of allocated capacity. At a special node of the grid where there are not enough connections or where there is a lack of power generation, transmission capacity will be paid higher than the equilibrium. The price difference at different nodes reflects the social value of network externalities. However, in practice, congestion rent is mainly used for tariffs reduction and not for interconnection expansion (Glachant and Khalfallah, 2011).

Capacity Remuneration Scheme

Energy is such an inelastic market that price signals alone don't work as incentives for new infrastructure developments. Therefore, NRAs across Europe have been establishing a mechanism which would finance an installed capacity. Obviously, not all European countries have opted for such a capacity remuneration scheme (CRM), leading to a patchwork of solutions across the continent (Lambin and Léautier, 2019).

The diversity of adoption of the CRM has led to short term distortion such as free riders on capacity payments in countries with no CRM, leading to harmful effects on local consumers (Glachant and Khalfallah, 2011). Cross-border trade may be inefficient when market designs differ. Despite this, another issue lies in the long term with utilities under CRM investing in additional capacity. In the long run, it can create deep imbalance in investment development between countries. For instance, for a capacity market to be efficient, it should either have limited interconnections or reduce exports which is in complete contradiction with the internal energy market goal. The conclusion is to urge for the harmonization of a capacity remuneration scheme to suppress or drastically reduce distortions across Europe (Lambin and Léautier, 2019).

Conclusion

Efficiency improvements have been at the core of most European regulations since the unbundling of the energy system. Through carefully chosen ex ante revenue caps and other mechanisms, regulators have pushed utilities to reduce their cost in order to gain efficiency which would benefit the consumers. However, now that we are entering a phase of deep infrastructure development, these regulations are no longer bearable. Risks need to be more balanced between customers and TSOs in order to lift investments. The key for efficiency improvements in the coming decades lies in interconnection capacity pricing mechanisms. As more interconnections are being built, more distortions appear, which can lead to massive inefficiencies in the market. Therefore, neighboring countries take advantage of infrastructure developed by others.

Methodology & Data

3.1. Methodological Approach

To assess the impact of the network's expansion on different variables we used different methods. In the highly regulated energy sector, regulations govern the investment behavior of system operators. They also have a direct impact on their efficiency levels by setting tariffs, maximum revenues for network operation or other types of incentives. This is why we first collected qualitative data on regulations. This data will show us the decisions implemented by national regulators that will have an impact on the efficiency and investment of TSOs. Then, in order to explain the impact of network expansion and its causes, we collected quantitative data on the efficiency of operators, the type of energy generation, market concentration, financial results, etc. All data covers the period from 2006 to 2015 in order to study an evolution rather than a snapshot. This will allow for more robust results. In summary, the qualitative approach has allowed us to understand how regulations have evolved as a result of the urgent need to expand the network and the quantitative approach will provide, firstly, a context for the infrastructure needs, and secondly, it will provide precise data to explain the consequences.

We wanted to analyze the European operators but comparing the data of 43 TSOs from 36 countries would have been confusing. As a result, we decided to look at some TSOs in the Northern European bloc as well as Italy because these are countries that are particularly active in terms of regulatory developments in response to current challenges. Moreover, combined, these companies manage more than 50% of the European transmission network. The countries studied are therefore Germany, Belgium, France, Italy and the United Kingdom.

3.2. Data Collection

For qualitative data concerning the countries studied, the main sources of information were the annual reports provided by the TSOs themselves. The websites of the national regulators were also useful, as they are full of relevant retrospective analyses and

discussions on future regulations to be put in place through press-releases or reports. Secondly, web sites of supra-national bodies such as ENTSO-E and CEER were also valuable sources of data.

The collection of quantitative data was carried out mainly via 3 sources of information. The first was the Eurostat website. Eurostat produces European Statistics in partnership with the National Statistical Institutes and other national authorities in the EU Member States. The databases on production, consumption and energy mix are directly derived from them, as well as those on emissions and market concentration in the energy sector. This data is extracted for the period from 2006 to 2015 for the desired countries. The second important source of data was the ENTSO-E website which collects generation, transmission and load value data from European countries. Here too, the data could be extracted as it was. Finally, the financial data of the TSOs was extracted from the Bloomberg monitors provided by the Louvain School of Management of UCLouvain. Bloomberg terminals enable users to monitor and analyze real time financial market data. The access to the monitor allowed the collection of valuable data concerning the financial statements of the entities. Here we have retrieved operational cost data and total asset values of the companies in order to compute an OPEX/TOTAL ASSETS ratio.

3.3. Method of Analysis

Very little processing has been done on the primary data taken from Eurostat and the entso-e websites. The only manipulations were the reductions of the database to the period and countries we studied. As for the data collected on the Bloomberg platform, after extracting the desired information, we performed a simple calculation in order to obtain a desired ratio. Additionally, all the data was extracted and processed via excel and then transformed into csv format for analysis.

For the actual analysis, the data in csv format was imported into the RStudio software. RStudio is an integrated development environment for R, a programming language for statistical computing and graphics. Using this program, we were able to manipulate the

data in order to derive results and graphs providing very useful visual information. The manipulations performed were mainly linear regressions and correlation calculations.

We searched and retrieved information from the TSO reports on all the regulations implemented since the liberalization of the energy sector in relation to specific topics. These themes were investment incentives regarding the urgent need for grid extensions. Once specific regulations for new infrastructure investments were found (if any), we diagnosed whether or not they were measures that would guarantee a certain level of efficiency for the transmission operators. Thanks to the reports from companies and national and supra-national regulators, we have been able to gather and conclude on some trends. We were trying to identify themes and patterns across the study of regulations in different countries.

3.4. Methodological choices

For the analysis, we have adopted a particular approach that mixed a quantitative analysis with a qualitative part. We found several reasons that helped us decide that this would be the most relevant method. First of all, as explained in the theoretical part of this research, there are three main points that are relevant when studying network operators, regulation, investment and efficiency. The investments and efficiency of TSOs can be studied quantitatively. However, any in-depth study of the effects of a regulation must first study the regulation in question. This is why a qualitative study was required in order to gain a clearer view of the actions implemented by the regulators. This is the heart of the analysis.

The quantitative part brings explicit quantifiable evidence to the research. First of all, the data provides a clear and robust context for the reasons and needs for investment in network expansion. Then, further on in the analysis, following the qualitative analysis on regulations, the quantitative part provides clear and precise numerical results to enhance the validity of qualitative analysis. The construction of graphs also allows a clear and essential comparison between countries.

Analysis

4.1. Carbon impact

The greatest challenge facing humanity as a whole today is climate change. It is the direct consequence of decades of fossil fuel consumption that has released billions of tons of CO₂ into the atmosphere. However, we cannot emit these in the same quantity as the last 50 years if we want to live in a habitable world in the future. This is why, since the early 2000s, we have seen the rise of new forms of energy. Designed to be cleaner than fossil-fueled power plants, renewable energy has become the spearhead in the fight against climate change and plays a major role in mitigating global warming.

The following graph shows, on the left y-axis, data of primary energy consumption in the 28 EU countries between 2006 and 2015. Primary energy consumption in millions of tons of oil equivalent (TOE) is an indicator that measures a country's total energy needs excluding any non-energy use of energy such as materials used in the chemical industry or for tar used in road construction. It covers the energy consumption of end-users such as industry, transport, households, services and agriculture, plus the energy consumption of the energy sector itself for energy production and transformation, losses during energy transformation and losses in transmission and distribution (Eurostat, 2020).

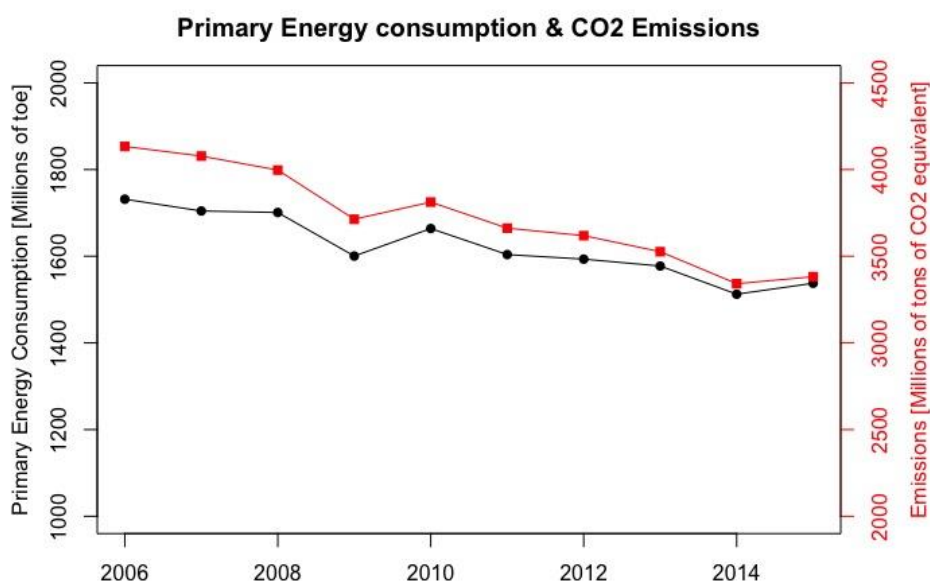


Figure 2: Primary Energy Consumption & CO₂ equivalent emissions in European Union 28 (2006-2015).

This data is compared with the evolution of carbon dioxide and carbon dioxide equivalent emissions for the same period and the same geographical area. The scale of CO₂ emissions is shown on the right-hand y-axis.

We can conclude from the graph that primary energy consumption has decreased by 11% in ten years, while emissions have decreased by more than 18%. It confirms the trend towards decarbonization that our economy has been going through since the beginning of the 21st century. The drop in emissions is mainly due to the decrease in our energy consumption. The fall in European carbon emissions is greater than the fall in energy consumption because, although they are closely correlated, energy is not the only sector to have a direct impact on emissions. Other sectors have a significant impact on our emissions.

The main driver of the decrease in our energy consumption is the development of renewable energy, which, as we will see in the next section, is growing exponentially and is decarbonizing the sector. Greener energy means less pollution. This trend is a positive sign for the future, but it has many consequences. In this analysis we detail, using the data we have collected, how this development has profoundly affected energy transport and, in particular, electricity transport in Europe. We studied the consequences for the European Union, but we will focus in particular on certain countries which together account for a large part of the transmission network. We analyzed the impact of integrating renewable energies into the system. How regulators have reacted to these needs for change, which they have put in place. Then what are the consequences of what has been put in place by the regulators and how the sector has reacted to this huge challenge.

4.2. Renewable Electricity Penetration

We have introduced above the reduction of emissions in Europe. In this section, we want to measure the impact of this increase in green energy production on electricity. This will allow us to confirm whether or not the integration of renewable energy has an impact on electricity. This then leads to the challenge of transporting this electricity, which is produced by new sources.

First of all, we decided to build a linear regression of the renewable electricity consumed in relation to the consumption of renewable energy in general. The objective is to observe the impact of an increase in renewable energy consumption on renewable electricity consumption. That is to say, when there is more renewable energy, in what proportion does this energy end up on the electricity grid.

Secondly, in order to understand the following analysis based on the graphs we have constructed, we need to clarify the axis on the graphs. The graphs have the same two axes. On the x-axis we have the share of renewables in the gross final energy consumption and on the y-axis, we have the share of renewables in the gross final electricity consumption. Each observation going from left to right on the graph refers to the years from 2006 to 2015 in the 28 countries of the European Union. In short, the first observation indicates that in 2006, the share of renewable energy in the European Union was 9.7% of total energy consumption, when the share of renewables in the electricity mix reached 15.3%.

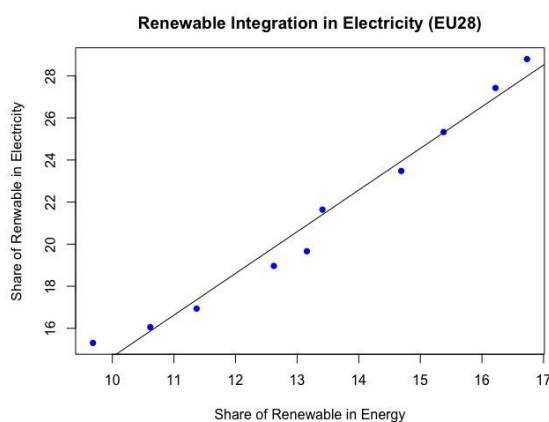


Figure 3: Linear regression between share of renewable in energy in the EU28 and share of renewable electricity in the EU28.

The linear regression for European data has a slope of 1.981. This means that the complete renewal of our electrical system will be achieved sooner than 100% clean energy because the integration of renewable energy in electricity production is proportionally twice as fast as in the production of all other energy. Indeed, the integration of renewables into electricity is growing faster than in other sectors, such as transport, where it appears to be extremely low.

The fact that the growth of renewables in electricity production is stronger than elsewhere is not without consequence. Regulated transmission operators have to connect new generation plants to the existing grid. This is an obligation imposed by regulators in order to foster competition between generators in the sector. This can be done reactively, when transmission is built in response to new generation sites, or proactively, when transmission planning anticipates RES developments (Costa-Campi *et al.*, 2020). In any case, both methods mean that new transmission lines have to be built. We have seen that renewable energy production sites are often located far offshore or at a certain distance from energy consumption centers such as cities. This adds complexity and costs for TSOs. Therefore, it is fair to conclude that the specific increase in renewables will have a strong effect on the need for transmission network expansion. This proves that the integration of renewables puts a strong pressure on the transmission network infrastructure.

Countries (from Figure 4 to Figure 8)

If we analyze the situation country by country, France has a very low integration of renewable energies in its electricity energy mix with a slope of 0.7929 but also in energy in general, with a slope of 0.7929. This is mainly due to France's dependence on nuclear energy for energy and electricity production (Le nucléaire, 2020). The penetration of renewables in the electric power sector is less than 1, which means that the electricity sector integrates renewables more slowly than other sectors. Consequently, the impact of this change on the transmission network is limited compared to other European countries. It should be noted, however, that despite a reduced growth in renewable energy production, renewable energy consumption of 15% is close to the European Union average.

Belgium has a slope (= repercussion of renewable energy in electricity) very close to that of Europe, at 2.0807, but with a very low overall level of renewable energy consumption (around 8%). This means low consumption of renewable energy in general but a very high impact on electricity production, which is going green at a very high rate. Less than 4 percent of electricity came from renewable sources in 2006 and around 16 percent 10 years later.

Italy is by far the best in its category, with renewable electricity consumption exceeding 33 percent in the last two years observed with an overall energy mix close to that of the Union. With a third of its energy production coming from renewable sources in 2015 for only 15% in 2006, the impact on generation sources and transmitters in the country is unprecedented. The growth in renewable electricity is significant with a 2.1866 slope for the regression line seen on figure 6.

The United Kingdom and Germany have seen the fastest integration of renewable energy, increasing from around 4 percent to 22 percent and 12 percent to 30 percent respectively. Their rate of renewables electricity consumption in regard to the renewable energy consumption is respectively of 2.7303 and 2.901. Which means that renewable electricity is growing almost three times faster than renewable energy in general. Such impressive growth will have an impact on the adaptation of the transmission network. Such a change in the type of energy production has repercussions on the means and locations for transporting energy. For each new offshore wind farms built or other renewable energy sources brought online, new high-voltage cable lines must be built to connect these new infrastructures to the consumption nodes.

With the evolution of the above countries, we see that the penetration of renewable energy in electricity consumption has increased sharply in Europe. The impact for the whole energy sector but more particularly for TSOs and generators is unprecedented in terms of investments.

Here are the graphs of the evolution of renewable energies and electricity consumption in the different countries mentioned above.

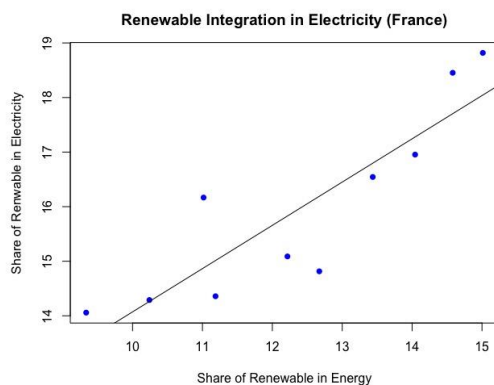


Figure 4: Linear regression between share of renewable in energy in France and share of renewable electricity in France.

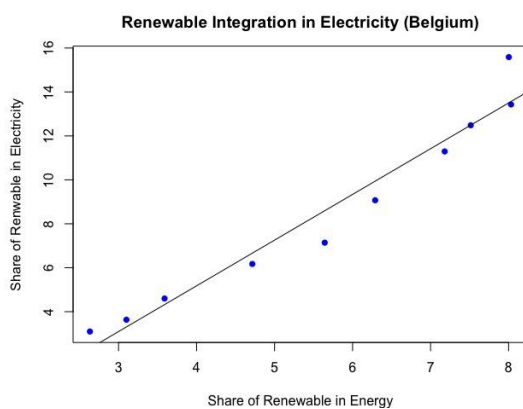


Figure 5: Linear regression between share of renewable in energy in Belgium and share of renewable electricity in Belgium.

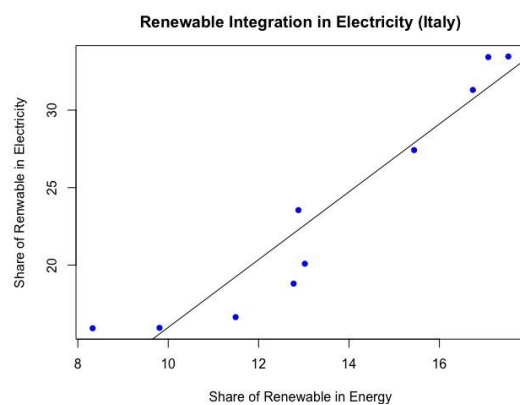


Figure 6: Linear regression between share of renewable in energy in Italy and share of renewable electricity in Italy.

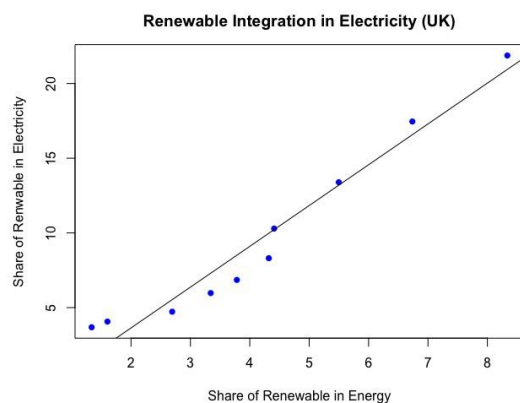


Figure 7: Linear regression between share of renewable in energy in the United-Kingdom and share of renewable electricity in the United-Kingdom.

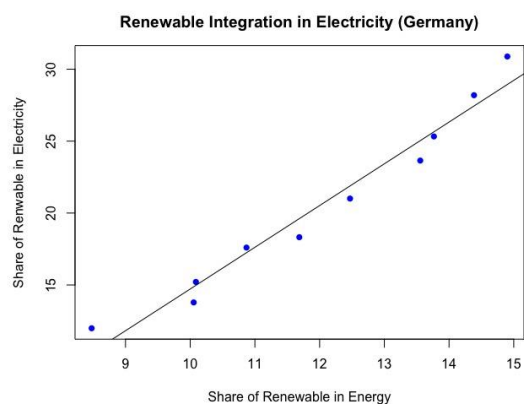


Figure 8: Linear regression between share of renewable in energy in Germany and share of renewable electricity in Germany.

4.3. Regulatory Schemes

National regulations are set by the national authorities for an agreed period, usually between 3 and 5 years (Haffner *et al.*, 2019, p.98). Regulators have a choice of different options to provide incentives to transmission system operators to achieve a certain target. Although regulation may take different forms and have different consequences, the goal is generally to balance the risk between customers and utilities.

We are currently in a period where there is a huge need for infrastructure expansion and engaging innovation. We are therefore going to analyze the solutions put in place by the regulators in order to make up for this lack. We will diagnose the regulations in force in European countries and see what they are putting in place to guarantee a sufficient level of investment while maintaining a certain level of efficiency. In doing so, we will highlight certain countries that together represent a large part of Europe's total transmission network. The analysis focuses on what the regulatory authorities in each country have established, regarding the possibilities for financing investment and how to deal with efficiency.

Belgium

First of all, let us analyze the case of the Belgian regulatory regime, which is reviewed every four years under the regulation of the CREG, which is the national regulator. The Belgian TSO, Elia, is subject to a revenue cap regulation coupled with cost control incentives (Haffner *et al.*, 2019, p.92). It operates as follows: a fair profit margin is granted to the grid operator as remuneration for the equity capital used to finance the regulated assets. Here, the margin consists of a percentage return based on the Capital Asset Pricing Model (CAPM). It takes into account the net return expected by investors as well as how this investment contributes to and evolves in relation to the general risk of the equity market. This percentage of return is applicable to the overall GOR and is generally not adapted to specific projects (CREG, 2020, p.7).

Nevertheless, a specific remuneration system for strategic investment projects exists. The CREG has agreed to introduce, during the previous regulatory period, a surcharge for projects that are of crucial importance for the safety of the community. These projects are

most often linked to the strengthening of the integrated EU energy market. (Elia Group, 2016, p.26). A concrete example of a project where this has been applicable is the modular offshore grid. This project consists of connecting different wind farms in the North Sea to a single offshore platform which is in turn connected to the onshore grid (Haffner *et al.*, 2019, p.101). The NRA is inclined here to include better profit margins in the tariff methodology due to the specificity of the project and its "positive" character with regard to the energy security of the community. This system has proven to be very effective for the development of investment projects.

While implementing and refining the new specific mechanism, CREG continues to encourage rigorous cost management. Indeed, the growth of investments can easily lead to an increase in tariffs if they are not managed properly. These are different types of costs that are subject to a revenue cap depending on the ability of the TSOs to control them. The more controllable the costs are, the stricter the regulations on them. Given that in a network industry, OPEXs are also determined by CAPEXs and that investments will change significantly in the current/future regulatory periods, it is no longer appropriate to change OPEXs by simply indexing costs to the cost levels of the first year of the regulatory period. The grid operator is therefore required to submit four individual and reasoned annual budgets for the OPEXs (CREG, 2018, p.8).

Italy

In the case of Italy, a combined price cap and rate-of-return model applies (Haffner *et al.*, 2019, p.93). In response to a powerful blackout in 2003, the Italian national regulatory authority decided that it would begin to promote significant extensions to the transmission network with the aim of reducing the risk of blackouts, improving market integration and enhancing competition in the energy sector. A framework was put in place for the first time during the regulatory period 2004-2007 and it took two further periods to refine it. It was a fairly simple scheme, highlighting key projects and offering specific support to them. In order to access the aid program, projects must be an interconnection or have been assessed as a transmission line that will reduce internal congestion in the country (Keyaerts and Meeus, 2017).

Today, after several periods of improvement, the system of specific incentives consists of three pillars. Firstly, there is a specific remuneration system for work in progress. Each year, projects must reach a certain development threshold (set on a case-by-case basis) in order to be credited a bonus. Then, if the construction of the project in progress falls below a certain level, the project developer must pay the authority a delay penalty, calculated on the basis of the total capital invested and the number of months of delay. However, each project eligible for this aid system can choose whether or not to participate in the reward/penalty system for the work in progress phase. The third part of the development incentive scheme takes place when the project is completed. Any transmission line has a level of remuneration set by the regulator. In this case, a certain increase in remuneration is granted to new strategic infrastructure for a defined period of time (Keyaerts and Meeus, 2017).

This combination of methods has led to a sharp increase in investment in Italy over the last decade, building key transmission corridors within the country as well as with neighboring countries and surrounding islands. The strength of the Italian scheme lies in its simplicity, which makes it inexpensive to administer, but it is far from perfect in terms of the individual assessment of projects that can benefit from it.

United-Kingdom

The UK national grid is under a revenue cap regulation based on return on investment. Recently, they have adopted an output-based incentive for the inclusion of premium TSO stakeholders. Under this new system, a transmission operator is assessed by a panel of independent experts. Depending on the results of the evaluation of the stakeholder engagement strategy, the TSO can receive 0.5% of its authorized annual revenue as additional revenue. This incentive is designed to financially reward companies whose commitment leads to high-quality results (OFGEM, 2017).

Regarding investment incentives, they are supported by a very high return on capital. The United Kingdom has seen a strong development of its grid with interconnection developments and future plans with all its neighboring countries in the previous decade (National Grid, 2020). This is counterbalanced by high efficiency targets on new investments that can significantly reduce margins (Glachant *et al.*, 2013, p.52). The use of

TOTEX provides an incentive to reduce costs and forces the transfer of efficiency gains to final consumers. It also increases the risks borne by the TSO itself, but these risks are mitigated by the use of a menu of contracts. The United Kingdom also has specific rules on investment in offshore projects. Under certain rules, TSOs are allowed to start construction even before the offshore plant is completed in order to speed up the construction process (Haffner *et al.*, 2019, p.101).

In conclusion, England has a relatively well-balanced regime with high remuneration and the possibility to finance investments through high return on equity as well as high incentives to reduce costs through the TOTEX approach. The length of the regulatory period (8 years for the UK) is facilitated by the menu of contracts.

France

The French electricity transmission network has been managed by the company RTE since 2000. The regulator of the French high-voltage grid, CRE, is responsible for implementing regulations for the national TSO. RTE is regulated by a mechanism of periodic revenue cap over 4 years, combined with a cost-plus instrument for non-controllable costs, while a ceiling is set *ex ante* for controllable costs.

With regard to efficiency, RTE has significantly reduced its costs during the first regulatory period (2000-2004) and has continued to do so to some extent (RTE, 2005). The national regulator sets efficiency targets according to the type of controllable costs. As in Belgium, the achievement of these targets is entirely the responsibility of the TSO and therefore none of the over- or under-performance is passed on to consumers' tariffs during the regulatory period. This ensures a certain level of dedication in achieving the efficiency targets.

Furthermore, revenues are set for each regulatory period on the basis of the TURPE model (currently TURPE 5 is in place), which represents remuneration for the use of the network. It foresees the revenues needed to cover the capital and operational expenditure related to the maintenance of the network (CEER, 2019). For investment, France has a relatively high WACC, calculated *ex ante* using the Financial Asset Pricing Model (CAPM). The rate is applied to the amortized RAB. In addition, CRE guides the French TSO in

interconnection projects with cost and time controls (CRE, 2019). It has also provided specific incentives for investments with key results. The financial incentive to make interconnection investments will take the form of a fixed annual bonus. The amount of bonus will be defined before the investment decision is taken, based on the interest of the interconnection for the community (CRE, 2013). This measure came into force during the previous regulatory period.

Germany

Germany is fragmented with 4 TSOs all subject to the same regulation (provided by BNetzA, the national regulatory authority) with the same regulatory period of 5 years. The setting of the revenue cap starts with the assessment of the total costs incurred by the TSOs. These costs then serve as a basis for the entire regulatory period. The costs are separated into controllable and non-controllable costs. Efficiency requirements are applied to the first category and only inefficient controllable costs are subject to reduction requirements. Cost effectiveness is calculated by comparing the costs of the previous period. All non-controllable costs are isolated from the benchmarking system. The costs are therefore classified according to the network supply obligations. That is, they are based on factors such as the area served, peak load, size of the network, etc. (The main tools, 2015).

Regarding investments, the rate of return is calculated by the regulator for each period. For this period, it is set at 9.05% before taxes (The main tools, 2015). However, this rate is achievable under efficiency conditions set by benchmarking. The German regulator also provided some adjustments to the revenue cap for specific investments. If investment plans are due to significant supply obligation changes and results in investment of network expansion, an instrument allows TSOs to obtain a modified revenue cap to cover the adjusted costs of expansions within the same regulatory period. Otherwise, utilities would have to wait until the next regulatory period to obtain a new cost assessment and would maybe not be able to finance the operation (The main tools, 2015).

Takeaways

Tackling the growing need for network expansion is not an easy task. Regulators have spent a decade defining and refining appropriate policies to encourage their national utility companies to invest in building new infrastructure. We have seen here that it takes

time and often several increments to achieve this. The countries studied are succeeding, but we are only at the beginning of the phase. It must be stressed that regulators do not want to make the easy mistake of over-investment that would lead to a sharp rise in tariffs in the future. They try to carefully balance incentives for expansion while keeping costs under control.

One of the disadvantages of European countries in implementing these practices is the fragmentation of decisions among individual countries. Some countries such as the United States uses the same methodology as Italy, but with a much more advanced system because they can apply economies of scale at the national level. Italy is limited to a simple model, as the cost of such assessments can seem extremely high, which considerably reduces the benefits (Keyaerts and Meeus, 2017). At a European level, such regulation would only be possible with the participation of a supranational agency responsible for evaluating development plans. For example, with ACER carrying out evaluations on a case-by-case basis, we could achieve economies of scale.

The analysis confirms that the majority of investments are financed by network charges (Haffner *et al.*, 2019, p.98). Countries such as the UK and Belgium set specific sets of rules to accelerate their advantage in operating offshore wind farms. Germany is taking advantage of the fragmentation of the sector to put in place a powerful benchmarking process to thrive in terms of efficiency while implementing a mechanism to accelerate investment.

As most schemes are only reviewed every 4 or 5 years, many have decided to allow for the inclusion of new costs in the current period. This not only ensures better financing capacity, but also saves valuable time on project development. They put in place effective regulation, focusing on the obligation to supply.

One country studied seems to be lagging behind. France has the largest network in Europe, but the rate of expansion remains very low. We think this could be due to the fact that France produces a lot of nuclear power, which is known to be stable and extremely dependent. Therefore, establishing strong links with other countries does not seem to be

a priority, although many new interconnections are planned and under construction for the future.

4.4. Network Efficiency

Operating Expenses

For Belgium, France and Italy, we were able to gather valuable data on their operating expenses between 2006 and 2015 from their financial statements available on Bloomberg. The OPEX level is a good indication of how the TSOs are managing their activities and their efficiency. In the current situation of grid expansion, TSOs will see the size of their assets increase significantly and will need to control their expenses to maintain a decent profit margin and continue to finance their development. A reasonable level of OPEX is therefore crucial for efficiency but also to maintain an adequate level of funding.

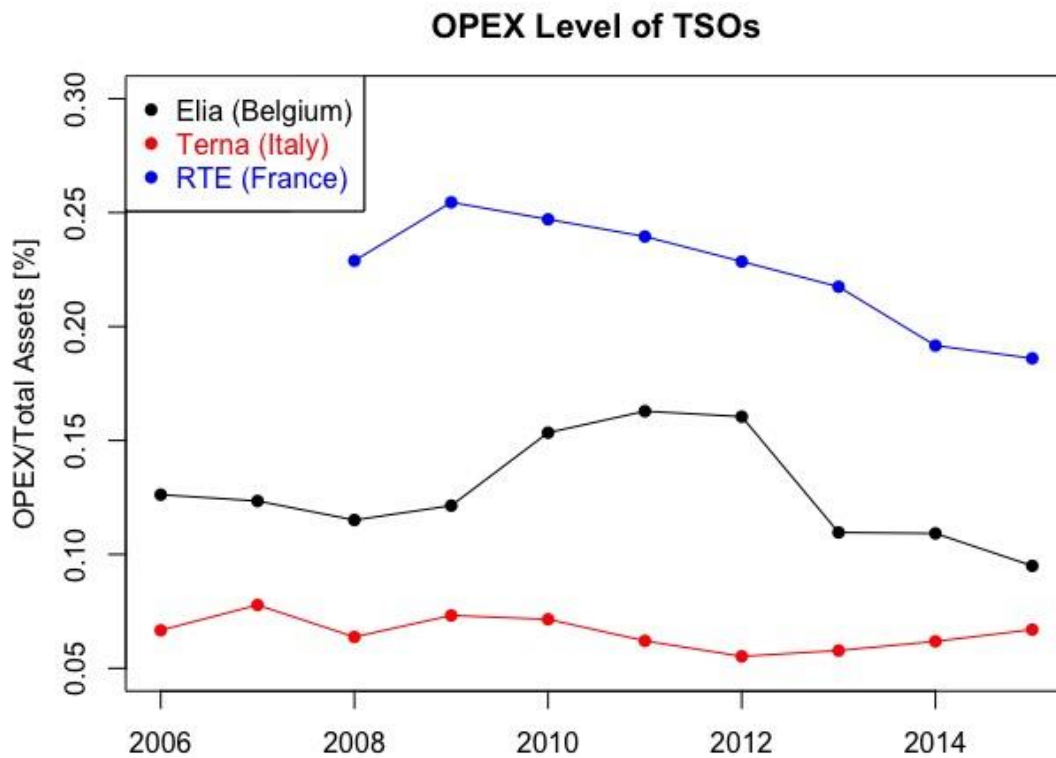


Figure 9: Graph of Operating Expenses on Total Assets ratio for Belgium, Italy and France.

The increase in Belgian operating expenses is explained by the acquisition of part of the German 50 Hertz TSO in 2010 by the Belgian TSO Elia. Despite this, Elia was able to lower its operating costs in only 3 years. Over the observed period of 10 years, they have been able to reduce operating costs from 12% of total assets to just under 10%. This

demonstrates the smooth functioning and responsiveness of the Belgian regulatory mechanisms.

In France, RTE has a much higher level of operating costs. This divergence between countries can mainly be explained by different accounting methods. Nevertheless, the revenue cap applied in France has shown great effectiveness in reducing operating expenses since the third regulatory period (2009-2013). They have been able to keep their expenses stable between 2008 and 2015 while total assets have increased by 25% in the same period.

Finally, Italy started its investment campaign earlier than most other European countries with the introduction of an additional compensation mechanism for investments deemed to be in the public interest. During the period under review, it saw the value of its total assets more than double. Despite this, they have shown a great ability to maintain a low level of operating expenses, which has allowed them to generate decent profits for other investments.

Network Losses

There is a significant gap between the energy produced and the final energy consumed by final consumers such as industry, households, the transport sector, etc. This gap is primarily explained by the difference between gross and net energy production. Every power plant needs energy to operate. The gross output of a plant refers to its actual production including the energy needed to operate it, while the net output indicates the energy available for consumption. At an EU level, this disparity between gross and net electricity production amounts to 156,712.9 GWh (EU28 gross product - EU28 net product) (Eurostat, 2020). It represents 4.83% of the total gross electricity production, which is about 1.5 times the production of a country like the Netherlands. However, this total is not a loss as it is the energy used by the energy sector.

Starting now from net electricity production, only 92.7% (Eurostat, 2020) was actually consumed by end users in 2015. The 7.3% that is lost has been accounted for as transmission and distribution losses. The losses can be separated into 2 main categories, technical and non-technical losses. The first represents all the electricity transformed into

heat during the transfer of energy due to the laws of physics. There are losses that occur in transformers or conductors in use. Non-technical losses relate to electricity supplied unmeasured or stolen (CEER, 2017, p.11).

In the following graph, we can see the overall distribution losses for the European Union as well as for the main countries between 2006 and 2015.

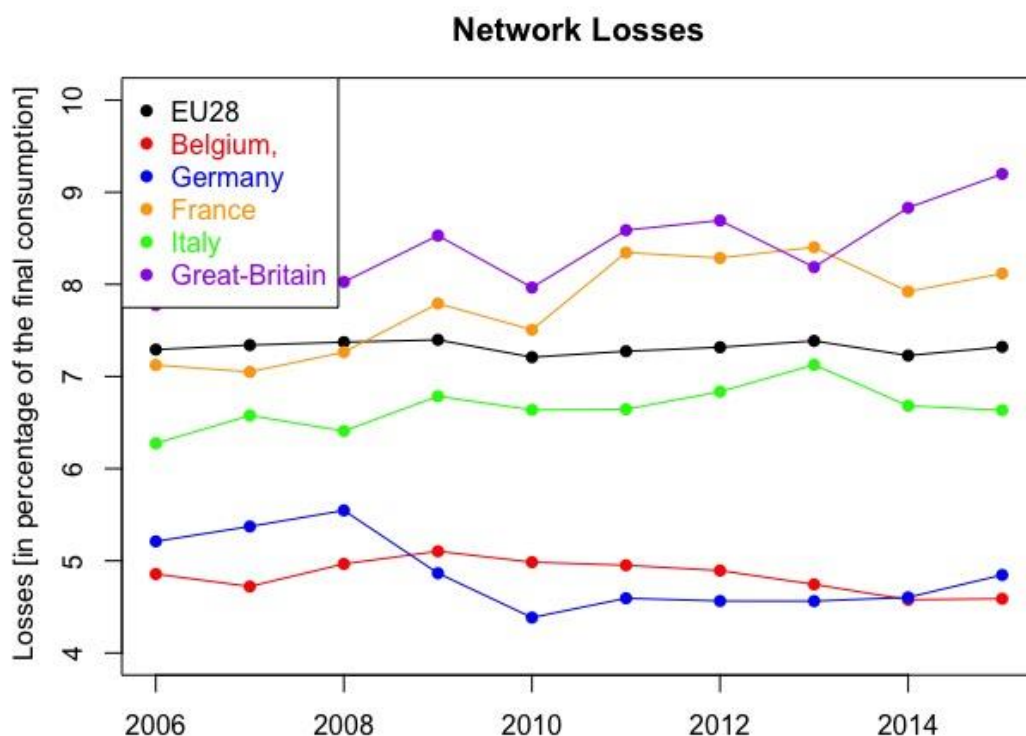


Figure 10: Graph of Total Distribution Network Losses in the EU.

It is easy to point out that the average losses in Belgium and Italy are lower than the EU average, at around 5%. Italy remains below the EU average with 6-7% network losses. France and Great Britain, on the other hand, have a slightly higher rate of distribution losses than the others, up to 9%. This can be explained by different factors such as the regulation applicable to losses in each country, the average voltage of their network, the age of the network, etc.

It is important to distinguish between transmission losses and distribution losses. We have analyzed here the data on aggregate losses, i.e. the sum of two. For losses related

solely to transmission networks in 2015, they vary between 0.89% and 2.77% of the power losses compared to total losses that were between 2.24% and 10.44% for the same period (CEER, 2017, p.7). This means that average transmission losses are between 25 and 40% of combined losses. These lower figures for the transmission network than for the distribution network can be explained by the voltage level at which they operate. Since variable losses are directly dependent on the current, it is normal that the transmission network is responsible for fewer losses because it operates at a much higher voltage. This explains why most of the losses (about 70%) occur at the distribution level (CEER, 2017, p.11). The difference between countries can be explained in part by the contrast in the electrical capacity of transmission lines in different countries.

Regulations

A report on power losses prepared by the Council of European Regulators indicates that regulatory measures could reduce the costs resulting from power losses by setting targets and deadlines for improving network losses. However, caution should be exercised when setting targets and guidelines, as inappropriate measures could easily lead to a worsening of the situation.

In the report, CEER collected data from European countries and most of them have only loss reduction incentives for DSOs. The practices used are models that consider the cost of losses as any other cost and are therefore part of the revenue cap mechanism. Other solutions offer rewards for achieving cost reduction targets, as well as penalties for not achieving them. These solutions could provide a good baseline plan for TSOs to establish.

A country-by-country approach shows that the Belgian DSO regulator includes the cost of energy losses in the revenue cap. In Germany, the cost of losses is also included in the revenue cap. Great Britain is currently collecting data through smart metering in order to implement an appropriate system in the future. While France is one of the only countries to set a regulation for TSO network losses, which is based on the volume of losses (CEER, 2017, p.24). It should be noted that, as stated at the beginning of this section, the greatest efficiency gains can be achieved by distribution system operators. This explains why national regulators have focused on this part of the energy sector.

Another very important conclusion of this report is the lack of consistency in the definition of these losses. Harmonization of their definitions would help to compare loss levels across Europe and would then play an important role in providing incentives to reduce them (CEER, 2017, p.36).

In addition, as network expansion is ongoing, the evaluation of future investments through life cycle analysis can have positive results. The most efficient transformers are more expensive to purchase, but if we consider the cost of future losses when making the investment, we may want to invest in high-end technologies that reduce costs over the long term.

4.5. Generators market concentration

In this last section, we thought it was important to talk about the concentration of the market of electricity producers in Europe. We will examine market concentration from a European, but also from a national perspective, to try to understand how the different regions of Europe have evolved since the unbundling of the energy sector.

To begin with, we should point out that there was no data available for the market share of each company involved in energy production. However, we were able to gather data on a number of players in most European countries as well as the market share of the largest player in those states.

We analyzed the countries by group according to the market share of the largest producer. On table 3 (in appendix), we can observe that out of the 34 available observations, Cyprus, Malta, Montenegro and Serbia are still in a perfect monopoly position with an entity controlling from 98.6 to 100% of the electricity production in 2015. In the following 13 states, more than 50% of production is controlled by a single utility company. In this list, France is the only Western European country with more than 85% of its electricity production controlled by a single company. In the next group, still with a high concentration of production in one hand, are Belgium, Luxembourg, Portugal, Sweden and Bosnia. Here the main generator holds 40-50% of the total production capacity. Next, the largest part of Western Europe is in Spain, Italy, Germany, Denmark, Norway, the United Kingdom and Finland, where the largest power generation company produces between 20 and 33% of the total production.

It quickly becomes apparent that there is a wide gap between Eastern and Western Europe. Richer and more western countries have developed a more decentralized system of energy production following the liberalization of the energy sector. However, it should be noted that states such as Romania, Bulgaria and Lithuania have a rather low Herfindahl index which proves that a certain liberalization is also taking place in Eastern countries. What they have in common is a large integrated market for renewable electricity which is not very large.

Despite the fact that a large part of the market is still in the hands of a few in more than half of Europe, the development has been impressive. We can already see in table 3 that concentration has decreased in almost all countries since 2005. The two most impressive observations are those of Belgium and Lithuania, which have gone from a player holding 82% of the market share to only 48% ten years later and from 70% to around 22% respectively.

Table 3 gives a very interesting and important picture of the situation in 2015; another very interesting analysis is the evolution of these figures since 2005. To add even more perspective, we were able to measure the total number of actors in each country observed over the same period. Even if the concentration is still high, with only 1 to 5 companies (see table 5 in appendix) holding a market share of more than 5% in each country, we are seeing an explosion in the number of small players. The number of production companies has increased exponentially in all countries except Hungary. We have seen impressive growth in Belgium, Italy, the Netherlands, Austria, Poland and Turkey. These countries may still sometimes have a highly concentrated market, but we clearly see a diversity of players in production that is not without consequences for the transmission system operators. Once again, France shows very little change, with only five major players, of which we know that one controls a huge part of the market. The United Kingdom also shows little sign of change, but its market was already much more fragmented.

In conclusion, unbundling of the energy sector has certainly led to a greater diversity of players, and many countries have seen a sharp increase in the number of competitors. However, new entrants are often small and incumbent producers remain dominant in their markets. There is also a gap between West and East in terms of power generation market integration. Finally, power generation on the islands and in some countries of the former Soviet Union is still controlled by a monopoly entity.

Renewable and market concentration

In a report written for the European Commission, we have seen that high market concentration has a negative impact on infrastructure investments and, on the contrary, increased competition in the market as positive consequences (Van Nuffel *et al.*, 2017). We did a simple linear regression between renewable electricity consumption and the

market share of the largest electricity producer with 2015 data to see if there is a conclusion on the relationship between market concentration and renewable electricity penetration. We found a correlation between the two, but the p-value is equal to 0.3 and the R-squared is extremely low (0.002965), which means that we cannot use this regression and draw any conclusion.

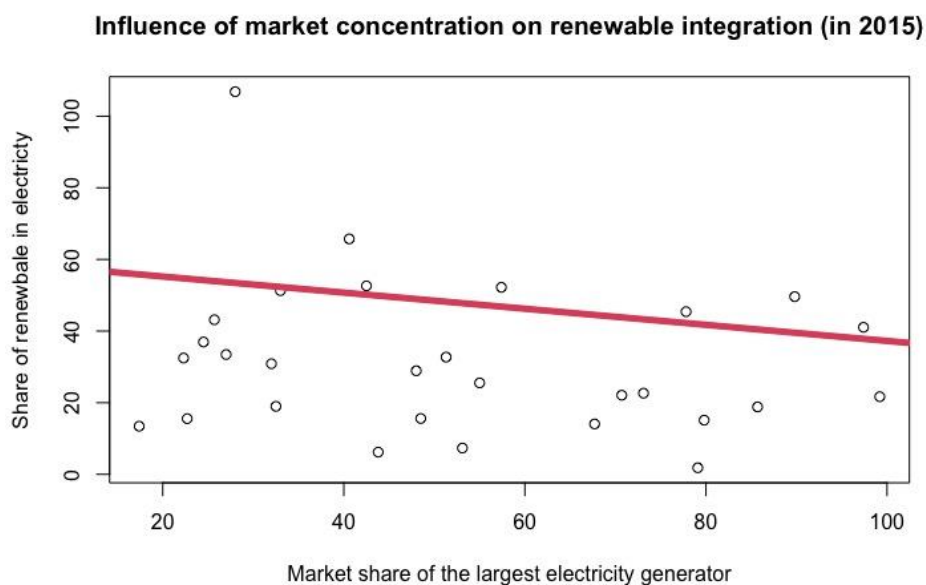


Figure 11: Linear Regression of Market share of the largest generator and share of renewable electricity in Europe.

Conclusion

5.1. Answering the Research Question

The aim of this work was to identify the causes and consequences of the need to expand the transmission network in the European Union. Enlargement of the network represents the high-voltage lines within a country as well as the interconnections between countries of the Union. Thanks to the data collected and the analysis carried out, we can confirm that the response to climate change has led us to produce our electricity and energy in general in a less polluting way. This non-polluting electricity production leads to the relocation of electricity production to windy regions, at sea, on mountain ridges, or in sunny countries. These locational changes have forced grid transmitters to connect to these new sources and thus expand their networks. However, we must point out that we are still relatively at the beginning of this trend with the share of renewables in electricity production reaching 30% in 2015. But with the EU's promise to achieve a clean economy by 2050, this trend will accelerate, which means considerable expansion for TSOs.

Operating in a highly regulated environment, TSOs expect adapted regulations to the new urgent needs of the network to be able to invest properly in their network with some guarantee from the regulators. Through detailed study of grid operator reports from some countries we have seen that regulators are slowly responding to the emergency. They are putting in place specific mechanisms to increase the remuneration of projects that they consider to be of major necessity for the security of the network and the security of electricity supply. These mechanisms are set up in different ways and reach different levels of 'aid' depending on the country. With countries such as Italy being very progressive in this area and others such as France lagging behind in adapting its regulations to encourage investment.

One of the direct consequences of grid expansion without good management could be a sharp increase in the operational costs of grid management. This is why adaptations to current regulations for funding support are also accompanied by measures to maintain a certain level of efficiency in the management of their network. These measures make it possible to update the revenue cap by adjusting the costs related to new investments

during the same regulatory period or by introducing new cost calculation methods. By helping TSOs to control their costs, regulators protect consumers who can rely on tariffs that do not skyrocket as a result of investment campaigns.

5.2. Method

We have adopted an approach of study that is both qualitative and quantitative. This method was chosen because of the particularity of the sector studied. The business of network transmitters being highly regulated, any quantitative analysis would have missed the fundamental consequences of network expansion that are the regulatory adaptations. The reaction of the regulators to this new challenge is as important as the response of the network operators because they govern a large part of the actions of the utilities. The quantitative study has therefore allowed us to gain a deep understanding of the behavior of regulators and the reaction of TSOs to it.

Quantitative studies on the evolution of greenhouse gas emissions, as well as the penetration rate of renewable electricity, explain the causes of these changes with robust data. As for the analysis of TSO operating costs, it allows an understanding of the evolution of the costs related to the operation of the network. It is also a direct link to investment and more specifically to the level of efficiency with which TSOs operate. The last quantitative part is about the energy generation business. It allows us to put into context the evolution that the energy sector has undergone over the last two decades. It allows the work to be placed in a more global context.

5.3. Recommendations

Based on these conclusions, we believe that one of the most effective solutions implemented by a regulator is in the case of Italy. By evaluating projects and selecting those that provide greater national energy security or reduce internal congestion, they have imposed a framework that promotes a strong electrical network. If we could implement such regulation across different countries, it would accelerate the

development of strategic projects in these countries. Furthermore, for projects concerning interconnections, a supra-national committee such as the CEER could act as a neutral party in the evaluation of projects that are key to the construction of a European energy market. Unilateral projects could of course still be possible, but those with the approval of a higher regulation could benefit from additional subsidies.

As Italy has already fine-tuned its regulation for strategic projects incentives over 4 regulatory periods, it could be an excellent knowledge base to be studied in depth. The case study of the United States can also shed some light on this subject. Indeed, their system for assessing the importance of key projects is already in place at a federal level. They benefit from a common federal government that can achieve economies of scale in costly project assessments. Analyzing and learning from their methodology could prove to be useful if we wish to set up a supranational specific project evaluation committee.

5.4. Contributions

In this study, we mainly focused on the evolution of the energy sector and how regulations are adapting to new challenges. We were able to observe in 5 major European countries the level of adaptation of their regulations. This study has allowed us to confirm that regulatory changes are slow. In order to grant the right type of incentives on the desired projects while not compromising the regulatory work done previously to reduce the operational costs, a robust system needs to be put in place. This explains the time required to put in place solutions that will promote the construction of new strategic infrastructures while maintaining a reasonable level of cost. Quantitative analysis on the efficiency of TSOs helps to understand this. It can be seen from the first graph in section 4.4 that controlling operational costs is still the priority for TSOs.

This country by country analysis has enabled us to dive deeply into the process of adapting regulations in certain countries. It is interesting to see that despite the relative slowness of this process; some regulators are adapting much quicker than others. A broader study with a quantified impact on the construction of new high-voltage lines

could be of interest. However, here we have preferred to focus on the adaptation of the regulations as such.

Finally, one of the interesting characteristics of this research is the quantitative analyses, which put the investment need in context and allows us to understand the fundamental causes of the need for infrastructure expansion.

In conclusion, in view of the challenges to be overcome, we can honestly say that regulators are making rapid progress in putting in place appropriate regulations to accelerate network expansion while maintaining reasonable cost levels that allow for fair transmission tariffs.

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Appendix

Appendix 1:

Table 3:

Market share of the largest generator in the electricity market, 1999-2018 (in %)

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	92.3	91.1	92.6	93.4	92.0	87.7	85.0	82.3	83.9	80.0	77.7	79.1	70.7	65.8	64.9	59.8	48.5	62.6	60.7	51.5
Bulgaria	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
Czechia	71.0	69.2	69.9	70.9	73.2	73.1	72.0	73.5	74.2	72.9	73.7	73.0	68.0	68.0	67.5	67.7	67.7	68.4	62.5	62.6
Denmark	40.0	36.0	36.0	32.0	41.0	36.0	33.0	54.0	47.0	56.0	47.0	46.0	42.0	37.0	41.0	36.6	33.0	35.2	33.3	32.8
Germany	28.1	34.0	29.0	28.0	32.0	28.4	31.0	31.0	30.0	30.0	26.0	28.4	:	:	32.0	32.0	32.0	33.5	32.2	30.2
Estonia	93.0	91.0	90.0	91.0	93.0	93.0	92.0	91.0	94.0	96.5	90.0	89.0	87.0	88.0	87.0	84.8	79.8	80.8	82.5	80.0
Ireland	97.0	97.0	96.6	88.0	85.0	83.0	71.0	51.1	48.0	45.6	37.0	34.0	38.0	55.0	54.0	51.0	55.0	47.0	43.0	44.0
Greece	98.0	97.0	98.0	100.0	100.0	97.0	97.0	94.6	91.6	91.6	91.8	85.1	:	77.0	67.5	71.5	70.7	72.0	58.7	58.2
Spain	51.8	42.4	43.8	41.2	39.1	36.0	35.0	31.0	31.0	22.2	32.9	24.0	23.5	23.8	22.0	23.8	24.5	25.4	22.5	22.4
France	93.8	90.2	90.0	90.0	89.5	90.2	89.1	88.7	88.0	87.3	87.3	86.5	86.0	86.0	83.8	86.8	85.7	82.5	79.9	82.1
Croatia	:	:	:	:	82.0	86.0	87.0	83.0	84.0	85.0	92.0	88.0	83.0	82.0	84.0	80.3	77.8	80.7	86.1	82.7
Italy	71.1	46.7	45.0	45.0	46.3	43.4	38.6	34.6	31.3	31.3	29.8	28.0	27.0	26.0	27.0	29.0	27.0	24.0	19.0	19.0
Cyprus	99.7	99.6	99.6	99.8	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Latvia	96.5	95.8	95.0	92.4	91.0	91.1	92.7	95.0	86.0	87.0	87.0	88.0	86.0	89.0	79.8	54.8	57.4	58.6	47.1	63.4
Lithuania	73.7	72.8	77.1	80.2	79.7	78.6	70.3	69.7	70.5	71.5	70.9	35.4	24.9	30.4	24.4	20.6	22.7	14.3	14.2	15.5
Luxembourg	:	:	:	:	80.9	80.9	:	:	:	:	:	85.4	82.0	81.8	58.4	61.3	43.8	18.0	17.8	14.4
Hungary	38.9	41.3	39.5	39.7	32.3	35.4	38.7	41.7	40.9	42.0	43.1	42.1	44.1	47.1	52.9	54.0	53.1	52.9	51.3	55.2
Malta	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	61.0	76.0
Netherlands	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c	c
Austria	21.4	32.6	34.4	:	:	:	:	:	:	:	:	:	55.3	56.6	:	:	:	:	:	:
Poland	20.8	19.5	19.8	19.5	19.2	18.5	18.5	17.3	16.5	18.9	18.1	17.4	17.8	16.4	17.3	17.9	17.4	16.0	17.7	17.1
Portugal	57.8	58.5	61.5	61.5	55.8	53.9	54.5	55.6	48.5	52.4	47.2	44.9	37.2	43.9	46.5	42.5	47.0	39.5	43.3	:
Romania	:	:	:	:	:	31.7	36.4	31.1	27.5	28.3	29.3	33.6	26.0	26.7	26.8	29.9	25.7	28.5	23.1	29.0
Slovenia	:	:	:	50.7	50.3	53.0	50.1	51.4	82.0	53.0	55.0	56.3	52.4	55.2	57.1	52.4	51.3	53.9	48.5	53.9
Slovakia	83.6	85.1	84.5	83.6	83.7	83.6	70.0	72.4	71.9	81.7	80.9	77.7	78.9	83.8	81.9	73.1	71.3	71.4	70.5	:
Finland	26.0	23.3	23.0	24.0	27.0	26.0	23.0	26.0	26.0	24.0	24.5	26.6	25.6	25.2	24.7	23.3	22.3	22.7	22.5	24.7
Sweden	52.8	49.5	48.5	49.0	46.0	47.0	47.0	45.0	45.0	45.2	44.0	42.0	41.0	44.0	44.8	42.9	40.6	42.0	42.4	43.6
United Kingdom	21.0	20.6	22.9	21.0	21.6	20.1	20.5	22.2	18.5	15.3	24.5	21.0	45.6	51.7	c	c	c	c	c	c
Norway	30.4	30.6	30.7	30.7	30.7	31.2	30.0	30.9	32.5	27.4	29.5	29.8	33.6	28.6	31.2	30.5	28.0	33.3	30.6	31.5
Montenegro	:	:	:	:	:	:	:	:	:	:	:	:	:	:	99.4	99.2	98.6	97.7	96.0	93.0
North Macedonia	:	:	:	:	:	:	:	:	:	:	:	:	:	92.6	90.0	91.4	89.8	81.3	78.0	82.4
Serbia	:	:	:	:	:	:	:	:	:	:	:	:	56.0	:	53.5	50.8	99.2	98.9	98.6	97.9
Turkey	79.0	75.0	70.0	59.0	45.0	39.0	38.0	c	c	c	c	c	c	c	:	:	:	:	:	:
Bosnia and Herzegovina	:	:	:	:	:	:	:	:	:	:	:	:	:	:	45.8	49.4	48.0	43.9	46.3	40.5
Kosovo*	:	:	:	:	:	:	:	:	:	:	:	:	:	:	98.8	98.7	97.4	96.0	96.6	94.3
Moldova	:	:	:	:	:	:	:	:	:	:	:	:	:	:	79.4	76.3	79.1	80.5	79.8	77.8

: data not available

c confidential data

(*) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

Note: due to statistical confidentiality, some countries do not provide individual market shares for individual electricity generators.

Source: Eurostat (online data code: nrg_ind_331a)

Source: Eurostat. (2020). *Statistics Explained*. <https://ec.europa.eu/eurostat/statistics-explained/pdfscache/9144.pdf>

Table 4:

Number of generating companies representing at least 95% of the national net electricity generation, 2003-2018

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	2	3	3	4	4	7	11	4	41	46	70	100	350	320	310	279
Bulgaria	13	14	14	15	15	15	15	22	20	28	83	55	75	79	113	133
Czechia	20	17	18	16	16	16	19	24	51	73	21	45	150	220	230	261
Denmark	>1 000	>1 000	>1 000	>1 000	>1 000	>1 000	>1 000	>1 000	>1 600	~1 300	1 450	1 550	1 300	1 350	1 300	1 300
Germany	> 450	> 450	> 450	>450	>450	>450	>450	>450	>450	>450	.	.	.	.	.	.
Estonia	2	2	2	2	2	2	5	6	6	5	8	10	11	11	9	9
Ireland	5	3	4	4	5	5	5	8	6	5	7	8	9	9	9	7
Greece	1	1	1	1	1	2	3	4	.	.	3	3	2	5	3	4
Spain	.	.	.	.	.	.	.	.	.	.	10	10	10	10	10	10
France	4	4	4	5	>5	>5	>5	>5	3	>5	5	5	5	5	5	5
Croatia	2	2	2	2	2	2	2	2	2	2	2	3	6	7	12	16
Italy	79	83	88	92	105	114	167	185	219	291	493	652	654	715	688	813
Cyprus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Latvia	5	7	6	2	8	8	10	11	17	17	43	76	80	84	96	72
Lithuania	5	5	6	7	7	7	8	9	10	17	20	20	23	27	25	25
Luxembourg	9	9	>12	>12	>12	>12	>12	3	4	4	10	10	10	10	10	10
Hungary	30	30	40	57	61	52	69	68	68	32	45	39	39	26	30	39
Malta	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3
Netherlands	≈87	120	100	200	1 000	1 000	900	700	700	800	700	350	650	300	350	350
Austria	34	39	53	91	106	137	128	126	129	145	169	201	192	226	228	226
Poland	31	54	70	51	54	55	59	68	73	111	103	128	162	197	211	202
Portugal	36	46	59	77	97	107	95	107	104	112	65	66	69	54	48	62
Romania	11	12	12	12	18	15	10	10	10	11	15	27	29	29	32	27
Slovenia	3	3	3	4	3	2	2	3	3	3	3	3	3	3	3	2
Slovakia	6	6	6	7	7	6	7	8	9	11	10	17	21	22	22	23
Finland	25	29	27	28	29	34	29	29	30	30	32	34	33	32	33	33
Sweden	7	14	14	11	9	8	11	24	64	74	35	32	33	33	33	32
United Kingdom	22	20	17	18	18	17	17	19	19	17	18	21	22	24	23	23
Norway	161	165	175	.	167	173	183	184	188	178	169	183	182	194	196	189
Montenegro	.	.	.	.	.	.	.	.	.	.	1	1	1	1	1	2
North Macedonia	.	.	1	1	2	1	1	1	1	2	2	3	3	4	3	3
Serbia	.	.	.	.	.	.	.	.	.	.	4	4	1	1	1	1
Turkey	148	172	29	30	36	39	69	60	60	54	87	150	209	225	246	277
Bosnia and Herzegovina	.	.	.	.	.	.	.	.	.	.	2	2	2	3	3	3
Kosovo*	.	.	.	.	.	.	.	.	.	.	1	1	1	1	1	1
Moldova	.	.	.	.	.	.	.	.	.	.	4	4	4	4	4	4

: data not available

(*) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

Source: Eurostat (This data is not yet available in the Eurostat dissemination database)

Source: Eurostat. (2020). *Statistics Explained*. <https://ec.europa.eu/eurostat/statistics-explained/pdfscache/9144.pdf>

Table 5:

Number of main electricity generating companies, 2003-2018

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Belgium	2	2	2	2	2	2	2	3	3	2	2	2	3	2	2	2
Bulgaria	5	5	5	5	5	5	4	5	6	5	5	5	5	5	5	5
Czechia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2
Denmark	2	3	3	2	2	2	2	2	2	2	2	3	3	2	1	1
Germany	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5
Estonia	2	1	1	2	1	1	1	1	1	1	1	1	1	1	1	1
Ireland	3	2	4	4	5	3	5	6	5	5	6	6	5	5	4	5
Greece	1	1	1	1	1	1	1	1	1	3	3	3	2	3	3	3
Spain	5	5	4	4	3	3	4	4	4	4	5	4	4	4	4	4
France	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
Croatia	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
Italy	4	4	4	5	5	5	4	5	4	3	4	3	3	3	3	3
Cyprus	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Latvia	1	1	1	1	2	2	1	1	1	1	1	1	1	1	1	1
Lithuania	2	2	3	4	4	4	3	5	6	6	6	6	6	5	4	4
Luxembourg	1	1	2	2	2	2	2	2	2	2	3	2	4	4	4	5
Hungary	6	4	3	4	5	6	3	3	3	4	2	2	2	3	4	3
Malta	1	1	1	1	1	1	1	1	1	1	1	1	1	1	3	3
Netherlands	4	4	5	5	4	4	4	5	5	4	4	4	4	4	4	4
Austria	7	5	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Poland	7	5	5	5	5	5	5	5	5	4	4	4	4	2	3	3
Portugal	3	3	3	3	3	3	3	2	4	4	4	4	4	5	5	5
Romania	7	6	7	7	7	7	6	6	6	5	5	3	3	3	3	4
Slovenia	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Slovakia	1	1	1	2	2	2	1	1	1	1	1	1	2	2	2	2
Finland	4	5	4	5	5	5	5	4	4	4	4	4	4	4	5	4
Sweden	3	3	3	3	3	3	3	5	5	3	3	3	3	3	3	3
United Kingdom	6	7	7	6	7	9	8	8	7	7	8	7	7	5	4	5
Norway	6	5	4	3	3	4	4	3	2	2	3	3	5	4	2	3
Montenegro	..	..	..	..	..	..	..	..	..	..	1	1	1	1	1	1
North Macedonia	..	..	1	1	2	1	1	1	1	1	2	1	1	2	2	2
Serbia	..	..	..	..	..	..	..	..	4	..	4	4	1	1	1	1
Turkey	3	4	3	3	3	3	3	2	2	2	2	2	2	2	3	2
Bosnia and Herzegovina	..	..	..	..	..	..	..	..	..	..	1	1	1	1	1	1
Kosovo*	..	..	..	..	..	..	..	..	..	..	1	1	1	1	1	1
Moldova	..	..	..	..	..	..	..	..	..	..	4	4	4	3	3	3

.. data not available

(*) This designation is without prejudice to positions on status, and is in line with UNSCR 1244/1999 and the ICJ Opinion on the Kosovo Declaration of Independence.

Note: companies are considered as "main" if they produce at least 5% of the national net electricity generation.

Source: Eurostat (This data is not yet available in the Eurostat dissemination database)

Source: Eurostat. (2020). *Statistics Explained*. <https://ec.europa.eu/eurostat/statistics-explained/pdfscache/9144.pdf>