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THE APPLICATION OF SOCIAL NETWORK ANALYSIS ON THE EU ELECTRICITY SYSTEM

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Abstract

This thesis aims at analyzing the developments in the EU electricity market over the period 2000 – 2016, by implementing Social Networking Analysis. This period is characterized by significant changes, such as huge penetration of Renewable Energy Sources (RES) in the energy sector, intensification of the efforts to address the climate change and the continuation of the procedure of the liberalization and interconnection of the electricity market at European level.

The thesis starts by describing the European energy strategy, presenting its three pillars: competitiveness, security of energy supply and sustainability. Particular emphasis is given to the procedure of the intergration of individual electricity markets. The purpose of a unified market is to contribute to the following issues: the competitiveness of the markets, the stabilization of electricity prices, improvement of energy efficiency and the confrontation of climate change. The electricity market's liberalization affects the competition among producers and supplies, but also the prices of wholesale and retail trade was based on the EU directives which are listed.

The Social Network Analysis is a popular method for analyzing different types of networks, however its implemention of the electricity market transformation is limited. By considering the European electricity market as a network and the regional markets as subnets, the Social Network Analysis enables the examination firstly of the degree of interconnection between the countries, both at regional and European level, and secondly of the role of each country into the energy grid. The countries that are are studied are the 27 EU – countries, with the exception of Cyprus, which is the only one EU member state, that is not interconnected with the rest of the EU network, and therefore the flows from and to the country are zero.

Through this study, conclusions can be drawn for the entire EU, for each country separately, as well as on how the network is changing over the years. The thesis provides a clear insight that the countries which have high considerable flows within the European energy network of the EU contribute to its transformation.. However, apart from the EU Member States, the non – EU countries are heavily involved in shaping the European electricity network, confirming the high dependence of the EU from these countries. Alongside, the study highlights the countries that operate as connecting links between isolated states and the rest of the EU network. Finally, it is confirmed that the geografic location of a country plays an important role in the interconnection and the energy transactions which take place.

1. Introduction

The need for electricity, at the early 20th centuries, has leaded to the creation of the electricity market, which, at most cases was controlled by the state. The states monopolies were responsible, not only for the construction and the appropriate function of the electricity power plants, but also for the distribution of electricity to residential, commercial and industrial consumers, whether the region was accessible or not.

The last twenty years, it was observed the countries' need to become independent on the state monopoly which controlled until now the electricity market. The development of technology that concerns the use of Natural Gas (Combined Cycle Units) along with RES and their penetration into the generation sector, gave the opportunity to small producers, to create their own electricity generation units, and increase the competition through this. That is occurred, due to the fact that the units based on Natural Gas and RES, are smaller and more economical than the traditional carbonate, lignite and petroleum units. So, because of the big competitiveness, Government Agenceis were forced to privatize a big part of the electricity generation units. Alongside, the penetration of the NG and mostly of the RES in this sector, was also helped the EU with the programs that has adopted, and target to the reduction of the greenhouse emissions and the confrontation of the climate change. Through those reforms, the inland competition started to be favored, and accordingly to timing and the topological specific issues, might the electricity price could be reduced.

Furthermore, the increasing inland needs in periods that the capacity could not cover the 100% of the needs, leaded to the increase of electricity imports from other states. Respectively, the fluctuation of electricity generation from RES, because of their seasonal character, had as a result the electricity surplus, which due to the lack of storage, it was exported to third countries. Those two opposite trends, affected the size of the transnational transactions of electricity. Today, all the EU – States (besides Cyprus) are interconnected at least with one country, either it belongs to the EU or not. This, tends to change through the next years and the countries that are considered to be isolated and dependent on one country, will be connected with even more countries.

So, the main purpose of this master thesis, is the study of the changes that took place in the EU electricity market, as a unit, but also per country as well, and how the climate change has contributed among with the penetration of RES in the industry developments. The innovative part of this study is the use of the Social Network Analysis (SNA). This method is mostly applied in theoretic science at the study of the interpersonal relationships. Today the range of applications has been expanded to different sectors: Medicine, Sociology, IT, etc. It is undeniable that technology and social networks are applied in every aspect of everyday life, by making our life easier. The SNA method, is implemented for the first time for the computation and annotation of topological characteristics and the index of interconnection of the electricity network. In conclusion, network illustration takes place and the way the countries interact with each other, but also the role each one has in the nerwork are observed.

2. The Energy Strategy of the EU

2.1. Introduction

Europe over the last decades aims at developing an internal energy market for electricity and gas needs, which it would offer to its citizen's security, efficiency, stability in prices, and interconnection between the countries. From 1997 until today, EU's aim, is to confront climate change through the energy packages, which can be signed not only from the EU member states, but also from many other states globally. At this chapter, the **basic packages** that EU has adopted over the last two decades are mentioned according the climate change. Furthermore, the energy strategy that EU has chosen to follow, with the three pillars of the strategy: **Competitiveness of the market**, **Security of the energy supply** and **Sustainability**, is analysed. Last but not least, the effect of the **EU – ETS** in the EU targets and the liberalization of the EU electricity market is presented.

2.2. The EU packages for the climate change over the years

The first attempt of the EU, for the climate change confrontation was in 11th of December in 1997 with the Kyoto Protocol, which is committed to reduce the CO2 emissions at least by 8%, the period 2008 – 2012, comparing to 1990. That agreement was a big challenge, for the industrial countries, which was obliged to reduce the 6 main emissions (CO2, CH4, nitrous oxide, hydro fluorocarbons, super fluorinated hydrocarbons and sulphur hexafluoride) which are responsible for the greenhouse phenomenon, and especially CO2 by 5.2% comparing to 1990, by 2012. The agreement was into force with the signature of Russia in 16th of February in 2005. [1]

In 2007, the need of a unified EU electricity market, made the EU Commission to make a new commitment, the Lisbon Treaty, which includes among others:

- The insurance of the energy market's function
- The insurance of energy supply's security's in the Union
- The promotion of energy efficiency and energy saving and the development of new and renewable forms of energy
- The promotion of the energy networks' interconnection.

The Treaty aims to show up the policies and EU measures for achieving the energy goals for 2020 and the predictions on energy targets for 2050. It actually makes clear the aim of achieving the EU's decarbonisation, and the need of securing the energy supply and competitiveness. [2]

The package that is now into force is the "European Targets 20 – 20 – 20", with the EU to set the targets higher, and more specifically:

- At least 20% reduction of emissions comparing to 1990 greenhouse gas (30%, if it is appropriate the conditions at international level, the European Council of 10-11 December 2009)
- Saving 20% of EU energy consumption compared to projections for 2020

- 20% share of renewable energies in EU energy consumption
- 10% share in transport, by 2020. [3]

By this agreement, the need of the interconnection of the Baltic countries, Iberian Peninsula, and the member states which are more isolated like Cyprus, Malta, and Greece, at least 10%.

At the heavy industrial and the electricity generation, the upper limit of the emissions' reduction is to 21% until 2020, according to EU – ETS. [3] At the electricity sector, the emissions come across with huge reduction, at the same time, due to the penetration of RES and the replacement of fossil fuel power plants with natural gas plants.

But it does not stop there. It has already announced the targets for the next 20 years through a new package named new package "EU Winter Package".

The EU Winter Package, was published on 30 November 2016, by the Commission, and its aim is to provide clean energy to all citizens, and to reform the EU electricity market structure.

The first category of measures are for the structure of the market, also known as the market design initiative (MDI) which includes a new directive amending and releasing Directive (2009/72) (E- Directive), a new regulation on internal electricity market (E- Regulation), and a new regulation on the ACER (ACER Regulation). Some measures are going to be into force at 1st of January in 2020.

The second category of measures concerns the climate change targets into the new market design. It will be a full revised Res Directive (RED), a fully revised Energy Efficiency Directive (EED), while both of them will be into force on 1 January 2021.

Last but not least, the third category, which includes the risk preparedness in energy market (the Risk Regulation) and the regulation on Governance of the Energy Union (the Governance Regulation), both will be in force on 1 January 2021.

To begin with, the increase of the RES sharing in electricity generation, in addition to decentralised production and self – consumption, gives the opportunity to more players and creates more roles like the aggregators and "prosumers". It is important to be mentioned that even though the markets are interlinked and are functioning well the risks of a crisis are difficult to be prevented, and surely the consequences will not be limited to national level. All these changes in order to be into force it is vital, for the governance of the EU electricity market to be revised. Another point is that EU member States, must define and publish a long - term schedule in relation to expected allocation for support, as well as a consultation of stakeholders on the design of the support, so the investors be ensured concerning the sufficient predictability of the planned support for energy from RES. Another sector that "EU Winter Package" tries to upgrade is the Network functionality, with the purpose that consumers meet a better experience. The Commission wants to ensure a co – ordinated regional approach to transmission system operations with the creation of new Regional Operational Centres (ROCs). To a certain extent the regulatory supervision of these entities will be carried out by ACER. Concerning the Distribution sector, EU is bound to strengthen the legislative framework for cooperation between DSOs and TSOs, in order all the necessary information is shared, and that the use of distributed resources is coordinated. [4]

In 2015, through the Paris Agreement, the EU Commission is committed for the targets for 2030, by setting the following commitments:

- 40% reduction in greenhouse gas emissions compared to 1990 levels
- At least 27% share of RES in the electricity generation
- At least 27% energy efficiency.

The aim of these targets is to ensure the new investments, to enhance the transparency, and policy coherence, to revise the limits of the Emission Transmission System (ETS) and improve the interconnection between the states. [2]

The European energy strategy has evolved through time, as it aimed to meet competing targets. However, in this long process there are some key targets as well as key instruments that were vital. Those basic targets, as well as the European ETS system are described in the next sub-sections.

2.3. Basic targets of Energy Strategy in the EU

In order to be able to tackle all those new challenges, European energy strategy set up three targets – pillars:

2.3.1. Competitiveness of the EU electricity market

The aim of the competitiveness in the market is for the electricity generation to become more efficient and cheaper, so it benefits more the EU citizens and the whole economy and offers a better quality of services. By increasing the competitiveness, the high global energy prices will drop down, and the cost for the production of the EU industrial products will be decreased.

That target will be achieved, by the usage of new technologies, more efficient and eco-friendlier, not only in the production of the energy but also in the demand sector, through actions which serve at the time other targets of the EU energy strategy.

Despite the important technological upgrade, the legal frameworks according the boost of the competitiveness are vague. The existence of the monopoly structure of the market in many countries, the dependence of a lot of member states from non-EU states, in a percentage more than 50%, and the unclear diminishment of the prices are the basic reasons for the non-informative legislation.

However, the penetration of RES in electricity generation has an important role in the liberalization of the market, and the increase of the competition, in EU level. The development of the RES technology, provides the opportunity to small producers, to construct their own generation unit, and produce electricity. In that way, the competition in the national level, and at the same time, the increased interconnection between countries, leads the competition outside boarders, with better quality of energy mixture trading, in more competitive prices. This also affects positively and the security of supply, by keeping the total cost of supply, in low limits, only if the demand and the supply are in equilibrium.

Despite the fact that the high competition has diminished in the wholesale trade prices, the retail prices, do not present big changes, and that's because of the taxes that are included in the electricity bills, as we will be analysed below. The innovations that technology offers to consumers these days are so many. By using smart meters, installing small – scale photovoltaic and wind generators, for individual electricity generation, the consumers are in position to have better information, and more control in what they consume to their energy bills, and in parallel the penetration of RES will become more and more in the energy sector and their efficiency will be increased. [5]

2.3.2. Security of Energy Supply

As it mentioned above, despite EU is the second biggest financial power in the world, in 2016 it imported more than 58% of its energy consumption, due to the reduced production of primary energy from the basic sources of energy (oil, natural gas, solid fuels, and nuclear energy) and increase of the RES. As it is presented at Figure 2, the basic degree of dependency remains constant for all the resources, except for solid fuels, that diminishes thanks to the EU measures that has been taken in order for the reduction of GHG emissions to be achieved. If the EU Commission doesn't take the necessary measures, then the EU will continue to be dependant at 65% for its energy needs for both oil and natural gas by Russia. The disputes that exist for years between Russia and Ukraine, force EU to find alternatives more quickly than it tended to. The Ukraine's exclusion from importing fuels from Russia, had as a result for half of Europe to be frozen. After that, EU moved to economic sanctions with US against Russia, something that brings instability to the region, and has negative affects to any business that intends to grow there. [6]

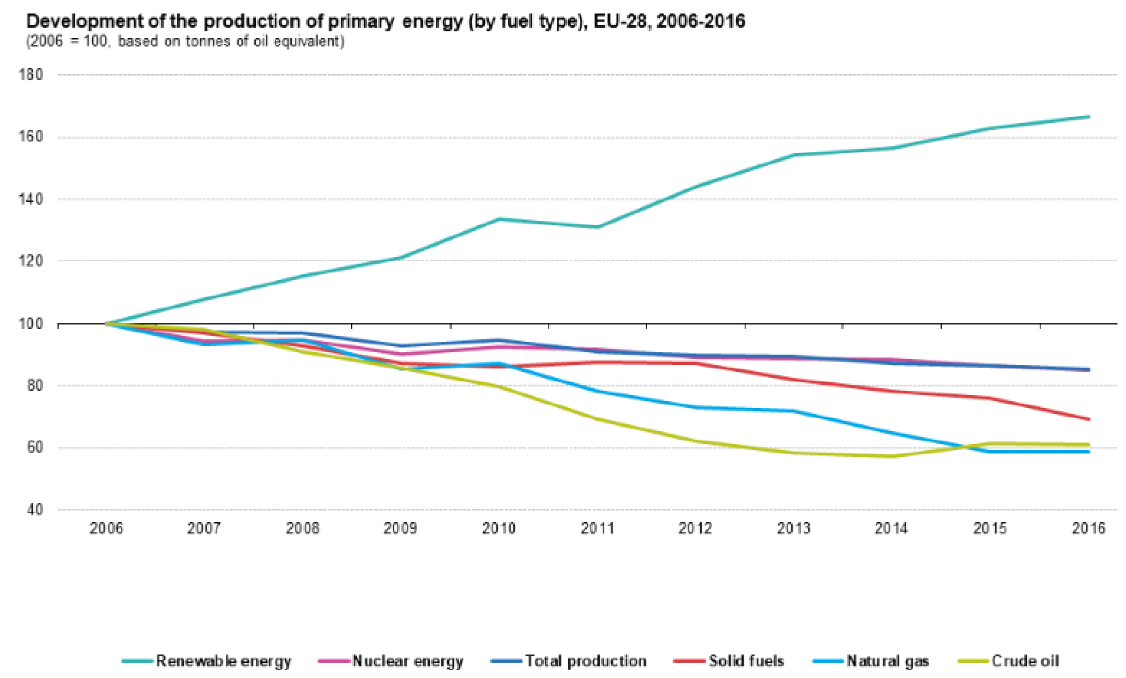


Figure 1 Production of primary energy (by fuel type) in the EU, 2006 - 2016

Source: [7]

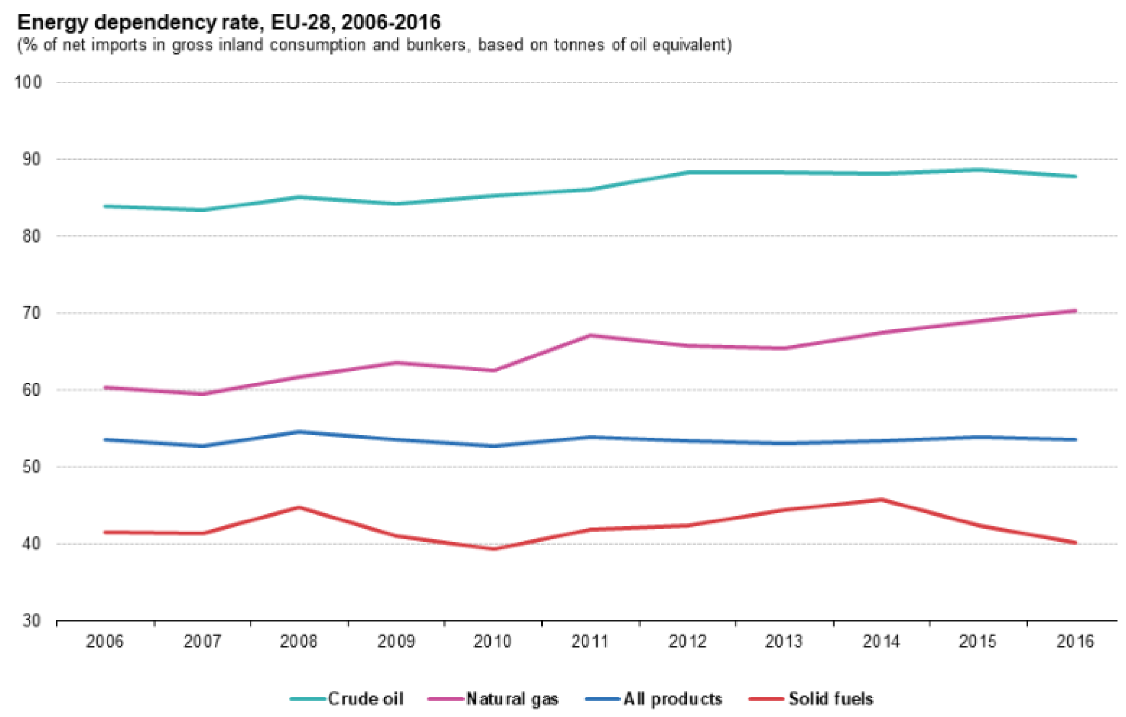


Figure 2% Net imports in gross inland consumption the years 2006 – 2016.

Source: [7]

Particularly high is the degree of security of energy supply, thanks to the stability that energy networks offer. However, there are member states such as the Baltic States that are exclusively dependent from Russia and Belarus, for their energy supply, two countries that are responsible for the managing and balancing of their networks.

It is considered as vital meaning to secure the infrastructure projects in the wider region, so in case of these networks' dominance from non-EU states, not to be manipulated, but their management would be based on the current legislation. Furthermore, in order for the supply system to be stabilized even more, it is important the achievement of the interconnection target, of all EU countries by 2030. It has to be said also that, the electricity system for most of the countries is dependent on the imported natural gas, mostly from Russia and Norway. This threatens the uninterrupted continuation of power generation in periods of instability, and thus the security of citizens' electricity supply.

It is obvious that, the continuous demand for electricity leads to new investments in the interconnection networks, and to new more eco-friendly power plants. So, through the unbundling of distribution/ transportation, the production/ supply, and the upgrade/ the interconnection of the networks with power plant stations from neighbouring countries and with RES stations, networks will become more flexible, based on the demand and the quantity of electricity that will exist in the grid.

Moreover, the liberalization of the electricity market, leads to the creation of a bigger system, with networks that will have enough capacity to ensure the continuous feed of electricity, in cases of electricity generation disruption in individual systems and for the electricity distribution to be balanced. In this way, the sudden increase of prices will be prevented, by offering autonomy to every country, and by offering better services to the consumers at the peak off points. [8]

2.3.3. Sustainability

The most important target that the EU has set is its contribution in the diminishment of the greenhouse gas, which are responsible for the increase of the Earth's temperature. According to Figure 3, it is obvious that, EU, from 2000 already, it was at the position to produce at least 40% of the total electricity production, from resources which are harmless to the environment, such as RES and Nuclear power. At this point it is vital to be mentioned that, RES percentage is due to hydro sector and a very small contribution of wind power. Over the years, the contribution of the conventional resources at the electricity generation is continuously decreasing, especially after 2008, which was the year of the Kyoto protocol measures set in force. In 2016 the contribution of the "eco-friendly" resources is up to 55%. We can also observe that the percentage of gas over the years is quite stable. More specifically, in 2016, RES percentage in the energy generation mixture was 30% and at the same time the percentage of nuclear power was 25%. [9]

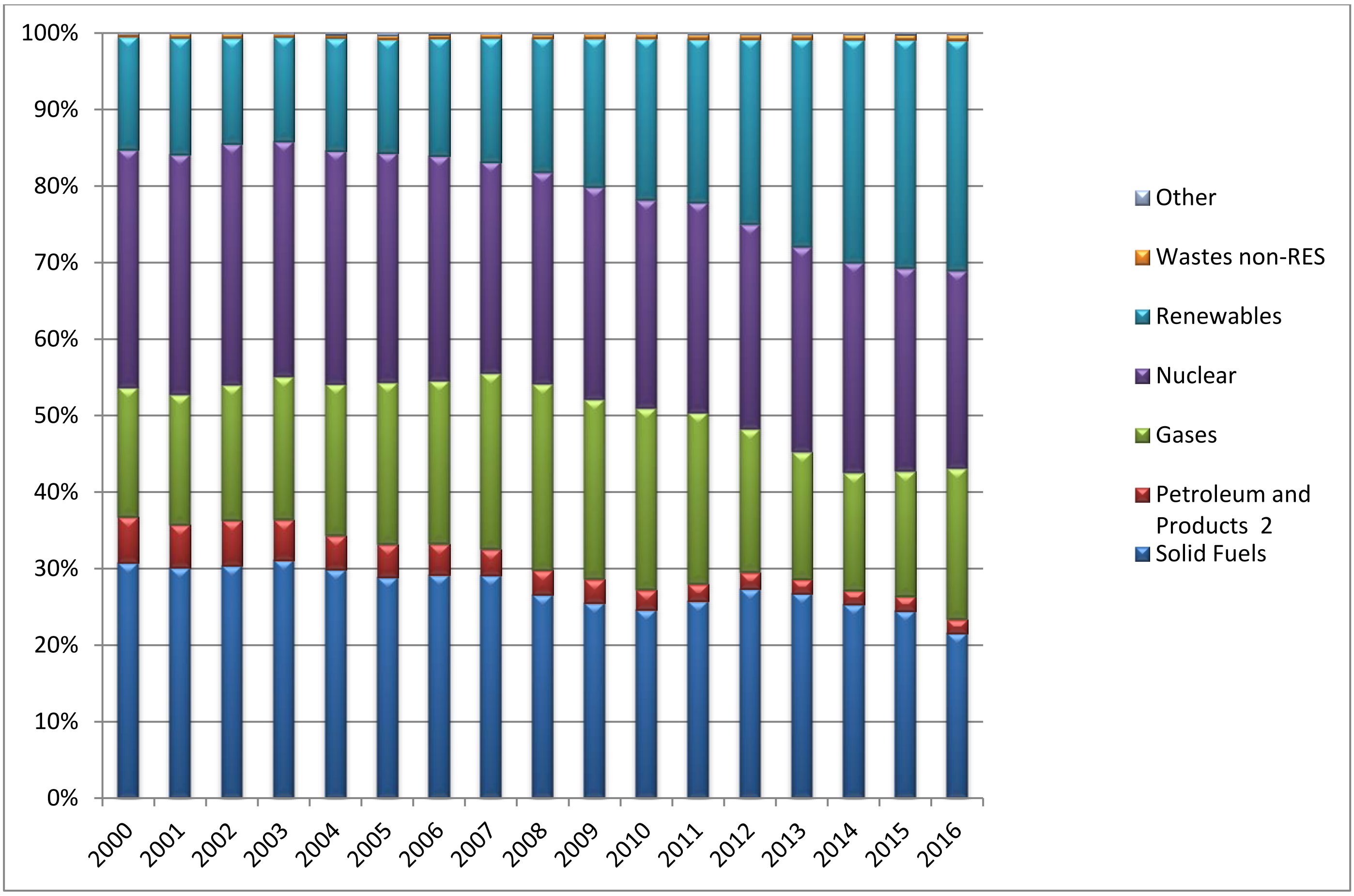


Figure 3 Contribution (%) of various resources in the electricity generation in the EU, 2000 – 2016.

Source: [9]

The decrease of the conventional energy sources in the energy mixture of the EU, is the result of the enormous increase of the RES percentage, in the electricity generation. In the Figure 4, is shown the participation of the solar and wind power from 2000 to 2016. At this point it is important to be mentioned that, if solar and wind power would be developed more in Mediterranean countries such as Italy, Greece, Cyprus, but also, Croatia, Iberian Peninsula, not only they would contribute to the energy mixture with electricity from RES resources, and bring the EU one step closer to accomplish its goals, but also, they could make these countries more independent, and competitive, as long as they would supply other countries with their surplus, and participate to the price formation.

Except for hydro power which was the master of RES for many years, it is doubtful the fact that wind power has an enormous increase all the sixteen years of our study, while at the same time solar power where become more important to the energy mixture after the 2008. That could be explained from the fact that many countries started to invest to photovoltaic panels, and persuaded citizens to buy and install more. Wind power is the same levels as hydro power in 2016.

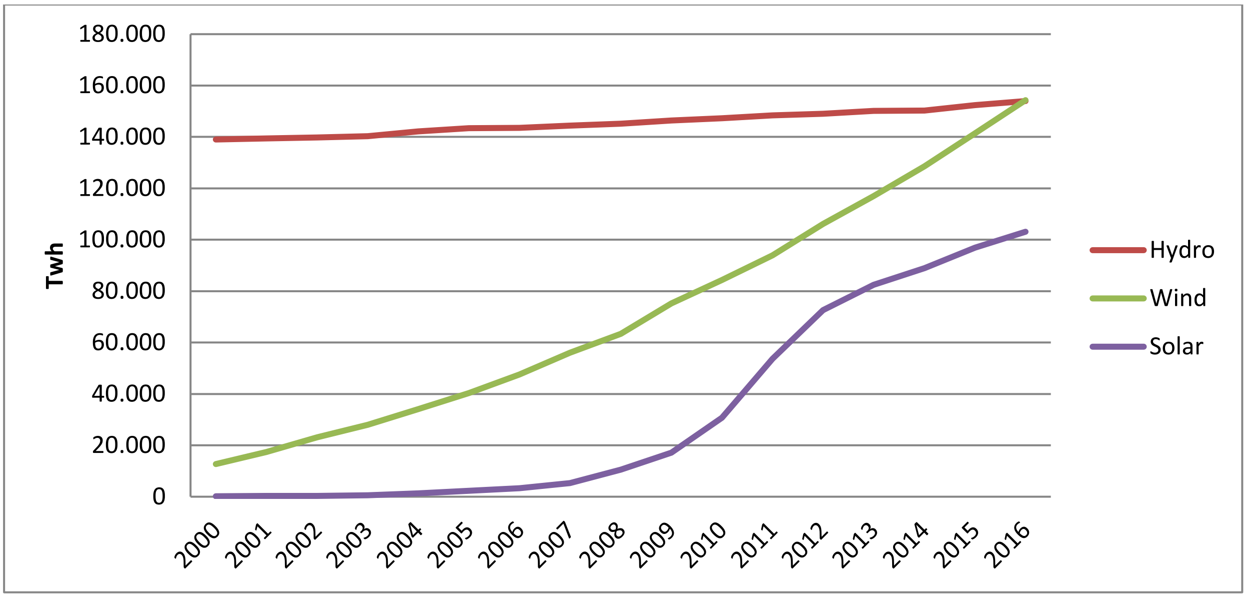


Figure 4 Generated Electricity Power (in TWh) in EU, 2000 – 2016.

Source: [9]

However, concerning the fact that, almost 60% of the EU consumed electricity, is imported from third countries, the percentage of the EU generated power, from eco-friendly sources, is undervalued. So, under this prism, the picture is totally different, at the level of the consumption of primary energy, as it is shown at Figure 5. The usage of fossil fuels at the domains of final use (industry, buildings and transportation), despite the measures of energy saving and the promotion of RES, is extremely high, which leads to respectively high environmental consequences. However, over the years, the usage of petroleum and solid fuels is reduced, while the usage of RES and gas, is quite constant all the years, at 20% and 10% respectively.

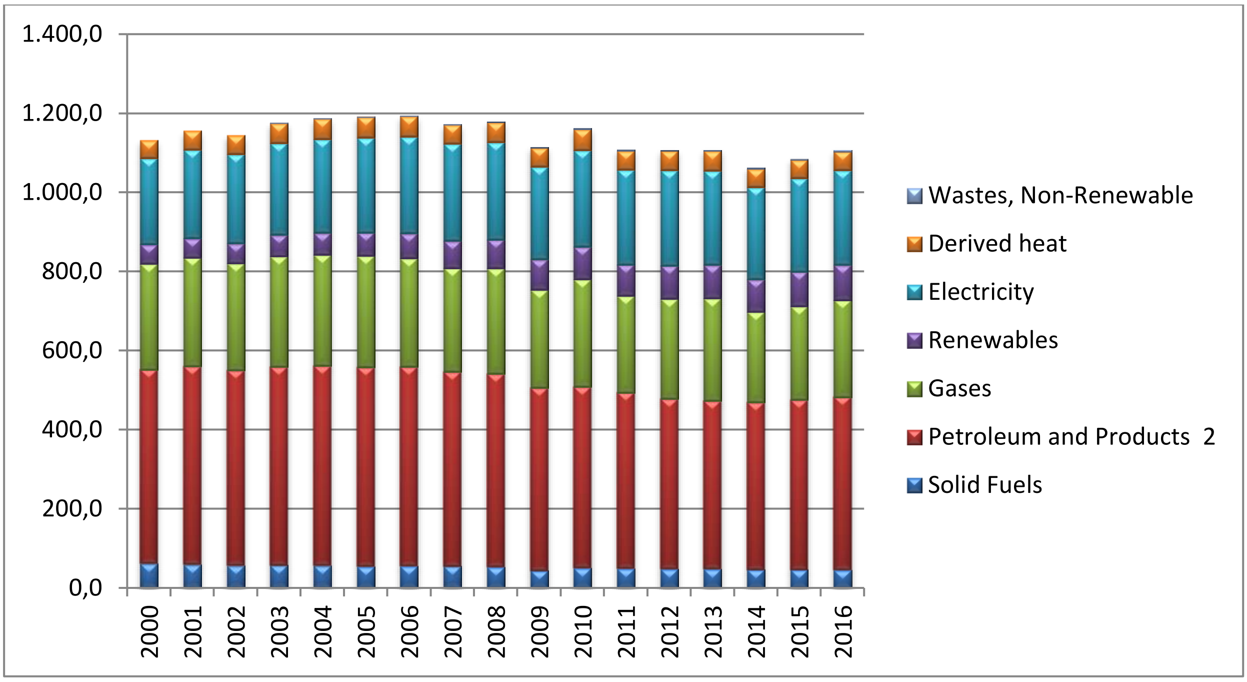


Figure 5 Total consumption of primary energy (to TWh) in EU, 2000 – 2016

Source: [9]

In addition to these, through the packages that EU has set in force from 1997 until today, the reduction of the emissions, is its priority. According to the database of Eurostat, the CO2 levels per capita in 2016 is 25% reduced comparing to 1990, surpassing the target for 2020, and showing this way that the 2030 target for 40% reduction is possible. [9] At Figure 6 and 7, it is shown the CO2 per capita, for each country, and for the EU as a unit, for the years 2000, 2007, 2013 and 2016, and for the years of this study respectively. As we can see, some countries, especially, Estonia, Greece, Spain, Croatia, Latvia, Lithuania, Luxembourg, Austria, Poland, Romania, Finland and Slovenia, has increased their CO2 emissions, in 2007, concerning the 2000's emissions, while EU as a unit, kept its emissions at a stable level. The stability in the EU is due to the fact that, industrial countries as Belgium, France, Germany, Ireland, Sweden and UK, diminished their emissions, the same time, while the economy, was at its best time. This shows that, the correct information of their citizens, and the measures were taken, concerning their industrial occupation, had positive effects to the emissions part. The picture changes at 2013, where the diminishment of emissions is more than obvious for most countries, except for Estonia, which has an increase. That change, is the result of economic crisis which has been troubled EU, but also to the adaptation of a new life style, by limiting the unnecessary needs, concerning the transformation and the consumption of energy – efficient goods, by substituting them with eco-friendly goods, by emitting less fuels and having higher energy efficiency. That diminishment is continued until 2016, where only in Netherlands there is a small increase.

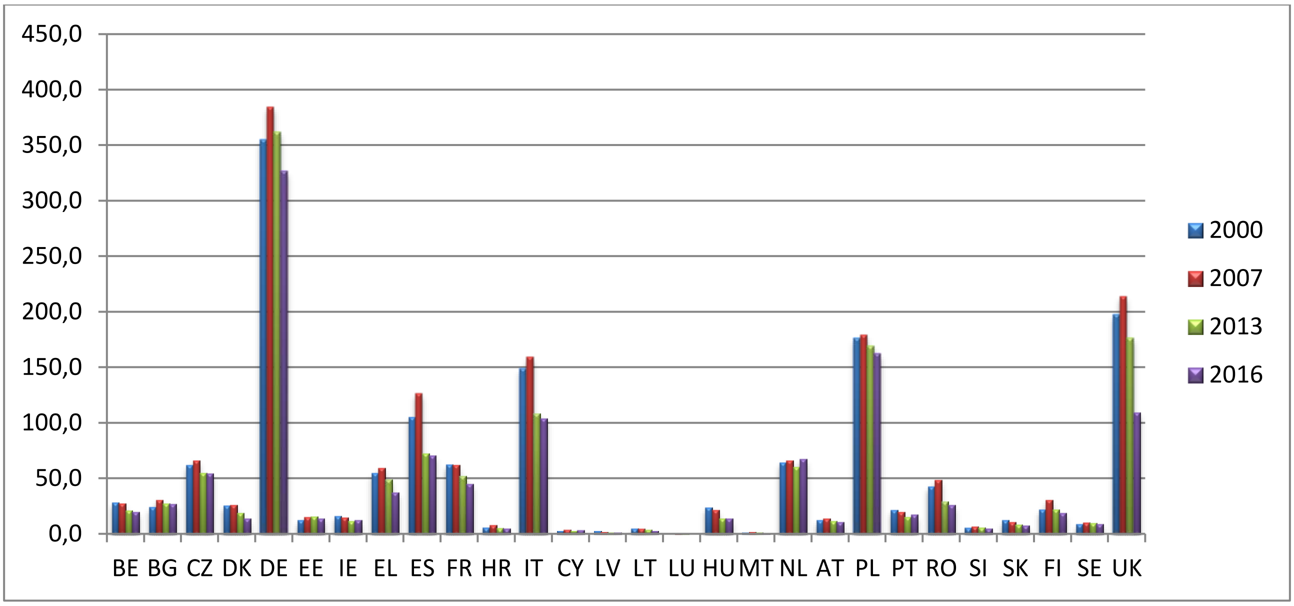


Figure 6 CO2 per capita (to kg) of the EU countries.

Source: [9]

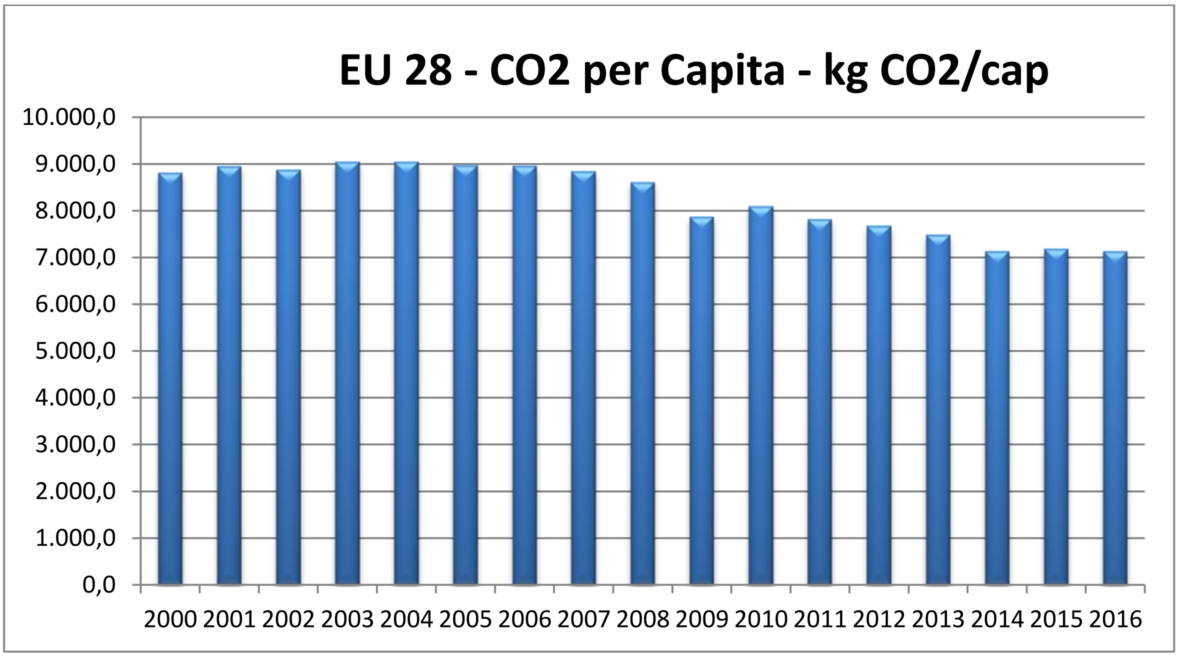


Figure 7 CO2 per capita (to kg) for the EU.

The limitation of the emissions, except for the change of the EU life style, it is also achieved by the penetration of the RES, which is increased in the gross inland consumption from 5.7% in 2000, to 13.2% in 2016, and it is 7 points far away from the 2020 target. More specifically, RES constitutes the 30.2% of electricity production in 2016 comparing to 2000 which was 14.8% [9] Last but not least, the energy efficiency in the primary energy consumption was diminished by 10% in 2016, compared to 2005 and the final consumption was 16.7% less the same year than the projections that made in 2007. [10]

It is clear that by limiting the useless electricity consumption, the transformation of the new buildings, to low or zero emitting gases building, and the usage of RES not only in the residential domain, but also in industrial domain, the EU states, are targeting to the zero energy consumption, and their only dependence will be from RES for their energy needs. [11]

2.4. The EU – ETS and its contribution to the liberalization of the electricity market.

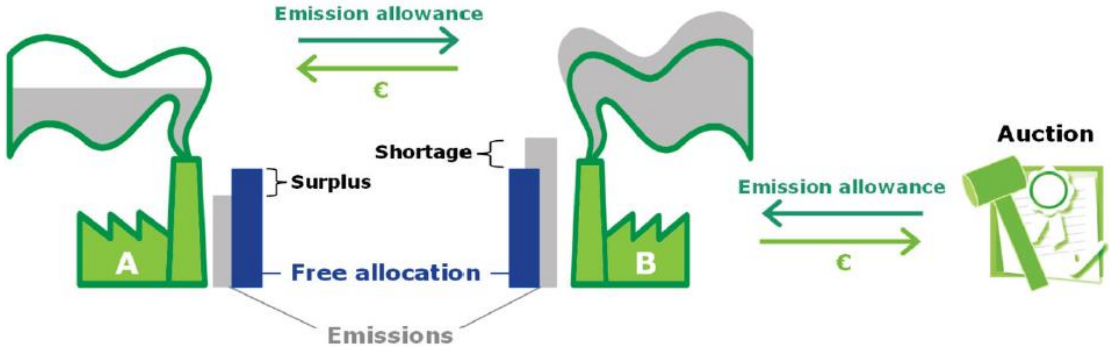
The EU – ETS is the first worldwide trading system that gets all the surplus coming from industrial and aircraft operations from the EU member states but also plus Iceland, Norway and Liechtenstein and trades them. This system was created due to the need of the EU to achieve the target of limiting greenhouse gases. It was observed that, while some countries managed to reduce their emissions below the EU target, by far, some didn't manage to reach the limit EU set for them. [12]

More specifically, EU ETS, was established in 1st of January in 2005, in order to help EU meet its goals with the Kyoto Protocol. It actually allows to countries to buy, when their CO_2 emissions are lower than its highest level that EU has set for them, and to sell when the opposite occurs. Industries are obliged to return one allowance for each tonne of CO_2 equivalent (tCO_2e). EU ETS covers only the emissions of the 27 countries of EU plus Iceland, Norway and Liechtenstein, and it controls almost 11.000 instalments, along with the power plants, which are responsible for the half of the total CO_2 emissions of Europe. [13]

EU – ETS is consisted by 4 phases:

- The 1st phase ran from 2005 – 2007 and it was a trial period, just to see how to be implemented, while at the same time, it was established as the world's biggest carbon market. Unfortunately, the allowances that were available, were much more than the estimated needs. The price of that period was zero in 2007.
- The 2nd phase, ran from 2008 – 2012. The first year, 3 more countries were joining the program, Iceland, Norway, Liechtenstein. The allowances were reduced by 6.5%, but the economic crisis, leaded to the diminishment of the emissions, and also the demand, so the allowances were for one more time in a surplus, and credits which continues to weigh on the carbon price. The last year of the period, aviation joined the program.
- The 3rd period ran from 2013 – 2020. The first year Croatia joined the program, while the allowances of the emissions were reduced by 1.74% each year, and the auctions of the allowances in place of cost – free allocation, get into force.
- The 4th period ran from 2021 – 2030. The legislative proposal was presented by the Commission in July 2015, in the Winter Package. [14]

Each year a number of allowances are given for free to certain industries, because if these industries were obliged to pay the full amount of their emissions, it would force them to move abroad and especially in Middle East, where the measures for the reduction of the emissions are not so severe. So, if an industry has insufficient allowances, then actions has to be taken in order to become more eco - friendly, or buy more allowances in the market. Industries can buy allowances either from the auction or from each other.



Source: [12]

Concerning the electricity sector, it started to participate to the auctions at 2013. The only exception is the free allocation for the modernisation of the power sector in certain member states. This might have negative effects to the competitiveness between the industries, which are not Members of the EU, due to the high cost of the production in the wholesale market. However, the revenues from the EU – ETS, are provided for innovative RES and storage projects and carbon reduction.

It can also be said that EU ETS has contributed to the green growth and the strengthening of the competitiveness of the European economy, by putting a price on carbon. By that, it reduces the risks concerning the increase of energy prices, while at the same time, it opens the road for new investments to RES technology, and therefore the independence from conventional fuels, but also it enhances the energy security. Last but not least, it contributes to the decarbonisation of the European economy, by stabilizing the environment policy for low carbon investments and clean technology.

On the other hand, the price on carbon raises costs associated with pollution, and there are concerns that there could be an impact on the competitiveness of certain industrial sectors relative to competitors in countries with lower levels of action to reduce GHG pollution. In order to address these concerns, industry sectors for which there is the risk of carbon leakage due to carbon price under the EU ETS, are supported through the provision of additional free emission allowances as well as by state aid by Member States.

By imposing a decrease in the cap of the allowances, it keeps stable the CO2 price, in the market, thanks to the possibility of the storage of the surplus of the allowances, for a future use. [14] [15]

The EU ETS supports the decoupling of energy consumption and GHG emissions from economic growth. To support the promotion of low-carbon investment at least-cost to society, the Commission has made proposals, based on lessons learnt, to improve the effectiveness of EU ETS. [12]

It is vital, to come across with a global agreement concerning the CO2 emissions, because the ETS is only for the EU, differently, its market will have to compete with the high production cost, which will be in favour of the import of the non-member States, where the CO2 price is very low, and its exports will be decreased.

To sum up, EU ETS is influenced by: the percentages of RES which are used in the electricity generation, the prices of allowances, which when they are increased, they make industries to use natural gas, instead of coal, due to lower emissions, and last but not least, the price of fuels, which is unstable. In order to avoid the purchase of the allowances, the electricity producers, try to find new, clean sources from other producers in or out of the country, and limit the use of old-fashioned plants. In that prism, ETS encourages the liberalisation and the unity of the electricity market. [14] [15]

3. The developments in the EU electricity system

3.1. Introduction

During the 1990s, most national electricity and natural gas markets were still monopolised. The European Union has prioritized their gradual liberalization, as this would enhance its competitiveness. The first liberalisation directives, known as the First Energy Package, were adopted in 1996 for electricity and in 1998 for natural gas. This has been adopted by Member States' legal systems within a two years period. The Second Energy Package was adopted in 2003, adopted in national legislation by Member States by 2004, with some provisions entering into force few years later, in 2007. This package has enabled initially industrial consumers and gradually all domestic consumers to choose their natural gas and electricity supplier. In 2009, a Third Energy Package further liberalised the internal electricity and gas markets facilitating the process for the implementation of the internal energy market.

The main target of the market's liberalization, is to ensure that the distribution of the electricity, will be based on equality and justice between the participants, while the consumers are having the chance to choose by their own their supplier, based on price which is more satisfying for them. By this, the competition of the sector is increasing, so the supplies can buy in lower price the electricity from different producers, and offer the product to a lower price.

The liberalised market is consisted of the wholesale and the retail market. Concerning the former, the producers compete each other, in order suppliers buy the commodity in the best price and more favourable terms. On the other hand, for the former, their purpose is to make the best deal with the final consumers, concerning the price, payment terms, guaranty etc.

3.2. The electricity market in the EU Member States

Like every market, electricity market has two district pillars: Supply and Demand. Both poles are influenced from technological changes and different policies, too. The effect of these domains at the electricity market are examined below.

3.2.1. Electricity Demand in the EU

The demand of electricity is counterbalanced:

- The increased, which is due to the better standard of living and the increased demands of the consumers. More specifically, this tendency is very high in periods of economic growth, while in periods of recession can be reversed.
- The decreased, which is due to the implementation of clean energy technologies, and the change of the consumers' behaviour to the road of the right use of energy.

It is obvious that, other factors influence the total quantity of demand, for instance: the prices, the degree of industrialization, the climate, etc.

In EU, the consumption of electricity presents an increase, comparing to gross and energy consumption, showing that electricity is becoming a substitute of other types of energy in the final demand (mostly, the solid fuels). For the record, the electricity demand has been increased per 28.8% the period 1990-2016 [9]. At the Figure 8, is presented the consumption of energy per capita at the EU states, in 2000, 2007, 2013 and 2016.

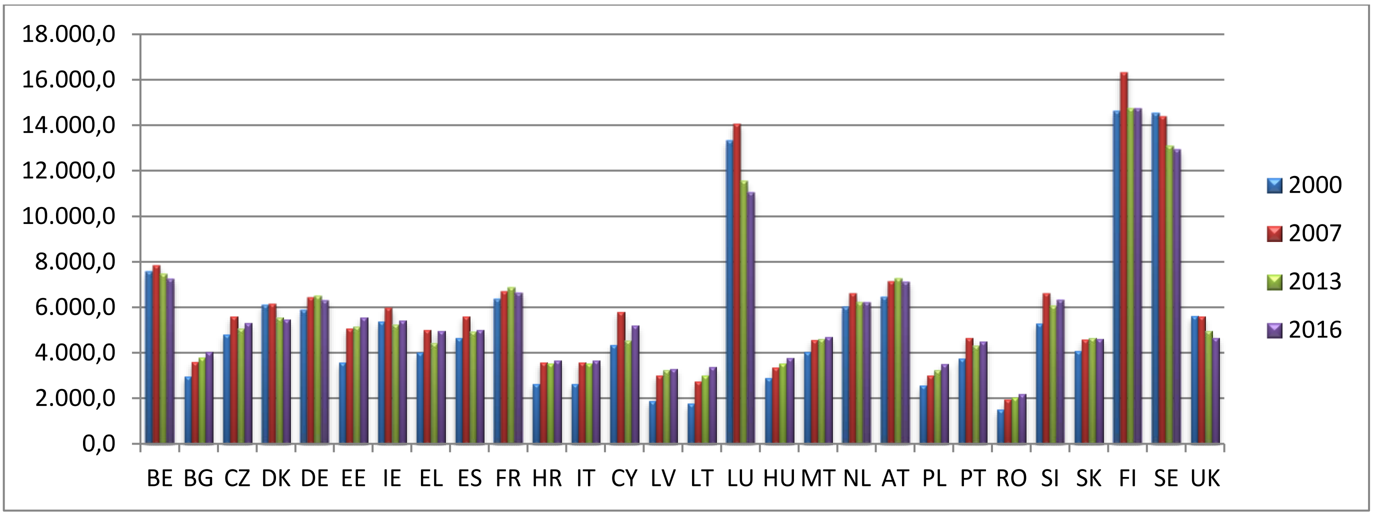


Figure 8 Energy Consumption per capita (in kWh) in the EU Countries.

Source: [9]

It is undeniable that, until 2007 the consumption per capita was increased for the majority of the member states, except for Sweden which presented a small diminishment according to 2000, and UK which's consumption remained constant.

The consumption per capita, is the most important factor which participated in the increase of the CO2 emissions the same period as it is mentioned at the previous chapter. This increase has its roots to the improvement of life style, and the prosperity that existed in the EU member states until 2007, making citizens to consume more electric power, in order to satisfy their augmented, and usually, unnecessary needs. In 2013, countries' consumption does not present the same route for all the states.

Most of the EU states, limit their energy consumption according to 2000, which is expected, by taking into account the economic crisis of 2008. The developed countries like Belgium, Denmark, Luxembourg, Sweden, Finland and U.K, has diminished their consumption levels, even more than 2000. This is obvious the result of the right education of their citizens, concerning the environmental awareness, by how they can use energy, in the most efficient way, in order to satisfy their everyday needs, and by buying products, which are based on ecologic design, in order to use less energy and be more efficient. Unfortunately, the results are not the same for the Eastern and South EU countries, and more specifically, Estonia, Latvia, Lithuania, Hungary, Poland and Bulgaria, which present a positive difference between the consumption of 2007 and the consumption of 2013. This is because of the continuous development of the countries, but without the right education of their people, like the other EU countries, in starting using goods of low energy consumption. In 2016, things are quite the same as 2013. The countries which presented an increase in 2013, they continue to consume even more than 2013, three years later. The same path is following countries like, Czech Republic, Greece, Cyprus, and Portugal, which proves that, the limitation of the consumption 3 years earlier, was the result of economic difficulties, people were dealing with, and not the correct usage of energy. The abovementioned developed countries, continue to present negative difference between the consumption of 2016 and 2000, which verifies the findings that mentioned before. The rest of the countries continue to present a stability, at the consumptions of 2016 and 2013.

3.2.2. Electricity Supply in the EU

The changes at the electricity supply are the reflection of the efforts to satisfy the increased demand, but also the policies for the restriction of the greenhouse gases. The total installed power is increasing from 680 GW in 2000 to 990 GW in 2016, which presents an augmentation of 45% [9]. That great increase is the result of the successful penetration of RES which are characterized by low technical efficiency (GWh/GW). At Figure 9, it is undeniable that in 2000, the installed power of wind park, is increasing with a stable rhythm, while photovoltaic are making their debut in 2005, and their penetration is enormous, if someone observes that in 2016 their instalment is 53GW less than hydro energy, which shows how important is their role in electricity.

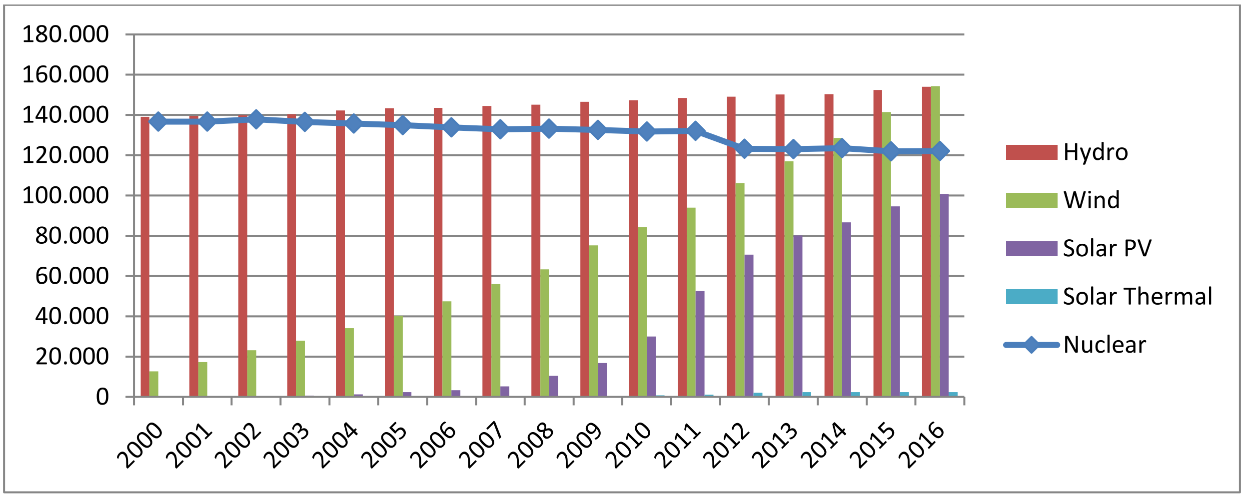


Figure 9 Installed Power of RES (in MW) in EU, 2000 – 2016.

Source: [9]

So, it is undeniable that, the energy mix of the electricity production of EU, changes significantly, with the participation of RES to be risen. According to Figure 10 it is obvious that Europe since 2000 was in position to cover 45% of its electricity generation from eco - friendly resources with zero greenhouse emissions, and more specifically from hydro plants and nuclear power plants. However, basic resource for the electricity generation are the nuclear power plants and the fossil power plants, which are the 50% of the total generation in 2016 [9]. Looking more closely to the same diagram, it is shown the constant diminishment of their participation in the energy mixture, and this a result of several reasons. Concerning fossil fuels, EU as it is mentioned before, tries to limit the greenhouse emissions, so it looks for new resources of power. On the other hand, the decrease of nuclear power, is due to the shutdown of a big number of nuclear power plants, all over Europe, due to the Fukushima accident in 2011, with the first country being Germany, according to many resources [16] [17]

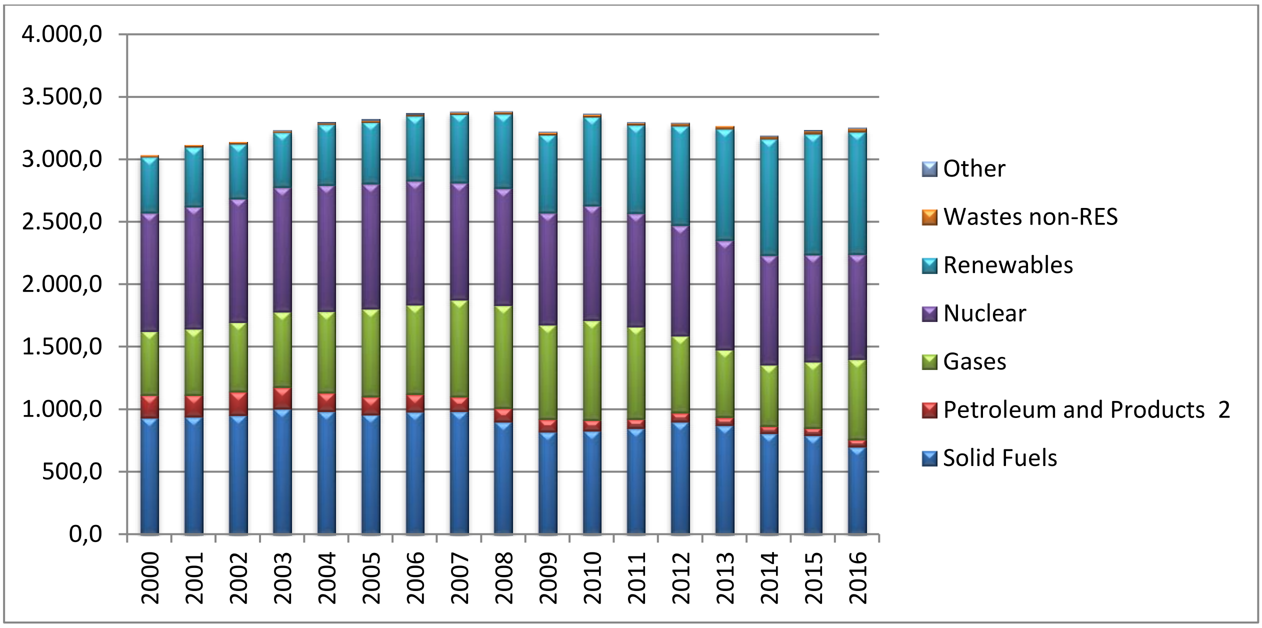


Figure 10 Energy mixture of the electricity generation (in TWh) in EU, 2000 – 2016.

Source: [9]

Another important observation is the pick of electricity generation in 2008, and the constant diminishment and its stability from 2010 and on. This behaviour is because of the limited demand for electricity from the EU member states, making clear, for one more time, the necessity of EU for a change, from a consuming are, to a Europe which has as its purpose the environment protection, through its independence from the conventional resources of energy, and the increase of their energy efficiency.

So, the need of the limitation of fossil fuel use and the petroleum products, in addition to the fear against to nuclear power plants, leaded to the development of new technologies, which targeted to the exploitation of natural elements. Based on Figures 11 and 12, it is observed that the participation of RES is constantly increased is a big percentage. In 2000, the 86% of power generation from RES, it was based on hydro power, with the next one in line being the biomass with 8% of the total production. It is true that hydroelectricity was the first energy of renewable resources, thanks to public units of electricity generation. Not only with the evolution of technology in the wind turbines and the photovoltaic panels , but also with the state's support to the private investors through tax exemptions, subsidies etc., the hydro power, was diminished by 45% in sixteen years, giving a chance to wind and more to solar power to participate more dynamically in the European mixture. An important increase presented biomass, with a plus 10% in the final production.

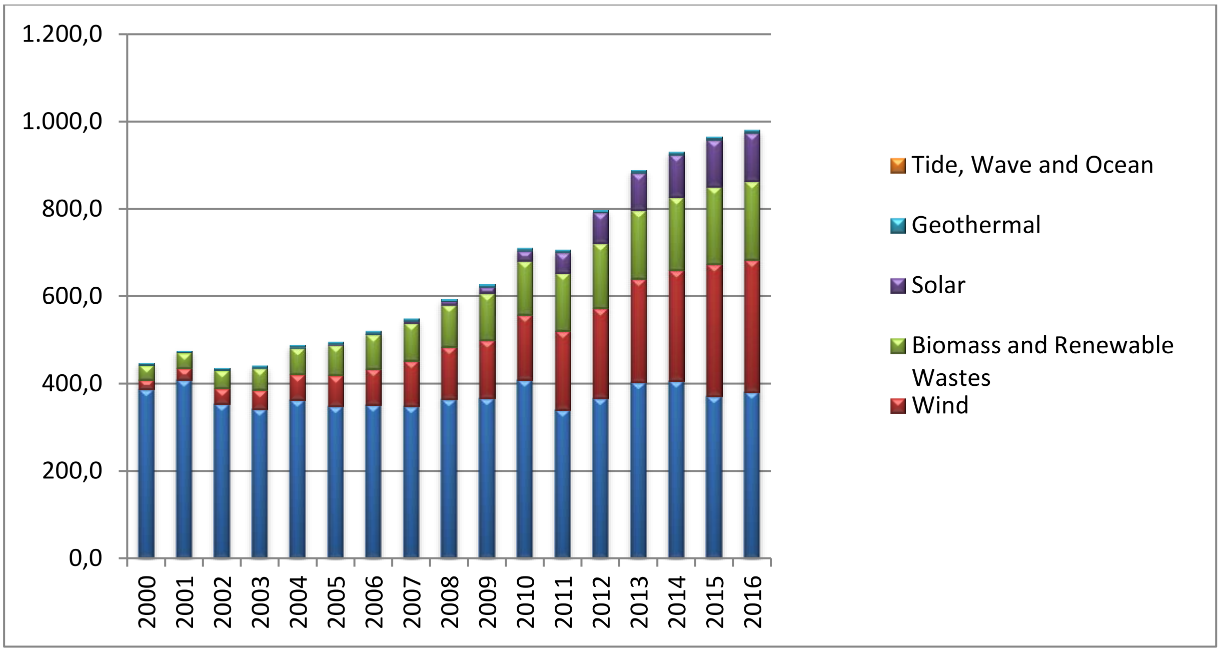


Figure 11 Electricity generation in EU (in TWh) from RES, 2000 – 2016.

Source: [9]

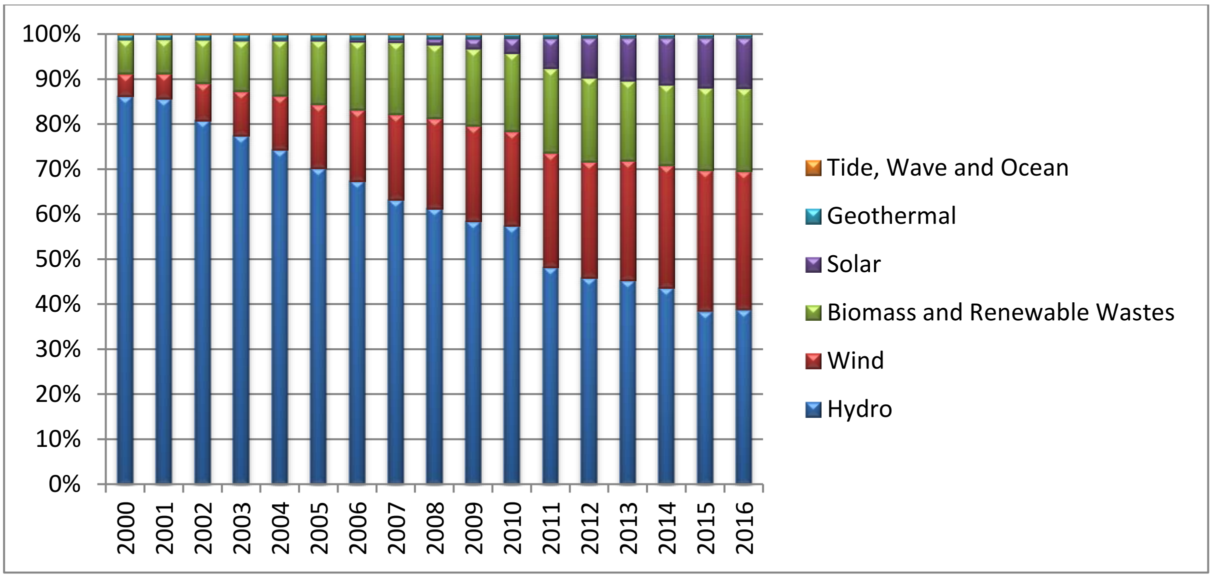


Figure 12 Percentages of different RES resources in the total electricity generation, 2000 – 2016.

Source: [9]

Looking more carefully the percentage of the RES penetration in the electricity generation in each country separately, it is obvious that the majority of the countries presents an augmentation of the RES usage at the electricity domain from 2000 to 2016, based on Figure 13. Positive impressions make the fact that Denmark, Luxembourg, Austria, Lithuania, Sweden, Croatia and Portugal, is in the position to cover more than 50% in 2016. Despite the total electricity power in EU from RES is increased, as it is shown in Figure 13, there are some countries which have diminished the electricity generation from RES in 2013, contrary to 2000, and more specifically Luxembourg, Latvia and Sweden. This behaviour does not mean necessarily the limitation of units that exploit the natural elements, but it does mean from the capacity increase, the big use of conventional resources in the electricity sector. More specifically, Luxembourg, from 2000 to 2013, has doubled the electricity generation through RES, except for liquid element, with the biomass and wind power, and the last years solar power, to be increased more and more. Of course, the increase of the homeland capacity, has helped and the increased use of natural gas, which covers now the 20% of the electricity generation in EU. In Latvia, on the other hand, the electricity production from RES, is diminished all the sixteen years of this study, with the electricity production to be augmented due to the augmented use of natural gas. The diminishment of RES percentage in Sweden in from 2007 to 2013 is due to the increased production of nuclear power plants and the stable production of RES at the same period.

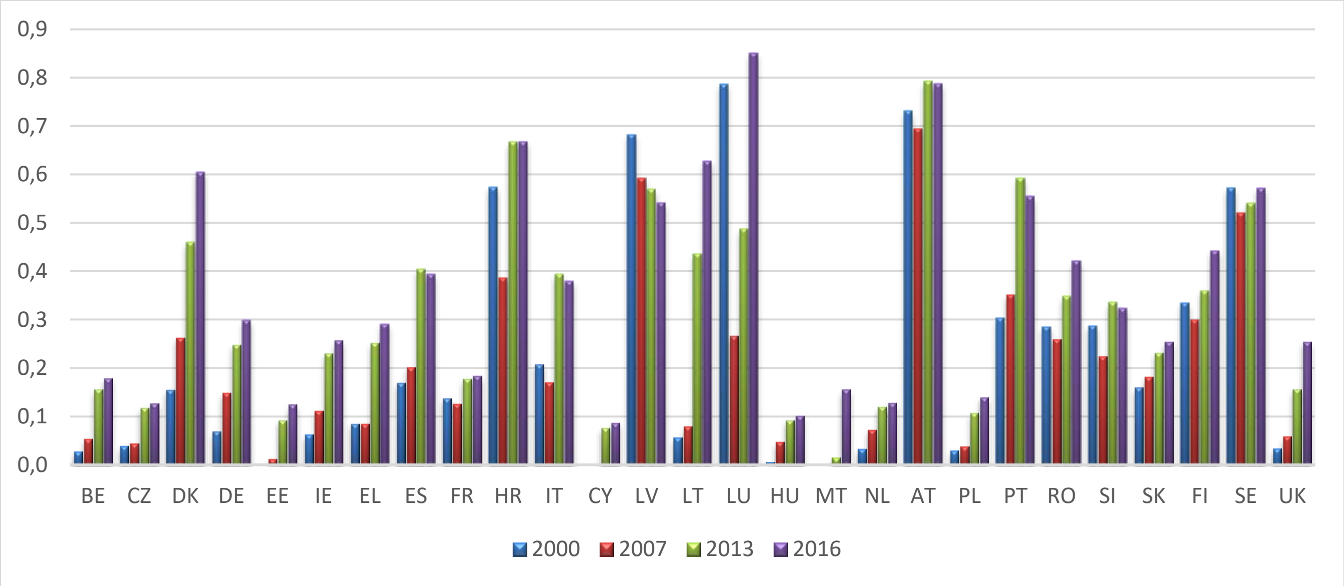


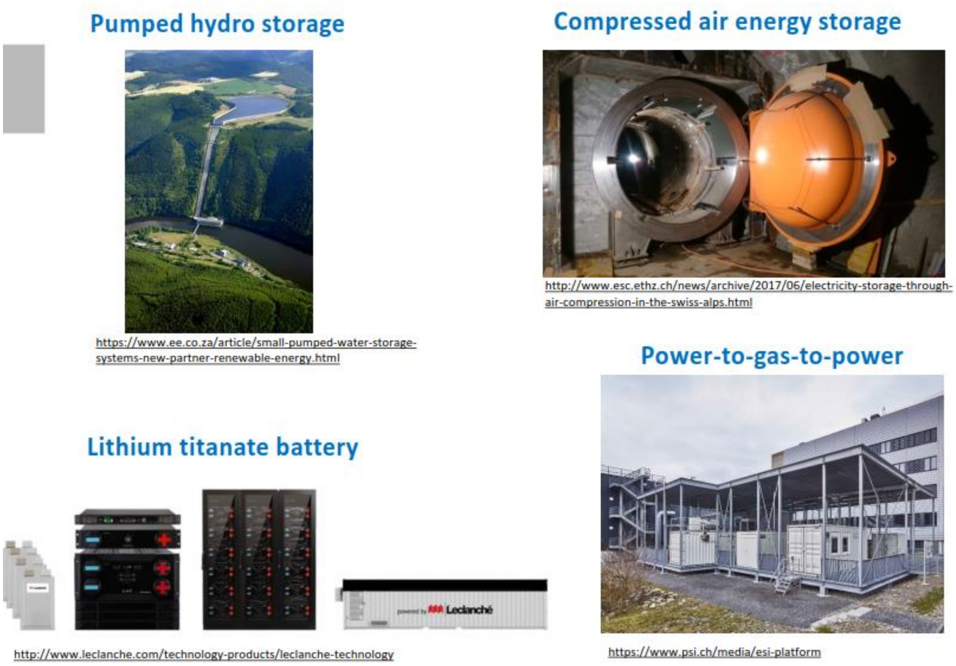
Figure 13 % Participation of RES in electricity generation for the EU member States.

Source: [9]

The disadvantage of RES units is that their production is dependent from the weather conditions which are going to exist at the certain time and this is a reason for making the states to invest more in order to base their total energy needs to these resources. It is very rear for the wind and solar power to be used to their full capacity at the time they are produced, it the energy network of EU, due to the limited demand and the contrary. The demand is increased but the RES power is not enough to cover this need. This problem is close to be solved as new technologies are making their appearances in order to storage the surplus of RES power to another useful resources, except for the traditional ways of electricity storage like pumping, compressed air, flywheels, accumulators or hydrogen conversion to secondary fuel. [18]

Until now the four technologies that are used for the electricity storage are the following. The Power – to – gas – to – power is a new way of storage, where the remaining electricity produced from RES, can also contribute to the climate goals of the EU. This target is going to be achieved through the production of clean gas that could be stored to:

- Support balancing the energy grid and providing gas for backup gas fired power generation,
- Be used as a clean fuel for transportation and heating
- Be used as chemical energy carrier, important for many industrial sectors. [19]



Picture 1 Types of electricity storage

Source: [20]

Generally, the insert of RES in the electricity production has helped to the liberalization of the market, as it allows to small producers and suppliers to participate to the electricity sector.

The main market mechanism for supporting the penetration of RES in European member states has been the feed-in-tariff system. As the levelized costs of electricity for RES production has been sharply decreased, this scheme is being replaced by schemes, such as feed-in premium, that provide a margin to RES producers on top of the wholesale spot price, or even by participation pf RES producers in the market without any subsidy. Moreover, it empowers the economy, through the creation of new labour positions, not only in the generation sector and the retention of power, but also to the construction sector and the instalment of wind and solar parks.

In conclusion, in order for the share of RES to be increased, not only it is necessary the adaptation of the thermoelectric power plants, so they become more flexible and bring balance to the energy grid but also the States to give more opportunities to investors that want to change the electricity market for the best. [21]

3.2.3. Interactive Trade of Electricity

The necessity of balance between supply and demand to every country is guaranteed through the international trade: imports in case of insufficient supply, and exports in case of supply's surplus.

Based on the following Diagrams, we can observe that the countries that are traditionally exporters through the whole period of the study, are France, German, Czech Republic, Austria and Sweden. On the other hand, importer - countries that have a significant distance between imports and exports the same period are Italy, Hungary, Netherlands, Portugal, Finland, Belgium, Greece and UK.

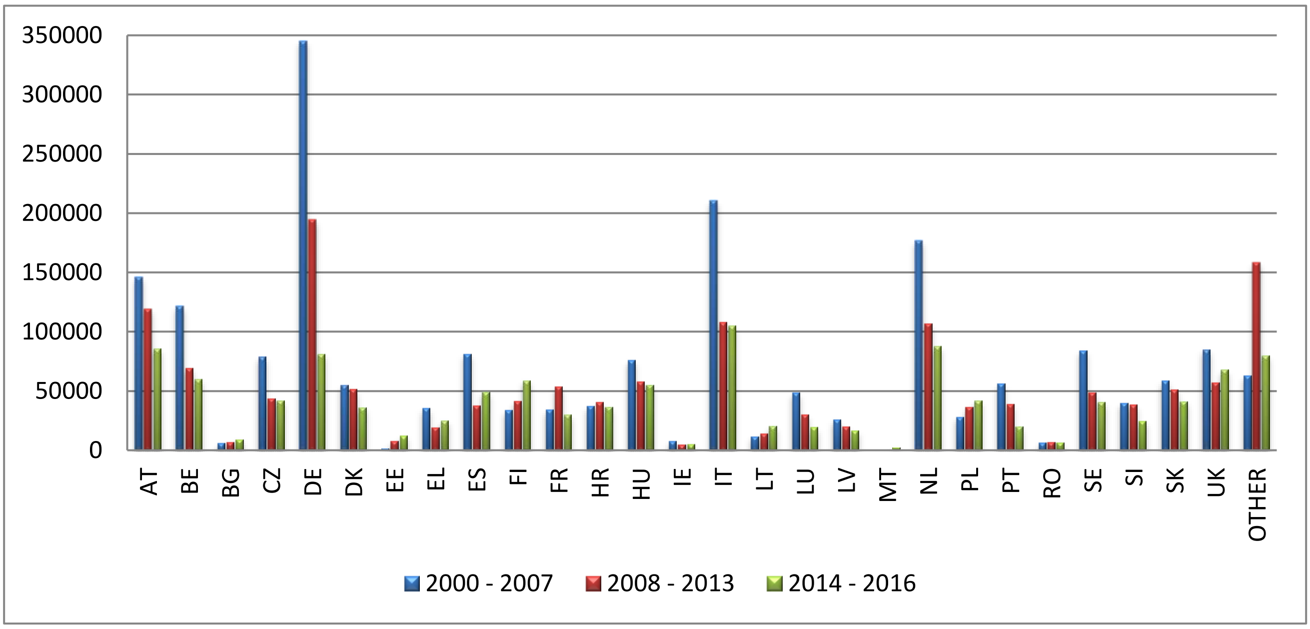


Figure 14 Total imports (in GWh) of the EU networks the periods 2000 – 2007, 2008 – 2013 and 2014 – 2016.

Source: [22]

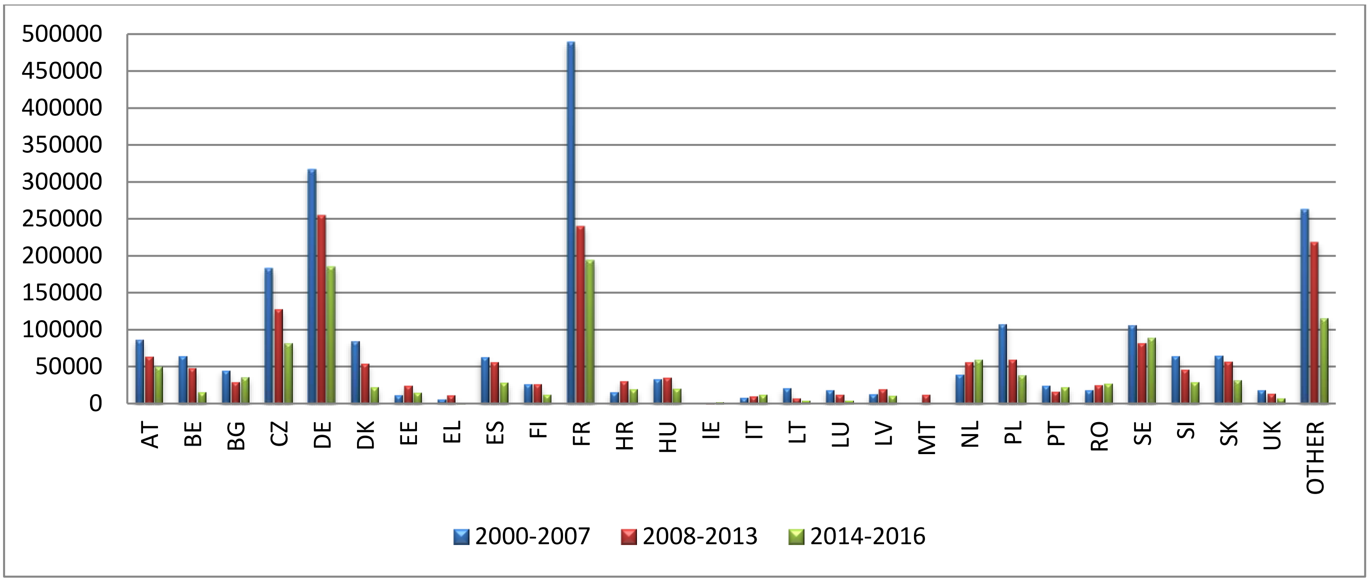


Figure 15 Total exports (in GWh) of the EU networks the periods 2000 – 2007, 2008 – 2013 and 2014 – 2016.

Source: [22]

At this point it is important to observe that the total electricity transactions of the EU, with the countries that are not belong to the Union, are high. More specifically, the exports that take place from the latter to the EU, especially the first period, 2000 – 2007, are much more in volumes from the imports of the these countries. This observation stresses even more the perception of a dependent EU.

However, it should be mentioned that the period 2008 – 2013, the volume of the total electricity transactions was reduced by 997.694GWh, compared to 2000 – 2008 at the energy network, supporting the abovementioned with the change of EU attitude to a more sustainable lifestyle and the unfavourable economic position of the EU.

The same picture is shown for the years 2014 – 2016, with the total imports and exports in general in and out of the EU are reduced the last three years.

Representing now the % of exports towards inland production , at Figure 16, it is shown that countries that export more than 50% of their domestic capacity, is not France, which exports only 10% of total electricity production all the seventeen years of our study, but Slovenia with Luxembourg in 2000, and Latvia and Lithuania in 2016. Lithuania's sharp decline in exports in 2010 is due to a dramatic decline in electricity production because of the cessation of nuclear power plants. In 2016, there is an increase in the export section and that is due to the increase of the RES share in the electricity generation that covered mostly the 'gap' that have been created from the absence of the nuclear power. Unlike Lithuania, Latvia increased its production due to the increase of natural gas in the energy mix, which led to increased exports to neighbouring countries. The same for Slovenia, which has enriched its energy mix by increasing its share of nuclear and hydroelectricity.

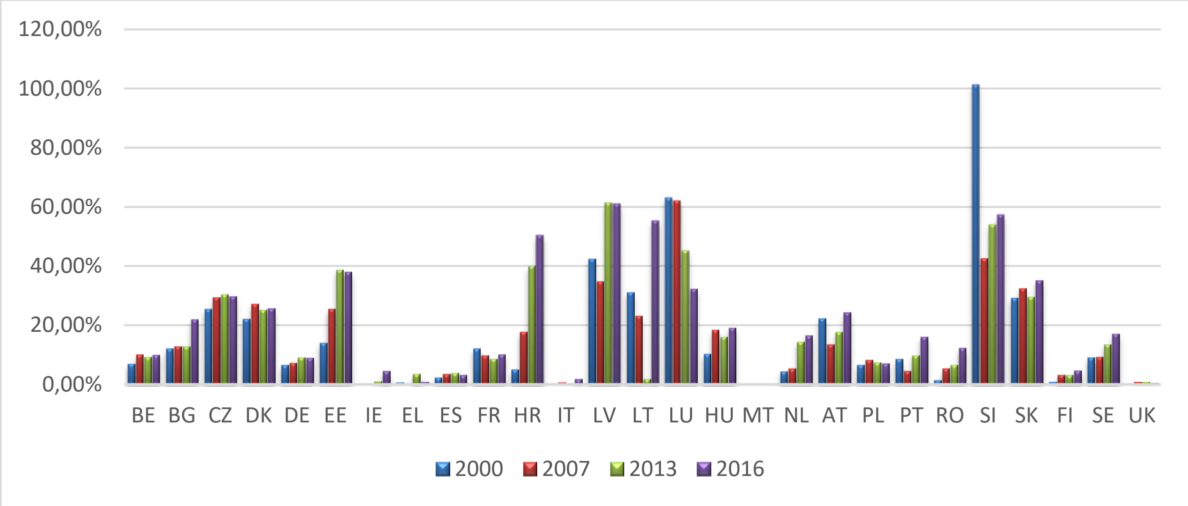


Figure 16 % exports towards inland production of the EU for the years 2000, 2007, 2013 and 2016.

Source: [9]

In addition, Figure 17 shows the % imports of countries relative to domestic consumption, highlighting the high dependence of Luxembourg on neighbouring countries, accounting for 111% more imports than domestic consumption. Croatia, Lithuania and Latvia also have a high degree of dependence on the countries close to their borders, especially the period 2013 – 2016. Lithuania was expected to increase its imports in 2013, due to reduced production and increased domestic demand for electricity. Latvia and Croatia, on the other hand, may not have a decrease in their domestic capacity, but their demand for electricity is increasing, and consequently turning to neighbouring countries to meet their needs. Concerning Luxembourg, it has seen an increase of its production over the years and a decline in domestic consumption, which greatly benefits its exports. Then for what reason the country is importing so much? Italy, which carries the largest volume of imports compared to its exports, according to Figures 14 and 15, making it the country with the most imports, in Figure 17, appears to be less than 20% of final domestic consumption covered by imports. The increased imports of these countries reflect the decline in domestic capacity in some countries and the increase in demand in others.

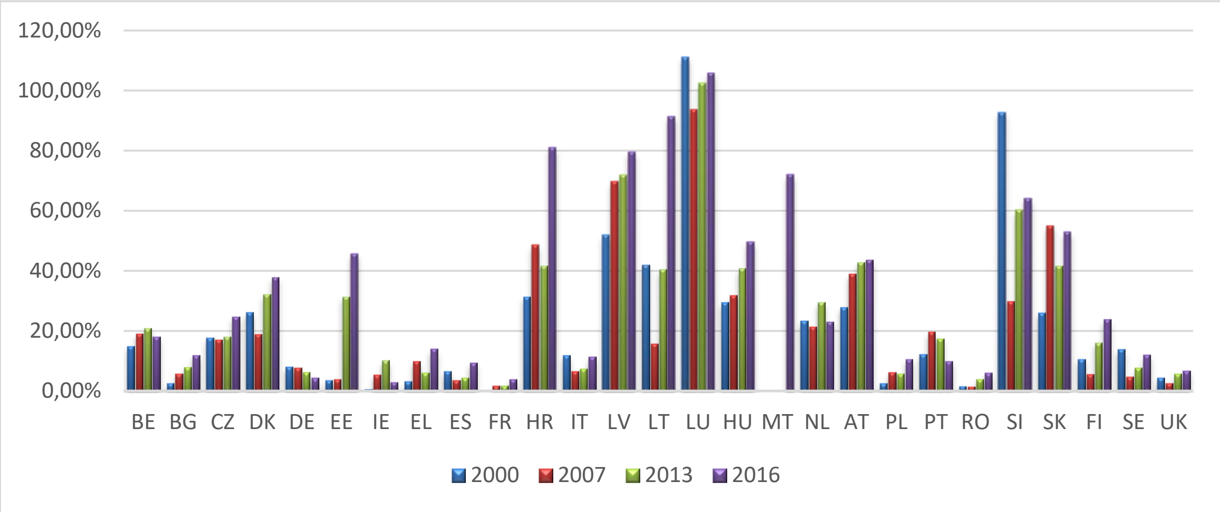


Figure 17 % Imports towards inland consumption of the EU for the years 2000, 2007, 2013 and 2016.

In conclusion, at the Figure 18 below, are presented the net imports to the inland consumption, which defines the countries to importers and exporters. The EU states that are in the positive axis of Y are the importers and the countries that are in the negative axis of Y the exporters. The main conclusion is that the volume of the energy transactions either they are importers or exporters is not enough to determine the nature of the country. Its true nature is shown only from the net transactions over the final consumption.

Therefore, it is obvious that four main countries – importers in 2016 are Luxemburg, Lithuania, Malta and Croatia due to the small inland production and the high imports. This automatically obliges them, to be dependent on other countries, and especially, when it comes to the Baltic Countries, from Russia and Belarus, which put at risk the national supply, and allow to other states, no matter they belong to the EU, to manage their energy networks.

On the other hand, for 2016 the countries – exporters are Estonia, Czech Republic and Bulgaria. Regardless the small inland electricity generation, contrary to Germany, France and Italy that make huge electricity transactions, the three countries managed to export almost the double percentage over what they import the same year, and to contain into small percentage concerning their inland consumption. This gives them the opportunity to cover their energy needs without being dependent on other countries for the energy supply.

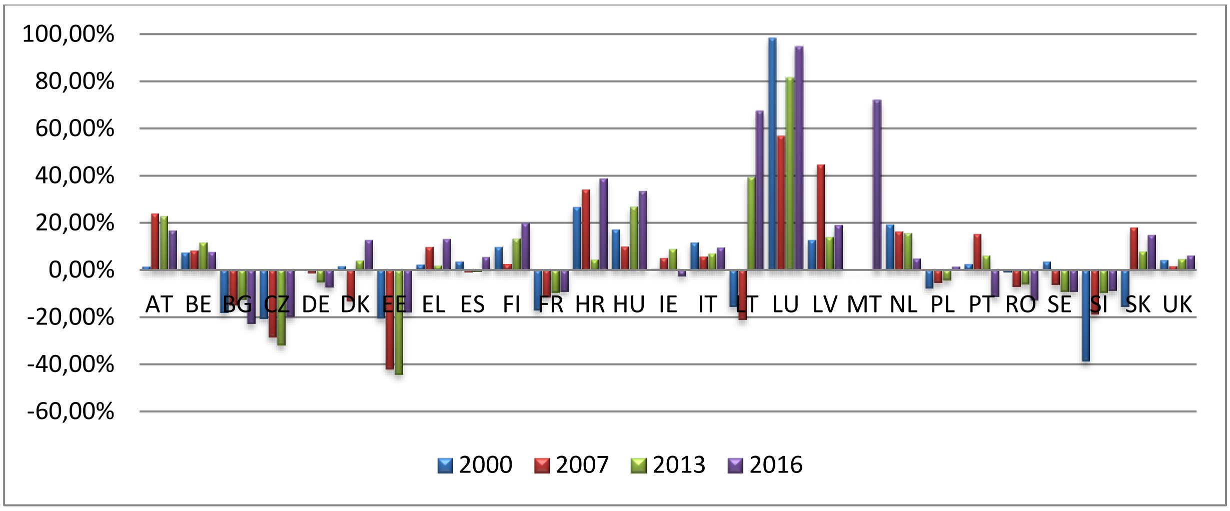


Figure 18 %net Imports towards inland consumption of the EU for the years 2000, 2007, 2013 and 2016.

3.3. The steps towards the liberalization of the electricity market

3.3.1. Community Directives on market liberalization.

Efforts to liberalize the electricity market in the EU began in the 1990s with full liberalization on 1 July 2007. The objective of the integrated electricity market is to a common energy policy on issues pertaining to the full coverage of each country's energy needs and on reducing the cost of providing electricity to consumers.

The Community Directives adopted by the European Council in these years aim at the gradual and smooth transition of the European electricity market from a monopoly market in many of its Member States to a free market where many electricity generators participate. Through the Directives established since 1996, it is now possible to impose common rules for all countries of the Union on the production, distribution and interconnection of countries in energy networks, the proper functioning of the European electricity market and the prevalence a single price in the wholesale and retail electricity markets of all countries. Initially, the first Council Directive (96/92 / EC) adopted by the Council in 1996 aimed at abolishing monopoly structures, eliminating discrimination and transparency between transactions. The first Directive was an important step in implementing this great idea, followed by its amendment with a new Directive (2003/54 / EC), which was adopted in June 2003. The new Directive laid down important rules to the process of release is speeding up.

The new rules were as follows:

1. Fully liberalize the electricity market for non-household consumers by July 2004 and for all consumers by July 2007.

2. Separate between the management of transmission networks and the distribution of electricity, from the production and supply sectors.

3. The role of the Energy Regulators of Member States to be more substantial and active.

4. Network costing is published.

5. Establish measures for security of supply.

6. Strengthen services of general interest for vulnerable consumers.

7. Lastly, common rules should be laid down on cross-border trade, namely to make cost accounting for the services and transport networks used and to adjust them on the basis of their national price.

At the same time, a European Commission Decision (2003/796 / EC) established the Florence Forum, which is responsible for compliance and identification of weaknesses, with a view to implementing new measures in the electricity market to meet them. In this way, the EU aims at the smooth functioning of the market among countries, as well as the prevention of the operation of monopolies.

The third and final Directive (2009/72 / EC) was adopted in the 2009, and provided for the following:

1. Terms of access to the network for cross-border electricity transactions.
2. The establishment of a body for the cooperation of the Energy Regulators of Member States and the oversight of the industry.
3. The freedom of the consumer to choose between the suppliers of electricity and to be able to change supplier whenever he wishes.
4. Create opportunities for new producers - suppliers to produce or import energy, and make use of new production technologies.
5. The development of cross-border trade to increase profits, and to ensure as low a price as possible.. [23]

3.3.2. The progress in the liberalization process in the EU.

The first remarkable attempts to liberalize the market began in 1970, when the view was made that growth in the electricity sector would take place with the single market and the introduction of more producers and suppliers. The above-mentioned Community Directives were adopted at the initiative of the EU and aim to establish regulations on which the Union will support the creation of a liberalized electricity market governed by meritocracy and equal opportunities for all producers - energy suppliers who participate in the energy network and influence supply and demand in the industry. Nevertheless, even after the introduction of the Directives, which clearly set the need for an increase in the number of energy-producing suppliers, in several countries [e.g. Greece (DEI), Lithuania (2 state units and one nuclear power station, before 2002), Poland (2 companies with a single division of production, transmission and distribution before 2004) [24] state monopolies have continued to dominate the electricity market, with the result that consumers are reluctant to switch to another supplier as they will have to bear the cost of switching. The emergence of state monopolies in the electricity market took place in the 20th century. At that time, they secured the citizens of every state the power to feed their homes and businesses with electricity, with the state itself responsible for the management of energy networks. Thus, the state has built the necessary infrastructure for the production and distribution of electricity, which could not be built and maintained by private investors due to the large capital and operating costs. In addition, he made use of the country's natural resources, such as fossil fuels, natural gas and petroleum products, which would otherwise not be available for use by individuals. Finally, he supplied electricity to inaccessible areas, which otherwise would not have been connected to the electricity grid. Although all that has been listed is on the list of advantages of state monopolies, the lack of competition limits the necessary technological upgrading, while it poses risks for price increases that are not dictated by the cost of the productive factors. [25]

Today, technology advances make it possible for small producers to participate in electricity production and the existence of monopolies may not favour the penetration of new investors in the energy sector. It is therefore imperative to reduce the share of the sovereign producers in each country and to completely separate the producer and supplier of electricity, thus increasing the jobs in the energy sector, from the introduction of new investors, as well as from competition, which will have a positive impact on the wholesale and retail prices of electricity. [3] [25]

It should be stressed that the course towards liberalization was initially not affected by the introduction of RES in electricity generation, but by the increasing participation of natural gas in electricity generation. Technological development, and in particular the combined cycle units, had much lower manufacturing costs and were also affordable for private investors. At the same time, the dramatic rise in fossil fuel prices in the 1970s when the two energy crises led to rapid technological advances in the RES sector, thus enabling small-scale producers to set up their own small power plants, exploiting mainly the wind. The great interest of investors in participation in power generation has led to the division of state-owned companies into smaller private production companies, separating at the same time production from transport and distribution of energy and assigning them to different companies [24]

Moreover, the establishment of the Independent Energy Regulators (RAE) contributed to the exclusion of the state from the full control of the market for the electricity market. The RAE are aimed at ensuring the proper conduct of national energy policies, in the control of competition, while ensuring that state rules are fully implemented by all those involved in the production and distribution of electricity. RAEs may be partially or wholly independent of the government of each state, depending on the structure of each market. Partially independent authorities act as consultants for the respective ministries, while fully independent authorities are aimed at decision-making and oversight of the electricity market without being accountable to the relevant ministries [25] From 2008 onwards, consumers have a choice between different energy suppliers in most EU Member States. In addition, infrastructure projects have been launched to connect disconnected countries to networks with the rest of the continent, with many of already be interconnected. An important role in the progress of the liberalization of the electricity market is played by European Union law which prohibits existing electricity companies from blocking a new competitive company from entering the energy sector or from stopping the construction of the grids while at the same time ensuring reliability wholesale energy transactions and price stability. [5] [26]

However, despite the positive steps that have been mentioned, some reforms that are crucial to the full liberalization of the market are vital. It is a commonplace that investment in the sector must be increased, in particular for the construction of networks linking the Iberian Peninsula, the Baltic Sea region and the British Isles with the rest of Europe. By 2020, three-quarters of infrastructure projects are expected to be completed with the EU. to apply common laws to all of its countries, and the government of the country concerned to intervene only when the secure supply of the state is not feasible. At the same time, more emphasis should be placed on cooperation between the neighbouring countries and their geographic location. Finally, the retail and wholesale electricity market must be more closely linked, so that low wholesale prices affect and reduce retail prices, which, as we shall see below, are much higher in most EU countries because of their overcharging. [5] [26]

3.3.3. Electricity Market Indicators

To make the degree of liberalization of the European electricity market more comprehensible, it is necessary to study the indicators that reflect the rate of liberalization of a market in quantitative terms. Two of the most characteristic indicators are:

- The largest producer's share
- The number of producers accounting for 95% of the electricity market

In other words, in order for a market to be liberalized, the percentage of the largest electricity producer in a country should be below 50%, which automatically shows the low dependence of the consumer on the main producer. It is therefore concluded that the number of producers will be increased in the country concerned, which will have a direct impact both on electricity prices on the wholesale market in particular and on competition in the industry. In addition, the index referring to the number of producers holding at least 95% of this total should be quite high, thus indicating the country's independence from state monopolies in the energy sector. Finally, we will observe the extent to which the development of RES contributes to the expansion of the electricity market.

Looking more carefully at the Table 8 of the Annex A, it is clear that for the majority of the countries that we study, the Market share of the largest generator in the electricity market - as a percentage of the total generation, is diminishing, through the years, either faster or slower. At the following Figure 19 it is shown the percentage of the larger generator of electricity for the years 2000, 2007, 2013 and 2016.

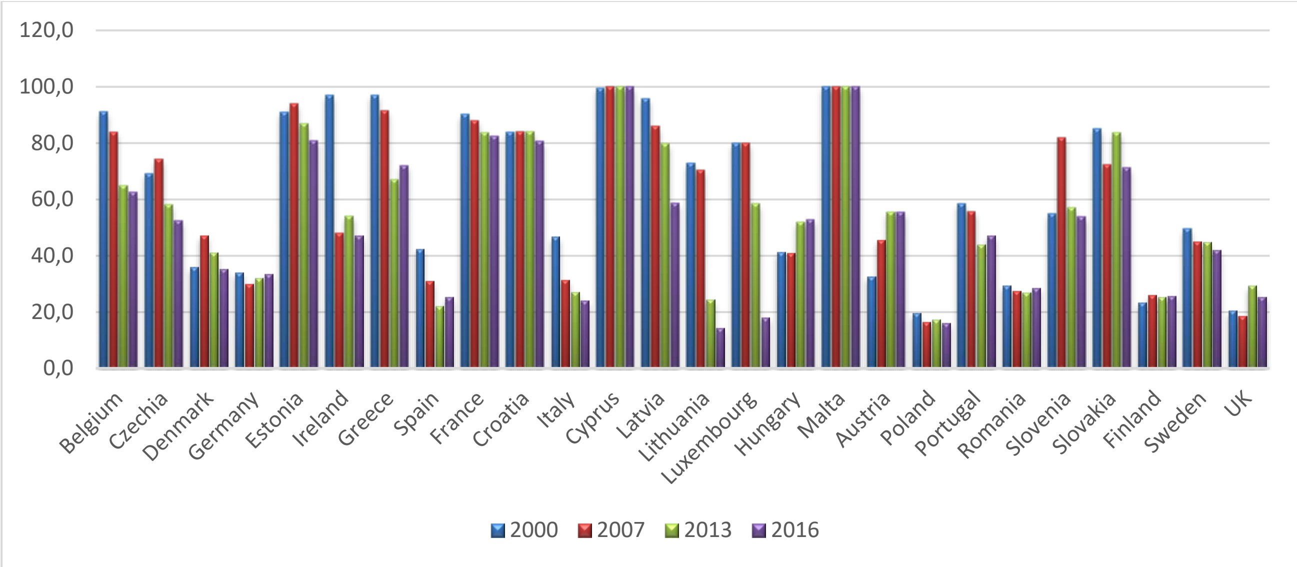


Figure 19 % Market share of the largest generator in the EU electricity market

Source: **[9]**

For a lot of countries such as Denmark, Germany, Spain, Italy, Poland, Romania, Finland and UK, the percentage of the indicator was below 50% since 2000, and remained at these levels for the years of study. This shows that these countries managed to liberalize their electricity market too soon. Some of these countries as Denmark, Spain, Romania and Finland, used the renewable resources in the electricity generation from the first year of the study, according to Figure 13 each country has a percentage of 15.46%, 16.95%, 28.46% and 33.41% respectively in 2000. However, it is important to be mentioned that the high percentages of RES in the electricity sector, for these countries except for Denmark is thanks to hydro power plants. On the other hand, Denmark, has developed, to a grand extent, the wind farms from 2000 until 2016. Clearly, through the years, the abovementioned three countries developed and more eco-friendly technologies, than the hydro plants, such as wind farms in Spain, and exploitation of biomass in Finland. The data that are used for the Diagram above do not contain information for the Netherlands.

On the other hand, despite the fact that Germany, Poland and the UK, had 6.89%, 2.99% and 3.36% respectively in 2000, for the RES penetration, the percentage of the largest generator was even lower from the countries with a high RES penetration. More specifically, for Poland which had 16% for both the largest generator in 2016 and RES percentage at the same year an explanation could be that these countries even though they did not have a big RES penetration in the electricity generation, and their energy mixture is consisted mostly of solid fuels and natural gas for the UK, these states chose to give the state power plants to more generators.

However, there are countries that have expanded in a big grade the electricity market from 2000 until 2016, such as Belgium, Ireland, Greece, Latvia, Italy, Lithuania, and Luxembourg, some of which managed to diminish this percentage below 40%. There is no doubt that in this development has a great contribution the technology of RES, mostly, due to the lower construction and maintenance cost of the unit in contrary to a lignite unit, giving the chance to small producers to construct small photovoltaic units and wind generators. More specifically, what comes from the Eurostat Statistics is that the countries which presented a significant reduction of the largest generator percentage and even more less than 50%, are mostly those which have a rich energy mixture in RES resources. Italy, for example, which limits the percentage around 24% in 2016, the RES share in the generation of electricity is approximately close to 38%, while Lithuania which has 14% in the largest generator, the share of RES in the energy mixture is close to 63% in 2016 based on Figure 13. The same picture presents and the other countries which achieved to diminish the certain percentage.

However, except for the countries that presented a great decrease of this indicator, there are countries such as Estonia, France, and Slovakia, are presenting a small diminishment of the indicator, which keeps the percentage up to 80%. Concerning France's percentage, where the country is considered to be a developed and financially strong EU – State, the high percentage of the indicator can be explained due to the fact that the state's energy dependence is from the nuclear energy. This makes the state as a monopoly of this resource due to high construction and maintenance costs of the unit from a private investor. Estonia, hasn't developed yet in a big degree the RES exploitation, because their energy needs are covered from solid fuels to a 79% in 2016.

Latvia, Slovakia and Croatia, despites the fact that they have a big percentage of the indicator, they also have high percentages in RES penetration. This could be explained from the fact that their markets are state – controlled, so the management of the RES units is from the states and not from private producers, which leads to the phenomenon of a monopoly electricity market.

However, there are some countries like, Austria, Hungary and Slovenia, which have shown an increase of the indicator through the sixteen years, which reflects the withdrawal of producers from the market and the redemption of units from bigger producers. This could be due to the economic recession that affected the countries, as the increase of the indicator is observed since 2008. Based on the available data, there isn't any reduction on the electricity production, except for Hungary, that presents a downward trend to its production after 2010, because of the reduced usage of natural gas in the electricity generation.

Last but not least, the two island - States of the EU, Cyprus and Malta, where the indicator is 100%, because the countries are not connected with the rest of EU, in order to exist the need of competitiveness with other markets, so the only producer in these states is the State itself.

Another indicator that shows the percentage of liberalization in the electricity market per country, is the number of producers representing at least 95% of the national net electricity generation. This indicator should be high enough in order for the market to be considered as liberalized. At the table 7, of the Annex A, is referred the number of producers that exist in each country from 2003 until 2016, because the three first years were not available. At the Figure 20 below is presented the certain percentage for the years 2003, 2007, 2013 and 2016 in logarithmic scale due to the big difference between the numbers of indicators of each EU – State.

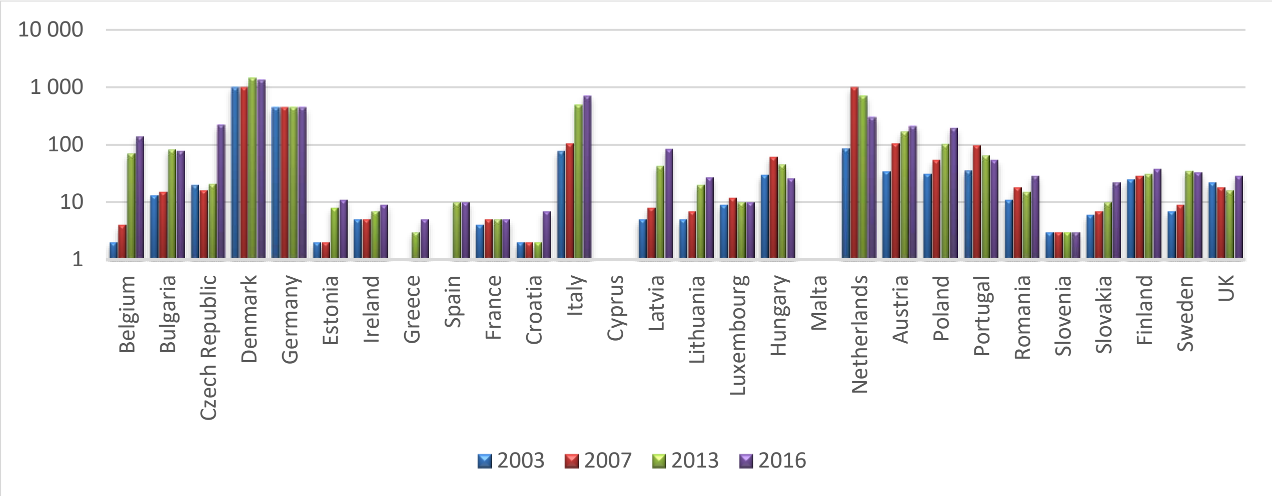


Figure 20 Number of generating companies representing at least 95% of the national net electricity generation

It is obvious the half of these countries that presented a sharp fall in the first indicator, they have a sharp increase of the producers who consist the 95%. More specifically, Belgium, Czech Republic, Italy, Latvia, Austria and Poland, managed to increase the number of their producers especially after 2008. This shows that the market reacts positively to the changes, concerning the penetration of RES in the electricity market and the percentage of the bigger producer in the market that leads to the faster liberalization of the market.

On the other hand, Ireland, Greece and Luxembourg, despite the percentage of the largest producers have diminished at the last years, the number of the producers who constitutes the 95% of the national market is augmented slowly. Generally, the three States have increased a lot the usage of RES in the electricity generation, from 6.2%, 8.4% and 78% approximately in 2000 to 25%, 30% and 85% in 2016. Concerning Luxembourg, it tries to reduce the usage of electricity in the context of energy saving policy, which is more clearly from the Diagram 3.1 where the electricity consumption per capita is reduced by 2.200kWh in the last sixteen years. This should lead to the reduction of the producers in the market because of the lower demand. However, by taking into consideration the largest producer’s share in the market, it is obvious that huge decrease of it, by 68%, let smaller players to participate to the market of energy, and actually to liberalize it faster.

As it concerns the EU –States that the first producer had a small percentage in the electricity market, we can observe that Germany, Denmark, Poland, and the UK have a great number of producers that consists the electricity market. Spain, Romania and Finland, which belong in the same category, have smaller but equally important increase of the producers' number. While, this is a result of the constant increase of RES in this sector, Hungary presents a negative "flow" after 2007. This behaviour could be due to the economic crisis, which affected negatively the new investments for the majority of countries, as we from what we can see the electricity per capita and the RES share are increased through the years.

Last but not least, countries that had more than 80% in the first indicator, present a small increase in the number of the producers, with the only exemption Latvia, which from the five producers in 2003 it increased it in 84. Concerning the other countries, the small augmentation of the number, is due to the grand dependence on the fossil fuels and the nuclear energy.

3.4. Electricity Market Regions

The most important step for the creation of a united EU electricity market, was the formation of the seven regional electricity market in the EU at 2006. The aim of this grouping is the unification of the separated markets to a bigger one, that will function under the supervision the several NRAs and under the guidance of the Regulator Authority, of one of the participated countries in the certain periphery. For the record, NRAs or by its full name, the National Regulatory Authority, is an independent administrative authority, responsible for ensuring that energy is evaluated properly and meet international standards of quality and safety. [27]

The integration of the several markets into groups and eventually into one market, helps to the improvement of the cross-border connections, to the cover of regulatory gaps, to the increase of the transparency and the limitation of tackling energy price inequality

The seven regional markets are the following:

1. ***Central Western Europe: (CWE)***: The Central Western Europe contains the following countries: Belgium, France, Germany, Netherlands, Luxembourg and it works under the guidance of the Belgium NRAs. It represents the 42% of the electricity EU consumption, and has some of the biggest markets of the sector. In particular, the markets of France, Belgium and the Netherlands have been tied together, and joint networks have been established to complete a single wholesale electricity market between France, Belgium, the Netherlands and France and Germany. The electricity generation is mostly dependent on nuclear power and the fossil fuels and secondly on natural gas and RES. It is expected the electricity prices in the CWE market to be influenced from the NG and fossil fuel prices, but also from the weather conditions that exist at the region. So, the diminished participation of RES provokes an increase of the electricity price, as the conventional energy resources, like fossil fuels and natural gas, are more expensive than RES.
2. ***British Islands & France: (FUI):*** It includes United Kingdom, Ireland and France, and it is coordinated from the UK's NRA, and it covers 30% of the electricity market of the EU. France has the role of the "bridge" between the islands and the European land.
3. ***Northern Europe: (Northern):*** this regional market includes the Scandinavian market (Denmark, Finland, Norway, Sweden) and the other two important Member – States, Germany and Poland. The certain region is based on a big percentage of RES, mostly Hydro plants and wind power, while in cases the stock is not enough, the needs are covered from nuclear power which is generated from Sweden, with Norway to be the cheapest market of electricity in the Scandinavia.
4. ***Baltic Peninsula: (BS):*** The Baltic Region contains Latvia, Estonia, Lithuania, it is coordinated from the Latvia's NRA and it represents the 0.71% of the EU energy consumption. This periphery is one of the most expensive of the EU, because the countries are fully dependent from fossil fuel and NG which is imported from Russia and Belarus.
5. ***Central and South Europe: (CS):*** Central and South Europe includes the following: Austria, France, Germany, Greece, Italy, and Slovenia. They are coordinated from Italy's NRA and it represents 51% of the EU market.
6. ***South – Western Europe: (SWE):*** Southern – Western Region includes France, Portugal and Spain, and it is coordinated from Spain's NRA, in order to connect the wholesale market of France with the Iberian Peninsula. Its percentage in the EU electricity market is close to 26%. The interconnection of the Southern West Europe was started since 1998, while the …... market was established in 2007, which doubled the two countries' interconnection.
7. ***Central – Eastern Europe: (CE):*** Central – Eastern Europe includes Austria, Czech Republic, Germany, Hungary, Poland, Slovakia, Slovenia and it is coordinated from Austria's NRA. [28] [29]

The observation we can make is that despite the fact that EU's electricity is generated from RES in a good percentage, the electricity prices are not at the same low levels, and that is influenced by the weather conditions of the region and the alternative resources that are used in order to cover the gap that RES cannot fill in. In addition to this, it is important to be mentioned that four EU member states: Bulgaria, Romania, Malta and Croatia are not included to a periphery, but the first two countries make more exports than imports especially to Central European countries and Balkans.

3.5. The consequences of the liberalization in the competition and the electricity price evolution

Despite the expectations that the liberalization of the market, not only would develop the competitiveness between producers and suppliers, but also there would be a downward trend of the electricity price, the result was exactly the opposite. There are some variables that affect the generation cost of electricity, the price of wholesale market, and finally the price of the retail market that concerns the consumers.

Based on the previous subchapter, the percentages of electricity production of the EU of coal, nuclear energy and RES are quite close (21.54%, 25.8% and 30.15% respectively). This, in addition to the big imports from Russia, USA, Columbia and South Africa the past few years, for the electricity production and heating, it is logical the price of the production cost to be affected from the wholesale price of solid fuels, due to the important percentage. On the other hand, the primer sources of RES, that differentiates the energy prices are hydro power, wind and solar energy, because the cost of the electricity generation from these sources are depending on the weather conditions and the availability of the hydroelectric resources. In general, the huge participation of RES in the energy mixture reduces the production cost, while the certain units are much more economic from the corresponding lignite units. One more countable resource of electricity generation is natural gas, which consists 19.73% of the energy mixture in 2016. NG's price is affected by the coal's price and the participation of RES in the production. When the electricity generation from RES is increased, then the price of NG is diminished, due to its limited participation in the generation. Furthermore, its price depends on the price of fossil fuels, so a decrease in the price of coal leads to a fall in the price of natural gas, while reducing the cost of electricity production. [28]

On the other hand, we couldn't ignore the factors that affect the wholesale's market prices, despite the interconnection of the single markets of EU by Periphery. These differences are because of the topological factors, which can provoke deviations of prices even between the countries of the same Periphery.

In the beginning, the changes in the composition of electricity power, play an important role in the wholesale price of electricity. For example, Spain and Portugal, which were in the group of the cheapest markets in second 2014, they became from the most expensive

To begin with, ***the changes to the power generation composition***, play an important role to the wholesale price of the electricity.

One other important factor is ***the reduction of the production's capacity***. The countries that decide to reduce their capacity, are leaded to the point either to import from neighbour countries in order to cover their needs, or to use more expensive resources, like fossil fuels. By this, not only do the cost of the electricity generation is increased, but also the wholesale price of the product is increased, too.

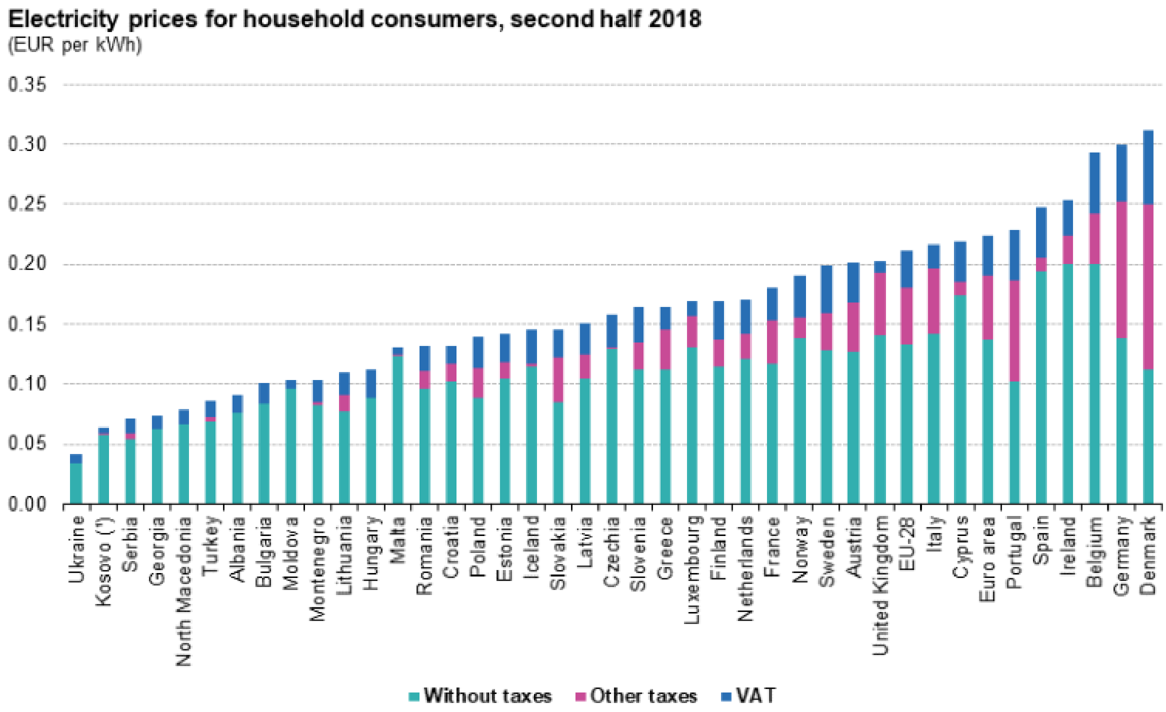
Last but not least, ***the interconnection between the countries***. It is obvious that States with very low interconnection, like Baltic countries, Iberian Countries, Greece and Ireland, are obliged to use fossil fuels, that have bigger cost of production than RES, when the weather conditions do not allow the use of the latter in the electricity generation, because they do not have the ability to cover their needs by importing electricity from cheaper markets.

So, despite the majority of the wholesale markets are consisted of a complex of neighbouring countries with lower cross – border electricity trading costs, this by itself cannot eliminate the differences on prices in the EU, while the topic abovementioned factors continue to be vital for the price formation.

All the above affect the retail prices, too. However, the final price, except for the others, it is affected from the transmission networks, and the policy of each country.

Three basic factors that affect the final price of the retail electricity price is the energy cost, the network cost and the VAT/taxation of each EU State. The energy cost is consisted of two parts. First of all, the wholesale trade cost, that consists the cost that the company gave for the primary fuel, the cost for the construction, the equipment and the function of the power plant units, and the cost for the energy to provide power into the grids. Second of all, the retail cost, that has to do with the expenditure for the energy sale to the final consumer. The network cost, is consisted of the maintenance costs and the network extension, the network services and the energy loses. Often the network cost is burdened with the expenditures for the public services cover, and the technical assistance. Last but not least, VAT/ taxation, could be simple VAT and excise duties, or special contributions that have to do with the energy and climate policy [30]

Despite, the electricity generation from RES, has leaded to the reduction of the wholesale price, due to the lower production cost, compared to conventional sources of energy, the final affection in the electricity prices for household consumers, is not the same the average price of electricity in the EU, was increased from 0.1149€/kWh in 2008 to 0.1329€/kWh, no taxes/ VAT included. This prices are differentiated from country to country, from 2.5 to 4 times, depending on its taxation. From the Figure 21, the second half of 2018, Denmark has the biggest electricity price for the household consumers, due to the high taxation. The final price is consisted of 67% of taxation and 33% of the good's price, which is among the lowest prices in the EU, thanks to high percentage of RES in the electricity mixture. On the other hand Spain, Portugal and Ireland, have the most expensive electricity price, due to the limited interconnection with other countries. There are also countries like Malta and Luxembourg that have low taxation. [31]



(¹) 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 (online data codes: nrg_pc_204)

Figure 21 Electricity prices for household consumers, second half 2018 (€/kWh).

Source: [31]

As for the industry, the retail price presents a reduction from 0.0846€/kWh in 2008, to 0.0804€/kWh. At the Figure 22, it is shown the retail prices of the industry of each country for the second half of 2018, including taxation. We can observe that the bigger taxation is in Germany that constitutes the 53% of the final price, with Italy to follow with 35% taxation in the final price. The lowest taxation is in Czech Republic, Sweden and Bulgaria, which tends to zero! Furthermore, we could observe that the final price for the residential is 40% more than the industrials. This difference is due to the low taxation that exists for the industry, in order to limit the investments for moving to countries with lower taxation and especially out of EU. [31]

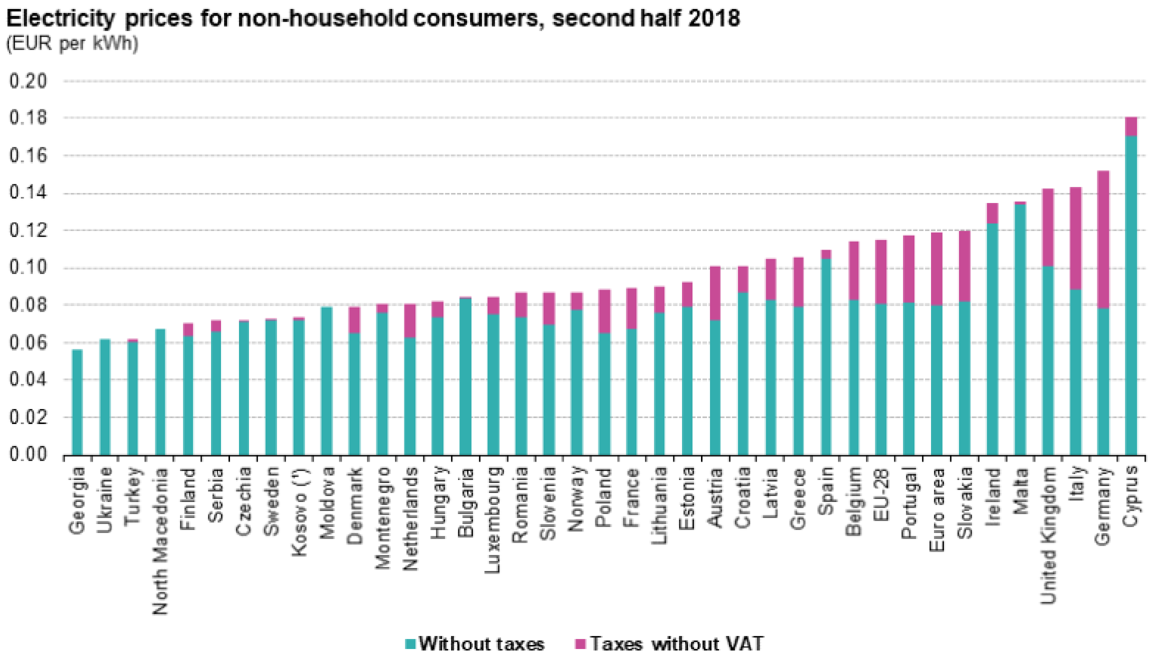


Figure 22 Electricity prices for non – household consumers, second half 2018 (€/kWh).

Source: [31]

For the industry sector, EU tries to ensure equal terms for the existence of antagonistic price of energy, with the increase of the energy subsidies to the local industries and the same terms for the confrontation of the energy goods' exports from all the Member – States. Furthermore, in case the measures are insufficient, the financial interventions, the exemptions and the tax reduction belong to the means of protection for the industrial consumers from the increase of the energy cost, according to the state rules and the rules.

Concerning the share of the costs of transport and distribution of energy in the final price, are increased a little bit from 2008 to 2015 for the households while for the industry are quite stable the same period. [32]

In conclusion, it is obvious that the electricity prices are not the same for any country, while for the same country, the price differs from customer to customer (households and industries). The final price of the product is affected by: the geographical characteristics, the supply and the demand, the taxation, the interconnection, the costs of the resources that are used for the production, and the costs from the CO2 allowances. Countries with high share of RES in the electricity generation, the wholesale prices are lower than others, while with the integration of the market's liberalization, wholesale prices' convergence is expected. However, it is not the same for the retail market, where the networks, the taxation and the climate policies, provoke the price fluctuation. The price for the householders could be reduced if the networks' efficiency and the better network management from the TSOs and DSOs. Consequently, the agreement for a single taxation in the energy sector is vital for all countries, and the possibility for choosing a more economic supplier, in order for the prices' stabilisation to come in the retail trade. [30] [33]

3.6. Prospects for the electricity market in Europe

Despite the fact that the share of RES has increased and there is a surplus of CO_2 allowances the last decade, the wholesale prices are still increased, due to the increased price of coal, that is the main resource of electricity for many countries, and the increased electricity consumption in the EU as a unit.

The turn to RES, leads to disengagement from the conventional resources, where their facilities are unprofitable. Through the wind generators and the photovoltaics, make the electricity generation more attractive and flexible. Based on the geographic location and the weather conditions, it is necessary a stable annual production from natural elements, even though the weather does not allow it.

In order to become this a reality, it is needed a network with high electric power, that would connect not only the countries that belong to the same region, but also among the regions. With the market integration the flexibility demands that arise from the development of the wind and solar power, are diminishing due to the geographical smoothing just like the storage needs, while the value of the wind generators and the photovoltaic parks is increased. The internal market, does not eliminate all the flexibility needs and what we have to think is how the conventional resources are going to be adapted to an energy system with higher share of RES in the market. It should change the structure and the way that network functions, with power plants that contribute in peak load time and others that respond between the basic load and the peak load (mid- merit). In addition, it is needed flexibility to the allocation and storage of the electricity.

Besides the big change that is needed to be done to the power plant stations, in order to exploit the RES, there are important challenges both for the regulatory authorizations and the producers – supplies.

In the beginning, the regulatory authorities are obliged to secure that the electricity power from RES, could contribute to the economic independence from conventional fuels with the existed applications, in the electricity generation and transmission of the energy. The transmission of energy is one of the most expensive stages to reach to the consumer that is why there are some challenges that need to bring through the authorities:

- Covering the maximum mileage of existing units, based on environmental criteria, and respecting emission limits.
- Success of balance between the antagonism and all the other risks (the choice of RES from the consumers or the state, the distribution networks that burden the consumers) holding the capital cost in high levels.
- Redefining of pricing structures. With the reduction of demand, the increase of self – production and the revolution of technology, the conventional electricity generation is getting a serious damage. The redesign of the expenditures for the structures and the review of the invoices of the consumers, would lead to stable costs. With stabilization of the price in all the EU, the consumer’s expenditures of each country, would be disproportionate comparing to its consumption, due to the different

taxation that exists to each state. So, it is important the tax convention to a constant percentage, in order for the invoice differentiation to be smoothen in the EU.

- With the penetration of RES and the security of energy supply, efficiency is improved of the existed stations, with further reduction of the costs and the optimisation of the incomes between the wholesale market and their additional benefits.

However, the RES producers should make their remunerations with transparency and not be regulated retrospectively while should have an idea for the wholesale price because this could be depended on European targets and not on feed in prices. Furthermore, it must have their power plant stations been connected on the network in the specific place, in the specific moment, while when there are goals for specific technologies (for example offshore capacities) it shouldn't change all the time because it can provoke problems in the network supply and in the provision of services.

Concerning the TSOs and DSOs, they are obliged to modernize the networks, in order those that are constructed for transmitting low voltage energy, be able to storage electricity and allow the reverse of the flow. In Germany, overhead wires are constructed for the transmission of wind power from the North to replace nuclear energy in South. However, the system operators, will face very soon the reduction of the demand thanks to self – production, and they must find a new way to increase their income.

Finally, the trades of the retail market have to deal with the increase of antagonism, and the fact that the consumers have become prosumers. The self – production is not necessarily negative for the trade if it is supported by themselves and find a way to involve with the required equipment of the customers and provide services to them in order to improve their energy systems. Traders have the biggest share comparing to other sectors that are occupied with energy and by offering their services can increase their profits. [34]

4. Social Network Analysis

4.1. Introduction

A social network is defined as a set of individuals or groups that are linked to different types of interdependence, whether they are information flows, or online or personal relationships, or transactions. The groups or individuals that make up the network are called nodes, while the flows from one node to another, and links, thus converting the network into a dynamic system that contains information about all nodes. [35]

Social networks can be studied through the Social Network Analysis, which aims at evaluating links and exploring the topological features of the networks. It is a statistical method that studies and depicts the flows that take place between the nodes of the network. A notable feature of this method is the gravity it gives to the relationships between the nodes that interact, as the links that exist between them characterize the network as a whole. Nodes that are the most central node in the network are also the ones who have the greatest influence in it and can control it to a greater extent. On the other hand, nodes that indirectly connect other nodes that otherwise would be cut off from the rest of the network are of great importance for the network. Therefore, this method offers qualitative and quantitative results for the network that studies through different angles. [35]

4.2. Chronology

Social Network Analysis has its roots in the late 1800s, where scientists from the theoretical sciences industry began to use the term social networks and study it from the point of view of the kind of relationships formed between social groups, are direct personal ties, or social ties. [38] The first depiction of social networks was made in 1937 by Monero, who developed the sociogram, a kind of graph depicting a set of points (knots) that are joined by lines (edges). The subject of study was the interaction between individuals, that is, the nodes, within small social groups, and in particular the way of choosing friends among the children, thus identifying the children that were more social and the most isolated. [38] [39] Monero was followed by Lewin, who attempted to interpret the relationships that develop between individuals and the influence these bonds have on both individuals and social groups involved. Thanks to his research, mathematical models were constructed that described the structure of the groups and developed the theory of graphs, which introduced the concepts of density and centrality in social networks. In 1954, Barnes defined the basic concepts of networks, such as the concept of links and the kind of groups that are divided into marginal groups such as family, friends, and social, such as ethnicity, gender, etc. [36] . [36] [37] [37]

In the 1960s-1970s, a group of sociologists developed the theory of the "small world", which argues that the number of social contacts between two people, unknown to each other, anywhere in the world, is "limited." This theory was based on psychologist Stanley Milgram in 1967, who, through social experiments, proved that the two-person ties between two people are six, making the phrase "six degrees of separation" known. [38] It is therefore perceived that positive sciences have helped to understand social networks through graphical statistics and theory. [36]

Following the rapid advances in IT technology, network analysis has also begun to expand through this through the creation of web sites designed to create social contacts between individuals, organizations or groups, with common interests, independent from the distance between them.

Today, the breadth of applications of social networking has been broadened, with the same application being applied across different domains. Primarily in sociology and psychology, studying social phenomena such as acquaintances - relationships that are created in a society and the impact on individuals and society. In medicine, for the study of spreading a virus to a population, for the interconnection of professionals in the industry, transferring knowledge and ideas to each other, but also for interconnecting people suffering from the same type of illness through social networks such as «PatientsLikeMe». In addition, a further use of social networks is in mass surveillance, which is applied in many countries to identify a threat to citizens, and their use in education, through the creation of forums and other educational websites, so teachers can come closer to their pupils, enhancing them with more knowledge and outside of the sheds. Of course, well-known social networks such as Facebook, Twitter, LinkedIn, etc. are used by companies and individuals who want to show the general public their domain of work, use them to find work, or the dissemination of political, environmental, artistic and other ideas. [36] [38] It is indisputable that technology and social networks are now applicable to every aspect of our everyday life, making our lives easier, searching for information and establishing contacts with organizations or other people.

In the energy sector, the implementation of the social networking method is limited. Some applications of the method have found an impact on the study of the evolution of the network structure of biomass-to-energy conversion technologies worldwide, based on centrality and interconnection. [39], but also, in exploring the relationships between the 30 most research-intensive countries in the field of reduced carbon dioxide emissions and the relationship of the top 30 producers in the field of emissions reduction research. [40]

Particularly in the electricity sector, network analysis has contributed to the study of the information network exchanged between intermediaries to achieve an objective or to solve problems in the liberalized electricity markets [43], the reconstruction of the individual electricity markets in Naples , as a single market, and on the transition from gas to electricity from 1862 to the First World War, highlighting the strong links between the markets, the advancement of technology and the financial markets. [44] Another application of the method is through the socioeconomic analysis of the electricity market in Brazil and the assessment of social policies for the introduction of RES in the sector. [45] It is therefore understandable that this method has not been applied to a large extent in the electricity market. [41], [42] [43] .

In Greece, this method has been extensively used in computer science with many diplomatic and doctoral theses to use it to study the structure and technology of social media (Facebook, LinkedIn, etc.) [38] [39] [46]

The review has identified that the SNA methodology has numerous applications, however its application on the evolution of European electricity market is rather limited. This gap is the focus of our research and is described in the next chapter.

The following sub-sections provide the basic terminology of SNA as well as the main computational tools.

4.3. Basic Terminology of Social Network Analysis

Social Network Analysis uses graph theory to visualize the network being studied, and various indicators divided into two categories: the indicators that characterize the network as a whole, i.e. the topological features of a network and the indicators that characterize the location which each node in it, that is, the central network indices. The topological features include the interconnection mode (links) of each node, the types of which are discussed in the following subchapter.

4.3.1. Types of Bonds

The links that nodes can develop between them can be either direct or indirect. Direct links are created between two nodes, while indirect ones are characterized by links where two nodes are joined together by third parties. Direct links can be divided into one-way and two-way bonds. One way is where the flow of information or transactions is made from one node to another, that is, one node has the only role of the transmitter and the other the role of the receiver. Conversely, if both nodes are directly connected, they act as both transmitter and receiver at the same time, then the bond is two-way. It is a commonplace that a two-way link is more powerful because even if a node stops being both a transmitter and a receiver, it will remain connected to the other node through its other property. Of course, one-way links are important when the node that performs one-way links is important for joining two isolated nodes – sub networks.

An additional separation of the bonds is that of the strong and the weak. Strong bonds are those who "carry" a large amount of information or transactions between nodes, while patients are the links with a much smaller volume of flows on the rest of the network. Patient links are mostly made by network nodes, but they can play an important role by connecting nodes / sub networks to the network, which otherwise would not be able to connect. Consequently, the influence of this node on the isolated node / subnet is large, irrespective of the volume of flows that they exchange between them. [44]

4.3.2. Topological Features of the Network

The basic topological features of a network are as follows:

- **Node**: Each node is a social group or an individual. The size of the node is affected by the power exercised by the individual or group on the network, as the strongest person will have a larger node size, so it will also be more independent.
- **Edge**: is the direct or indirect interconnection of the nodes between them.

- **Path**: is the set of bundles involved in connecting two nodes within the network. To define a path as a path, nodes should only appear in the path once.

- **Distance**: is the number of links that link one country to another.

- **Average Distance or Characteristic path Length**: the average distance is the number of bundles passing from one node to another within a network, following the shortest route. Figure 23 shows two different networks. The average distance to the first network is 1.9 and the average distance to the second network is 2.4. This means that most nodes are connected to others with no more than 2 nodes, while the second node mediates more nodes in the interconnection of two nodes. Generally, the smaller the value of the average distance, the more closely the nodes of a network are connected. [44]

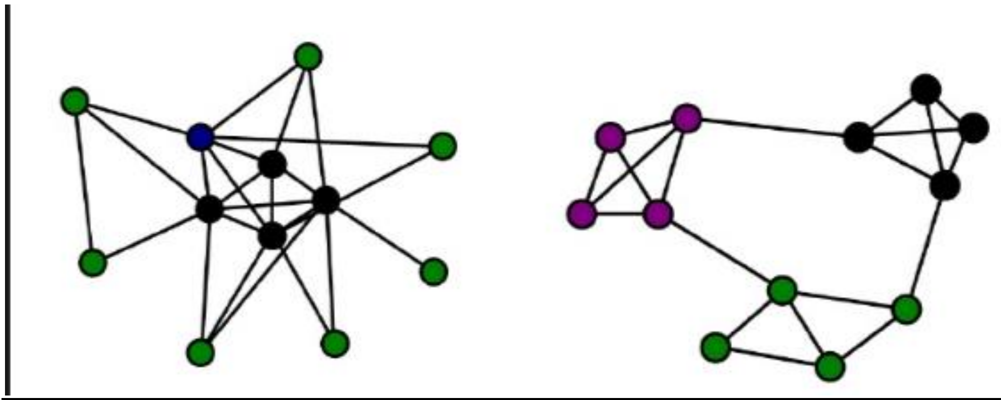


Figure 23 Typical Network with different average distance.

Source: [45]

- **Geodesic Distance**: is the shortest path (with the fewest links) that connects two nodes to a network. For example, Figure 24 shows the interconnection between the nodes in a network. Obviously, nodes 1 and 8 can be directly connected by a bond, or indirectly, through node 7, creating two bonds. The geodetic distance of the two nodes will be equal to the fewer ties between them, i.e. equal to one.

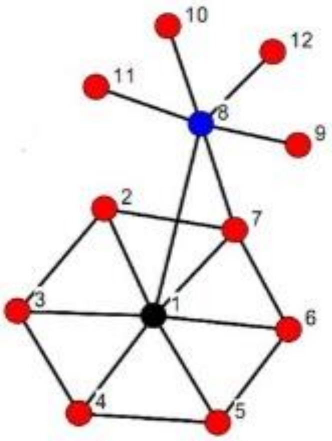


Figure 24 Geodesic Distance between two nodes

Source: [45]

- **Density**: The density of a network is defined as the number of links created in it, to the potential number of links that could be formed. The set of values that the density can take is from 0 to 1 and its calculation formula is:

$$d = \frac{l}{n * \frac{n-1}{2}}$$

, where n: nodes and l: the bonds.

In the event that all nodes are directly connected to each other, then the density will be equal to the unit. In general, the larger the network, the density will decrease, as the potential links will increase. [44]

- **Clustering Coefficient**: The clustering coefficient checks whether the nodes directly connected to a particular node are directly linked to each other by taking values from 0 to 1. Clustering Coefficient is calculated as:

$$\frac{the\ number\ of\ edges\ between\ the\ nodes\ that\ are\ directly\ connected\ \text{with the node i}}{The\ potential\ number\ of\ edges\ between\ neighbours}$$

[46]

Figure 25 shows three networks with different interconnection of the nodes. The network (a) has a clustering factor equal

10 * 2/(5 * 4)= 1

, the network (b)

$3 * 2/(5 * 4) = 0.3$

and in the network (c) the clustering factor is zero, since its neighbours are not directly connected to each other.

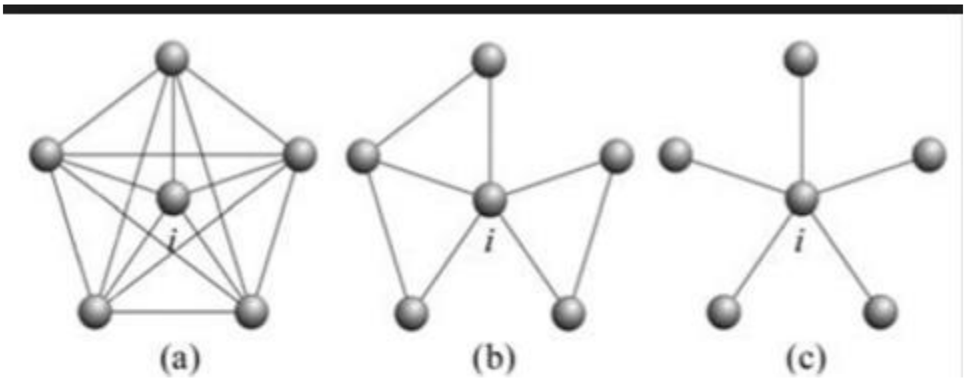


Figure 25 Clustering Coefficient of the Networks

Source: **[46]**

Therefore, it is easily understood that in networks with a high clustering coefficient most nodes are directly connected to each other, so they are more independent since they are not bound by a small number of nodes. At the same time, however, the power they exert on the network decreases due to the more options the nodes have.

4.3.3. Centrality of the Networks

The Centrality of a network denotes the position-power that has been hosted within the network, separately. The determination of nodal centrality is based on various indicators and is evaluated by different criteria at a time. Some of the key centrality indicators are analyzed below:

- **Degree of interconnection and influence (Degree centrality)**: The degree of interconnection and influence of each node equals the links it performs with other nodes. The set of nodes surrounding a node is called "neighbourhood", which forms the size of the interconnection degree. The total network interconnection level is twice the number of links that take place on this network. This is true as each link is counted twice when measuring the degree of each node. The higher the degree of interconnection of a network, the more direct links exist, and the nodes are more independent, since they do not depend on a small number of links. The centrality of this node does not in any case guarantee the great influence it exerts on the network, as the node can be characterized as a central node but in a subnet rather than in the whole network due to the weak links it carries. [35]
- **Closeness Centrality:** Explains how far a node is from the rest of the network, based on the sum of its distances from the other nodes. The sum of the distances of a node gets a small value when it is central and is a short distance from others, so the degree of proximity to this node is high. If the node is connected to many nodes but which

are not as central to the network, then it is a central node but for the subnet that the nodes it connects to. [35]

- **Betweenness Centrality**: The degree of mediation and control of information is calculated by considering nodes that act as a bridge between nodes or subnetworks that would remain disconnected from the network in the absence of that node. To make it clearer, observing Figure 26, we will see that node A has a high degree of mediation, since, thanks to it, the two subnetworks come into contact, which would not be the case of its absence. [44]

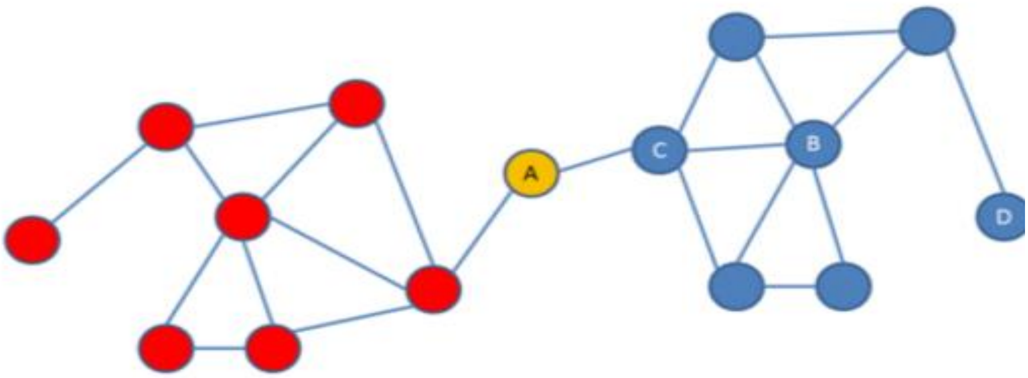


Figure 26 Betweenness Centrality and information control

Source: [47]

- **Eigenvector Centrality**: The Link Quality Index considers the quality of the links in a single node. In particular, the links created by a node with other central nodes are more important than those with less centralized nodes. Therefore, the node with the highest link quality index is usually the one with the largest network interface. [35]

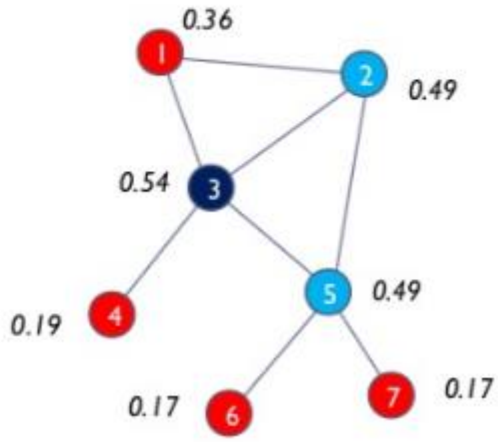


Figure 27 Eigenvector Centrality of a node

Source: [48]

For example, in Figure 27, we notice that the node with the highest degree of interconnection is 3, which is connected to most nodes in the network, but also to the most powerful, according to the quality indicators that are next to each node.

4.4. Computational Programs of the SNA

For Social Network Analysis, there is a wide range of programs that perform qualitative and quantitative network analysis. The most common of these are:

- Agna
- Ucinet, E-NET
- Walsh's Classroom Sociometrics
- InFlow
- FATCAT, MultiNet, Negopy
- Pajek
- SIENA

Etc. [49]

The program that was used for the certain study is Ucinet 6.0. This program was developed in the early 1980s when Lin Freeman collected a number of different network analysis programs and put them on floppy disks. The programs were written in different languages and had different forms of entry and exit. The version used is 6.4. [50]

In order to load the statistics of the EU countries to the program the steps were taken are the following:

I. Quadruple tables were produced for each year separately, with the countries of the energy grid being at the forefront and column of the tables. The diagonal has zero values, while above and below the diagonal are the exports and imports of the countries, respectively, to the other countries.

II. Then, the squares were introduced into the Ucinet program, and the topological characteristics of the various tables were calculated through Network →Cohesion → Density / Geodesic Distance / Clustering Coefficients and Centrality and Power → Degree / Eigenvector / Freeman Betweenness / Closeness.

III. Then the time was merged into two periods: 2000 – 2007, 2008 – 2013 and 2014 – 2016, with the network display through the command Draw → Open →Ucinet data → Network, where they pass the data of the square tables for each period, while in Attribute Data, they pass the data referring to the ranking of countries in regions, based on which nodes are coloured.

IV. Finally, through Analysis -> Centrality measures and Properties → Nodes / lines, we determined the size of the nodes based on the Degree and the determination of the size of the arrows based on the energy flows of each country.

5. Implementation of the SNA method in the EU Electricity Market

5.1. Introduction

The countries' participation in networks offers many advantages, both for the country itself and for the European market. Initially, by participating in an energy grid, the country has the potential to enrich its energy mix with better quality than its own. In addition, the options for the availability of electricity are increasing with the addition of new countries to the networks, with the result that countries become more and more independent through co-operation with more countries when their geographic location permits and cease are dependent on a small number of states. Even when the country is an importer, it is indispensable for the network, as it is in the advantageous position to negotiate the wholesale price of electricity to buy cheaper than many countries. The cooperation of countries with a large number of Member States, apart from market integration, also ensures the security of national supplies, since under no circumstances, by doing energy transactions with other states, they will not be in an unfavourable position to interrupt the electricity supply of certain because of the inability to meet needs with domestic capacity. Finally, consumers benefit from the existence of networks, as through this process all participating countries are obliged to provide their product at a similar price in order to remain competitive on the wider market. Of course, state markets in an 'unfavourable' geographic location, such as Ireland, Portugal and the Baltic States, have a higher electricity price due to their low interconnectivity with the rest of Europe and their dependence on a small number of countries. Therefore, with the formation of a wider European energy network, the electricity market is released and its price stabilized.

5.2. Data and assumptions

This thesis studies the natural network of electricity market in the EU, the period 2000 – 2016. This network consists of 28 nodes, of which 27 are EU countries, with the exception of Cyprus. The latter is excluded from our study because it is geographically isolated and does not engage in energy trade with other EU countries. The 28th node is the variable “OTHER”, which includes all the non-EU countries that carry out energy trade with the Member States of the Union. The edges between the nodes are the energy flows, the imports and exports that take place between the countries at that time.

The data used in this method are derived from Eurostat statistics. [22] At this point, it should be noted that since the imports of the country B from country A are not the same with the corresponding exports from B to A, the data that are used and are available at the tables in Annex A, have been formed with the averages resulting from the corresponding data.

The social networking analysis was applied for each year separately, but also for the periods 2000-2007, 2008-2013, 2014 - 2016 and for the whole 2000-2016. Through this analysis, the following features of the physical network are highlighted:

- ✓ Information is provided on the energy flows to the network, per year and the total of fourteen years. From this, conclusions are drawn both on the course of liberalization of the market in the EU and on the impact of RES on the electricity sector.
- ✓ It highlights the independent and dependent countries, and the importance that each country has for the network through the strength of the bond.
- ✓ In addition, countries that are a link between two or more subnetworks, which would be isolated under different conditions,
- ✓ And it seems the EU's dependency rate as a whole from countries outside the Union.

Finally, through network study and graphical depiction, the system's capacity is observed, as the network mostly is consisted of the same countries throughout the period we are examining, but the flows between them and the links change with the passing of years. The reasons that contribute to these changes may be either country – by – country policy and its alliances with others, or the low capacity of some countries at a given point of time, which may create new links to meet needs or cut the bridges with countries that fed, or the price and composition of the energy mix it exported.

The network was examined for the topological characteristics, centrality and interconnection of countries. Initially we study the topological features of the network, which are:

- Nodes
- Edges or links
- Density
- Average Distance
- Geodesic Distance
- Clustering Coefficient

The calculation of the edges was made by adding up the degree of interconnection for the exports of each country for all countries each year and by dividing it by the two. Linking was done in this way, as a link is counted twice, one for one node and one for the other.

Next, a survey of the individual indicators of centrality for each country, each year from 2000 to 2016, is carried out and is as follows:

- Degree Centrality
- Closeness Centrality
- Betweenness Centrality
- Eigenvector Centrality

These indicators provide important information both on the influence of each country on the network and on how the network changes overall over the years. It should be noted that the degree of interconnection and influence was examined in terms of exports and imports made by each country.

Next, we examine the overall centrality indicator of each country that makes up the EU electricity market for the same time, and is shown in charts, depending on the Region that belongs to each country. A clarification at this point is necessary as there are EU countries which do not belong to any of the Regions analysed in a previous chapter, namely Croatia, Bulgaria and Romania. It is important to observe how the indicators of centrality of these countries change, and whether the existence of Regions in the way of linking countries to electricity networks ultimately plays a role.

The following steps were used to calculate the overall centrality index of each state: Initially, individual indices were calculated using the Ucinet program, and ranked using the rank order from the least central country, with the highest-ranking, the most central the smallest number from 1 to 26. Then, the sum of the individual indices of each country was calculated for each year separately and ranked with the rank order from the most central country according to the highest sum, with the smallest the number ranking, the more distributed the largest number ranking, from 1 to 28.

Finally, the graphical depiction of the network was carried out for the periods 2000 – 2007 2008 – 2013, 2014 – 2016 with the Ucinet draw → draw command. It is necessary to note at this point that the network depiction was based on the region belonging to each country, giving the corresponding colouring to the nodes. The choice of time frames was based on the emergence of the economic crisis in Europe in 2007-2008, with the aim of examining the impact of the crisis on the electricity market and the process of liberalization and the new measures that EU took to confront the climate change 2013 – 2014. Countries participating in more than one region are portrayed in a different colour from the regions to which they belong. Also, EU countries that do not belong to any of the regional markets mentioned in a previous chapter, and the node "OTHER", are displayed with a different colour on the network. The size of the nodes takes sizes from 4 to 24, depending on the degree of interconnection of the respective countries, while the arrows representing the energy flows take the sizes from 1 to 4. When a transaction has a large volume, then the arrow resulting in that node is larger and its line thicker.

5.3. Results

5.3.1. Topological characteristics of the Network.

The study of topological features is based on the three main pillars of the network that we study, namely, the nodes that make up our natural network, the connections between them and the energy flows that take place over the period 2000-2016, which are presented to Table 1. The nodes throughout the time we are studying are the same countries, EU 27 and the additional node that includes countries outside the EU.

It is evident that interconnections between the nodes vary between 49 and 59, with an average of 54, showing small fluctuations over the years, so the network does not change. Maximum connections are displayed over the entire range of the period we are studying. By calculating the connections that correspond to each node, we will see that each country performs on average, two edges, that it is linked to at most two other countries.

Energy flows, on the other hand, show an unstable behaviour in the first three years, as in 2002 the maximum energy trading has taken place over the sixteen years we are dealing with, and a year later the energy transactions are the few that have been done in under study network. After 2003, energy transactions show a slight increase per year by 2016. We can say that the maximum number of connections does not entail an increase in energy flows. By contrast, a big increase in energy flows in 2015 is recorded in the minimum edges. By carefully observing the column of Table 1 with energy flows by link, we can see that, over the years, the electrical energy corresponding to each link decreases until 2013 and there is a sharp increase the last 3 years. This leads us to the conclusion that, on the one hand, new co – operation between states strengthens the EU's effort to create a single electricity market, whereby the electricity flowing through the network is increasing. On the other hand, the reduction in energy burden by link shows the efforts made by countries to stop relying on a limited number of countries to meet their energy needs through the creation of new link. Of course, this reduction, apart from the independence of states in the electricity sector, also reflects the reduction in electricity demand from most European countries, and the effort made to save energy. However from 2014 until 2016, the sharp increase of the energy flows between the nodes shows that the demand in the EU is starting to be increased again, and that is due to the entry of a new country in the network, Malta.

Table 1 Nodes, edges and energy transactions of the EU network for the period 2000 – 2016

Year	Nodes	Edges between EU and non EU States	Edges per Node	Edges in the EU	Energy Flows of EU and non EU States (1) (GWh)	Energy Flows per Edges (1)	Energy Flows of EU (2) (GWh)	Energy Flows per Edges (2)	%Energy Flows in the EU
2000	27	52	2	43	307743	5918	200841	4671	65.26
2001	27	58	2	48	315092	5480	205276	4204	65.15
2002	27	54	2	45	341561	6325	218816	4865	64.06
2003	27	56	2	47	300450	5341	231869	3699	77.17
2004	27	54	2	44	300600	5593	231288.5	4193	76.94
2005	27	53	2	44	300750	5701	257338.5	3692	85.57
2006	27	55	2	46	300900	5521	249146.5	3682	82.80
2007	27	56	2	47	301050	5376	249438.5	3489	82.86
2008	27	59	2	50	301200	5105	238529.5	3375	79.19
2009	27	58	2	48	301350	5241	186860	3457	62.01
2010	27	55	2	46	301500	5457	220009.5	3555	72.97
2011	27	57	2	47	301650	5339	251760.5	3266	83.46
2012	27	57	2	47	301800	5342	284316.5	3457	94.21
2013	27	58	2	48	301950	5251	275123.5	3306	91.12
2014	27	54	2	45	376969	6980.91	304153	6758.96	80.68
2015	28	49	2	47	365632	7461.88	323167	6875.89	88.39
2016	28	58	2	49	387316.5	6677.87	296443.5	6049.87	76.54

It should be noted that the study of connections between the nodes and the energy flows was made by taking into account the energy transactions carried out by the countries with non-EU countries. However, it is of great interest to compare the links and the energy flows among those that include Non – EU countries and those that take into account only transactions made between Member States. Starting from the connections between the states, according to Table 1, it is clear that the links created between the EU Member States are fewer, with 21% of the links on the total connections being created with non – EU countries. Observing the Figure 28, with the help of Table 1, it is clear that the energy flows that take place within the EU this time period is on average 70% of the total energy flows. Taking a closer look at the results of Table 1, we can see that, until 2004, energy trade between member states follows the course of total energy flows, i.e. they increase until 2002, they decrease sharply in 2003 and are rising in 2004, and from 2005 onwards they show a declining path, contrary to the one followed by total energy transactions until 2010. Through this observation, in addition to the percentage of links created with countries outside the EU, it is easy to conclude that the EU's dependence from the non EU countries, to meet the needs of Member States for electricity is high and is constantly increasing. However, after 2010, we can see an increase in the energy flows inside the EU countries and that is due to the new interconnections and the connection of the isolated Malta to the network, from 2015. Besides these facts, no one can deny the fact that the influence that Russia, Norway and Belarus have to the energy sector of the EU is still countable, and the EU has to make faster decisions to make its countries independent and the EU market more competitive.

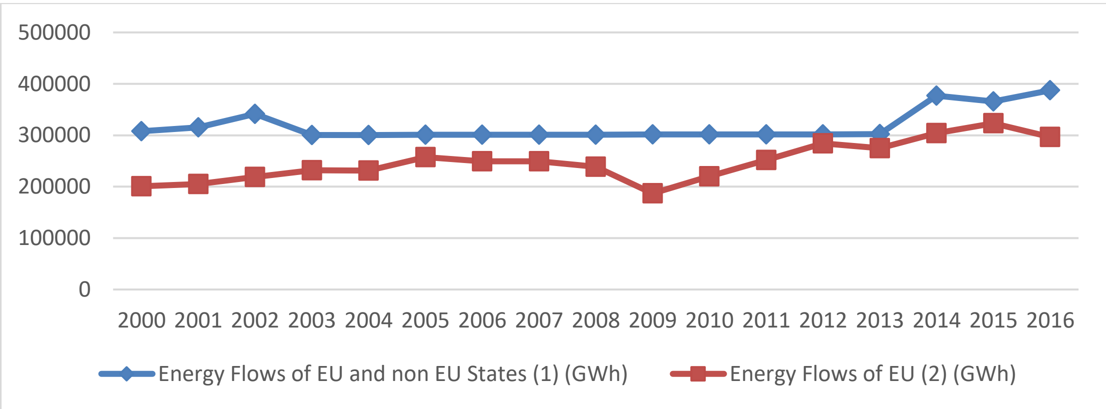


Figure 28 Energy Flows (in GWh) between the EU and the non – EU countries the period 2000 – 2016.

Apart from the three topological features mentioned, there are others that confirm the need for interconnection between EU countries and the creation of a single competitive market. Another dimension that characterizes the network is the density, which shows the links created in it to the potential number of bonds that can be formed. At this point, it would be good to be noted that the density of the network indicates the way that nodes are interconnected, so a high-density value represents a dense network with independent nodes.

Observing the density column in Table 2, it is clear that over time, the density is at a low level and remains almost constant, with an average of 16%, showing small fluctuations. From this, important conclusions are drawn for the network, as it highlights the inability of full interconnection between countries. At the same time, looking at the average Degree Centrality of all countries on the network, according to Table 2, we can see that it remains stable, with years, and equal to 4.

Continuing with the study of the mean geodetic distance of the network, it is obvious that the geodetic distance remains at constant levels, as well as the previous features we studied, equal to 2, except for 2015 where the characteristic is increased to 3. This shows that most countries are connected at most in two steps with the others. In other words, the states that constitute the network have a close connection, although some countries have a geodetic distance of four, five or seven, according to the column of maximum geodetic distance. This is due to the fact that countries which are geographically isolated use more links to come into contact with countries across Europe. A prominent example is Ireland, which has a large geodetic distance in its effort to reach the countries of Central Europe, Scandinavia and the Baltic.

In conclusion, it would be an omission if we did not examine the Clustering Coefficient factor that -shows whether the countries that are directly linked with a state, are directly linked to each other, too. According to the corresponding column of Table 2, we observe that the grouping index ranges from 0.24 to 0.55, following a relatively declining course over the years, with an average of all times close to 0.38. These results make it clear that direct links between countries are declining over the years, and therefore they become more dependent on a smaller number of countries, or they become more self – satisfied. Regarding the average Clustering Coefficient, it is understood that 38% of the countries create direct links with countries, directly linked to a particular state, so in general more than a half of the countries are remaining dependent on a limited number of countries.

Table 2 Topological Characteristics of the EU network for the period 2000 – 2016

Year	Density	Average Degree Centrality	Average Geodesic Distance	Maximum Geodesic Distance	Clustering Coefficient
2000	0.15	4	2	5	0.554
2001	0.16	4	2	4	0.525
2002	0.15	4	2	5	0.428
2003	0.16	4	2	5	0.479
2004	0.15	4	2	4	0.479
2005	0.15	4	2	5	0.470
2006	0.16	4	2	5	0.385
2007	0.16	4	2	5	0.388
2008	0.17	4	2	5	0.439
2009	0.16	4	2	5	0.414
2010	0.16	4	2	5	0.387
2011	0.16	4	2	5	0.414
2012	0.16	4	2	5	0.406
2013	0.16	4	2	5	0.459
2014	0.14	4	2	5	0.383
2015	0.15	4	3	7	0.242
2016	0.15	4	2	5	0.358

By comparing the topological indices between them per year, we can easily conclude that the topological features are stable over time, with the exception of Clustering Coefficient and density that present small fluctuations, at low prices. Based on average density and average Clustering Coefficient, it is clear that, although the links created in the network are much less than those that could be formed, half of them are direct. If it is also noted that the average geodetic distance of the network is 2, then it is easy to see that, irrespective of the small number of links created by countries in the network, a large proportion of these connections are direct, and, their interconnection is tight.

5.3.2. Centrality indicators analysis of the EU

Initially, the degree Centrality of the countries participating in the EU energy network can be studied in terms of two parameters: the exports made by each country and its imports based on Tables 10, 11 and 12 of Appendix B, and on the Figures 14 and 15. It is obvious that the degree Centrality for the majority of countries, regardless of which parameter we are considering, remains almost constant over the years, with small fluctuations of one to two points between the years.

Apart from this, it is noted that countries with the lowest degree Centrality, between 1 to 3 units, are the Baltics, Iberian Peninsula, British Isles and some Central and Southern European countries, namely Greece, Bulgaria, Belgium, Luxembourg, Croatia and Slovenia. It is therefore confirmed what has been said in previous chapters about the limited interconnection between the states, because of their geographical position, particularly the Iberian Peninsula and the British Isles, and their great dependence on a fairly limited number of countries. In addition, there appears to be a need for the formation of Regional Electricity Markets, which contribute to the consolidation of the European electricity market, starting from the interconnection and integration of the markets of neighbouring countries.

However, this is not the case for the Central European countries belonging to more than one Regions, i.e. Germany, Austria and France, which act as “bridges” between the Regions and carry out energy transactions with a number of countries. Nonetheless, apart from the above countries, there are two more countries belonging to more Regions, Slovenia and Poland that are not as interconnected as the above-mentioned countries. This is due to the fact that the citizens’ electricity needs and final consumption per capita, based on what has been said above, is much lower than the other three. In addition, with regard to state energy transactions, it is clear that Poland and Slovenia are doing much lower energy deals with France, Austria and Germany, where the first is also the one with the largest volume of exports to the EU. Of course, by comparing these two countries, we can see that Poland has a higher degree of interconnection from Slovenia because of its geographical position, which allows it to trade with more countries.

Moreover, with regard to Romania that does not belong to a Regional Market, we can observe, according to the same Tables in Annex B, that it is showing a sharp increase in its degree of Centrality with regard to its exports in the period 2005-2009, by keeping constant the degree Centrality related to its imports. This behaviour may be due to the fact that the Romanian market at that time was much more economical than the rest of the Central European markets, with the consequence of developing co – operation with other countries by exporting, according to Figures 8 and 16, per capita consumption in Romania remains almost at the same level in the years 2000, 2007 and 2013, while net imports in the same years compared to consumption are quite low, showing that it is a state which is not relying on third parties to meet its energy needs.

More generally, given the above, it is understandable that countries with a large volume of electricity imports or exports are those that have a central position in the grid due to the more direct links they create to carry out their transactions and thus exercise greater influence on the electricity market. In addition, we must not forget that most of the connections over the years are presented by the countries cooperating with the EU but they do not belong to it, making it once again understandable that, EU relies on these countries to meet its electricity needs due to reduced power generation in the EU and the non – competitive electricity market.

Looking at the degree Centrality from the point of view of imports and exports, we can see in Figures 29 and 30 that mainly until 2007, there are countries that show great differences between these two indicators. In addition to Romania mentioned above, France, the Netherlands and the non – EU countries show a big difference in 2000.

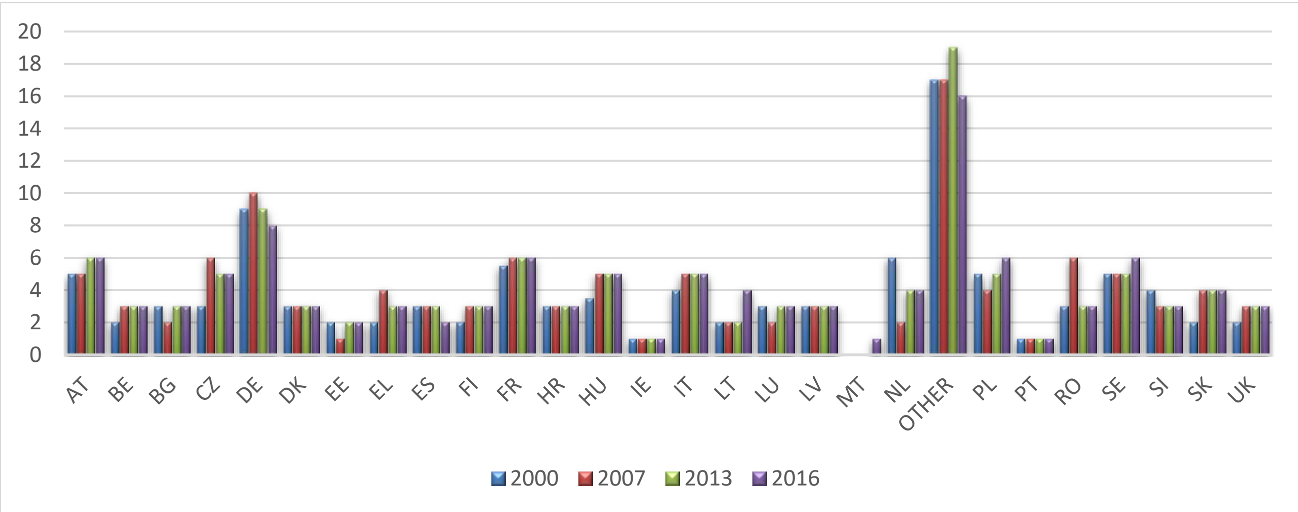


Figure 29 Degree Centrality of the imports for the electricity network, the years 2000, 2007, 2013 and 2016

More specifically, France has two more links on its exports, which confirms its strong export position, making it necessary for a significant number of countries. The opposite is the case for the Netherlands, which shows in 2002, according to Table 10 of Annex B, six more energy-related ties due to reduced domestic electricity production, which is not enough to meet domestic demand, and forces it to import, according to its net imports in 2013, 80% of the energy it consumes, as we analysed in Figure 18. Finally, with regard to countries outside the

EU, Figures 29 and 30 and Tables 10, 11 and 12 of Annex B, between 2000 and 2007, from the neighbouring states, since exports to member states are by two more links. However, this is not the case for the period 2008 – 2013, where, according to the same tables and the same Chart, it seems that the situation is normalizing and the difference between the interconnection rates of imports and exports tends to be nullified. From this, we can conclude that countries have begun to create more ties to carry out their energy transactions, and therefore the interconnection of countries, especially Central Europe, has become more intense. Nonetheless, countries with weak interconnection with the rest of Europe have not shown any change in their degree of interconnection over the years.

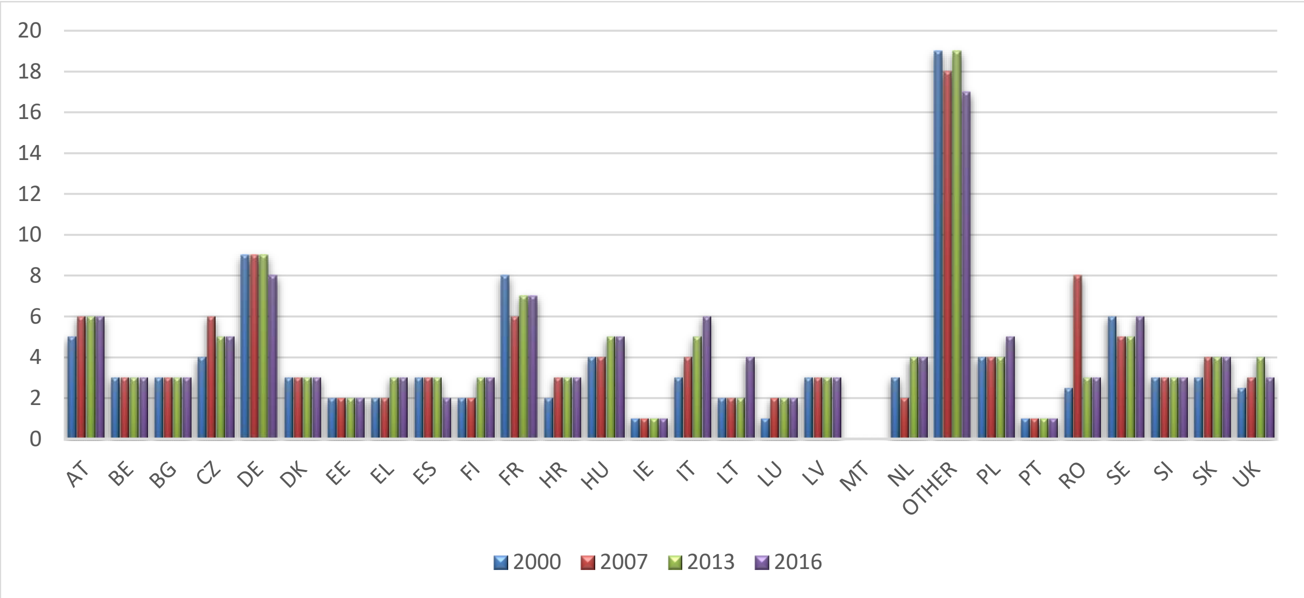


Figure 30 Degree Centrality of the exports for the electricity network, the years 2000, 2007, 2013 and 2016

We can therefore conclude that:

- The price difference in electricity trade determines the position of countries in the grid. Cheap markets are the ones with the most direct links with other countries, while the most expensive are almost disconnected from the rest of the network, in line with what has been said in the sub-chapter on electricity prices
- The geographic location of some countries does not allow for adequate interconnection with energy networks, making them dependent on one or two countries to meet their energy needs.
- The EU is largely dependent on countries that do not belong to it, not just for domestic coverage but for exports to them.

As far as it concerns the Betweenness Centrality, the factor is high for countries that function as a "bridge" between two other countries that under different conditions they could be connected with each other. More precisely, according to Tables 14, 15 and 16 of Annex B, Figure 31 shows that countries with Betweenness Centrality more constantly more than 7 for all the seventeen years of the study are the United Kingdom, Germany, France, Spain and non EU countries. Given the definition of this factor, it is not surprising that the above-mentioned countries are also the ones with the highest grade over the years. Starting from the United Kingdom and Spain, they are two countries that are at a key geographic location, thanks to which Ireland and Portugal respectively are connected to mainland Europe and to the wider energy network. As far as France and Germany are concerned, they are two countries that are involved in many regional markets, bringing together countries that would otherwise not be associated. With regard to the four non-regional countries, we can observe that Bulgaria, Malta and Croatia have a consistent low interconnection below 1.5, due to the fact that their geographic location do not favour them to function as " countries – bridges "among other states.

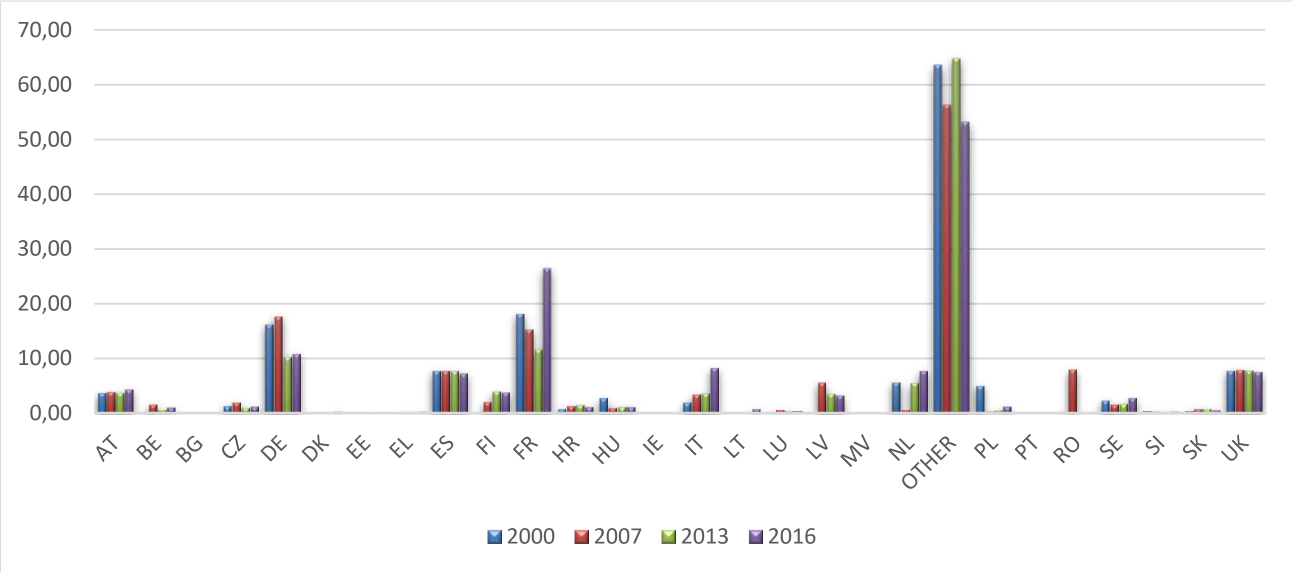


Figure 31 Betweenness Centrality of the Network the years 200, 2007, 2013 and 2016

Concerning the forth country, Romania, there is a sharp increase in 2006 - 2007, with 2010 the rate of mediation being back below 0.5. The period 2006-2009 coincides with the time when the country has a high degree Centrality. It is therefore confirmed that at that time the country developed energy transactions with new countries, namely with Hungary, Montenegro and Serbia, and thus functioned as a link between the cooperating countries and the new states, especially the two that do not belong to the EU.

Similarly, unstable behaviour in the price of the factor was observed for the Netherlands and Poland, with the former to sharply cut its factor from 5.49 in 2003 to 0.49 in 2004, while in 2011 it rose sharply from 4.91 to 8.02, and the latter to decrease from 5 in 2000 to 0.81 in 2001. The Netherlands, as seen in Figure 18, is an importing country. According to the European Commission [9], it is clear that, in 2004, where the factor is falling sharply, domestic electricity production is higher than any other year. This has led it to cut off some links with other countries that fed it with electricity, since it was able to meet this share of demand with domestic production. With the same rationale, it also responded to reduced electricity production in 2011, creating new partnerships with countries that would supply it with electricity, in particular with Norway and the United Kingdom. However, this was not the case for Poland, which, based on its net imports in relation to domestic consumption, in Figure 18 is a marginal importer country while exporting 10% of its production. The decrease in the Betweenness Centrality is due to the fact that domestic electricity production after 2000 had a downward trend, thus deciding to limit exports by stopping trade with Sweden, as a result of no longer having the status of "intermediary" between the Central and Eastern Europe and Scandinavia. Undeniably, we can say that France and Germany continue to be the two central countries of our energy network and have a great influence on its shaping.

The Closeness Centrality, on the other hand, expresses how far is the country from the others that cooperates. We observe, that it is almost constant for most states with small fluctuations in the sixteen years of study. It shows an increase for Austria, Germany, Spain, France, Italy, non-EU countries, Sweden and the United Kingdom, in 2013 based on Figure 32. Therefore, in the countries that appear to be elevated, they are those of the five countries with a high Degree Centrality, but also for the countries with an increased Betweenness Centrality factor. Countries with a high degree Closeness Centrality, are also those with the most central position in the network and therefore the distance of the links that create is small. However, in 2016, the certain factor is decreased, which shows that countries are losing their power in the market, and we are leaded to a conclusion that all countries tend to become equal due to the better interconnection between all the network.

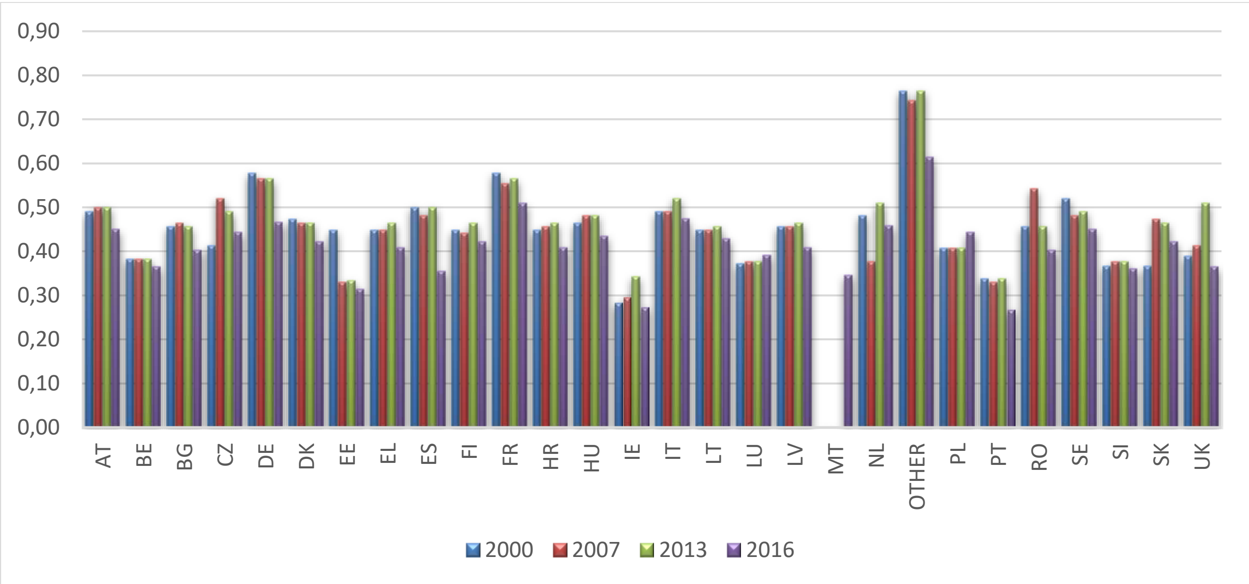


Figure 32 Closeness Centrality for the years 2000, 2007, 2013 and 2016

Regarding the Eigenvector Centrality, which expresses the “importance” of the links that are created by a country, according to Tables 17 and 18 of Annex B, it is observed that for most countries it is unstable within the period of time we are studying, with seven of them showing a large drop in the index, concerning Figure 33, from 2000 to 2016. It is clear that two of the major network countries, France and Italy, show a significant reduction in the Eigenvector Centrality, with the former to diminish the factor from 0.48 to 0.20 and the latter from 0.42 to 0.20. For France, this reduction, coupled with a reduction in the degree Centrality, leads to the conclusion that the country has stopped energy transactions with some countries that have an impact on the shaping of the electricity market in the EU.

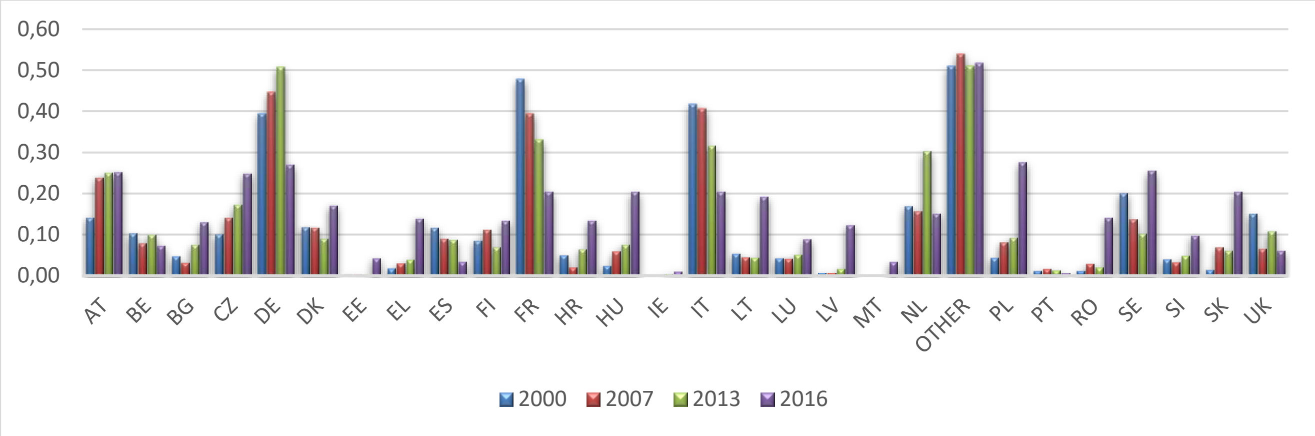


Figure 33 Eigenvector Centrality for the years 2000, 2007, 2013 and 2016

On the other hand, Italy, while cooperating with more countries over the years, based on Figures 29 and 30, the Eigenvector Centrality is downward. This is explained by the fact that the countries that Italy has formed energy edges are countries that do not determine the faith of the EU's energy network, i.e. non-central. Unlike to this, there are some states that greatly increase the quality of the years, such as Poland, Sweden and Slovakia. The Netherlands naturally forms links with Central European countries, which have a great influence on the grid to meet its domestic electricity needs. Taking into account Figure 33, we can see that the countries with the biggest Eigenvector Centrality are France, Italy, Germany, the Netherlands and non-Union countries, with a rate of more than 0.3 until 2013, while in 2016 the only group that maintains the indicator greater than 0.3 are the non – EU countries, showing once again the importance of the group for the electricity grid of the EU.

It is clear that countries on which a large number of states depend to carry out their energy transactions are those of Central Europe, i.e. France and Germany, but also non-EU countries, which shows once again that the liberalization of the EU market is not complete, while the neighbouring countries have a significant impact on the evolution of the electricity market in the Union.

5.3.3. Analysis of the Overall Degree Centrality

The overall Degree Centrality, is a size that takes into account all of the above mentioned degrees, and the states with the smallest Degree Centrality is the one with the highest power in the grid.

In Figure 34, it is remarkable that countries with Overall Degree Centrality less than 5 are Germany, France, Austria, Sweden and Italy. It is not surprising that Germany, France and

Austria are the first three countries with the lowest degree of centrality, making it clear that they are those with the greatest power in the energy grid and that many countries are dependent from them. Sweden, on the other hand, is a country where its unique central degrees are quite high in relation to the rest of the countries. We should not omit the fact that Sweden, according to the degree Centrality and influence and the Betweenness Centrality, is a country that has been associated all the years with at least five other countries and acts as a link between the Northern Region and the rest of Europe until 2006, whereby Finland takes over this role. This change in the degree of mediation is also reflected in Figure 34 with Finland reducing the centrality index by six points and Sweden increasing by one unit. However, apart from Finland, which has reduced the Overall Degree Centrality to such an extent, the Netherlands, Spain and Denmark are experiencing major changes in the second and third period. The Netherlands shows a sharp drop of 8 points, and this is due to the fact that after 2008 the Betweenness Centrality, the Eigenvector Centrality and the Closeness Centrality are increasing. This is due to the increase of domestic production and due to the co – operation with countries that are important for the electricity market. However, this is not the case, for Spain and Denmark, which increase their Overall Degree Centrality after 2008. This increase for both countries is due to the decline in the index Eigenvector Centrality, thus showing that although both countries are linked to three others to carry out their transactions, the second period, 2008 to 2013, have been linked to the same number of countries but to countries that are not as important for the network.

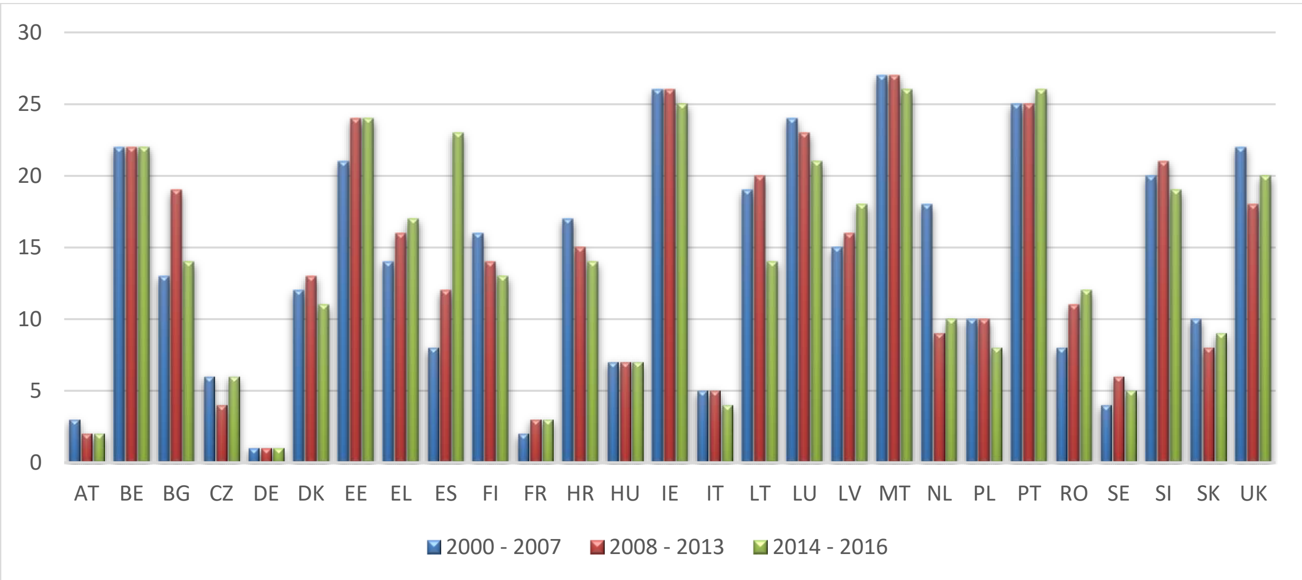


Figure 34 Overall Degree Centrality of the EU network for the years 2000 – 2007, 2008 – 2013, 2014 – 2016.

5.3.4. Analysis of the Overall Degree Centrality based on Regional Markets

It is also interesting the diagrammatic illustration of the Overall Degree Centrality per Regional Market.

Central Western Europe: In Figure 35, the Netherlands present an unstable behaviour for the period 2001-2004 and 2008-2010. This is due to the fluctuation of the degree Centrality and more specifically, to the interruption of partnerships with other countries. This has led to the diagramming reduction of the degree from 2003 to 2008 and the recovering of some links after 2008.

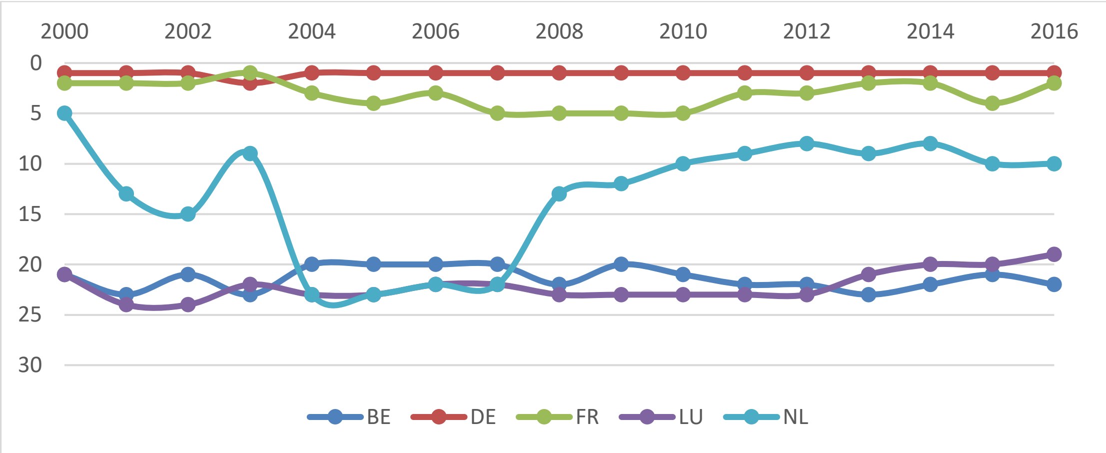


Figure 35 Overall degree Centrality of Central Western Europe.

British Islands and France: In Figure 36, it is obvious the unstable course of the Overall Degree Centrality of the UK. This behaviour is mostly because of the instability of the Eigenvector Centrality. The country after 2011 doubles its edges with other countries. The great dependence of electricity generation from natural gas, according to European Commission [9], is depending on the exploration and exploitation of the latter that tends to reach the levels of the fossil fuels' availability. In general, the UK market is very sensitive to the changes of the NG prices, and that is why the country creates a lot of links when its market is not profitable.

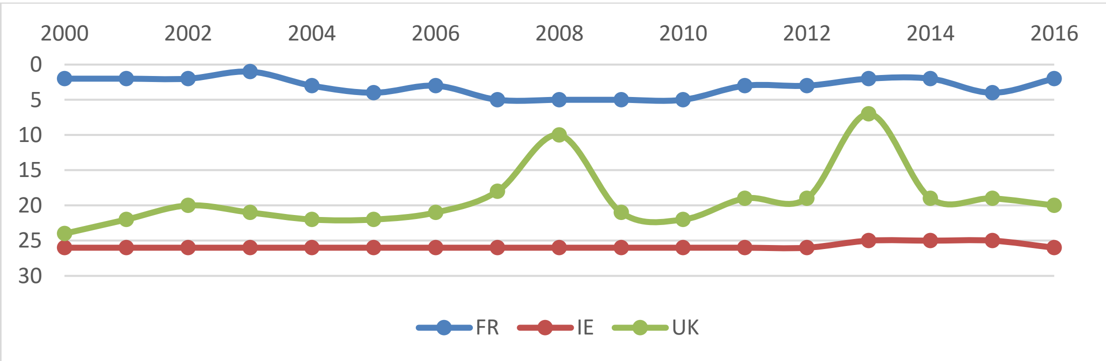


Figure 36 Overall degree Centrality of British Islands and France.

Northern Europe: At the Figure 37 below, it is confirmed what it is mentioned before for Sweden and Finland. In general, it is undeniable that Sweden is the one that is actually the link between the Scandinavian countries and rest of Europe. However, it is affected from the increase of Finland's interconnection with the EU countries, which leads to the decrease of its influence in the market. We should mention that Finland and Sweden are two countries that exploited from the first time the RES in the electricity generation sector. This contributes to the configuration of the index, because the years were the RES were reduced, Finland, as a country – importer, based on Figure 18, it creates new links for the demand cover, with countries with great power in the European market. The opposite is occurring with Sweden, which is self-sufficient, and the reduction of the power generation from RES, leads to the decrease of the index, either due to cooperation interruption with other countries, or due to energy trading with countries that are not so important for the electricity market formation.

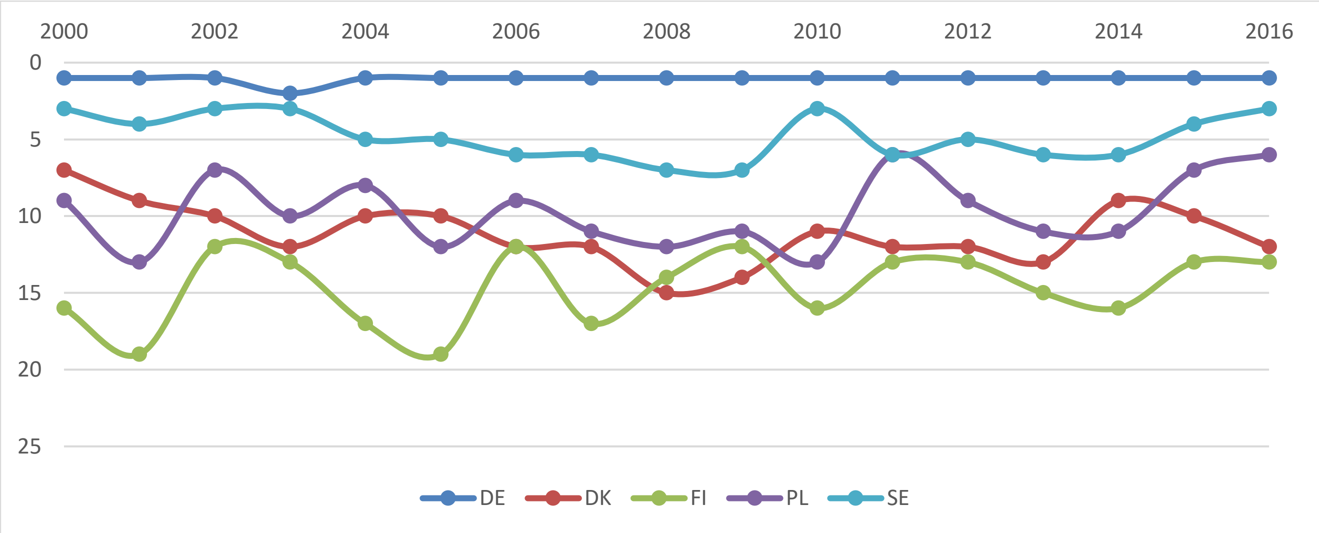


Figure 37 Overall degree Centrality of Northern Europe

Baltic Peninsula: In this region, the one that is more central in the region is Latvia that has very low index in the total grid. Latvia, is a country that has less electricity generation than Estonia, which is based mostly on RES. This that makes it more central in contrary to other two countries is the high Betweenness Centrality. However, in general, the Baltic Peninsula, has very low degree Centrality, and high dependence on Russia and Belarus.

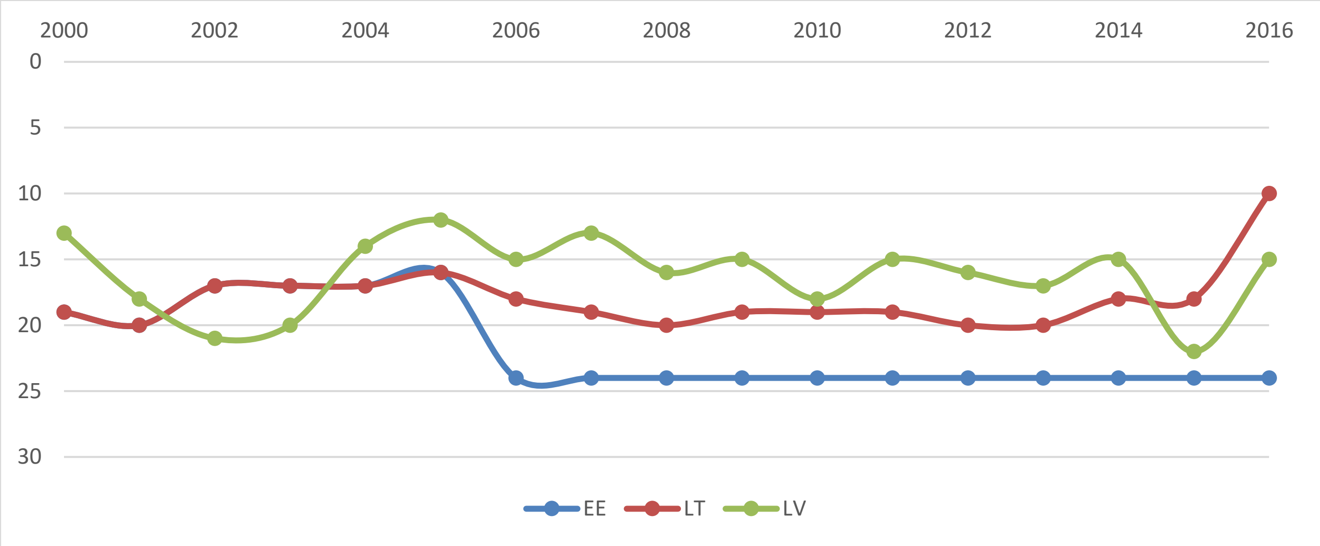


Figure 38 Overall degree Centrality of Baltic Peninsula

Western and South Europe: One more region that is worthy to be analysed is the Western and South Europe, where we can see the importance of Spain in the electricity market of the EU, regardless the small number of countries which is cooperated. It is considered as a central country for the network, because thanks to Spain, Portugal is able to be supplied electric power from the European network, while otherwise it would be obliged either to increase the inland electricity production, for its needs, something that has happened over the years, or to move forward to electricity cut off to some cities, in order to deal with the increased demand. Here, it is once again clear the need to disengage certain states from a single country and their energy interconnection to the wider energy network.

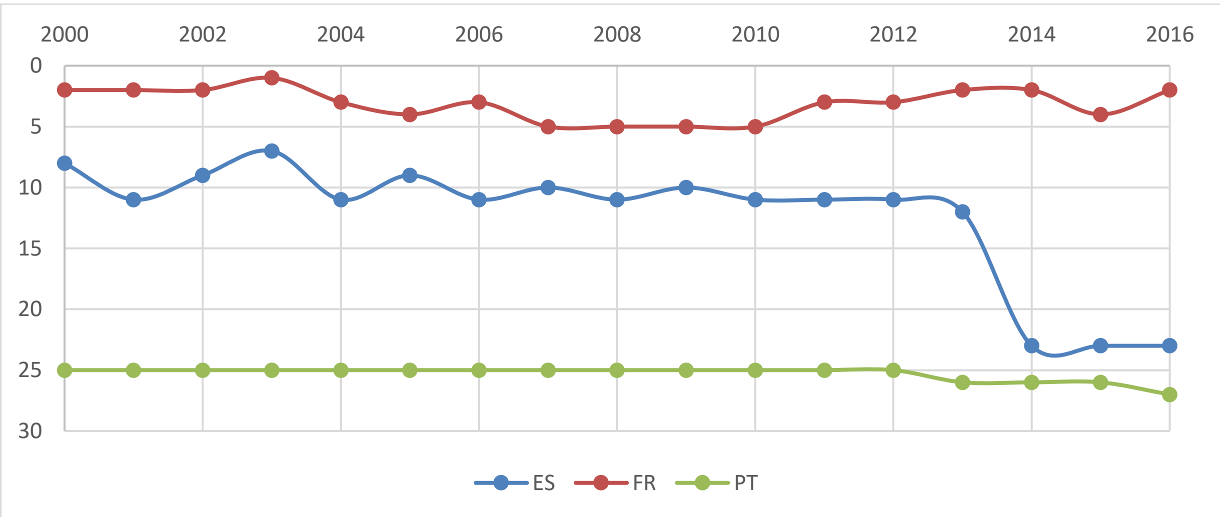


Figure 39 Overall degree Centrality of Western and South Europe

Central and South Europe: this region it is consisted of four of the most important countries for the electricity market, France, Germany, Austria and Italy, which have the lowest index. On the other hand, Slovenia's and Greece's index is between 10 and 24, and put them in the last position with the most decentralized countries. The fact that the index is so low, is due to the geographic position of the states, that do not allow them to be connected with a big number of countries, but even though there is a connection with the other countries, they are not so powerful to the network.

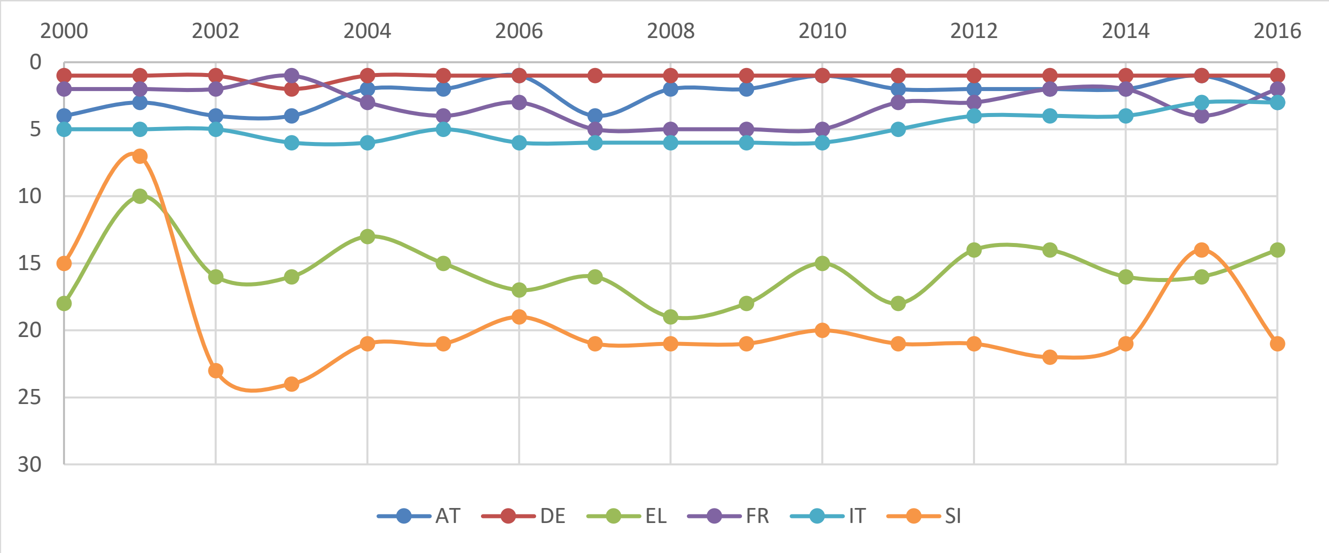


Figure 40 Overall degree Centrality of Central and South Europe

Central and Eastern Europe: It includes many countries that belong to other regions, along with Hungary, Czech Republic and Slovakia. It is obvious that the total index of these three countries are quite the same, because all of them are in an advantaged geographic position that allows them the creation of links with many countries.

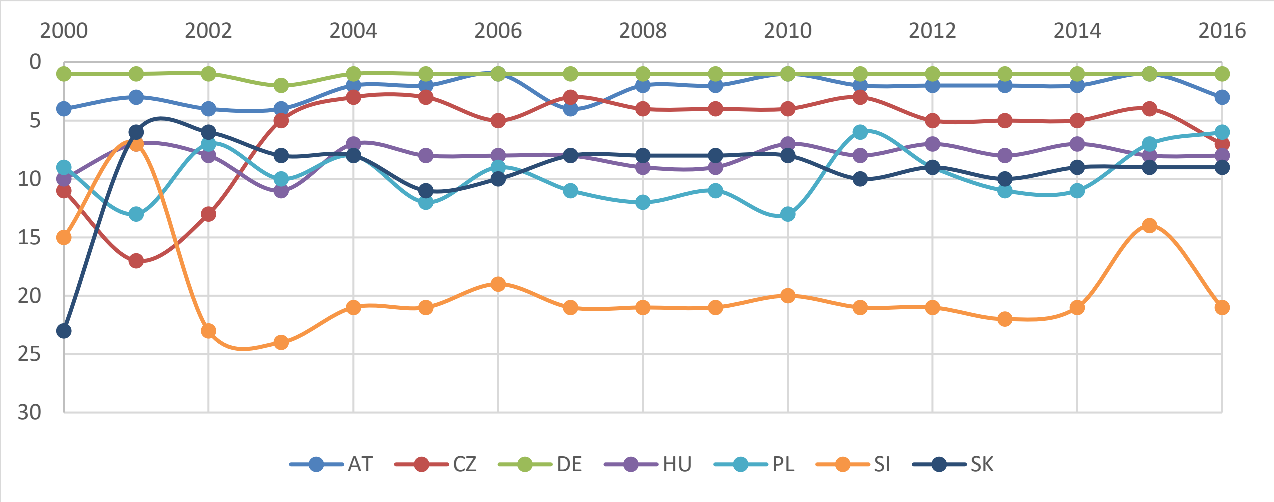


Figure 41 Overall degree Centrality of Central and Eastern Europe

5.4. Network illustration

5.4.1. Introduction

This sub chapter represents the EU electricity market network for the periods 2000 – 2007, 2008 – 2013 and 2014 – 2016, with and without flows from countries outside the Union. As mentioned in the assumptions, apart from the seven regional markets defined above, two more were considered. The eighth region, which includes the countries belonging to more than one region and the ninth, that consists of the OTHER, Romania, Croatia, Malta and Bulgaria because they do not belong to any other region. The colouring of each region is indicated in Table 1.

Table 3 Colouring illustration of EU countries depending on the regions

Region #	**Region**	**Country**	**Colour**
1	Central Western Europe	Belgium, Netherlands, Luxemburg (France, Germany)	Yellow
2	British Islands & France	UK, Ireland (France)	Grey
3	Northern Europe	Denmark, Finland, Sweden (Germany, Poland, Norway)	Pink
4	Baltic Peninsula	Estonia, Latvia, Lithuania	White
5	Central and South Europe	Greece, Italy (Austria, France, Germany, Slovenia)	Purple
6	South – Western Europe	Spain, Portugal (Frane)	Green
7	Central – Eastern Europe	Hungary, Slovakia, Czech Republic (Austria, Germany, Poland, Slovenia)	Dark Purple
8	Countries that belong to more than one regions	Germany, France, Austria, Poland, Slovenia	Blue
9	Countries that do not belong to any region or non – EU countries	Bulgaria, Croatia, Romania, OTHER	Orange

The depiction of the EU electricity market is a good option to graphically support what has been said about the position of states in the network, the contribution of regional markets to the shaping of the single European market, the course of liberalization the second time we are studying, as well as the high dependency of states from outside the EU.

5.4.2. Results' Analysis

Figure 42 illustrates the electricity market network for the period 2000-2007. We note that the most important nodes in the network, based on the degree of interconnection of each country are Germany, Romania, the Netherlands, France and Austria due to the larger size of the nodes. This result is the expected as, as we have seen in the analysis of the interconnection and influence of the States, Germany, France and Austria are among many sub-networks - regions, according to the colour of their nodes, making a large volume transactions in relation to other countries and acting as links for the Central-South Region, the Central-West Region, the Northern Region and the Central-Eastern Region.

Romania, on the other hand, does not participate in any regional market but deals with many countries during this time, such as Bulgaria, Greece, Czech Republic, Germany, Italy, Luxembourg, Austria, Slovakia, the UK and the Hungary, without having to cooperate with all the countries over the eight years. Of the size and the intensity of the line coming from and coming to Romania, it is clear that its energy transactions as a country are weak compared to the previous three, confirming that Romania only deals when production is inadequate or when it has an energy surplus. Therefore, the country is important because it is connected with many countries, but on the other hand the links it makes are relatively weak.

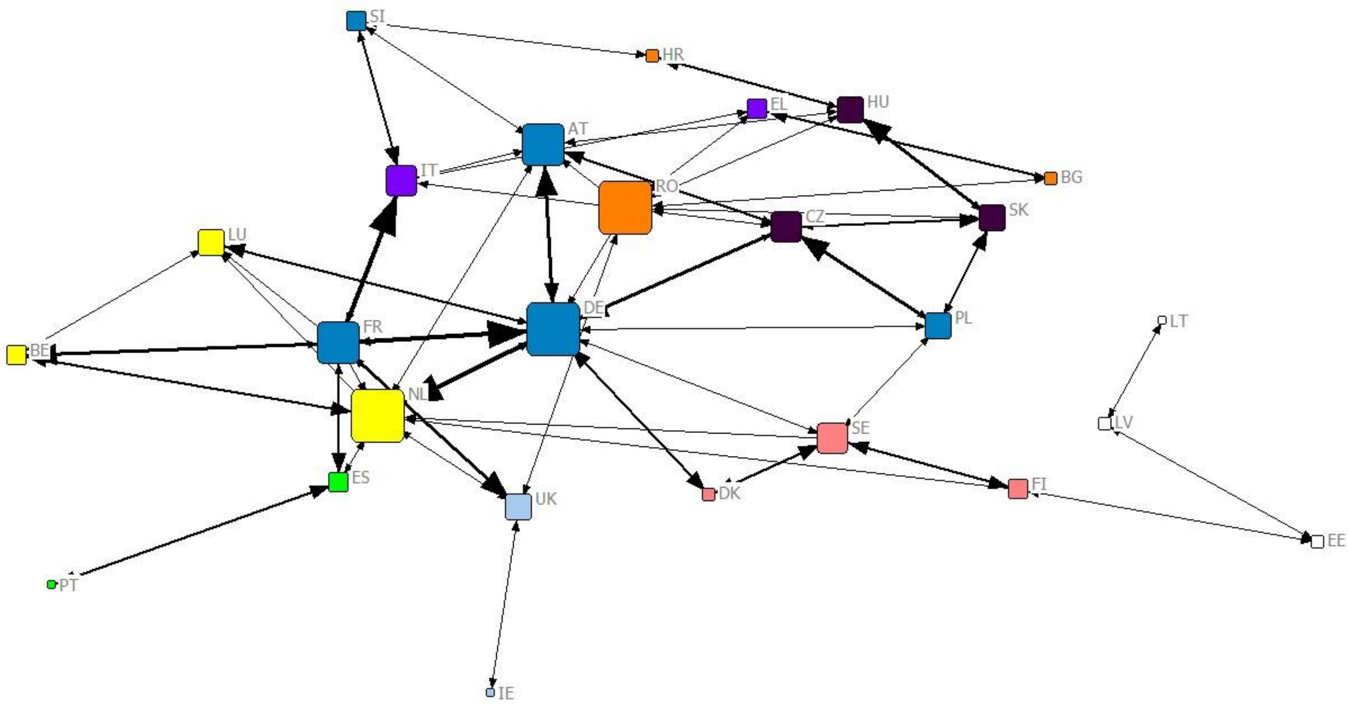


Figure 42 EU Network for the period 2000-2007

In the case of the Netherlands, it is a country which has had a great deal of interconnection, mainly for the realization of its imports in 2000 – 2003, based on its degree of interconnection, thus increasing the size of its hub. The Netherlands is part of a region including France and Germany, with Germany and Belgium largely depending on it. Generally, based on Figure 42, we observe that the country's exports are very low, thus giving a basis for the country's designation as an importing country.

The largest volume of exports is shown by France, followed by Germany, which is shown with a stronger arrow. From Figure 42, it is understood that countries with a central geographic location are also the most tied, irrespective of their strength, thus being able to exert more influence on the evolution of the electricity market. Based on what has been said in previous chapters on the degree of interconnection of states in the EU energy network, it cannot be denied that several countries such as the British Isles, and in particular Ireland, Portugal, The Baltic Sea, Scandinavia, and Bulgaria, are the most dependent countries of one or two other countries, stressing once again the need for greater interconnection between countries so that these markets can become competitive on the market, and to secure it too security of their energy supply.

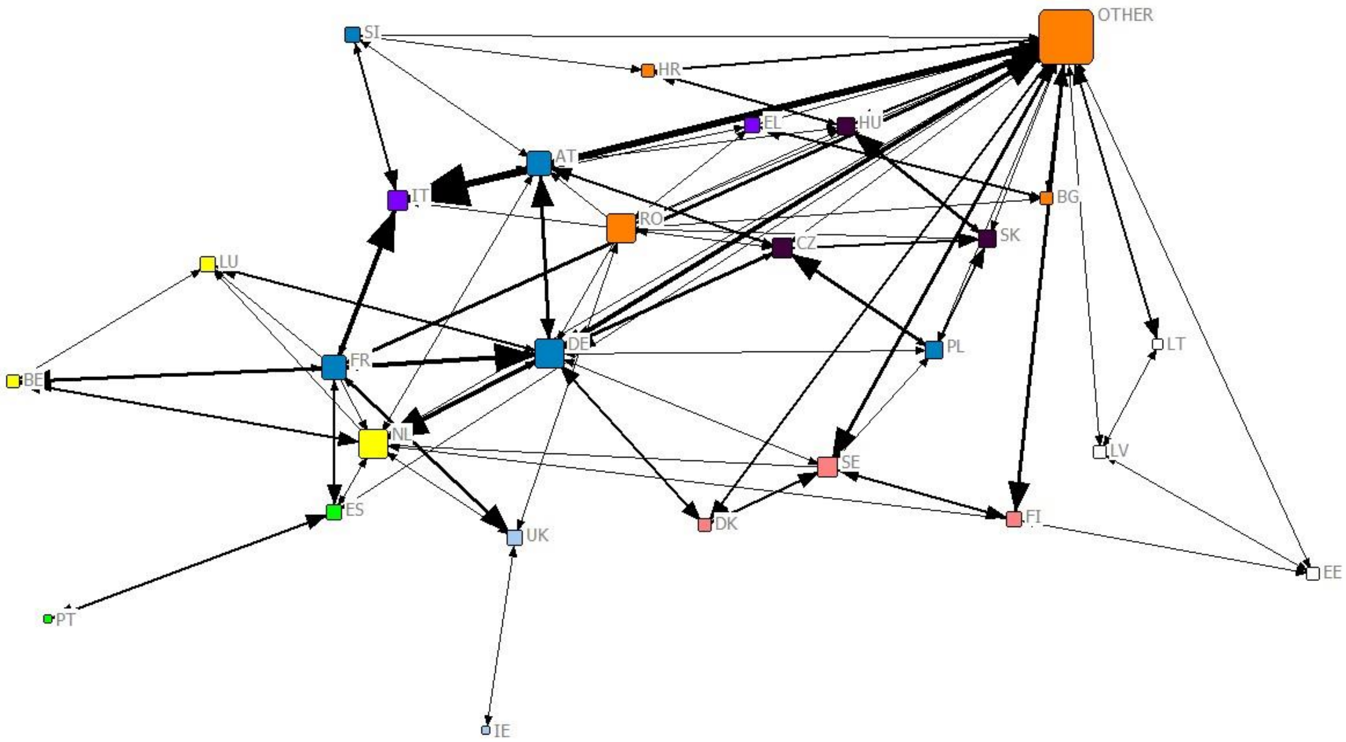


Figure 43 EU Network for the period 2000-2007, by adding the Node OTHER

The image of the network varies considerably with regard to the fragmented countries when the OTHER node containing the countries outside the EU is introduced. As shown in Figure 43, Lithuania creates strong ties with neighbouring countries, in particular the Russia and Belarus due to the high volume of imports and exports. In addition, Scandinavian countries also trade, mainly Sweden and Finland with Norway and Russia. However, almost all countries, except the British Isles, the Iberian Peninsula, Belgium and Luxembourg, depend to a greater or lesser extent on third countries, concluding, once again, that the EU is not able to meet its energy needs with domestic production, nor to protect the energy supply of states that are largely co-operating with foreign states, thus conceding surveillance of national energy networks to countries outside the Union.

For the period 2008 – 2013, the same situation exists for countries with the largest node size, concerning Figure 44. Nevertheless, we have to note that the size of the nodes in relation to the previous periods has decreased for all countries, and this is a consequence of the decrease in the volume of transactions over the given period due to the economic situation in the EU, but also in limiting unnecessary energy and choosing more efficient and eco-friendly goods.

Another difference is observed in the flows of Spain to Portugal, to the flows of Latvia to Lithuania but also between Latvia and Estonia, to Croatia's exports to Slovenia and to Germany's exports to Poland. With regard to the ties, between 2008 and 2013 another link was established between Romania and Luxembourg, while the Netherlands's ties with the Nordic countries, Spain, Luxembourg and Austria were discontinued.

The EU network depiction with the addition of the OTHER node in Figure 45 does not show any significant change except the interruption of energy transactions between Estonia and third countries and those identified in Figure 44 for the period 2000 – 2007.

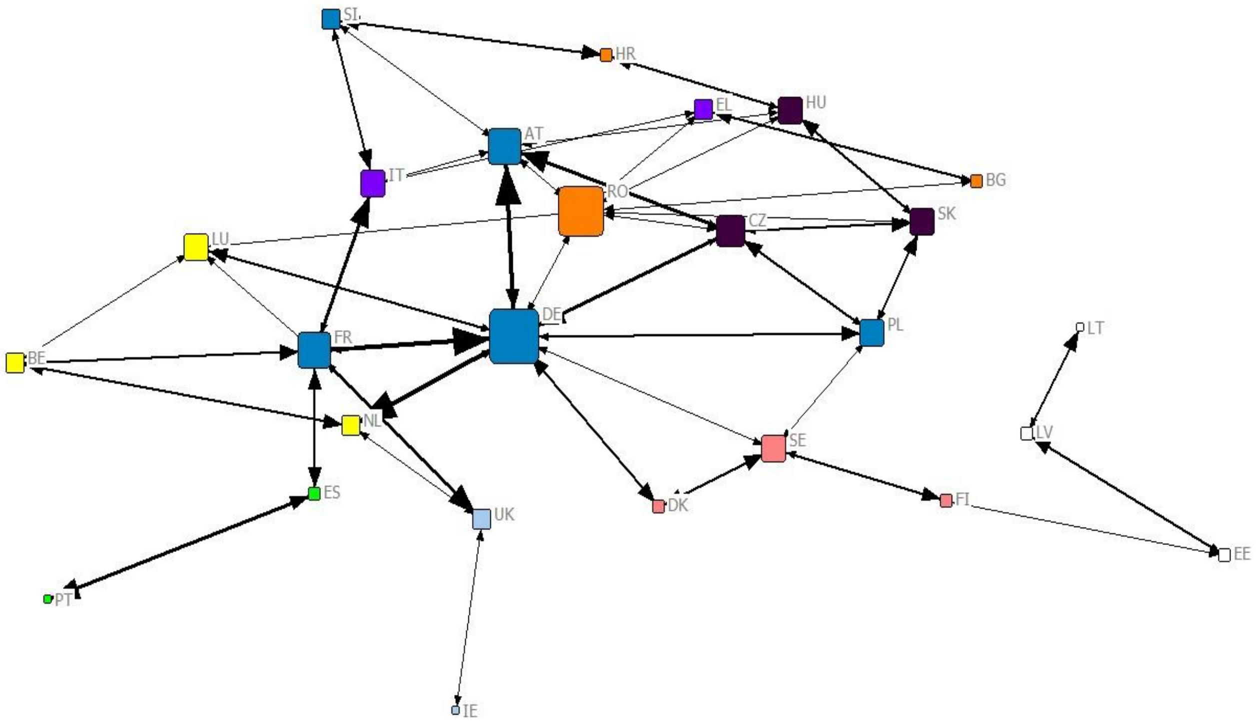


Figure 44 EU Network for the period 2008 – 2013

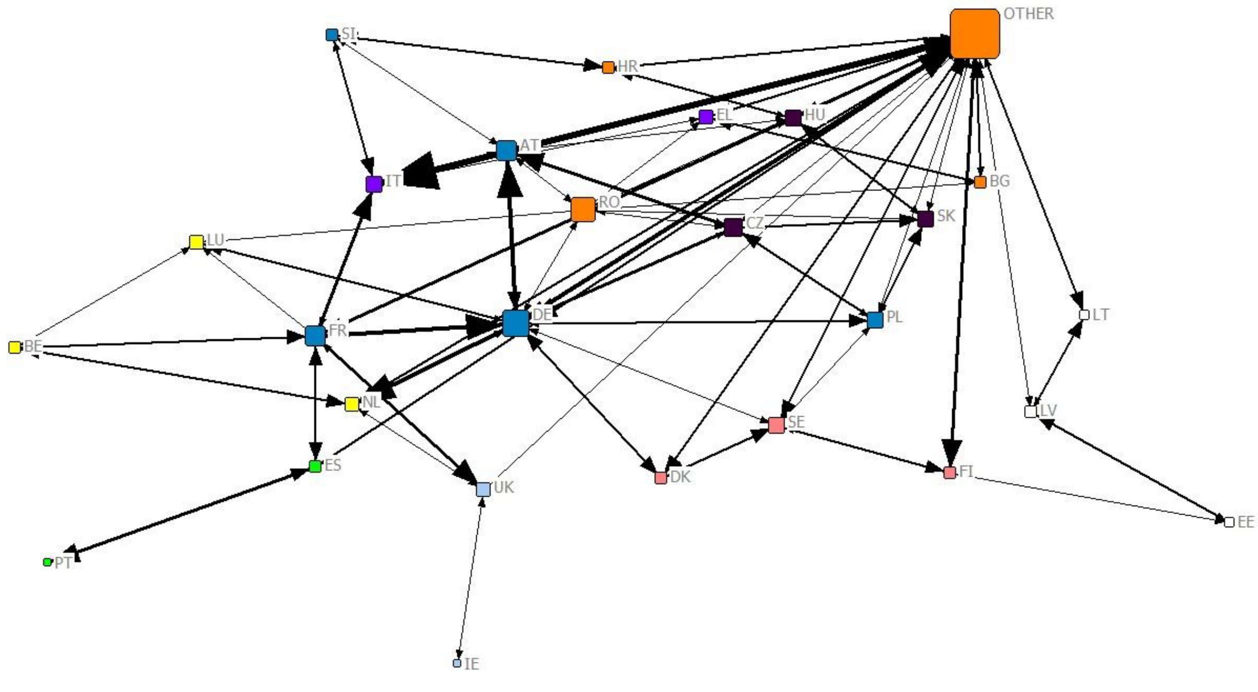


Figure 45 EU Network for the period 2008 – 2013, by adding the Node OTHER.

Last but not least, at Figures 46 and 47 are presented the EU network with and without the node OTHER for the years 2014 – 2016. At the EU network, besides the fact that the Degree Centrality of powerful countries, like Germany, Romania and France, are becoming even smaller, countries like Baltics are becoming bigger. This shows that the majority of EU States are becoming more independent, and try to find new suppliers to connect with and cover their needs. This has as a result to make weaker the countries that used to be more powerful and the centre of electricity supply.

Furthermore, there is a new entrance in the countries, and more specifically Malta's. The country, for fourteen years was isolated from the rest of the grid, just like Cyprus, but in 2015, it became the energy trade with Italy. More specifically, in 2016, Malta covered 68% of its electricity needs through the undersea interconnector that connects the island with Sicily. In 2015, its 48% of its needs were covered from Sicily. [51] The energy flows between the countries seems to be the same as the energy network the previews period.

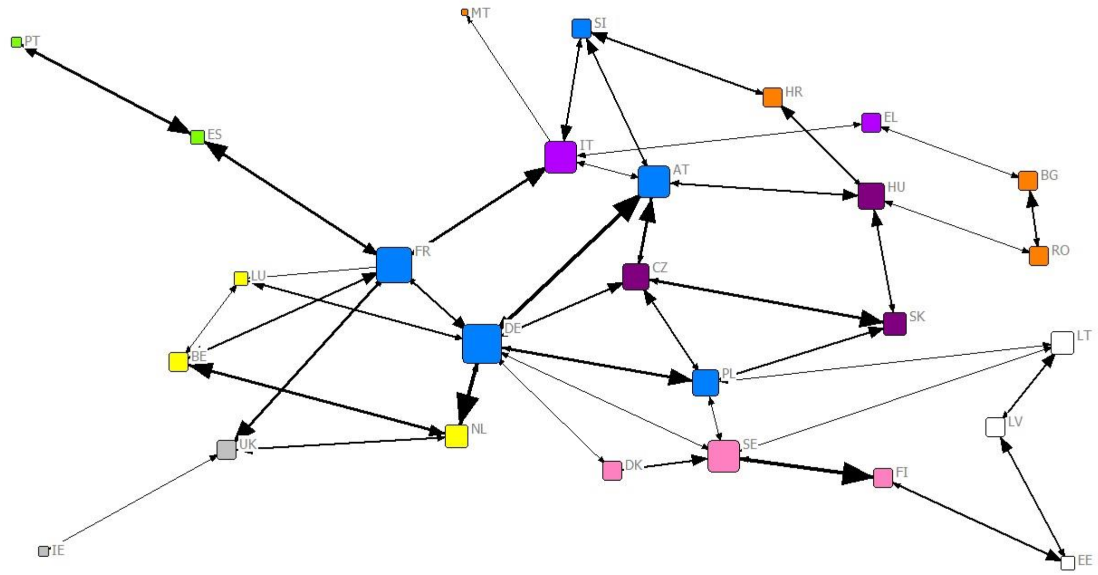


Figure 46 EU Network for the period 2014 – 2016

Concerning the Figure 47 where the node "OTHR" is added, it is obvious that even though the non EU countries are remaining important for the electricity cover in the EU region, its size has become smaller, which lead us to a the point that EU tries really hard to become independent.

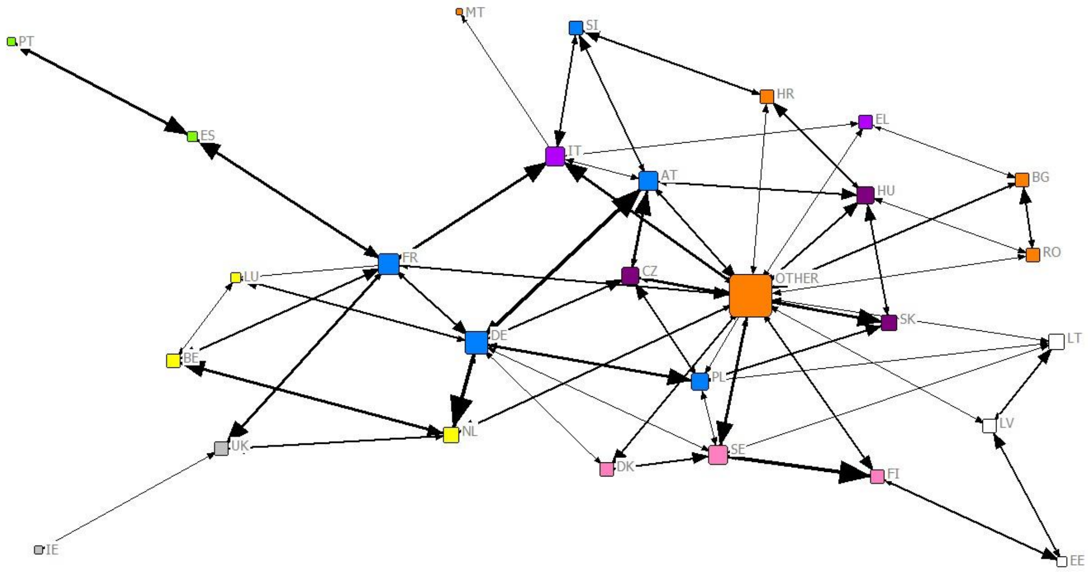


Figure 47 EU Network for the period 2014 – 2016, by adding the node OTHER

Taking all of the above into account, we can conclude that the electricity market is a "living" organization that is affected by all countries that constitute it, no matter how dominant their position in the network is, as with the withdrawal of a country from the grid, the EU automatically will become more dependent on third countries to meet demand. In addition, country capacity plays an important role in designating the country as an importer, exporter or a self-sufficient country.

6. Conclusions

This thesis implements the Social Network Analysis for analysing the transformation of European electricity market over the period 2000-2016. The analysis provides, several conclusions concerning the following:

- ✓ The shape of the electricity market and its liberalisation in European markets,
- ✓ The influence and the role of the EU Member States, but also
- ✓ The dependence on non EU countries.

The thesis describes the generic framework of the European energy strategy, which affects the developments and transformation of the electricity markets. Prioritizing climate change, enhancing the penetration of renewables and the integration of European energy markets have played an important role on the development of the electricity markets. The EU has prioritized climate change through the introduction of various programs to reduce greenhouse gas emissions in the region. In particular, in the area of sustainability, it has achieved a significant reduction at the carbon dioxide emissions per capita, achieving a 25.47% reduction in 2016 compared to 1990 levels and by setting even higher targets for 2030. The significant reduction in pollutants reflects a change in the mentality of Europeans, who have significantly reduced primary energy consumption, while reducing electricity demand. The negative one is that even in 2016, the primary energy consumed by European citizens, albeit reduced compared to previous years, consists mainly of oil and fossil fuels, making it clear the continent's high dependence on conventional energy sources, mainly in the transport and heating sectors. However, the emission limitation, apart from the implementation of the EU - ETS in the European area, is also due to the large introduction of RES in power generation that leads to further reduction of the use of conventional energy sources in the electricity sector. Significant is the fact that, in 2016, RES represents 30,15% of the energy mix produced in the EU, mainly due to the increase of the installed photovoltaic power from 2010 onwards, but also to the increased use of wind turbines , from the beginning of the period we are studying.

Renewable Energy Sources, apart from their positive effect on gas emissions, have also contributed to the liberalization of the EU electricity market, which seems to bear fruit. Even after the economic crisis hit the EU, the market continued to be liberalized at a steady pace, paving the way for many producers to set up their own power plants and to participate in the production and supply of electricity. Larger producer rates in most countries have fallen considerably, while the percentage of producers accounting for 95% of the electricity market is rising in some countries with faster and some slower. It is also worth mentioning that the new sources gave a glimpse of the economy, creating new jobs, not only in the production and distribution of electricity, but also in the construction, installation and maintenance of small or large units of wind turbines or photovoltaic panels.

The energy mix of electricity in Europe can change gradually by increasing the share of renewable energy sources and replacing a large share of conventional sources, but energy trade over the years is decreasing, especially after 2008. This decrease is mainly due to the economic crisis affecting the region of Europe, but also the switching of consumers to goods that are less energy – efficient and more environmentally friendly but also to the limited use of unnecessary goods.

However, the positive course of the EU to the liberalization and integration of the electricity market, its prices not only have they failed to be stabilized, but also they present an increasing course, causing fluctuations between countries and making some markets even uncompetitive. This is mainly because prices are vulnerable to changes in raw material prices in most European countries. The great dependence of states on conventional sources, the taxation and the additional burdens imposed by each state, are responsible for this destabilization. Therefore, there is an urgent need to introduce a single taxation on the electricity market for EU countries, in order to balance and stabilize prices, especially in retail trade.

We cannot fail to comment that the EU may have taken positive steps in terms of sustainable development in the region but security of energy supply has not been fully achieved because of its dependence on third countries in raw materials such as solid fuels, gas, oil, etc., but also to meet its electricity needs, is high. More specifically, in 2016, 58% of the primary electricity consumed in the EU came from third countries, putting the supply at risk due to the concession of the sovereignty of certain energy networks in these countries.

The study of the EU electricity market, using the Social Network Analysis method, **confirms its great dependence on third countries**, but also **highlights** the **interconnection rate of European countries** in the energy network and the **role of each country** within it.

The **calculation of topological features** reinforces the view that third countries play an important role in shaping the electricity market. Moreover, although the network density is quite low and equal to 16%, indicating the low interconnection of the states, the low geodetic distance indicates that the average of the countries is at most two steps, revealing a relatively close interconnection. Concerning the conclusions coming from the topological features, we see that over the years, the direct links between the countries that are united with one state in the network are diminishing, thus making the countries dependent on a small percentage of countries.

By analysing the **Degree of Centrality of each state**, conclusions are drawn on the position of states in the network and the interconnection of countries. It has become clear that France, Germany, Austria, Sweden, Spain, the United Kingdom and non – EU countries have the largest influence on the network. The first three countries, have high levels of centrality, therefore, with no doubt, their power in the electricity market is significant. Spain, Sweden and the United Kingdom, on the other hand, have a high index of Betweenness Centrality, so they are valuable to the countries that connect with the rest of the network but also to the European market, which benefits from the existence of a large number of countries. In addition, one cannot ignore the fact that the least interconnected countries such as Ireland, Portugal, Scandinavia and the Baltic States do not show any significant change in the centrality indicators, thus reflecting the difficulty of interconnecting these countries with the rest of the energy network, mainly because of their geographical location. Last but not least, an important development was the connection between Malta and Italy, one of the two EU countries that managed to create a link with the core of the Europe the last 2 years of our study. This shows the efforts of the EU to bring together all its members, including Cyprus, the only EU country that stays out of the electricity network until now.

Moreover, the network depictions of the states made it clear that the **geographical location of a country plays a leading role in its networking**. The most central countries create more links and are more independent than others. Also, the capacity and standard of living of countries contribute themselves on what position they have in the market, since countries which do not depend on others have great production, because it is able to cover most of their needs, while at the same time they carry out a large volume of exports. On the other hand, countries which are not so central, but self-sufficient, do not carry out large volumes of trade with neighbouring countries.

In conclusion, the results that came out from the use of Social Network Analysis method, for studying the developments that have taken place in the EU, the period 2000 – 2016, shows that the **basic concept of the electricity market is constant, with small changes in the interconnection and the centrality of the countries, over the years**. The implementation of such a **method in the energy sector is innovative**. However it has some considerable limitations. The top down overview of the thesis over a large period does not allow to study in depth the electricity market over the months, and understand better the relationships between the electricity trading considering the prices as well, which could be characterized as a key indicator. The extension of its application in other electricity markets or its application on different energy networks, such as the gas market is potential for future extension of the thesis.

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Annex A.

Figures on EU electricity network over the period 2000 – 2016

Table 4 Total electricity imports (in GWh) of the EU countries over the period 2000 – 2016.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AT	14405.5	14056	15602.5	18637	16569	21686.5	22190.5	23037	21404.5	20918	21090	25984.5	24917	26237	27706	30951	27013.5
BE	11601	14959.5	16774	14503	14653	14320.5	18852	15832	17089.5	9496.5	12411	13251.5	16950	17341.5	21809	23729	14708.5
BG	651.5	712.5	1011	692	371	534	783	1556	1753.5	1398.5	655.5	1175	1356	2214.5	2774.5	2948.5	3462
CZ	8710	9303	9402.5	9759.5	9422.5	11719.5	10793.5	9742.5	7746.5	7698	6063.5	9414.5	11085.5	9644.5	11884.5	16247	13879.5
DE	39333.5	40830.5	43550	43674.5	42943.5	51715.5	42828.5	40559	36645.5	36582	38418.5	45751	40504	33179.5	30832	28040.5	22526.5
DK	8494	6323.5	6112	6627.5	7355	8277.5	5598.5	6354	7809.5	8935	9703.5	9822.5	13109.5	10009	10491	13887.5	11825
EE	184.5	361.5	268	65.5	322	255	205	270	758.5	1804.5	692	1101	2126.5	2139.5	3629	5245.5	3339.5
EL	1377.5	2713.5	4712	4173	5182	6362	5777.5	5479.5	6391	3731	3889	5287.5	3482.5	2953.5	8042.5	9487	7505.5
ES	12269	10217.5	12544.5	9590	8226.5	10234	9229	8905.5	5875	6762.5	5181.5	7921.5	7785.5	10048.5	12304	14939	21833
FI	8026	4561.5	5937	662.5	715	6831.5	2391	4846	4788.5	3316	3825.5	6865.5	14742.5	12866	19929	19583.5	19268
FR	1707.5	2596	2087.5	5224	3827.5	5092	6088.5	7650.5	6782.5	14649.5	14743.5	7430.5	8677.5	8162.5	4923	7774.5	17285.5
HR	3714.5	4007	4370.5	4627	3219.5	5293.5	4642.5	7486.5	7515	6881	6574	9879.5	10967.5	6278.5	10898.5	13162.5	12397.5
HU	8675	8546	9655	9515.5	8309	10535	10149.5	10750	8845.5	7945.5	7535	12522.5	15507	14221	20060.5	16531.5	18461.5
IE	151	54.5	356.5	631	1574	2059.5	1787.5	1397	563	695.5	569	549	602	2466.5	2776	1674	776.5
IT	32286	35007	24332.5	24928.5	26360.5	24874	22749.5	20107.5	19182	22046.5	22792.5	21882.5	20120	21295	34565	37814	32725.5
LT	2601	1529	1476.5	1247	1293	1300	818.5	1391.5	1434	1495	3053	2735	3229.5	3626	5769	5710.5	8913.5
LU	6427	6386	6385	5645.5	5525	5847	6258	6286	6248	5511	6334	6329	5885	6358	6205	6538.5	6738
LV	2326.5	2545	2835.5	3554	3623	3563.5	2838	4605	3841	4497	2929.5	3542	4234.5	4725	5987	5746	5150
MT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1049	1525
NL	22390	21146	16930	20731.5	21407.5	23691	27349.5	23144	21871	12640.5	14871	19045.5	29450.5	30873.5	32960.5	30864	24282
PL	2496	3079	3194.5	2802	3441.5	3113	2887	7110	7687	7136	6241.5	6728	9330	7180	13559	14460	13957.5
PT	4698	3731.5	5329	5898	8571.5	9628	8628.5	9645.5	10748.5	7603	5818.5	6743	10767	7913	7247	8077	4616
RO	544.5	482	339.5	800	1474	1422	823.5	638.5	258	322.5	526.5	1850	2386	1598.5	1523	2469.5	2631
SE	17998	5402.5	7530.5	19296.5	13116	3447	11346.5	6101.5	5429	7175.5	14424.5	10217	7184.5	9589.5	14886	10741.5	15328
SI	9762.5	3085	3608.5	4624	4774.5	5808.5	4523.5	3963	6230.5	7782	8615	7041.5	7455	7521	7254	9045	8359

SK	0	5734.5	6175.5	8277	8485.5	7911	8559.5	13524.5	8624.5	8847.5	7105	11281.5	13455	10470.5	12976	14980.5	13216.5
UK	14538	11570	9778.5	5683.5	10527	11817.5	11911	9056	13008	7248.5	7863.5	9363	14371.5	18144.5	23967.5	23574	20639

Source: **[22]**

Table 5 Total exports (in GWh) of the EU countries the period 2000 – 2016 .

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
AT	13665.5	12392	10867	10977.5	10134	10612.5	8597	8829.5	8854	11674.5	10864	5432.5	14378	12151.5	15889.5	17516.5	16634
BE	5885.5	5759.5	9647	10172	6798	8016	8690	9037.5	6552.5	7534.5	11835	7006.5	6990.5	7679.5	4187	2580	8507
BG	4974	7100.5	5216	4537	5040	5820	6652	5538.5	5984.5	4143	4702.5	2823.5	5815	5616.5	12319	13207	9972
CZ	18688	18841	21202	25973	25138.5	24084.5	23117	25942.5	19187.5	23151.5	20871	10011.5	28219.5	26504	28168.5	28775.5	24853.5
DE	38528.5	36923	26353.5	36564	39354.5	42078.5	50655	46632	46900.5	39524.5	42616.5	14863.5	52530	58341.5	59797.5	66686	58702
DK	7964.5	8826	9968.5	13561.5	9768	11367.5	12497.5	10697.5	10758	9073.5	9713	5230.5	10428.5	8771.5	7233.5	6627	7844.5
EE	1193.5	957.5	708.5	1322.5	1428	1673	901	3105.5	3124	3659.5	4507.5	3099	4343	5147	5161	5079	4626.5
EL	416.5	202.5	495	1136	1454	711.5	945	173.5	194.5	2192	2312	1714	2540.5	2043.5	121.5	633.5	465.5
ES	5293	4936.5	5556.5	6543.5	9329.5	10382	10106	10754.5	12410	2347.5	9326	6743	13794.5	11117	9635.5	9877	8945.5
FI	665	2290	2195.5	7669.5	6974.5	1163	2587.5	2703	3251.5	10774.5	5022.5	3114	1640	2226.5	3704.5	5233	3260
FR	65820	65105.5	69317.5	60072	57153	57064	59101	55960.5	48336.5	35456.5	39610.5	20459	46312	49565	69209.5	68115	56310.5
HR	560.5	271.5	450	608.5	2814	4459	3720	2242.5	4926.5	5196.5	6556.5	4583.5	2886.5	5631	6586.5	5950	6455
HU	3616.5	3561.5	3624.5	3614.5	1840.5	4350	4659	7390	7432	3719.5	4049.5	6172.5	8461.5	4852	6399.5	7616	6092.5
IE	56	199.5	101	64.5	0	1	9.5	67.5	227.5	682	218	181	266.5	302.5	558	888.5	1388.5
IT	441	518	851	490	783.5	969.5	1189.5	2580	2997.5	1414.5	1129.5	1001	1674	1215	2621	4063.5	5492.5
LT	3556	3075.5	2127	2231.5	2195	1890.5	1939	3239	2711	3066	235	443	292	88	571	455.5	2361.5
LU	737.5	1107	2928	2379	2756.5	2749	2873	2485.5	2056.5	2236	2530.5	1539	2003.5	1304.5	1530.5	1202	710.5
LV	1756.5	1813.5	1744.5	1312.5	1615	1555	1020	1661.5	2148	3188.5	3490	2735	3785.5	3805	3074	3509	3924
MT	0	0	0	0	0	0	0	0	0	0	11616	0	0			0	0
NL	4025.5	4697.5	4401.5	3934	5137	5398	5938.5	5566.5	9083.5	9905	2888	4517	14913.5	14642.5	18011	21892.5	19125.5
PL	9660.5	11112	11518.5	15115.5	14563	16149	15722	13092.5	9667.5	13264	3190	8220	12601.5	12223	11344.5	14792.5	12017.5
PT	3767	3484	3430	3104	2121.5	2801.5	3179	2153	1313.5	0	2506.5	3929.5	2871	5136.5	6344.5	5811	9701.5
RO	734.5	979.5	2040	1553.5	1821	3116	4445	3372	4255.5	5643	6657.5	1501	2880.5	3908	9143.5	9547	8058.5
SE	13291.5	17901.5	13169.5	6932.5	11683.5	20131	9282	13924	15036.5	8866.5	1217	5132	30460.5	20831	30005.5	32426	26708.5
SI	13813.5	5094	5165.5	6101	8599.5	10537	8409.5	6416.5	7833.5	10832	5207	4778	8366	8684.5	9971.5	9034.5	9477
SK	0	9571	10226	9375	8008.5	9189.5	8919.5	9116	7606.5	6135.5	15946.5	8118	10247.5	8518	10642	11250.5	9510
UK	684	983.5	1439.5	3713	2338.5	2838	2725.5	3651.5	1479	4023.5	1174.5	1367	2054.5	3149	2800.5	1856	2233.5

Source: [22]

Table 6 Final Electricity consumption per capita in the EU for the period 2000 – 2012.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
BE	7,573.10	7,613.60	7,609.00	7,699.20	7,753.50	7,677.90	7,858.70	7,832.00	7,751.70	7,184.50	7,685.60	7,326.10	7,377.60
BG	2,960.70	3,017.70	3,060.30	3,220.00	3,215.70	3,344.70	3,524.30	3,593.60	3,811.90	3,595.40	3,651.80	3,856.60	3,800.20
CZ	4,804.50	4,972.70	4,982.10	5,141.60	5,280.10	5,421.30	5,576.90	5,581.50	5,610.60	5,266.40	5,182.80	5,116.10	5,129.10
DK	6,089.50	6,088.00	6,056.60	6,012.10	6,108.80	6,183.60	6,225.00	6,145.70	6,049.00	5,705.40	5,792.10	5,693.40	5,587.50
DE	5,884.00	6,020.80	6,168.20	6,235.00	6,316.00	6,330.40	6,404.40	6,430.90	6,416.80	6,064.00	6,508.70	6,551.10	6,546.10
EE	3,578.90	3,710.70	3,856.10	4,069.30	4,327.90	4,444.90	4,804.90	5,059.90	5,233.00	4,978.50	5,181.20	4,984.00	5,265.60
IE	5,370.90	5,485.30	5,582.20	5,810.50	5,723.50	5,922.70	6,149.70	5,959.10	5,983.70	5,588.60	5,587.50	5,441.20	5,265.30
EL	4,004.50	4,110.60	4,279.70	4,454.60	4,546.30	4,640.30	4,772.80	5,000.90	5,121.30	4,931.40	4,777.30	4,656.30	4,692.00
ES	4,656.70	4,941.60	5,008.10	5,209.40	5,421.50	5,594.50	5,592.50	5,599.80	5,585.70	5,185.60	5,266.10	5,218.00	5,131.50
FR	6,357.30	6,490.30	6,406.10	6,601.60	6,745.00	6,734.90	6,752.00	6,693.60	6,760.70	6,495.00	6,868.20	6,527.80	6,783.20
HR	2,630.90	2,793.90	2,950.20	3,013.00	3,182.30	3,344.30	3,496.60	3,566.50	3,742.40	3,599.00	3,686.40	3,668.00	3,589.80
IT	4,795.50	4,875.70	4,961.60	5,101.20	5,140.00	5,198.80	5,317.90	5,312.60	5,273.70	4,915.50	5,056.80	5,084.30	4,996.10
CY	4,338.90	4,458.50	4,797.80	5,108.40	5,186.10	5,402.00	5,602.10	5,785.60	5,969.10	5,961.60	5,959.90	5,621.90	5,114.80
LV	1,879.70	1,947.40	2,103.40	2,261.90	2,373.80	2,546.50	2,757.30	2,990.70	3,024.00	2,821.80	2,930.90	2,984.20	3,349.00
LT	1,764.50	1,848.60	1,946.10	2,092.10	2,250.70	2,377.50	2,563.00	2,725.90	2,815.50	2,629.20	2,651.80	2,810.70	2,970.10
LU	13,318.70	13,309.80	13,295.80	13,789.90	14,051.80	13,333.90	14,099.80	14,059.60	13,637.90	12,389.10	13,131.70	12,670	11,881.40
HU	2,880.30	2,994.50	3,094.40	3,095.50	3,145.10	3,202.60	3,298.50	3,352.20	3,417.20	3,304.80	3,415.80	3,458.90	3,524.40
MT	4,030.80	4,008.50	4,198.80	4,545.70	4,476.50	4,614.20	4,575.30	4,563.40	4,543.50	4,154.00	4,405.50	4,496.50	4,660.60
NL	6,020.10	6,088.80	6,137.20	6,196.40	6,322.70	6,419.10	6,482.40	6,609.10	6,628.30	6,368.80	6,515.80	6,493.10	6,216.60
AT	6,440.90	6,684.20	6,678.60	6,866.10	6,972.90	6,987.10	7,103.50	7,138.10	7,093.50	6,862.30	7,172.00	7,171.30	7,220.60
PL	2,563.10	2,567.80	2,535.30	2,634.90	2,728.20	2,750.70	2,899.40	2,992.50	3,074.60	2,944.90	3,121.50	3,191.90	3,209.60
PT	3,744.10	3,865.80	3,989.80	4,132.70	4,265.00	4,413.90	4,543.70	4,654.50	4,581.70	4,530.40	4,718.20	4,574.40	4,386.20
RO	1,511.40	1,618.10	1,629.90	1,733.90	1,801.70	1,817.30	1,927.10	1,939.10	2,026.30	1,839.80	2,035.90	2,114.70	2,109.20
SI	5,292.90	5,498.20	5,862.00	6,038.50	6,284.20	6,378.70	6,571.50	6,597.80	6,370.30	5,556.60	5,835.40	6,097.00	6,046.20
SK	4,076.90	4,360.10	4,231.30	4,276.40	4,472.70	4,253.00	4,402.40	4,573.30	4,606.50	4,291.40	4,477.40	4,601.30	4,429.20
FI	14,635.60	14,936.20	15,338.90	15,532.70	15,924.00	15,420.10	16,369.80	16,312.80	15,575.60	14,472.50	15,603.30	14,903.00	14,944.50

SE	14,526.40	14,893.40	14,695.80	14,477.80	14,523.80	14,503.60	14,457.30	14,383.70	14,009.60	13,329.90	14,047.90	13,236.40	13,422.80
UK	5,610.70	5,642.70	5,634.80	5,663.20	5,674.60	5,797.00	5,698.00	5,598.90	5,553.80	5,187.90	5,262.60	5,045.60	5,014.50

Source: [9]

Table 7 Final Electricity consumption per capita in the EU for the period 2013 – 2016.

	2013	2014	2015	2016
BE	**7,454.60**	7,258.20	7,271.20	7,236.10
BG	**3,779.50**	3,819.40	3,933.00	4,039.50
CZ	**5,066.50**	5,067.90	5,184.70	5,310.90
DK	**5,552.00**	5,468.90	5,456.10	5,458.70
DE	**6,497.50**	6,349.50	6,339.20	6,296.00
EE	**5,166.00**	5,248.40	5,211.20	5,546.60
IE	**5,250.10**	5,204.30	5,360.00	5,411.00
EL	**4,434.10**	4,530.10	4,677.40	4,957.70
ES	**4,924.00**	4,878.20	4,995.50	5,006.80
FR	**6,865.50**	6,434.60	6,540.70	6,629.20
HR	**3,536.30**	3,492.70	3,631.20	3,651.00
IT	**4,815.20**	4,631.20	4,728.70	4,714.80
CY	**4,528.40**	4,621.20	4,829.90	5,185.50
LV	**3,249.30**	3,288.60	3,253.10	3,292.10
LT	**3,013.20**	3,138.10	3,197.90	3,375.40
LU	**11,546.60**	11,244.70	11,057.70	11,049.00
HU	**3,519.40**	3,516.80	3,682.30	3,775.80
MT	**4,615.30**	4,669.00	4,807.90	4,693.40
NL	**6,220.20**	6,038.90	6,101.00	6,221.10
AT	**7,253.00**	7,088.30	7,112.70	7,109.00
PL	**3,246.20**	3,297.10	3,363.20	3,498.80
PT	**4,315.40**	4,334.30	4,415.70	4,482.30
RO	**2,029.40**	2,100.80	2,165.50	2,189.10
SI	**6,061.20**	6,044.90	6,199.10	6,310.00
SK	**4,635.90**	4,460.30	4,495.40	4,604.80
FI	**14,732.00**	14,518.30	14,340.20	14,730.40
SE	**13,082.60**	12,669.00	12,809.50	12,942.40
UK	**4,950.40**	4,707.60	4,679.10	4,648.10

Source: [9]

Table 8 Number of generating companies representing at least 95% of the national net electricity generation

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Belgium	2	3	3	4	4	7	11	4	41	46	70	100	350	140
Bulgaria	13	14	14	15	15	15	15	22	20	28	83	55	75	79
Czech Republic	20	17	18	16	16	16	19	24	51	73	21	45	150	220
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
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
Ireland	5	3	4	4	5	5	5	8	6	5	7	8	9	9
Greece	1	1	1	1	1	2	3	4			3	3	2	5
Spain**											10	10	10	10
France	4	4	4	5	5	5	5	5	5	5	5	5	5	5
Croatia	2	2	2	2	2	2	2	2	2	2	2	2	6	7
Italy	79	83	88	92	105	114	167	185	219	291	493	652	654	715
Cyprus	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
Lithuania	5	5	6	7	7	7	8	9	10	17	20	20	23	27
Luxembourg	9	9	12	12	12	12	12	3	4	4	10	10	10	10
Hungary	30	30	40	57	61	52	69	68	68	32	45	39	39	26
Malta	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Netherlands	87	120	100	200	1 000	1 000	900	700	700	800	700	350	650	300
Austria	34	39	53	91	106	137	128	126	129	145	169	201	192	209
Poland	31	54	70	51	54	55	59	68	73	111	103	128	162	197
Portugal	36	46	59	77	97	107	95	107	104	112	65	66	69	54
Romania	11	12	12	12	18	15	10	10	10	11	15	27	29	29

Slovenia	3	3	3	4	3	2	2	3	3	3	3	3	3	3
Slovakia	6	6	6	7	7	6	7	8	9	11	10	17	21	22
Finland	25	29	27	28	29	34	29	29	30	30	31	30	36	38
Sweden	7	14	14	11	9	8	11	24	64	74	35	32	33	33
United Kingdom	22	20	17	18	18	17	17	19	19	17	16	17	22	29

Source: [9]

Table 9 Market share of the largest generator in the electricity market - as a percentage of the total generation

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BE	911	92.6	93.4	92	87.7	85	82.3	83.9	80	77.7	79.1	70.7	65.8	64.9	59.8	48.5	62.6
CZ	69.2	69.9	70.9	73.2	73.1	72	73.5	74.2	72.9	73.7	73	69.4	68	58.2	57.5	55.4	52.4
DK	36	36	32	41	36	33	54	47	56	47	46	42	37	41	36.6	33	35.2
DE	34	29	28	32	28.4	31	31	30	30	26	28.4	0	0	32	32	32	33.5
EE	91	90	91	93	93	92	91	94	96.5	90	89	87	88	87	84.8	79.8	80.8
IE	97	96.6	88	85	83	71	51.1	48	45.6	37	34	38	55	54	51	55	47
EL	97	98	100	100	97	97	94.6	91.6	91.6	91.8	85.1	0	77	67	71.5	70.7	72
ES	42.4	43.8	41.2	39.1	36	35	31	31	22.2	32.9	24	23.5	23.8	22	23.8	24.5	25.4
FR	90.2	90	90	89.5	90.2	89.1	88.7	88	87.3	87.3	86.5	86	86	83.8	86.8	85.7	82.5
HR	83.9	:	:	82	86	87	83	84	85	92	88	83	82	84	80.3	77.8	80.7
IT	46.7	45	45	46.3	43.4	38.6	34.6	31.3	31.3	29.8	28	27	26	27	29	27	24
CY	99.6	99.6	99.8	100	100	100	100	100	100	100	100	100	100	100	100	100	100
LV	95.8	95	92.4	91	91.1	92.7	95	86	87	87	88	86	89	79.8	54.8	57.4	58.6
LT	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
LU	80	:	:	80.9	80.9	:	:	80	:	0	85.4	82	81.8	58.4	61.3	43.8	18

HU	41.3	39.5	39.7	32.3	35.4	38.7	41.7	40.9	42	43.1	42.1	44.1	47.1	51.9	53.5	53.1	52.9
MT	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
AT	32.6	34.4	:	:	:	:	:	45.5	:	:	:	55.3	56.6	55.5	:	:	55.5
PL	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
PT	58.5	61.5	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
RO	29.3	:	:	:	31.7	36.4	31.1	27.5	28.3	29.3	33.6	26	26.7	26.8	29.9	25.7	28.5
SI	54.9	:	50.7	50.3	53	50.1	51.4	82	53	55	56.3	52.4	55.2	57.1	52.4	51.3	53.9
SK	85.1	84.5	84.5	83.6	83.7	83.6	70	72.4	71.9	81.7	80.9	77.7	78.9	83.8	81.9	73.1	71.3
FI	23.3	23	24	27	26	23	26	26	24	24.5	26.6	25.6	25.2	25.3	25.2	25.9	25.6
SE	49.5	48.5	49	46	47	47	45	45	45.2	44	42	41	44	44.8	42.9	40.6	42
UK	20.6	22.9	21	21.6	20.1	20.5	22.2	18.5	15.3	24.5	21	45.6	51.7	29.3	:	:	25.3

Source [9]

Table 10 % usage of RES in the electricity generation in the EU for the period 2000 – 2016.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
BE	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	20.00%	20.00%	20.00%
BG	10.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	20.00%	20.00%	20.00%
CZ	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
DK	20.00%	20.00%	20.00%	20.00%	20.00%	30.00%	20.00%	30.00%	30.00%	30.00%	30.00%	40.00%	50.00%	50.00%	60.00%	70.00%	60.00%
DE	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	30.00%	30.00%	30.00%
EE	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
IE	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	10.00%	20.00%	20.00%	20.00%	30.00%	30.00%	30.00%
EL	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	10.00%	20.00%	30.00%	20.00%	30.00%	30.00%
ES	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	30.00%	30.00%	30.00%	30.00%	40.00%	40.00%	40.00%	40.00%
FR	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	20.00%	20.00%	20.00%	20.00%
HR	60.00%	60.00%	50.00%	40.00%	60.00%	50.00%	50.00%	40.00%	50.00%	60.00%	60.00%	50.00%	50.00%	70.00%	70.00%	70.00%	70.00%
IT	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	30.00%	30.00%	30.00%	30.00%	40.00%	40.00%	40.00%	40.00%
CY	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%
LV	70.00%	70.00%	60.00%	60.00%	70.00%	70.00%	60.00%	60.00%	60.00%	60.00%	50.00%	50.00%	70.00%	60.00%	50.00%	50.00%	50.00%
LT	10.00%	0.00%	0.00%	10.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	30.00%	40.00%	30.00%	40.00%	50.00%	50.00%	60.00%
LU	80.00%	60.00%	30.00%	30.00%	20.00%	20.00%	20.00%	30.00%	30.00%	30.00%	40.00%	40.00%	40.00%	50.00%	50.00%	70.00%	90.00%
HU	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
MT	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	20.00%
NL	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
AT	70.00%	70.00%	70.00%	60.00%	70.00%	60.00%	70.00%	70.00%	70.00%	70.00%	70.00%	70.00%	80.00%	80.00%	80.00%	80.00%	80.00%
PL	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%
PT	30.00%	30.00%	20.00%	40.00%	30.00%	20.00%	30.00%	40.00%	30.00%	40.00%	50.00%	50.00%	40.00%	60.00%	60.00%	50.00%	60.00%
RO	30.00%	30.00%	30.00%	20.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	40.00%	40.00%	40.00%
SI	30.00%	30.00%	20.00%	20.00%	30.00%	20.00%	20.00%	20.00%	30.00%	30.00%	30.00%	30.00%	30.00%	30.00%	40.00%	30.00%	30.00%
SK	20.00%	20.00%	20.00%	10.00%	10.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	20.00%	30.00%
FI	30.00%	30.00%	30.00%	20.00%	30.00%	30.00%	30.00%	30.00%	40.00%	30.00%	30.00%	30.00%	40.00%	40.00%	40.00%	40.00%	40.00%
SE	60.00%	50.00%	50.00%	40.00%	40.00%	50.00%	50.00%	50.00%	50.00%	60.00%	60.00%	60.00%	60.00%	50.00%	60.00%	60.00%	60.00%

UK	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	10.00%	20.00%	20.00%	30.00%	30.00%

Source [9]

ANNEX B.

Social Network Analysis Indicators for the EU and the non – EU countries the period 2000 – 2016

	2000		2001		2002		2003		2004		2005	
ID	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
AT	5	5	7	7	7	5	6	5	6	5	6	6
BE	3	2	3	3	3	3	3	3	3	3	3	3
BG	3	3	3	3	3	2	3	3	3	3	3	2
CZ	4	3	4	4	4	3	5	5	5	5	5	5
DE	9	9	9	9	8	9	9	9	9	9	9	9
DK	3	3	3	3	3	3	3	3	3	3	3	3
EE	2	2	2	2	2	2	2	1	2	1	2	1
EL	2	2	4	4	2	4	3	4	4	4	2	4
ES	3	3	3	3	3	3	4	4	3	3	3	3
FI	2	2	2	2	3	2	3	2	2	2	2	2
FR	8	6	7	6	7	6	7	6	6	6	6	6
HR	2	3	3	3	2	3	3	3	3	3	2	3
HU	4	4	4	4	4	3	4	4	5	5	4	4
IE	1	1	1	1	1	1	1	1	0	1	1	1
IT	3	4	5	5	4	5	4	5	4	5	4	6
LT	2	2	2	2	2	2	2	2	2	2	2	2
LU	1	3	2	2	2	2	2	3	2	2	2	2
LV	3	3	3	3	2	3	2	3	3	3	3	3
NL	3	6	4	6	2	8	4	8	2	2	2	2
OTHER	19	17	19	18	19	16	19	17	18	18	18	18
PL	4	5	3	5	4	5	4	5	4	5	4	4
PT	1	1	1	1	1	1	1	1	1	1	1	1
RO	3	3	3	5	3	4	3	4	4	4	6	3
SE	6	5	6	4	6	5	6	5	5	5	5	5
SI	3	4	4	4	3	3	3	3	3	3	3	3
SK	3	2	5	3	5	3	5	3	4	4	3	3

UK	3	2	3	3	3	2	3	2	2	1	2	2

Table 11 Degree Centrality of Exports and Imports for the years 2000 – 2005

Table 12 Degree Centrality of Exports and Imports for the years 2006 – 2010

	2006		2007		2008		2009		2010	
ID	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
AT	6	6	6	5	6	7	6	6	7	6
BE	3	3	3	3	3	3	3	3	3	3
BG	3	1	3	2	3	2	3	2	3	2
CZ	5	5	6	6	6	6	6	6	5	5
DE	9	10	9	10	10	10	10	10	9	9
DK	3	3	3	3	3	3	3	3	3	3
EE	2	2	2	1	2	2	2	2	2	2
EL	2	4	2	4	2	4	2	4	2	3
ES	3	3	3	3	3	3	3	3	3	3
FI	3	3	2	3	3	3	3	3	3	3
FR	6	6	6	6	6	6	6	6	6	6
HR	3	3	3	3	3	3	3	3	3	3
HU	4	5	4	5	4	5	4	5	5	5
IE	1	1	1	1	1	1	1	1	1	1
IT	5	5	4	5	5	5	4	5	5	5
LT	2	2	2	2	2	2	2	2	2	2
LU	2	2	2	2	2	2	2	2	2	3
LV	3	3	3	3	3	3	3	3	3	3
NL	2	2	2	2	3	3	3	3	3	3
OTHER	17	17	18	17	19	19	19	18	18	18
PL	4	5	4	4	4	5	4	5	4	4
PT	1	1	1	1	1	1	1	1	1	1
RO	6	3	8	6	8	6	8	5	4	4
SE	5	5	5	5	5	5	5	5	5	5
SI	3	3	3	3	3	3	3	3	3	3
SK	4	3	4	4	5	4	4	4	4	4
UK	2	3	3	3	3	2	2	2	2	2

Table 13 Degree Centrality of Exports and Imports for the years 2011 – 2016

	2011		2012		2013		2014		2015		2016	
	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
AT	6	6	6	6	6	6	6.00	6.00	6.00	5	6.00	6.00
BE	3	3	3	3	3	3	3.00	3.00	3.00	3	3.00	3.00
BG	3	2	3	3	3	3	3.00	2.00	3.00	1	3.00	3.00
CZ	5	5	5	5	5	5	5.00	5.00	5.00	4	5.00	5.00
DE	9	9	9	9	9	9	8.00	8.00	8.00	8	8.00	8.00
DK	3	3	3	3	3	3	3.00	3.00	3.00	3	3.00	3.00
EE	2	2	2	2	2	2	2.00	2.00	2.00	2	2.00	2.00
EL	2	3	3	3	3	3	2.00	3.00	2.00	2	3.00	3.00
ES	3	3	3	3	3	3	2.00	2.00	2.00	2	2.00	2.00
FI	3	3	3	3	3	3	2.00	3.00	3.00	3	3.00	3.00
FR	6	6	6	6	7	6	7.00	6.00	7.00	5	7.00	6.00
HR	3	3	3	3	3	3	3.00	3.00	3.00	2	3.00	3.00
HU	5	5	5	5	5	5	4.50	5.00	5.00	4	5.00	5.00
IE	1	1	1	1	1	1	1.00	1.00	1.00	1	1.00	1.00
IT	5	5	5	5	5	5	5.00	5.00	6.00	4	6.00	5.00
LT	2	2	2	2	2	2	2.00	2.00	3.00	2	4.00	4.00
LU	2	2	2	2	2	3	2.00	3.00	2.00	3	2.00	3.00
LV	3	3	3	3	3	3	2.50	3.00	3.00	2	3.00	3.00
MT							0.00	0.00	0.00	1	0.00	1.00
NL	4	4	4	4	4	4	4.00	4.00	4.00	4	4.00	4.00
OTHER	19	19	19	18	19	19	17.00	15.50	4.00	16	17.00	16.00
PL	5	5	4	5	4	5	4.00	5.00	5.00	4	5.00	6.00
PT	1	1	1	1	1	1	1.00	1.00	1.00	1	1.00	1.00
RO	3	3	3	3	3	3	3.00	3.00	3.00	2	3.00	3.00

SE	5	5	5	5	5	5	5.00	4.00	5.00	5	6.00	6.00
SI	3	3	3	3	3	3	3.00	3.00	3.00	3	3.00	3.00
SK	4	4	4	4	4	4	4.00	3.50	3.00	3	4.00	4.00
UK	3	3	3	3	4	3	3.00	3.00	3.00	3	3.00	3.00

Table 14 Closeness Centrality for the years 2000 – 2016

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
AT	0.49	0.55	0.53	0.50	0.50	0.50	0.49	0.50	0.50	0.50	0.51	0.50	0.50	0.50
BE	0.38	0.39	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
BG	0.46	0.46	0.46	0.46	0.45	0.45	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
CZ	0.41	0.42	0.42	0.49	0.49	0.49	0.48	0.52	0.50	0.50	0.49	0.49	0.49	0.49
DE	0.58	0.58	0.57	0.57	0.57	0.57	0.55	0.57	0.58	0.58	0.57	0.57	0.57	0.57
DK	0.47	0.48	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46
EE	0.45	0.45	0.45	0.46	0.45	0.45	0.32	0.33	0.33	0.33	0.33	0.33	0.33	0.33
EL	0.45	0.46	0.46	0.46	0.46	0.45	0.44	0.45	0.46	0.46	0.45	0.46	0.46	0.46
ES	0.50	0.50	0.49	0.51	0.48	0.48	0.47	0.48	0.49	0.49	0.48	0.49	0.49	0.50
FI	0.45	0.46	0.46	0.47	0.44	0.44	0.45	0.44	0.46	0.46	0.46	0.46	0.46	0.46
FR	0.58	0.58	0.57	0.57	0.55	0.55	0.54	0.55	0.55	0.55	0.55	0.55	0.55	0.57
HR	0.45	0.46	0.46	0.46	0.46	0.45	0.45	0.46	0.46	0.46	0.46	0.46	0.46	0.46
HU	0.46	0.48	0.48	0.47	0.47	0.46	0.48	0.48	0.47	0.47	0.49	0.48	0.48	0.48
IE	0.28	0.29	0.28	0.28	0.20	0.27	0.27	0.30	0.33	0.27	0.27	0.28	0.28	0.34
IT	0.49	0.52	0.50	0.50	0.49	0.49	0.49	0.49	0.51	0.50	0.50	0.51	0.51	0.52
LT	0.45	0.45	0.45	0.46	0.45	0.45	0.44	0.45	0.46	0.46	0.45	0.46	0.46	0.46
LU	0.37	0.38	0.38	0.38	0.38	0.38	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.38
LV	0.46	0.46	0.32	0.32	0.46	0.46	0.45	0.46	0.46	0.46	0.46	0.46	0.46	0.46
NL	0.48	0.43	0.38	0.41	0.38	0.38	0.37	0.38	0.47	0.47	0.47	0.51	0.51	0.51
OTHER	0.76	0.76	0.76	0.76	0.74	0.74	0.72	0.74	0.76	0.76	0.74	0.76	0.76	0.76
PL	0.41	0.40	0.41	0.41	0.40	0.40	0.40	0.41	0.41	0.41	0.41	0.48	0.41	0.41
PT	0.34	0.34	0.33	0.34	0.33	0.33	0.32	0.33	0.33	0.33	0.33	0.33	0.33	0.34
RO	0.46	0.46	0.46	0.46	0.46	0.48	0.52	0.54	0.52	0.52	0.47	0.46	0.46	0.46
SE	0.52	0.54	0.51	0.50	0.48	0.48	0.48	0.48	0.49	0.49	0.49	0.49	0.49	0.49
SI	0.37	0.48	0.39	0.38	0.38	0.38	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.38
SK	0.37	0.48	0.48	0.47	0.46	0.45	0.45	0.47	0.47	0.46	0.46	0.46	0.46	0.46
UK	0.39	0.39	0.38	0.39	0.37	0.37	0.37	0.41	0.49	0.37	0.37	0.38	0.38	0.51

	2014	2015	2016
AT	0.45	0.45	0.45
BE	0.37	0.33	0.37
BG	0.41	0.35	0.40
CZ	0.44	0.42	0.44
DE	0.46	0.48	0.47
DK	0.42	0.35	0.42
EE	0.31	0.25	0.31
EL	0.41	0.35	0.41
ES	0.36	0.33	0.36
FI	0.41	0.31	0.42
FR	0.52	0.46	0.51
HR	0.42	0.37	0.41
HU	0.44	0.40	0.44
IE	0.28	0.25	0.27
IT	0.48	0.45	0.47
LT	0.41	0.33	0.43
LU	0.33	0.34	0.39
LV	0.42	0.28	0.41
MT	0.17	0.13	0.35
NL	0.46	0.38	0.46
OTHER	0.63	0.32	0.61
PL	0.39	0.40	0.44
PT	0.27	0.25	0.27
RO	0.41	0.35	0.40
SE	0.44	0.38	0.45
SI	0.36	0.36	0.36
SK	0.42	0.37	0.42
UK	0.37	0.33	0.37

Table 15 Betweenness Centrality for the years 2000 – 2007.

	2000	2001	2002	2003	2004	2005	2006	2007
AT	3.63	6.34	6.07	3.62	3.83	4.29	4.11	3.80
BE	0.23	1.01	1.32	0.73	1.51	1.67	1.64	1.56
BG	0.15	0.00	0.00	0.08	0.00	0.00	0.00	0.00
CZ	1.28	0.63	0.56	0.99	1.10	1.29	1.09	1.97
DE	16.22	15.05	15.76	12.60	17.45	17.99	18.20	17.69
DK	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EE	0.00	0.00	1.85	1.85	0.00	0.00	0.15	0.08
EL	0.00	0.31	0.23	0.35	0.44	0.08	0.21	0.21
ES	7.69	7.69	7.69	8.65	7.54	7.69	7.69	7.69
FI	0.00	0.00	0.00	0.00	0.00	0.00	4.00	1.97
FR	18.12	17.87	19.92	18.49	18.71	22.41	19.65	15.29
HR	0.74	0.10	1.18	1.30	1.29	1.13	1.30	1.27
HU	2.75	0.65	0.44	0.53	1.09	0.56	1.40	0.95
IE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IT	1.87	1.64	3.63	3.78	3.50	4.04	3.84	3.42
LT	0.00	0.00	1.85	1.85	0.00	0.00	0.00	0.00
LU	0.26	0.38	0.39	0.42	0.49	0.49	0.52	0.52
LV	0.15	0.15	0.15	3.92	3.77	3.92	3.38	5.56
NL	5.62	4.91	2.92	5.49	0.49	0.49	0.52	0.52
OTHER	63.55	60.20	61.81	61.86	60.09	62.50	58.45	56.30
PL	5.00	0.81	1.93	0.49	0.56	0.33	0.56	0.33
PT	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
RO	0.23	0.48	0.45	0.37	0.31	0.46	6.71	7.94
SE	2.31	1.65	1.57	1.32	1.35	1.35	1.92	1.55
SI	0.39	0.37	0.46	0.33	0.33	0.36	0.26	0.33
SK	0.40	2.26	2.27	0.84	0.77	0.64	0.63	0.77
UK	7.69	7.81	7.69	7.69	3.85	7.69	7.77	7.93

Table 16 Betweenness Centrality for the years 2007 – 2013.

	2008	2009	2010	2011	2012	2013
AT	3.92	3.59	6.34	3.65	3.75	3.68
BE	1.05	1.22	1.01	0.97	0.97	0.60
BG	0.00	0.00	0.00	0.08	0.15	0.15
CZ	1.06	1.19	0.63	0.52	0.95	0.94
DE	12.90	13.94	15.05	11.48	12.39	10.26
DK	0.00	0.00	0.00	0.00	0.00	0.00
EE	0.15	0.15	0.00	0.15	0.15	0.15
EL	0.16	0.16	0.31	0.12	0.23	0.23
ES	7.69	7.69	7.69	7.69	7.69	7.69
FI	3.95	3.95	0.00	3.90	3.95	3.94
FR	13.79	20.01	17.87	13.63	13.70	11.59
HR	1.37	1.30	0.10	1.43	1.38	1.46
HU	0.53	0.60	0.65	1.05	1.11	1.11
IE	0.00	0.00	0.00	0.00	0.00	0.00
IT	3.48	3.64	1.64	3.78	3.78	3.59
LT	0.00	0.00	0.00	0.00	0.00	0.00
LU	0.48	0.49	0.38	0.40	0.42	0.42
LV	3.44	3.44	0.15	3.49	3.44	3.45
NL	2.30	2.31	4.91	8.02	8.01	5.43
OTHER	61.93	60.36	60.20	64.53	63.18	64.78
PL	0.41	0.44	0.81	0.46	0.46	0.45
PT	0.00	0.00	0.00	0.00	0.00	0.00
RO	1.98	1.66	0.48	0.15	0.15	0.15
SE	1.61	1.61	1.65	1.13	1.67	1.62
SI	0.26	0.33	0.37	0.26	0.26	0.26
SK	0.63	0.54	2.26	0.26	0.73	0.73
UK	7.69	7.69	7.81	7.77	7.77	7.77

Table 17 Betweenness Centrality for the years 2014 – 2016.

	2014	2015	2016
AT	4.14	16.37	4.31
BE	1.00	1.48	1.01
BG	0.07	0.46	0.14
CZ	1.42	3.62	1.19
DE	10.44	28.98	10.83
DK	0.44	1.16	0.32
EE	0.14	2.11	0.14
EL	0.11	1.17	0.29
ES	7.12	7.27	7.27
FI	3.59	7.68	3.78
FR	25.88	25.18	26.42
HR	1.15	0.73	1.14
HU	1.14	10.71	1.13
IE	0.00	0.00	0.00
IT	4.48	14.86	8.21
LT	0.00	3.29	0.76
LU	0.39	0.70	0.39
LV	3.25	1.20	3.21
MT	0.00	0.00	0.00
NL	7.83	10.91	7.69
OTHER	54.87	20.96	53.15
PL	0.67	10.78	1.20
PT	0.00	0.00	0.00
RO	0.14	4.22	0.14
SE	1.86	9.06	2.77
SI	0.29	2.78	0.36
SK	0.71	3.29	0.57
UK	7.34	7.92	7.48

Table 18 Eigenvector Centrality for the years 2000 – 2013.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
AT	0.14	0.13	0.14	0.16	0.17	0.24	0.23	0.24	0.24	0.27	0.25	0.24	0.25	0.25
BE	0.10	0.14	0.13	0.10	0.09	0.06	0.11	0.08	0.09	0.06	0.06	0.07	0.09	0.10
BG	0.05	0.06	0.05	0.03	0.02	0.03	0.04	0.03	0.04	0.06	0.07	0.09	0.08	0.08
CZ	0.10	0.10	0.11	0.15	0.18	0.17	0.17	0.14	0.13	0.15	0.14	0.16	0.16	0.17
DE	0.39	0.38	0.39	0.42	0.45	0.49	0.48	0.45	0.46	0.40	0.44	0.44	0.47	0.51
DK	0.12	0.07	0.08	0.11	0.11	0.16	0.09	0.12	0.16	0.11	0.12	0.09	0.16	0.09
EE	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00
EL	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.07	0.08	0.06	0.05	0.04
ES	0.12	0.09	0.11	0.07	0.08	0.06	0.07	0.09	0.09	0.09	0.08	0.08	0.08	0.09
FI	0.09	0.10	0.10	0.13	0.14	0.13	0.12	0.11	0.13	0.16	0.15	0.12	0.09	0.07
FR	0.48	0.50	0.49	0.46	0.44	0.36	0.42	0.39	0.35	0.33	0.37	0.42	0.33	0.33
HR	0.05	0.04	0.04	0.03	0.03	0.06	0.06	0.02	0.06	0.08	0.09	0.06	0.04	0.06
HU	0.02	0.03	0.04	0.06	0.04	0.06	0.06	0.06	0.06	0.06	0.05	0.06	0.07	0.08
IE	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IT	0.42	0.47	0.45	0.42	0.39	0.35	0.36	0.41	0.37	0.42	0.38	0.38	0.33	0.32
LT	0.05	0.07	0.08	0.08	0.08	0.05	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04
LU	0.04	0.04	0.04	0.04	0.04	0.04	0.05	0.04	0.05	0.04	0.05	0.04	0.05	0.05
LV	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.02
NL	0.17	0.14	0.10	0.12	0.17	0.17	0.22	0.16	0.22	0.12	0.12	0.13	0.28	0.30
OTHER	0.51	0.51	0.52	0.53	0.50	0.53	0.50	0.54	0.54	0.58	0.56	0.54	0.51	0.51
PL	0.04	0.05	0.05	0.08	0.09	0.08	0.08	0.08	0.09	0.08	0.07	0.07	0.11	0.09
PT	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.02	0.01
RO	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.03	0.04	0.03	0.03	0.03	0.02	0.02
SE	0.20	0.11	0.15	0.14	0.17	0.17	0.10	0.14	0.14	0.12	0.13	0.10	0.18	0.10
SI	0.04	0.04	0.04	0.05	0.06	0.06	0.05	0.03	0.05	0.09	0.08	0.05	0.05	0.05
SK	0.01	0.02	0.03	0.04	0.05	0.05	0.05	0.07	0.04	0.05	0.03	0.06	0.08	0.06
UK	0.15	0.12	0.09	0.05	0.10	0.08	0.09	0.07	0.09	0.05	0.06	0.06	0.08	0.11

Table 19 Eigenvector Centrality for the years 2014 – 2016.

	2014	2015	2016
AT	0.27	0.28	0.25
BE	0.08	0.09	0.07
BG	0.13	0.14	0.13
CZ	0.26	0.25	0.25
DE	0.28	0.28	0.27
DK	0.17	0.18	0.17
EE	0.04	0.04	0.04
EL	0.15	0.15	0.14
ES	0.04	0.04	0.03
FI	0.13	0.14	0.13
FR	0.22	0.23	0.20
HR	0.14	0.15	0.13
HU	0.22	0.22	0.20
IE	0.01	0.01	0.01
IT	0.21	0.23	0.20
LT	0.11	0.14	0.19
LU	0.10	0.10	0.09
LV	0.11	0.12	0.12
MT	0.00	0.04	0.03
NL	0.16	0.16	0.15
OTHER	0.52	0.51	0.52
PL	0.25	0.19	0.28
PT	0.01	0.01	0.01
RO	0.15	0.15	0.14
SE	0.23	0.22	0.26
SI	0.10	0.11	0.10
SK	0.21	0.20	0.20
UK	0.07	0.07	0.06