MSc Program
Environmental Technology & International Affairs

Achieving Energy Security and Energy Independence through Renewables in the EU

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Affidavit

I, **MARIE-THERES ENGELMAYER, BA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "ACHIEVING ENERGY SECURITY AND ENERGY INDEPENDENCE THROUGH RENEWABLES IN THE EU", 60 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

53% percent of the energy consumed within the European Union is imported. In other words, more than half of the energy we consume to enable our society's modern life, has to be imported. Our computers, our phones, our elevators, our trading system run on energy, which the European Union imports. These imports from a few foreign states led to a high degree of dependency – with a high price: Every day the European Union pays around one billion Euros for the imports. Regarding the background of always faster spinning geopolitics and a changing global hegemony, stakeholders, politicians and executives became aware of the importance of energy security and energy independence. Renewable energies became the core element to achieve these two targets, as their characteristics fit the dimensions of energy security and energy independence. Hence, legal framework within the European Union was created to achieve legally binding targets of a 20% share of RES of the final energy consumption within the European Union by 2020, and 32% by 2030. This master thesis tries to explain how renewable energies contribute positively to achieving these two targets as well as shedding light on the emerging challenges and potential problems, which might emerge when integrating renewable energies into the grid and the urge to adapt to the new category of technology. Firstly, renewable energies contribute to energy security and independency as their fuel is present everywhere – although with varying potential within the European Union. Hence, with the deployment of the renewable energy sources within the European territory, the energy dependency would sink drastically. Secondly, renewable energy technologies bring an energy generation mix along, which creates a broader spectrum of energy sources, that creates stability.

However, the main characteristics of renewable energy sources are a high degree of unpredictability and volatility. This is the Achilles's heel to energy security. But with new and innovative technology, such as better forecast systems, real-time grid management and furthermore better transmission lines, this weakness-gap can be closed. Nowadays, the deployment of renewable energy sources is slowed down by long lasting legal processes. Experts urge stakeholders to draft a speeded-up process, to keep the pace of the energy transition high. This also includes fair mediation processes to balance out interests as well as one-step procedures.

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List of abbreviations

CEF	Central European Fund
DFIG	Double fed induction machine
ECSC	European Community on Steel and Coal
EEA	European Environmental Agency
EEC	European Economic Community
EEC	European Economic Community
EFSI	European Future Innovation System Centre
ESIF	European Structural and Investments Funds
EU	European Union
EURATOM	European Atomic Energy Community
EURATOM	European
G8	Group of 8
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GW	Gigawatt
Gwh	Gigawatt hours
IEA	International Energy Agency
JRC	Joint Research Centre
kV	Kilovolt
kWh	Kilowatt-hours
MS	Member States
Mtoe	Tonnes of oil equivalent
MW	Megawatt
mWh	Megawatt hours
NATO	North Atlantic Treaty Organization
OECD	Organization for Economic and Cooperation Development
OTEC	Ocean Thermal Energy Conversion
PV	Photovoltaic
RED	Reverse ElectroDialysis
RES	Renewable Energy Sources

RES-E	Renewable Energy Sources- Electricity
STATCOM	Static Synchronous Compensator
SVC	Support Vector Regression
TFEU	Treaty of the Functioning of the EU
TW	Terawatt
TWh	Terr watthours
UK	United Kingdom
UN	United Nations
UV	Ultraviolet
VAT	Valued added tax

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There are many people I would like to mention here. Thank you to my godmother, who’s contribution made this master’s program possible in first place. Thank you, my grandmother and my late grandfather, for giving me a home after school and encouraging me to strive for deeper knowledge always and find happiness in small things in life.

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1. Introduction

Energy is the key factor for today's society. The core elements, around which our society is created, are based on energetic input. More specifically, electricity will become increasingly important nowadays. Wherever you look, our life has been imbued by electricity. Our professional life is based upon the electricity factor: we rely upon electricity- driven computers, telephones and an always available WiFi. Our daily life is based on working machines, cash desks, traffic lights, ATMs and even automatic doors, which all run on electricity. If blackouts occur, it is undoubtingly the case, that the impacted region, will suffer from economic losses, which could create a further instability. But our dependence as a society on electricity does not stop at our private life and our economy. Electricity supply is needed for military purposes as well. If there is no guarantee of the security of electricity supply, there is no guarantee for a working military in case of emergency. Hence, the security of energy, and more specifically, electricity, holds the main ingredient for a modern and developing, but also a peaceful society.

The global outlook of electricity demand shows that we are only at the start of a global upwards trend. Even though developing countries, such as China and India are the main factors for the growth, the 28th countries of the European Union (EU) make up a big share of the biggest electricity consumers. Electricity is also interesting and of upmost importance to look at, as its main characteristic is, that it cannot be stored up to a satisfying amount, unlike conventional fuels, it is a perishable good. Therefore, the production, trade and consumption of electricity follows different patterns than the conventional fuels. The whole system needs to be adapted to this key characteristic. Energy production needs to follow the pattern of peak consumption, otherwise it cannot be used and sold.

Wake-up calls were the Ukrainian-Russian conflicts in 2006 and again in 2014. Gas supply was cut short and European authorities realized, that strategies against energy dependence of Europe had to be elaborated. Under the Juncker Commission, the Energy Union was created. However, experts criticize the lack of advancement of this integration project. While fossil fuels guaranteed an energy security for the last century, nowadays, with the exhaustion of the fuels, regional crisis, which can mount to global conflicts and consequently volatile and rapid price fluctuations, fossil fuels are not as reliable as they used to be.

There is more to energy security – especially for electricity. Today, the European Union fights a battle on two fronts, while ensuring energy security: One side is the security of supply, while the other one is ensuring the reduction of Greenhouse gas (GHG) emissions. The members of the European Union committed to the reduction of their national emissions in order to keep the global warming below 2 degrees Celsius in compliance with the Kyoto Protocol its successor contract the Paris Agreement signed in 2015. In other words, the main drivers for renewable energies are energy security and climate change mitigation actions.

Renewable Energy Sources (RES) can bring a positive value to the discourse of energy security as well climate change mitigation, especially regarding electricity. As RES do not use any fossil fuel, but rather wind or UV- light and hence do not emit any Greenhouse gas-classified Carbon dioxide.

Furthermore, Renewable energy technologies contribute to energy security in several aspects. First, RES bring a diversification of the production of electricity, which means that electricity producers do not have to rely on one kind of electricity production. Another positive effect of RES is the possibility of a decentralized grid. A centralized transmission grid is more vulnerable to attacks, human error or simply technical failure. As regions would produce their indigenous electricity, a failure of one grid would not create an impactful loss. Furthermore, the region’s dependency rate on imported energy and electricity would decline. The more diverse the energy mix and the lower the dependency, the higher the energy security. Hence, RES contribute to energy security through their characteristics.

However, there are down sides to RES as well. RES are variable and depend on different fluctuating natural cycles, such as tides, diurnal light phases or wind speed. In other words, RES are more variable and less predictable, which is problematic for the electricity market. Additionally, there are certain restrictions for RES as legal obligations and social acceptance come on the way to build up infrastructure needed to exhaust the potential of renewable energy within the EU.

1.1. Motivation and Research Question

The research question is the fundament of every scientific work. My research question was constructed under the motivation to gain more knowledge about energy security as well as climate mitigation measures as main drivers of Renewable Energy Sources and how the European Union laid the framework for this development from a legal perspective as well as from an infrastructure angle. With a high dependency rate of energy imports while having a fast-changing geopolitical situation on the globe, the chosen topic sheds light on how fragile our energy trading is, but also reveals in who's hands power is resting. Hence, I wanted to dedicate my Master Thesis to a topic, which fits my background as a political science undergraduate student, but as well is considered a current topic of our time from a technological and legal perspective. Therefore, my research question asks the following:

"Can the EU achieve Energy Security and Energy Independence through the implementation of Renewable Energies?"

My research should explain the status quo of the energy market within the EU, trends and if renewable energies could help achieve independency from external sources as well elaborate on the security of supply implications through RES. This master thesis also tries to explain challenges emerging from the integration of RES into the grid and infrastructural projects, which need to be executed in order to guarantee energy security with and through RES.

2. Background

In this section I will explain the main principles of the European Union and Energy Security, as well as the basics of Renewable Energies.

2.1. European Union

2.1.1. Geographical

The European Union (EU) comprises the territory of the following 28 member states (MS), listed after in alphabetical order according to the national language: Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, the Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden and the United Kingdom, although the last country is in current negotiations to leave the Union. Serbia, Montenegro, Turkey, Bosnia Herzegovina and the Former Yugoslav Republic of Macedonia are candidates to join the Union. On the global scale the European Union is the leading player of RES-deployment worldwide. Right now, the EU-28 are contributing to the RES energy production with a share of 15% - second behind China, which is contributing 17% to the overall production.[1]

Fig. 1: Territory of the European Union, 2019
Source: EU[2]

[1] Resch et al., "Potentials and Prospects for Renewable Energies at Global Scale," 4050–52.
[2] Borchardt, *The ABC of European Union Law*, 7.

2.1.2. Political and Economic Situation

The European Union is a special case – in every sense. It is not a supranational organization like the UN, but it is also not entirely an international organization like the NATO or an intergovernmental organization. "The EU is a unique economic and political union."[3], which was created after the Second World War, creating many milestones to what it is today: a 28- country strong Union, with an almost complete democratic fundament of legislature and judicature with a single market, a wide range of competencies, and a common currency. The power is balanced between the European Parliament, the European Council and the Council of the EU, as well as the European Commission. The European Parliament houses 753 Members of Parliament, who represent the citizens of the EU. The European Council constitutes of the Head of States. In the Council the sovereign governments of the MS are represented, the Court of Justice and the European Commission is the guardian of the treaties and acts in its capacity within the interests of the Union. The EU acts within their competences and creates law, which can override national law.

The ordinary legislation process is initiated by the Commission and later voted on by the European Parliament and the Council. There is a process laid out that foresees three possible rounds for a legal text to be adopted – or rejected.[4]

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[3] Anonymous, "The EU in Brief."
[4] Anonymous, 7–9.

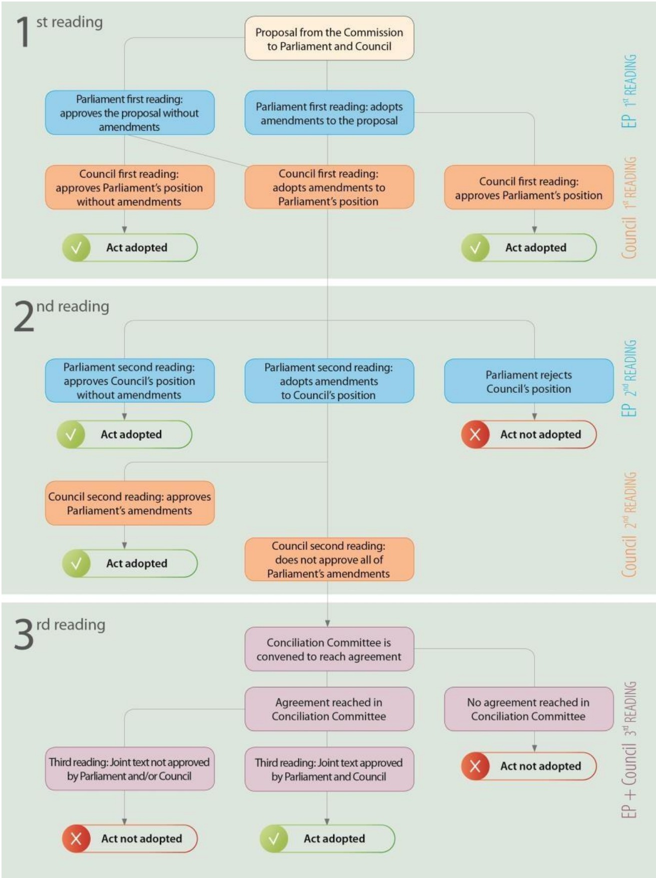

Fig 2: Legislative Procedure of the EU

Source: European Parliament[4]

Although the population of the EU just amounts to 7% of the world's population, the economic power of the Union is undisputable. The total value of all goods and services produced (GDP) of the EU is estimated at €15.3 trillion. Although the economy's growth dropped on average a 4% after the financial crisis in 2009, one can observe a slow growth of approximately 2% since 2014. Additionally, the EU is the second largest player of the export/import sector, right after China.[5]

2.2. Energy and the European Union

Energy was an important driver for the creation of the predecessors of the European Union. On May 9th, 1951 the foreign ministers of six European countries took the first step to an energy union, by signing the Treaty of Paris, which formally established the European Community on Coal and Steel (ECSC). The ECSC was called into life after the Second World War to reduce the risk of another bloody war between France and Germany by uniting the two nations regarding the co-development of energy policy. Only

[4] "The Ordinary Legislative Procedure."

[5] "The European Economy since the Start of the Millennium - Chapter 1.1."

six years later this community was broadened by the signing of the Treaty of Rome, introducing the European Atomic Energy Community (EURATOM) and the European Economic Community (EEC) – the three organizations which were later merged and built the fundament for what is known today as the EU. The peaceful use of nuclear energy was the main objective of the EURATOM as well as a shared system on how to handle highly enriched uranium as well as securing energy supply and independence from non-EU states.

Within the frame of the Single European Act under then- European Commission President, Jacques Delors, in 1987, which aimed to create an internally open market, energy policy was in the focus as well. A market liberalization was initiated, the "*unbundling*" of the European energy sector began with the de-monopolization of statenear companies and freshly distributing processes.

A big change was brought by the implementation of the Lisbon Treaty. As further laid out later in this Master Thesis, the treaty brought a shift in competences and encouraged the integration of the energy sector within the EU. The latest developments happened under the Jean-Claude Juncker Commission when the Energy Union – to establish a common approach and strategy on energy policy – was created. The constant focus on energy with the constant integration of energy policy and energy sector hence can be seen as a main driver for a greater cooperation of the EU and its member states. [6]

[6] Langsdorf, "History of EU Energy Policy.", page 1- 4

3. Energy Position of the EU- Status Quo

3.1. Energy Demand: Gross Inland Consumption

In 2017 there were 511.8 billion people living within the European Union (EU). 511.8 billion potential energy users. The number is expected to increase- although slowly. Currently, 28 countries are within the Union – but the number will decrease to 27 due to *Brexit*. However, there are seven countries in negotiations of an accession to the EU at the moment. The territory of the Union amounts to 154,539.82 km^2, although natural abundances are very different throughout the territory. [7] [9] The total gross-inland consumption of the EU-28 amounts to 1,627 million tons of oil equivalent (Mtoe). The energy consumption plunged in 2010, after a global recession, ever since there are high fluctuations in the European gross-inland consumption. The highest share is still delivered by petroleum with 34.6%. Only at the fourth place with 13.3% RES are contributing to the gross-inland consumption.

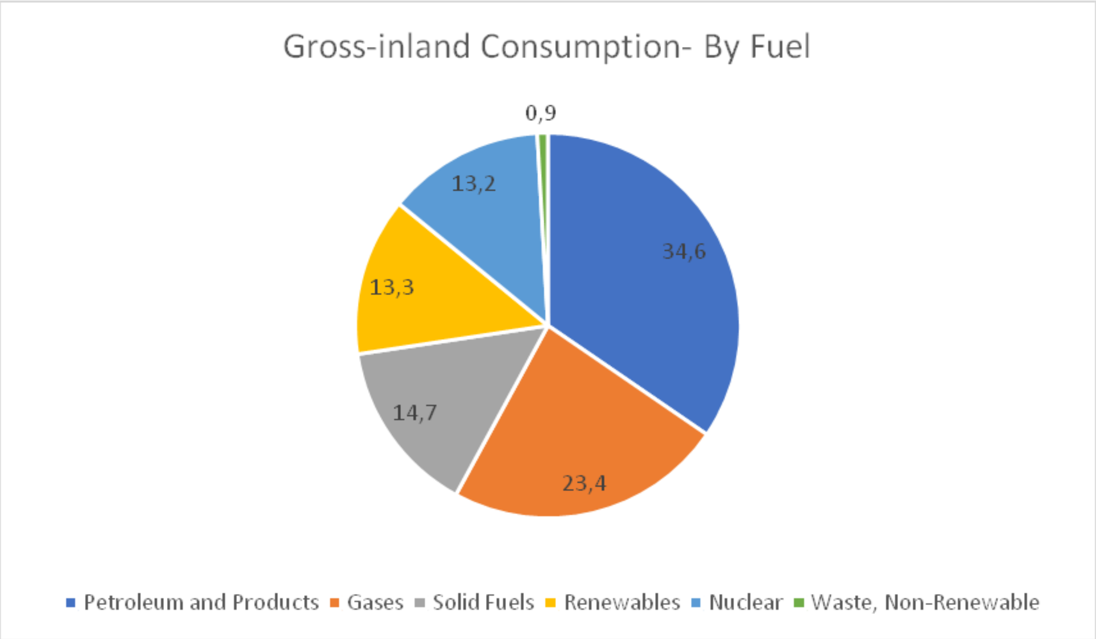

Fig. 3 : Gross-inland consumption- by fuel, 2016, EU-28

Source: Eurostat[8]

[7] Anonymous, "Territorial Status of EU Countries and Certain Territories."

[8] Shedding Light on Energy on the EU."
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3.2. Uses of energy by sector

However, the end-use by sector has been stable for the last years. The highest energy end use was required in the following categories: With 33.1 % most energy was used for transport, 25.4% was used in households, slightly behind that with 25.3% industry is considered the third largest group of end use consumption categories.[9]

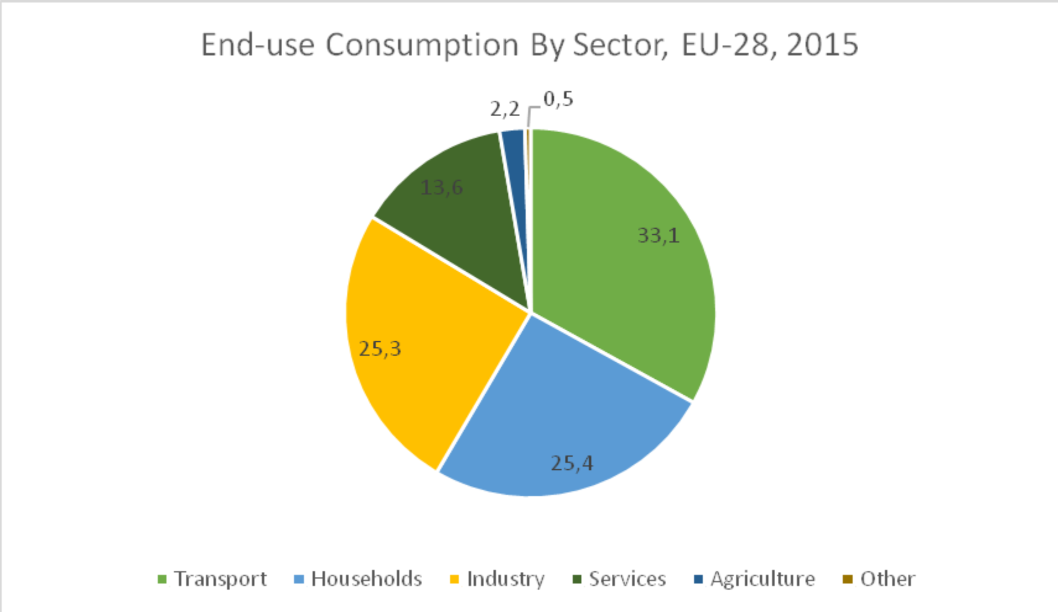

Fig. 4: End-Use Consumption, 2015, EU-28 Source: Eurostat[10]

3.3. EU Energy Supply: Primary Energy Production and Dependency Rate

Regarding the primary energy production within the EU, the number lies much lower. Following a negative trend, the EU-28 have produced 767 million tons of oil equivalent (Mtoe) in 2015. Ten years ago, the primary energy production within the EU territory was a 15.2% higher. Reasons for the descending developments are exhausted resources or uneconomical processes.

[9] Europeiska kommissionen and Eurostat, *Key Figures on Europe*, 2017, 154–59.
[10] Shedding Light on Energy on the EU."
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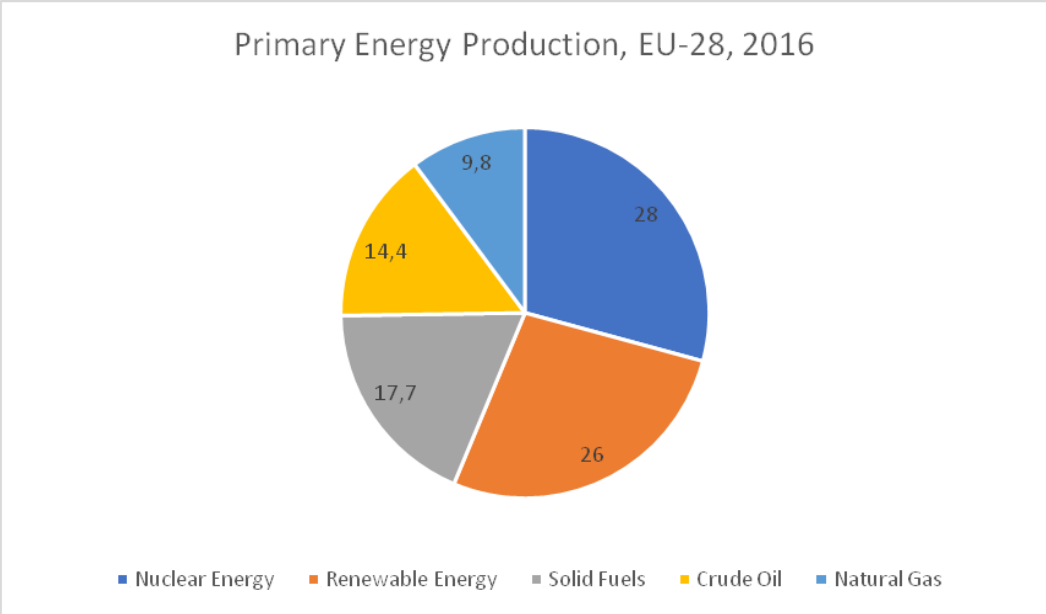

Fig. 5: Primary Energy Production, 2016

Source: European Commission[11]

In the production of primary energy in the EU-28 the share of renewable energy currently is estimated at 27.8% (2016). Within those 27.8%, or 205 Mtoe, the biggest share is taken by biomass and waste, about 42%. The second place is taken up by wind power, estimated to have contributed around 13.8%. With 11.4% hydropower contributed only on the third place, only leaving solar energy (6.4%) and geothermal energy (3%) behind.

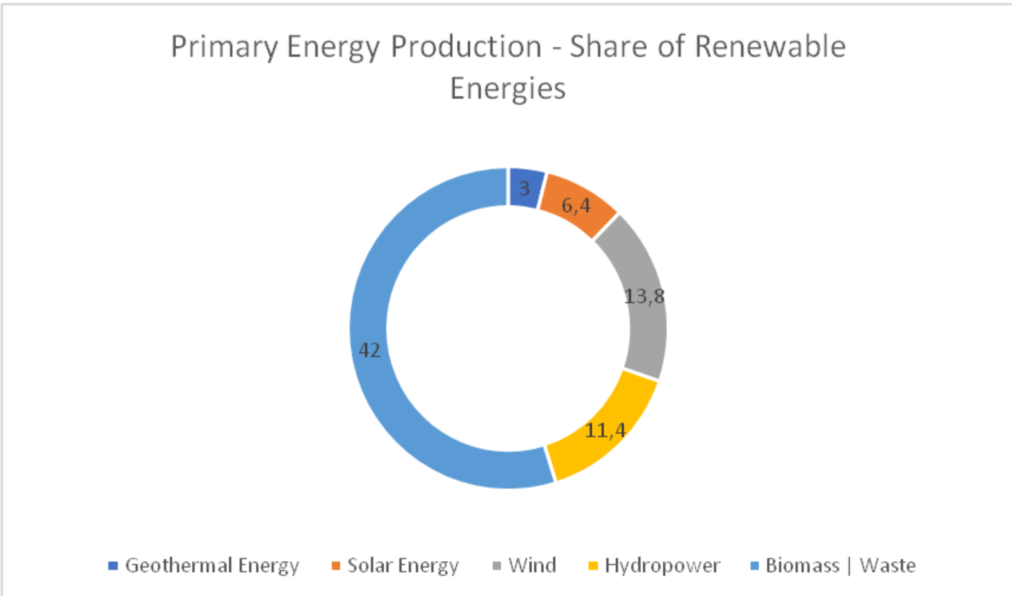

Fig. 6: Primary Production of Renewable Energies, EU-28, 2017

Source: European Commission[12]

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[11] "Shedding Light on Energy on the EU."

[12] Renewable Energy Statistics - Statistics Explained."
"

Looking at the share of RES within the electricity production, a much higher – and in fact – leading share can be observed. With 29% RES are contributing to the generation of electricity within the EU. This is a high increase in comparison to the share from 2005 with only 14%. Electricity generated from nuclear power plants or coal plants have both decreased more than 5%. About 3,255 TWh were produced in Europe in 2016.[13] There is an overall increase in electricity consumption, however, some more developed countries like the UK or Germany report a decrease of energy consumption.[16]

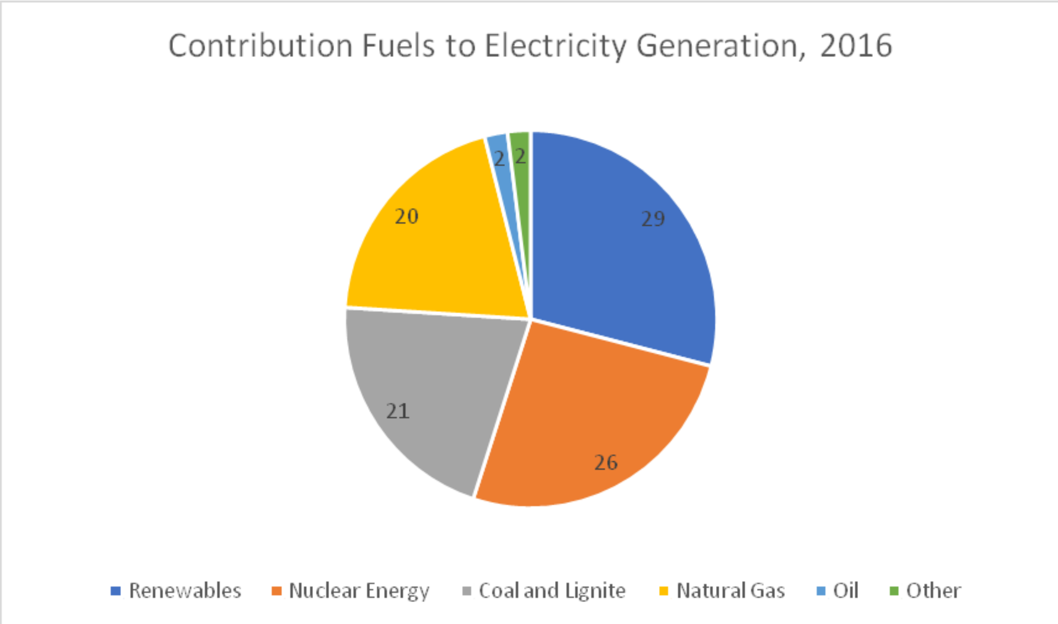

Fig. 7: Contribution Fuels to Electricity generation, 2016 Source: EEA[14]

Even though the overall share of fossil fuels in gross electricity generation is still higher than the RES share, it still decreased 21 %, reducing the share to 43% in 2016.

With a plus of 107% RES became one of the largest shares within the gross electricity production. In 2016, the largest contributor with 37% of renewable electricity was hydro-power, followed by wind-power (32%), biomass (19%), solar-power (12%) and geothermal- power (1%). [15]

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[13] "Electricity and Heat Statistics - Statistics Explained." [16] "Overview of Electricity Production and Use in Europe."

[14] "Primary Energy Consumption by Fuel."

[15] "Overview of Electricity Production and Use in Europe."

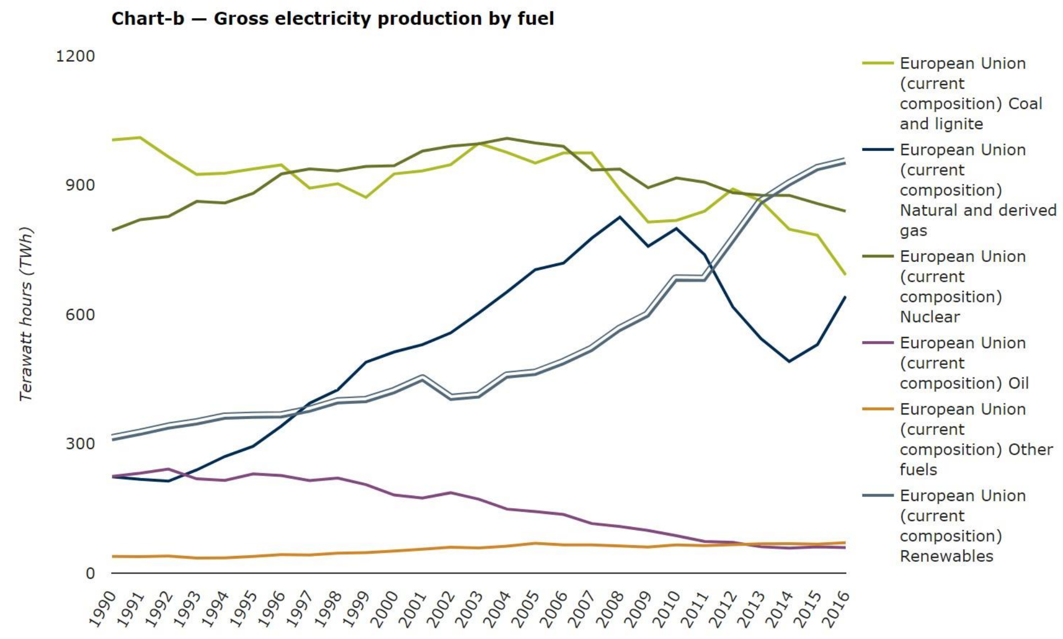

Fig. 8: Gross electricity production by fuel over time Source: EEA[16]

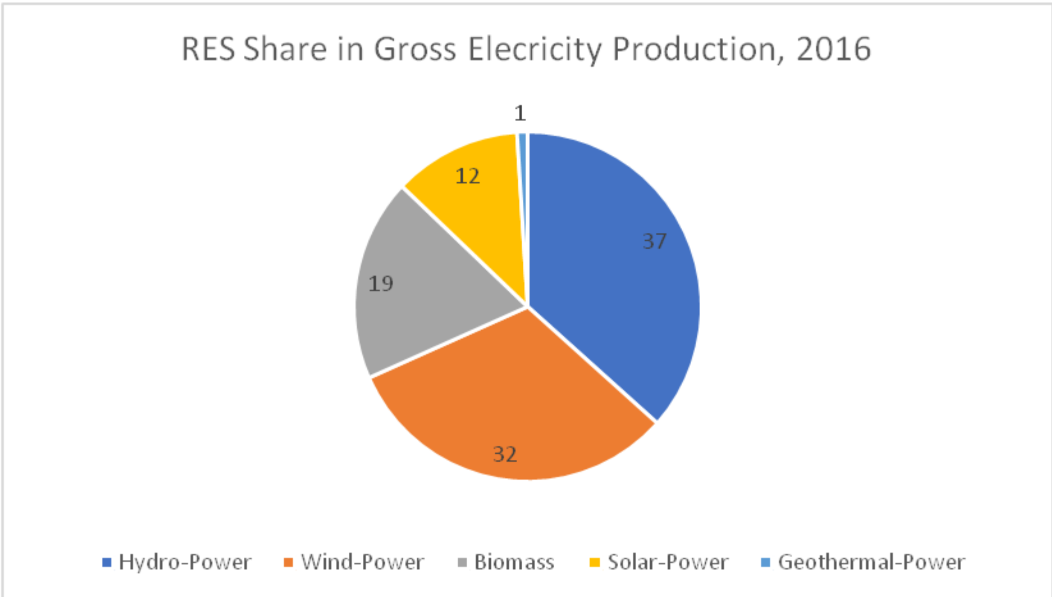

Fig. 9: RES Share in Gross Electricity Production, 2016

Source: EEA/ Eurostat[17]

However, different from the primary energy production, is the EU's legally binding target of achieving a 20% share of RES at the gross final energy consumption. Right now, the

[16] "Overview of Electricity Production and Use in Europe."
[17] "Overview of Electricity Production and Use in Europe."

share is estimated at 17,6% (2017). Three years before the deadline for the 20% share, eleven MS (Bulgaria, Czechia, Denmark, Estonia, Croatia, Italy, Lithuania, Hungary, Romania, Finland and Sweden) have already achieved their national action goals. Additionally, two countries (Latvia and Austria) are very close to achieve their national goal. The highest rate and contribution with 54% and therefore exceeding the original national goal of 50%, was achieved by Sweden. The second highest result was delivered by Finland with a share of 41%. On the lower scale of countries, which have not achieved their national coal, we can find the Kingdom of Malta with a 3% gap to the target, Luxembourg and the Netherlands with a 4,5% and an 8,4% gap.[18]

3.4. Dependency rate

As the consumption versus production numbers indicate, Europe is dependent on foreign import of energy. The dependency rate is defined by "proportion of energy that an economy must import. It is defined as net energy imports (imports minus exports) divided by gross inland energy consumption plus fuel supplied to international maritime bunkers, expressed as a percentage."[19] The higher the dependency rate, the more imports of energy units have to be made and vice versa.

To put this in numbers, the imports regarding gross energy consumption has been rising since 1990 over a 14%, lying now at 53.6%. The main reason for the increase of the rate are the exhaustion of resources within the EU territory. Ten out of those EU-28 have a higher dependency rate in 2016 than two decades earlier in 1996. Since 2004 the import rate is greater than the domestic production. The highest dependency rate is observed for crude oil with around 89% net imports needed to cover all demand. The fastest increasing number within the dependency rates is nevertheless the dependency rate for natural gas with about 69%, but which has been growing 12% as of 2005. There is a vast difference in the dependency rates of the different MS of the European Union. The highest dependency rates can be allocated to Luxemburg and Cyprus with both states having a dependency rate above 90%. The lowest percentages can be attributed to Poland, Romania or Denmark with dependency rates below 30%.[20]

[18] Palen, Renata, "Share of Renewable Energy in the EU up to 17.5% in 2017," 1–2.
[19] "Shedding Light on Energy on the EU."
[20] Europeiska kommissionen and Eurostat, 154–164.

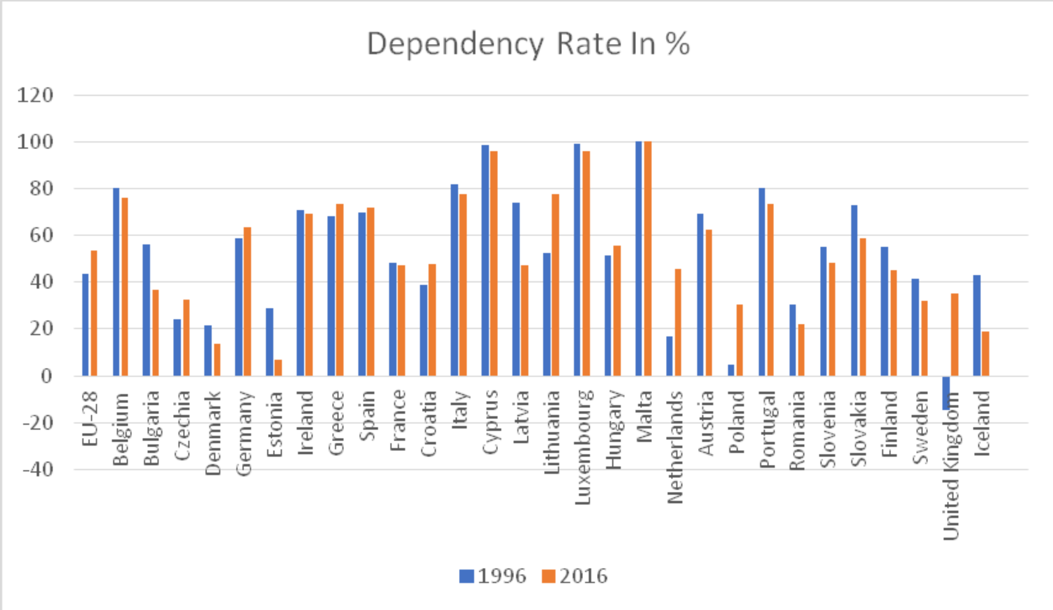

Fig 10: Dependency Rate in %, 1996 versus 2016 Source: Eurostat[21]

But on whom is the European Union dependent on regarding the energy imports? Regarding crude oil, the biggest importer for the EU is the Russian Federation with a 31.9% import rate. The Russian Federation is followed with a great gap by Norway with 12.4%.[22] The Scandinavian country is associated to the EU with a membership agreement but is hence not seen as a full member state of the European Union. [23]

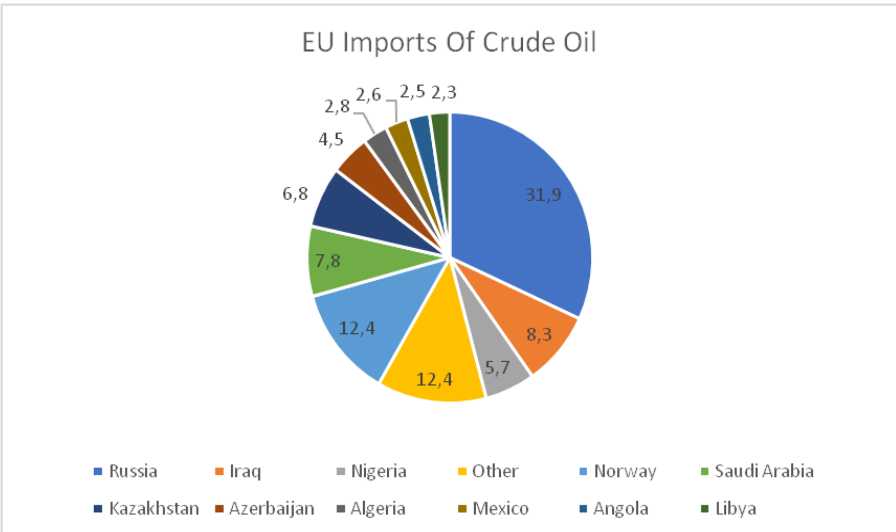

Fig. 11: EU Imports of crude oil per country, Source: European Commission[24]

[21] "Energy Production and Imports - Statistics Explained."
[22] European Commission, "From Where Do We Import Energy and How Dependent Are We?"
[23] Delegation of the European Union to Norway, "Norway and the EU."
[24] European Commission, "From Where Do We Import Energy and How Dependent Are We?"

4. Energy Pricing

4.1. Electricity Prices

As the European Commission defined the stableness of prices as one of the factors to define energy security, it is of utmost importance to explain the formation of these prices and the different variation of the numbers throughout the EU.

The prices of electricity within the EU are dependent on various factors such as the taxation, the energy mix of each country, but as well as the geopolitical situation. There are two categories established by the European Union, which creates a report on the electricity prizes every year: The household consumers, which are defined with a 2,500 kWh < consumption < 5,000 kWh and the industrial consumers with a 500MWh < consumption < 2,000 MWh. The household consumers in Germany, Denmark and Belgium have to pay the highest prices with around 0.26 to 0.30 Euro per kWh. Although, what must be mentioned here is, that a large share of the high price is due to taxes and the valued added tax, shortly VAT. The lowest prices have to be paid in Hungary, Lithuania and Bulgaria with around 0.10 Euro per kWh. A special case can be seen with Malta, where the basic price for a kWh is even higher than in Denmark, but as there is no VAT added, the price is estimated at 0.13 Euro per kWh and hence counts to one of the cheapest countries for electricity consumption within the household sector in 2016.

Germany and Italy were the countries with the highest prices for electricity in the industrial sector, although the basic price was lower than the average price of the EU28. The highest basic price had to be paid by Malta and Cyprus. Industrial consumers had to pay approximately 0.13 Euro per kWh. The two island countries also coincide with the highest ranking of the dependency rate for energy. On the opposite end of the scale we can find Sweden and Austria with about 0.6 Euro per kWh as the basic price. Both countries have a rather lower dependency rate as well as a good performance to achieve the 2020 target.

The electricity market in Europe in general has been going through a transformation as the Union sought in the 1990ies to open the market and liberalize it. Until today, one can observe this process, as more and more monopolies are broken up and there is a price competitiveness among the different national markets. Prices fell for the first time in 2017 after a decade of rise.[25] The overall price is still very dependent on the price of fossil fuels and gas, rather than RES, as the largest share of electricity generation is done by combustion of fossil fuel with 48%, followed by nuclear energy (26%) and then RES (25%).[26]

Regarding the price volatility, the European Commission has elaborated a multidimensional approach. The implementation of a single market with interconnections, a dynamic pricing and coupled markets was the first measure to mitigate price shocks. Additionally, taxation helped ease some bottlenecks and provide for new investments which had to be made in order to further enable the energy transition. Thirdly, the cost of energy is being in the focus rather than the costs per unit, as it allows a more specific analyzation of consumer behavior. Lastly, there has been a large-scale concept within the EU, so-called "Investment Strategy for Energy", which contains detailed plans and tactics about the market design and financial instruments.[27]

4.2. Gas and Oil Prices

Gas prices in the EU have been dependent on the global fossil fuel price. As oil prices rose, so did the gas prices. Between 2014 and 2016 the oil prices sank drastically, but today we can observe an upward trend. Instability to prices is added due to geopolitical challenges and fluctuations in the exchange rate. As already mentioned above, taxations helps keeping the price stable, but those instabilities are also seen as main drivers for energy efficiency in the "European Commission's report called "Report From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions: Energy Prices and Costs in Europe".[28]

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[25] European Commission, "Report From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions: Energy Prices and Costs in Europe."
[26] Europeiska kommissionen and Eurostat, *Key Figures on Europe*, 2017, 160–65.
[27] European Commission, "Report From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions: Energy Prices and Costs in Europe," 2–4, 12–13.
[28] European Commission, 4–7.

5. Legal Framework of the European Union for Energy Security Strategy and Renewable Energy

In 2009 when the Lisbon Treaty came into force, energy policy was made a shared competence of the European Union and the Member States, but this does not undermine the sovereign right of every MS to choose independently its own resource of energy. The reasons for the competence expansion were laid out in Article 194 of the Treaty on the Functioning of the European Union, shortly TFEU: "are a functioning energy market, interconnected energy networks, security of energy supply, promotion of energy efficiency and saving, and the development of new and renewable forms of energy."[29] Alongside with that the EU environmental policy is laid out in 191 TFEU, with the main objective to mitigate the consequences of climate change.[30]

Hence, two objectives are fought for by deploying RES within the EU. First, a higher degree of energy security as the production reduces the dependency rates of EU member states and secondly, to meet the Agreements of Greenhouse Gas emissions reduction. This double-benefit can be found in the interlinkage of legal frameworks regarding the mitigation of climate change and achieving energy security by deploying RES.

The European Energy Security Strategy was drafted after "wake-up calls" as there were scarcities of energy supply in the winter of 2009. In the light of scarcity, high dependency rates from especially one non-EU country and the high costs of import, the European Union created a strategy to avoid threats to supply-security. Within the document eight pillars of measures were identified to help ensure security of energy supply:

"1. Immediate actions aimed at increasing the EU's capacity to overcome a major disruption during the winter 2014/2015;

2. Strengthening emergency/solidarity mechanisms including coordination of risk assessments and contingency plans; and protecting strategic infrastructure;

3. Moderating energy demand;

4. Building a well-functioning and fully integrated internal market;

5. Increasing energy production in the European Union;

6. Further developing energy technologies;

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[29] Gregor Erbach, Martin Svasek, Alina Dobreva, "Briefing: Energy Supply and Energy Security," 2.

[30] (Gouardères 2018) (Gouardères 2018) (Gouardères 2018)

7. Diversifying external supplies and related infrastructure;

8. Improving coordination of national energy policies and speaking with one voice in external energy policy."[31]

Especially the fifth point is of interest regarding renewable energies. The European Commission intends to reverse the declining trend of energy production within EU territory with improved national support schemes, reduced administrative barriers and an increased financial support for renewable energies deployment. [32]

Another key point within this document, which was released in 2014, is not only the transformation of the energy sources, but also the compliance with other policy frameworks:

> *"In the long term, the Union's energy security is inseparable from and significantly fostered by its need to move to a competitive, low-carbon economy which reduces the use of imported fossil fuels. This European Energy Security Strategy is, therefore, an integral part of the 2030 policy framework on climate and energy and also fully consistent with our competitiveness and industrial policy objectives."*[33]

With this cross reference of the Energy Security Strategy to the Policy Framework on Climate and Energy, we can see that achieving energy security, is closely interconnected with targets to fulfill the environmental dimension as well as the specific legal framework created by the Renewable Energy Directive.

The Renewable Energy Directive in general melts the above-mentioned aspects of interdependence between energy security and climate change mitigation efforts with the help of renewable energy deployment.

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[31] Communication From The Commission To The European Parliament And The Council European Energy Security Strategy, Brussels, 28.5.2014 COM(2014) 330 final, page 3

[32] Communication From The Commission To The European Parliament And The Council European Energy Security Strategy, Brussels, 28.5.2014 COM(2014) 330 final, page 13-14

[33] Communication From The Commission To The European Parliament And The Council European Energy Security Strategy, Brussels, 28.5.2014 COM(2014) 330 final, page 3

The Renewable Energy Directive aims to establish a share of 20% by 2020 and a share of 32% by 2030. The directive was revised in 2017, where the 27% were lifted to 32% for 2030. However, a clause to revise these targets by 2023, was incorporated within the directive. The gross final consumption from RES from each MS will be calculated according to Article 5:

"(a) gross final consumption of electricity from renewable energy sources;

(b) gross final consumption of energy from renewable sources for heating and cooling; and

(c) final consumption of energy from renewable sources in transport."[34]

Under Article 4 member states (MS) are required to elaborate a National Energy Action Plan, which should give insights how the share of renewable energies is being implemented on a national level. The Commission will then evaluate the plan for its compliancy and may hand out recommendations for improvement. Furthermore, Article 7 to 11 contain cooperation mechanisms, which provide a framework for the joint projects.

After almost ten years, a new legal framework has been worked on: The Energy Union. It was launched in February 2015 and aims to reach a Europe based on a modern energy market and a frontrunner of RES in order to "make energy more secure, affordable and sustainable"[35]. The Energy Union is built upon five pillars:

1. *"Security, solidarity and trust;*
2. *A fully integrated internal energy market - enabling the free flow of energy through the EU through adequate infrastructure and without technical or regulatory barriers;*
3. *Energy efficiency - improved energy efficiency will reduce dependence on energy imports, lower emissions, and drive jobs and growth;*
4. *Climate action, decarbonizing the economy - the EU is committed to a quick ratification of the Paris Agreement and to retaining its leadership in the area of renewable energy;*

[34] Directive 2009/28/EC Of The European Parliament And Of The Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

[35] European Commission, "Building the Energy Union."

5. *Research, innovation and competitiveness - supporting breakthroughs in lowcarbon and clean energy technologies by prioritizing research and innovation to drive the energy transition and improve competitiveness".*[36]

The EU's objective with the creation of the diverse interlinking legal texts about energy security and the promotion of RES, are various:

"The framework helps drive progress towards a low-carbon economy and build an energy system that

1. *ensures affordable energy for all consumers,*
2. *increases the security of the EU's energy supplies,*
3. *reduces our dependence on energy imports,*
4. *creates new opportunities for growth and jobs and*
5. *brings environmental and health benefits – e.g. through reduced air pollution"*[37]

Three points of their aims will be covered by deploying RES: less dependency, less climate pollution and more energy security. Point 1 and 2 are in line with the European Commission's definition of energy security, but the legal framework crafted by the EU even covers broader definitions of energy security, such as the Trilateral Commission's definition incorporating of the environmental dimension, or the scholar's definition of Sovereignty, as RES deployment decrease the dependency rate of energy imports.

[36] https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/building-energy-union

[37] https://ec.europa.eu/clima/policies/strategies/2030_en, 4th April 2019

6. Renewable Energy Sources

Photovoltaic energy, hydro-power, wind-power as well as geothermal-power and biomass are all considered as renewable energy sources (RES). The important numbers for the EU are derived from the gross final consumption of energy, which are considered "according to specific calculation provisions of Directive 2009/28/EC on the promotion of the use of energy from renewable sources and Commission".[38] To put this into numbers, 1,000 Terawatt (TW) could be generated by solar power alone, 10 TW by wind-, hydro- and geothermal-power. The actual primary energy demand in fact is much lower, which is estimated at 18 TW. This means the global energy demand could be covered by far with RES The growth of RES is a global trend: up until 2013 the EU28 was the leading player in the RES deployment, ever since China has emerged as the biggest RES deployer on the international sphere. [42]

6.1. RES and Electricity

The 2050 Roadmap published a proposal for a target that 97% of the electricity demand could be covered with RES by 2050. Nowadays, the electricity demand, is the one sector, with the highest RES share. As laid out in the chapter "Energy Market – Status Quo", the RES share of gross electricity generation is estimated at 28% or 400 Gigawatt (GW). Renewable Energy Sources contributed to the mitigation of CO2 emissions although the worldwide GDP rose a 6.6%, RES were used to produce 90% of supplementary electricity in 2015.[39]

6.2. Photovoltaic

Photovoltaic or solar-power, is one of the most promising technologies in this field. As the supply of the resource is given worldwide and goes 7,000 times beyond the current world's energy demand. Undoubtedly, the supply variates according to the geographical region. The next figure shows the different values of energy, which can be harvested throughout Europe, ranging between 800 kWh/m^2/a (in northern regions) and 1,400 kWh/m^2/a (in southern regions).

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[38] Palen, Renata, "Share of Renewable Energy in the EU up to 17.5% in 2017." [42] Elliott, *Renewables*, 1–3.

[39] Erbach, European Parliament, and Directorate-General for Parliamentary Research Services, *Promotion of Renewable Energy Sources in the EU*, 10–11.

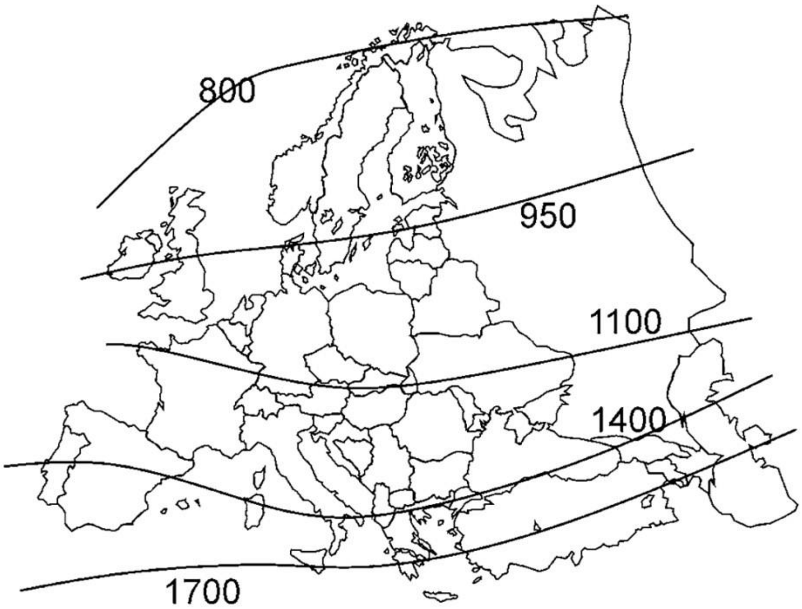

Fig. 12: Global Radiation, Europe, in kWh/m^2/a
Source: Günther Brauner[40]

A photovoltaic cell is made from semiconductors, which convert the UV-light into direct current electricity. Visible UV-light enters the cell, which is made out of three layers: The top layer, which is made out of silicon and phosphorus, which contains excess electrons. The middle layer contains only a few more electrons than the third and thinnest bottom layer, which is constituted of silicon and boron, having less electrons. Whenever solar light hits the cell, the middle layer sends one electron to the top layer and one effective positive charge to the bottom layer. The top and the bottom layer are connected through a wire, which gives the electrons a path to flow, creating ultimately an electrical current. The cells are grouped to accumulate the necessary capacity strength of 50-200 Watt (W).

6.2.1. Deployment and Potential

Reports by the Joint Research Center (JRC) by the EU show that the deployment of photovoltaic cells has increased. Only between 2014 and 2015, the Photovoltaic (PV)-deployment went up 8.7%. However, the potential for the generation of electricity with photovoltaic is very different within the territory of the Union. Naturally, the regions in the south are more gifted with approximately 2000 kWh/m^2. However, the countries who

[40] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*.

deployed PV the most were northerner countries such as the UK or the Netherlands, with around 1,200 kWh/m^2.[41]

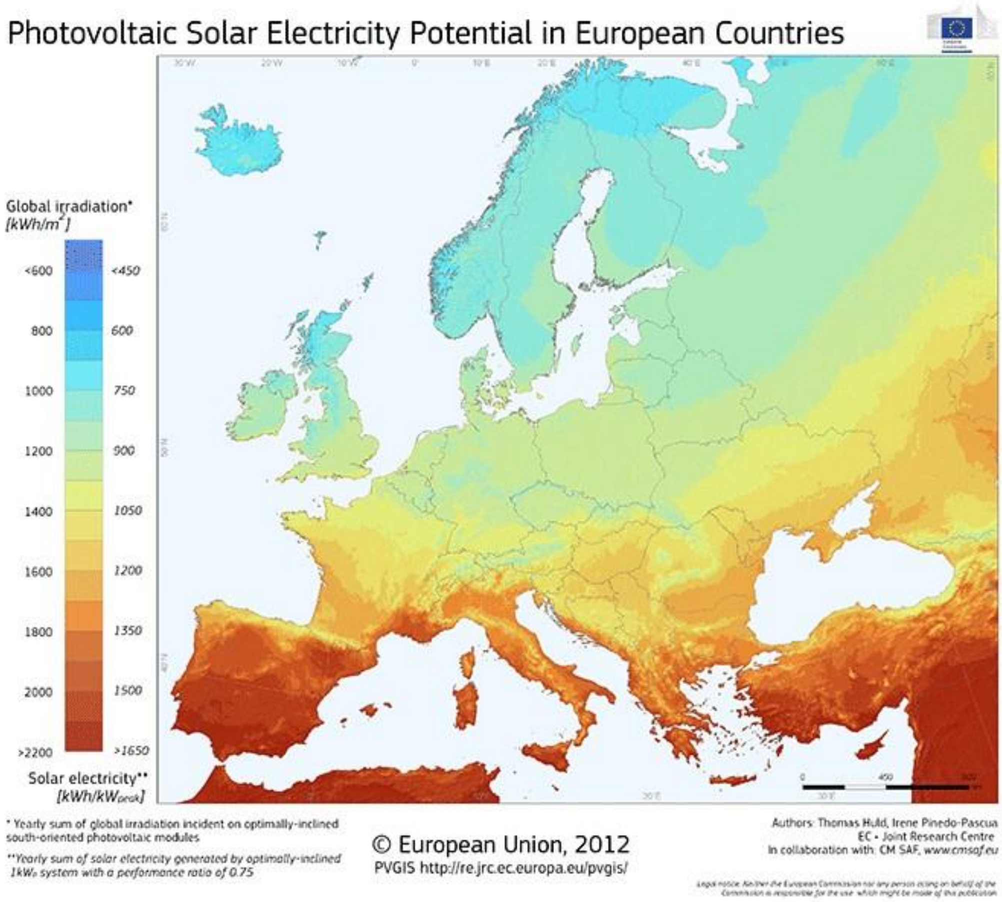

Fig. 13: Photovoltaic Solar Electricity Potential in European Countries, 2012

Source: JRC[42]

6.2.2. Environmental Impact

The environmental impact of solar deployed solar cells is yet little researched. There is no evidence on the danger of the Cadmium within the cells.[43] However, the impact on the soil, which the cells and furthermore the solar-parks, are based on is researched extensively. There are direct as well as indirect effects. One of the direct effects is the change of temperature, which is an important driver for the biosphere and the carbon cycle in general. For solar parks the temperature will change from 0.7 to 26 degrees Celsius.

[41] Lange, "Potential for Further Photovoltaic Capacity in EU Member States."
[42] "PV Potential Estimation Utility."
[43] Alsema, "Presented at the 21st European Photovoltaic Solar Energy Conference, Dresden, Germany, 48 September 2006 Environmental Impacts Of PV Electricity Generation - A Critical Comparison Of Energy Supply Options," 6.

Hence, the discharge and the intake of carbon dioxide and methane depends very much on the ecosystem's temperature, which will affect plant growth. Additionally, the covering of the soil creates a change in the micro-climate according to scholars. As the parks take energy for photosynthesis as well as soil moisture away from the soil, effects are being resumed, although their magnitude is not yet researched. [44]

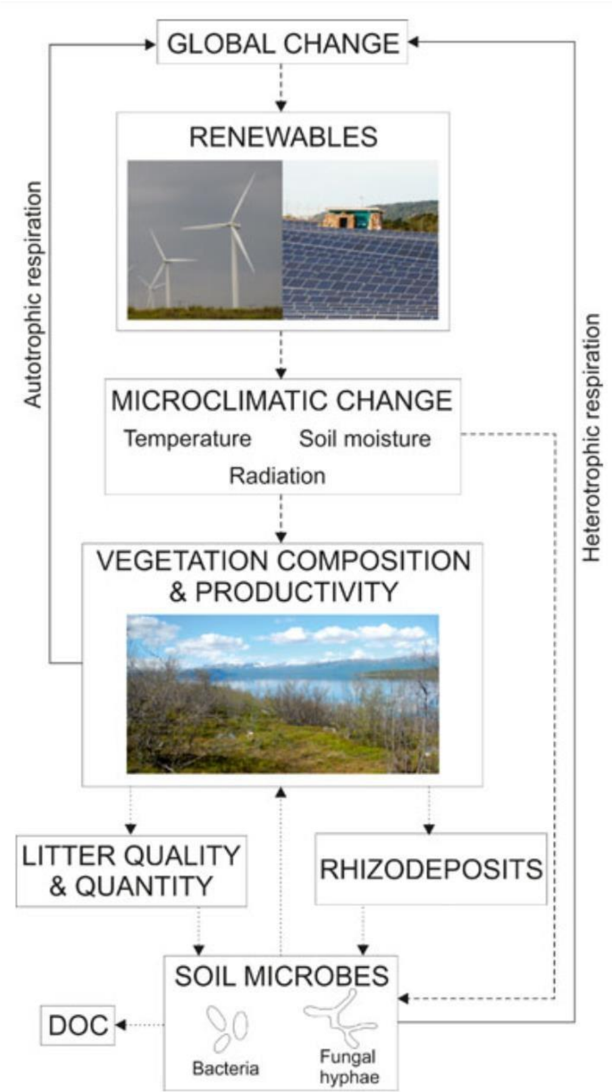

Fig. 14: Feedback-loops of RES and their direct and indirect impact on their environment. Source: Armstrong et al.[49]

[44] Armstrong et al., "Wind Farm and Solar Park Effects on Plant–Soil Carbon Cycling," 1701–2. [49] Armstrong et al., "Wind Farm and Solar Park Effects on Plant–Soil Carbon Cycling."

6.3. Wind energy

Energy from wind is used and later converted into electricity through “an aerodynamic rotor, which is connected by a transmission system to an electric generator.”[45] Generally, all modern wind turbines are equipped with three blades. Both their adaption to the wind direction (yawning) and speed (pitching), help increase the energy output. Energy is extracted from the wind at around 3 m/s up to 10 m/s. One wind turbine does not deliver sufficient energy, hence turbines are usually grouped up, making a “wind power plant” or a “wind farm”. Nowadays, the most popular type of wind turbine is the

“Doubly fed induction generator (DFIG)”. The turbine combines advantages of other models. “The rotor is connected to the grid through a back-to-back insulated gate bipolar transistor (IGBT) power converter that controls both the magnitude and frequency of the rotor current.”[46] This enables speed variation while ensuring a maximum capture of energy. “The converter provides decoupled control of active and reactive power, enabling flexible voltage control without additional reactive power compensation, as well as fast voltage recovery and voltage ride-through. Pitch control is also incorporated.”[47]

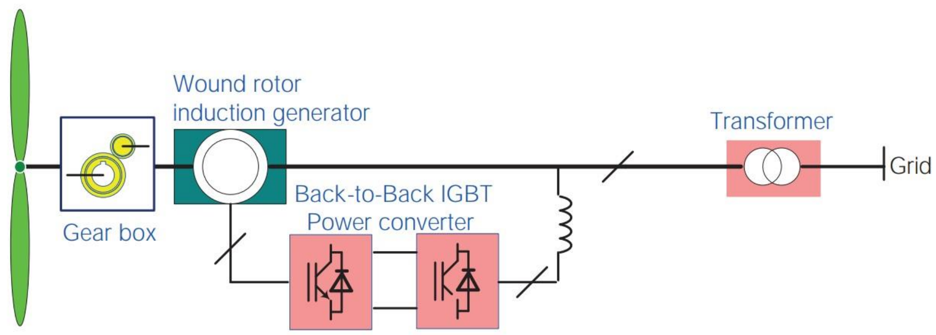

Fig. 15: Doubly fed induction generator (DFIG) Source: IEC[48]

They on-shore wind power plants are usually between 1.5 – 3 Megawatt (MW), while off-shore solutions are at approximately 5.9 MW. The capacity has been increasing linearly since the first off-shore deployment in the 1990. Advantages of an offshore windfarm are that they are more powerful, the deployment area is less environmentally impacted and

[45] IEC Market Strategy Board, *Grid Integration of Large-Capacity Renewable Energy Sources and Use of Large-Capacity Electrical Energy Storage*, 29–30.
[46] IEC Market Strategy Board, 32.
[47] IEC Market Strategy Board, 32.
[48] IEC Market Strategy Board, 33.

there are less limitations on transportation, size and less turbulences, which lead to an increased efficiency, the off-shore wind turbines deliver also more energy output. But there are significant disadvantages as well, as they are more expensive in their installation as well as their infrastructure and additional costs for the integration in the grid.[49] In 2017 extra net 3,148 MW were installed, which was an increase of 4% in comparison to 2015. According to *Wind Europe*, an organization based in Brussels with the target to promote wind energy, "560 new offshore wind turbines across 17 different offshore wind farms"[50] have been installed in 2017.

6.3.1. Environmental Impact

The environmental impact of wind parks is not as big as the photovoltaics' impacts. There are direct and indirect effects as well. For example, are changes in the surface meteorology observed. The wind speed, or the wind's pattern of turbulence or moisture might change due to the installation of wind parks. This might change the humidity of the soil and hence the plant productivity. While for photovoltaic farms the temperature changes were estimated at a high level, the temperature change for wind parks is only estimated to be between 0.7 to 3.5 degrees Celsius.[51]

6.3.2. Deployment and Potential

Regarding the wind power potential, Europe is very rich in resources. In fact, there are scholars, who believe that with wind power the EU's targets of 20% RES by 2020 can be only achieved by enhanced deployment of wind turbines. However, there are certain environmental, social and economic limitations to the potential. For example, the technical potential of onshore wind energy is estimated at 45 Terawatt Hours (TWh) by 2020, but at the end, the economically feasible and competitive potential is just a fraction of the original number: 9,600 TWh.

[49] Bilgili, Yasar, and Simsek, "Offshore Wind Power Development in Europe and Its Comparison with Onshore Counterpart," 906–8.

[50] WindEurope Business Intelligence, *Offshore Wind in Europe - Key Trends and Statistics 2017*, 7.

[51] Armstrong et al., "Wind Farm and Solar Park Effects on Plant–Soil Carbon Cycling," 1700–1702.

Table ES.1 Projected technical, constrained and economically competitive potential for wind energy development in 2020 and 2030

		Year	TWh	Share of 2020 and 2030 demand ([a])
Technical potential	Onshore	2020	45 000	11–13
		2030	45 000	10–11
	Offshore	2020	25 000	6–7
		2030	30 000	7
	Total	2020	70 000	17–20
		2030	75 000	17–18
Constrained potential	Onshore	2020	39 000	10–11
		2030	39 000	9
	Offshore	2020	2 800	0.7–0.8
		2030	3 500	0.8
	Total	2020	41 800	10–12
		2030	42 500	10
Economically competitive potential	Onshore ([b])	2020	9 600	2–3
		2030	27 000	6
	Offshore	2020	2600	0.6–0.7
		2030	3400	0.8–0.8
	Total	2020	12 200	3
		2030	30 400	7

Note: ([a]) European Commission projections for energy demand in 2020 and 2030 (EC, 2008a, b) are based on two scenarios: 'business as usual' (4 078 TWh in 2020–4 408 TWh in 2030) and 'EC Proposal with RES trading' (3 537 TWh in 2020–4 279 TWh in 2030). The figures here represent the wind capacity relative to these two scenarios. E.g. onshore capacity of 45 000 TWh in 2020 is 11–12.7 times the size of projected demand.

([b]) These figures do not exclude Natura 2000 areas

Source: EEA, 2008.

Fig. 16: Projected, technical and economically competitive potential for wind energy development in 2020 and 2030. Source: EEA 2008[52]

The full load hours – this means the hours a power plants runs with a full load and is typically used to describe the output of a power plant - are differently distributed within the Union. While the south typically holds less full load hours (below 1,000), while the central-northern part – inter alia the UK, the Netherlands or Northern Germany – accumulate from up to 1,500 to 3,000 in the shore regions. As the wind speed is higher offshore, the European Environmental Agency (EEA) concludes:

“Further out at sea, at 30 to 50 kilometers from the coast, the Baltic, the North Sea (including the English Channel) and the Mediterranean respectively account for 30 %, 30 % and 20 % of total wind potential. The total potential for this distance class is estimated as 3,300 TWh in 2030.”[58]

[52] European Environment Agency, *Europe’s Onshore and Offshore Wind Energy Potential. An Assessment of Environmental and Economic Constraints.* [58] European Environment Agency, 24.

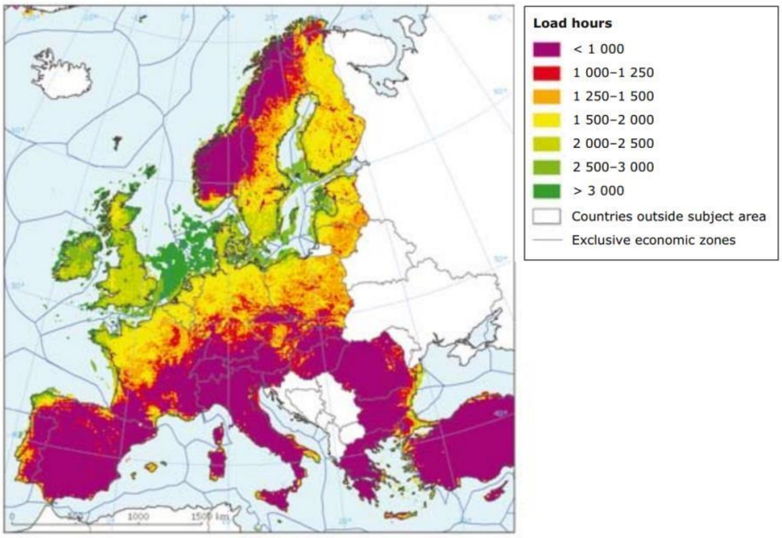

Fig. 17: Distribution of full load hours in Europe (80 m hub height onshore, 120 m hub height offshore) Source: EEA[53]

6.4. Hydro Power

Hydro power plants count to one of the oldest renewable energy sources. The plants are situated on a water flow to collect water behind a dam to generate potential energy.

When released the water's potential energy transforms into kinetic energy, which then powers turbines, which create electricity. The higher the potential energy is stored; the more energy output is generated. The technology is very advanced and reliable. But this RES brings disadvantages, too.

6.4.1. Environmental impact

The environmental impacts can be concerning. Not only the landscapes change due to the impact of the construction of the hydro plants on the river, but also climate change will affect the water level. The latter circumstance cannot be estimated at this point.

6.4.2. Potential

In the youngest EU-member state Croatia and in Romania the total electricity generation from hydropower is estimated at 59% and 37%, in other words, this is a substantial share of the electricity generation. Experts predict an even bigger potential of hydropower

[53] European Environment Agency, *Europe's Onshore and Offshore Wind Energy Potential. An Assessment of Environmental and Economic Constraints.*

within that area, although this potential is restricted by poor economic standards and a lack of investments.

The role models for hydropower are the Scandinavian countries such as Norway or Sweden. There is high potential not only from their geographic characteristic, but also due to water-richness. They are already generating electricity from hydropower. However, these countries are reluctant to create new plants, as environmental concerns are raised in the public concern.

France, Austria and Italy are already among the most developed countries in the sector of hydropower. Scholars argue that their potential is nearly exhausted. [54]

The next figure shows the gross hydropower potential calculated according to the formula:

$$GP = m \cdot g \cdot h \quad (8.1)$$

m: Mass of runoff

g: Gravitational acceleration

h: Height (elevation above sea level)

There are two options to calculate the potential: The first method, called "A", takes the height difference of the elevation (1,000 Meters) down to the sea level of each cell, while method "B" calculates the height difference between the starting cell and the next downward cell. Both methods are justified as the first shows where potential for hydropower is initiated, while the later one describes, where it can be utilized.

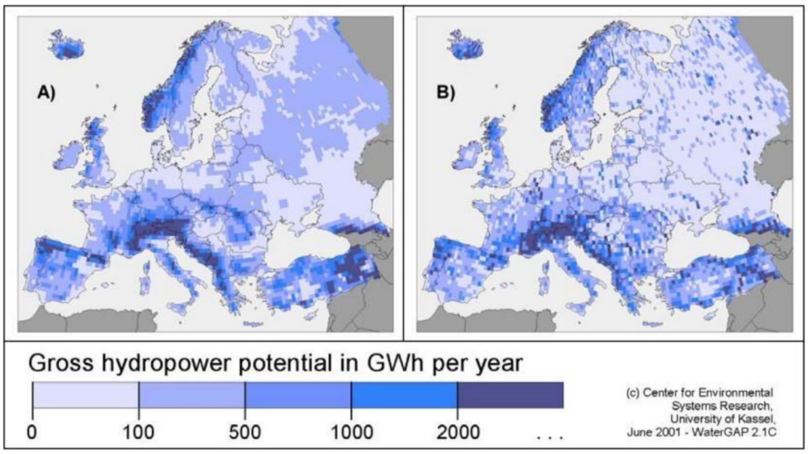

Fig. 18: "Gross hydropower potentials for Europe, calculated by applying average (1961-90) runoff and discharge values of WaterGAP 2.1. A) Each cell is assigned its total gross hydropower potential down to sea level. B) Only the portion of the gross hydropower potential that can be locally utilized down to the next downstream cell is allocated to each cell."[61] Source: Eurowasser[55]

[54] Lehner, Czisch, and Vassolo, "Europe's Hydropower Potential Today And In The Future," 7–8. [61] Lehner, Czisch, and Vassolo, 8.

[55] Lehner, Czisch, and Vassolo, "Europe's Hydropower Potential Today And In The Future."

6.5. Geothermal Power

Geothermal Power is a renewable energy, which extracts thermal heat from the earth's inorganic substances, which is mostly rock. This form of renewable energy does not pollute, nor does it require fossil fuels. There are four types of geothermal energy generation: hydrothermal, geopressured, hot dry rock and magma. Only the first type is eligible for generating electricity, the other types are only used for heating and transport. The generation of energy is measured with the enthalpy of the geothermal fluid.

6.5.1. Deployment and Potential

While countries in the East of Europe like Hungary, Slovenia, Slovakia, as well as Austria and France have a high enthalpy, countries of the north have a smaller enthalpy, which means less geothermal potential. Right now, the countries with the highest direct usage of geothermal power are Italy, followed by Hungary and France.

As the geothermal share within the European Union is still very low yet it is increasing.

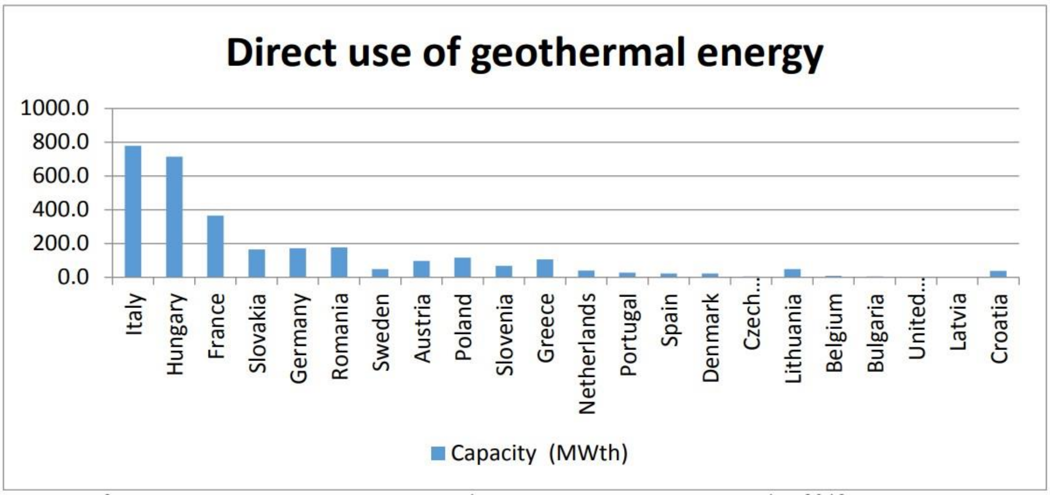

Fig. 19: Direct Use of Geothermal Energy within the EU, 2012

Source: Pacesila, Mihaela [56]

The country with the highest share of geothermal energy used for electricity production was Italy.

[56] Pacesila, Mihaela, "GEOTHERMAL ENERGY," 5–17.

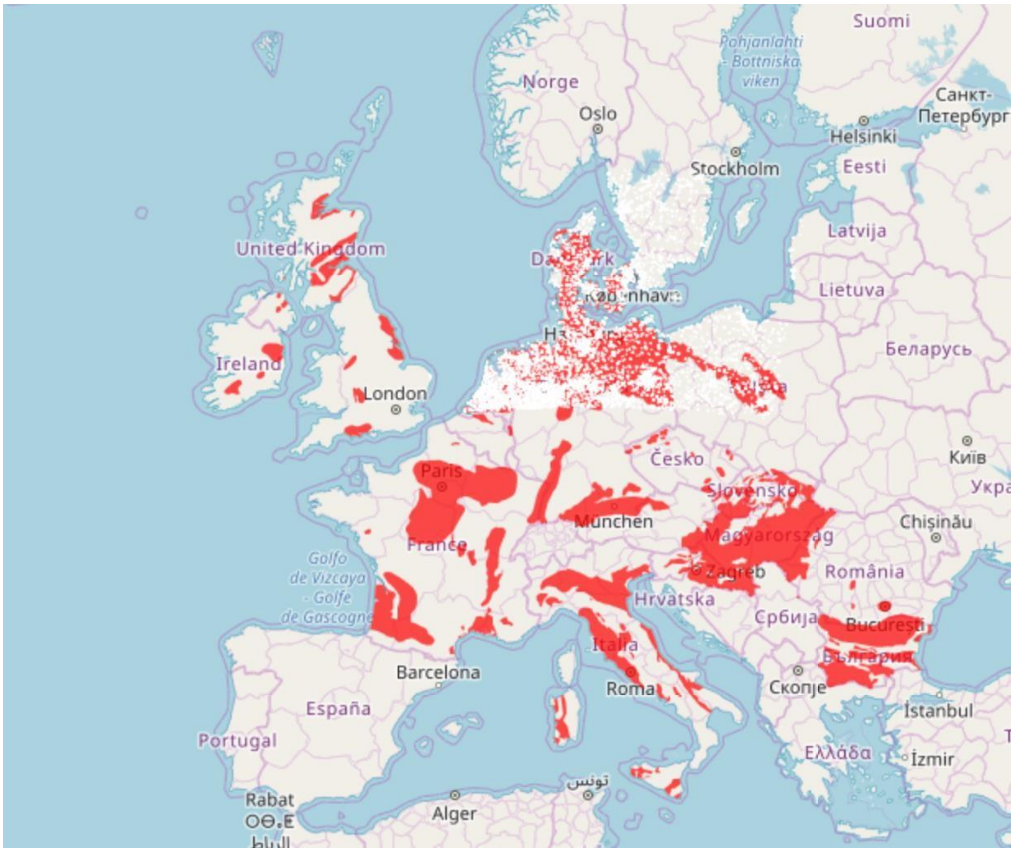

Fig. 20: Geothermal potential for district heating within the EU

Source: Heatroadmap.eu[57]

6.5.2. Environmental Impact

However, there are certainly disadvantages to the usage of geothermal power, such as higher seismic activity in the areas, where this kind of energy is generated. Therefore, there is a higher social limitation on the geothermal power potential.[58]

6.6. Ocean Power

Ocean Power forms the smallest share within the RES deployment of the EU. Even though the concept is not new, the technology is still being developed, as the turbines have to grasp complex water movements to ensure an efficient conversion. Ocean power is an indirect energy from wind power and furthermore solar power, as their forces effect the formation of waves. There are five main categories of ocean power, of which not all are applicable within the EU territory:

- tidal stream

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[57] "Peta4 – Heat Roadmap Europe."

[58] Pacesila, Mihaela, "GEOTHERMAL ENERGY," 5–11.

- wave
- tidal range
- salinity gradient
- ocean thermal gradient (OTEC)

6.6.1. Deployment and Potential

OTEC is not efficient within the EU, as warmer water temperatures are needed, which are only possible for countries, which are located near the equator, such as Hawaii. This technology is currently being tested in EU overseas territories.[59] Salinity gradient is a technology to produce electricity from the different salt levels from sea water and fresh water. Through a cation and anion exchange mechanism electricity can be generated.
This technology is called "Reverse ElectroDialysis" (RED). This process is very limited to locations, where freshwater mixes with seawater.

With 24 hours a day wave power of possible usage and the EU's relatively long shoreline the potential of this energy source is interesting for policy makers as well as investors. Right now, prototypes are installed. The potential of wave energy can be easily calculated according to following formula:

"$P = 0.55\, H^2_s\, T_z$ (kW per metre of wave crest length), where H_s = significant wave height of random waves in metres. T_z = zero crossing period in seconds. "[60]

In this case high latitudes are more favorable. The potential lies here between 20 to 70 kW/m.[68]

The most important category for the EU is the tidal power. Tidal range is being deployed within the EU since the 1960s. The energy gained, is derived from the differences of the gravitational pull of the tide. Regarding the technology, the barrage is similar to a low head hydropower plant. Tidal range is very stable, within the changing condition of seasons and moon phases, rather than weather conditions.[61] However, due to high costs of tidal range deployment, tidal current systems are more likely to be deployed faster. "Tidal turbines harness the lateral flow of currents to produce clean, predictable

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[59] Ocean Energy Forum, *Ocean Energy Strategic Roadmap Building Ocean Energy For Europeotec*, 16.
[60] Ravindran, "Ocean Energy," 985. [68]
Ravindran, 985.
[61] Ravindran, 987–88.

renewable energy. Tidal turbines can be fixed to the sea bed or floating nearer the surface with moorings attached to the seafloor."[62] The turbines are similar to those of wind power, but since water has a much higher density than air - and hence the energy captures is much higher - turbines are smaller.[63] 3.7 MW of tidal stream capacity were deployed within the EU in 2018. In general, the number is much higher with deployed 26.8 MW since 2010.[64]

Regarding its potential and security, ocean energy offers important advantages such as a high degree of predictability and sustainability. The main challenge for this energy generation is the cost effectiveness. Therefore, since the price of conventional fossil fuels increased, more focus has been given to this abundant energy generation. Although technology is still advancing, experts believe that ocean power could deliver
10% of the EU's electricity demand by 2050.[65]

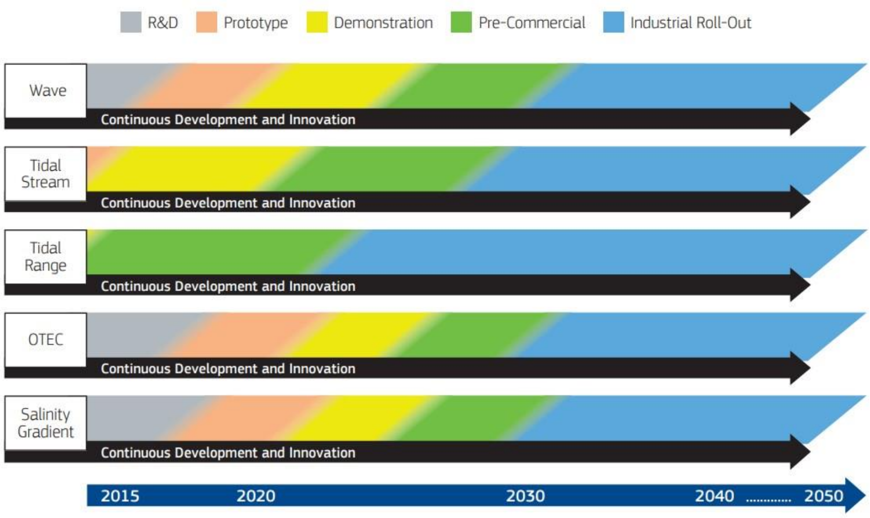

Fig. 21: Timeline for ocean energy technology
Source: Ocean Energy Forum[66]

Although Europe is still the leading player in ocean power with a production of 1,250 KW, the rest of the international world is accelerating too. In 2018, Europe deployed 3,900 KW worth of tidal stream turbines, while the rest of the world installed accumulated 2,700 KW.[75]

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[62] Ravindran, 988.
[63] Ravindran, 988.
[64] Parsons and Gruet, "Ocean Energy: Key Trends and Statistics 2018," 4.
[65] "Europe Needs Ocean Energy."
[66] Ocean Energy Forum, *Ocean Energy Strategic Roadmap Building Ocean Energy For Europeotec*, 23. [75] Parsons and Gruet, "Ocean Energy: Key Trends and Statistics 2018," 14–15.

6.6.2. Environmental Impact

Challenges, which the European Union has to face regarding ocean power, vary from high costs for the integration into the grid as well as expanding the transmission grid infrastructure. Environmental impacts of the ocean power systems have not been fully studied yet. The EU is encouraging research in this field within the frame of the Marine Strategy Framework Directive and for the environmental status within the Water Framework Directive.[67]

6.7. Bio Energy

Heating, cooling, electricity production as well as the transport sector depend on Bioenergy within the EU. Bioenergy means "the conversion of biomass resources into useful energy carriers"[68]. Biomass is another word for several organic materials, inter alia "agricultural and forest by-products and residues, organic municipal waste, energy crops or algae"[69]. About 70% of the biomass are agricultural by-products or forestry residues. The second largest group with 11% are biogas or biofuel feedstocks (inter alia crops or cereals). The municipal solid waste forms the smallest group with only 7% in 2015. The procession of the biomass can also be classified into two groups: the dry and the wet biomass conversion process. In the dry process, the biomass is grinded and dried in a first step. Later the biomass will be densified, which helps the optimization of the material for both moisture and transport purposes. In a third step the biomass is treated with a thermo-chemical conversion, which induced a higher calorific value. For the wet biomass conversion process, the energy from the material is being won by anaerobic digestion and fermentation.[79]

6.7.1. Deployment and Potential

The potential is big, but there are some challenges as the technology for biomass conversion can be optimized always, biomass producers have to face enormous bureaucratic challenges to obtain permissions and further the stability of supply as well

[67] European Commission, "Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions: Blue Energy Action Needed to Deliver on the Potential of Ocean Energy in European Seas and Oceans by 2020 and Beyond," 10.

[68] "Renewable Energy | Energy - Research and Innovation - European Commission."

[69] "Renewable Energy | Energy - Research and Innovation - European Commission."

[79] "How Is Biomass Processed in the EU-28?"

as costs of supply have to be ensured. Right now, central European and northern countries have a potential from up to 500 to more than 1,500 Gigawatt hours (GWh).[70]

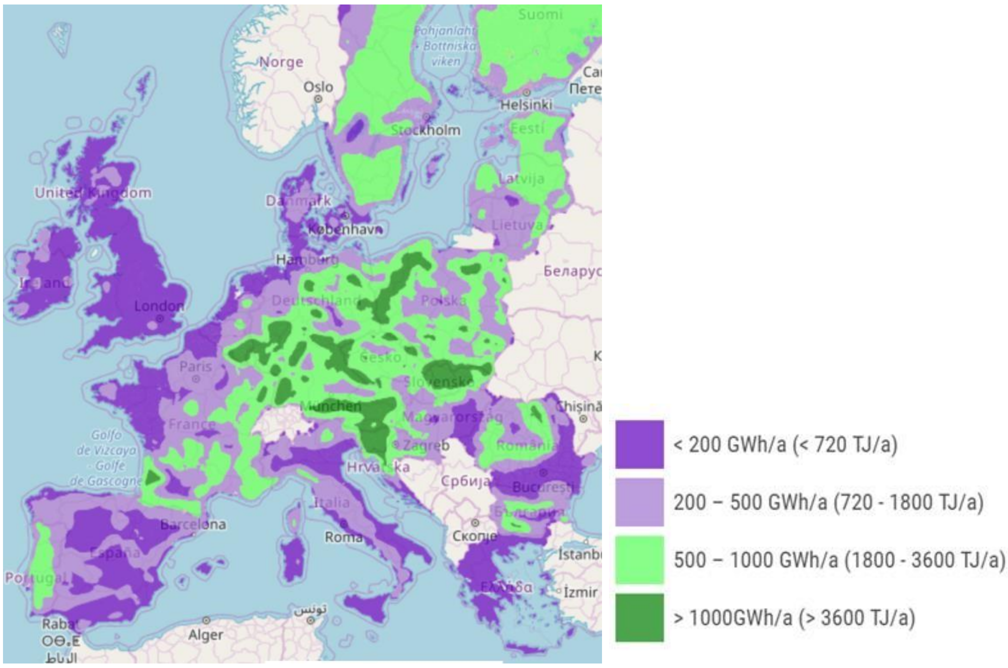

Fig. 22: Wood resources within the EU,
Source: Heatroadmap.eu[81]

Bioenergy institutions raise awareness of the EU’s dependency on conventional fuels. Biomass, in this case, has an enormous advantage, that the percentage of dependency for biomass from non-EU countries is only estimated at 4.1% - in comparison to 93.4% of petroleum products. [71]

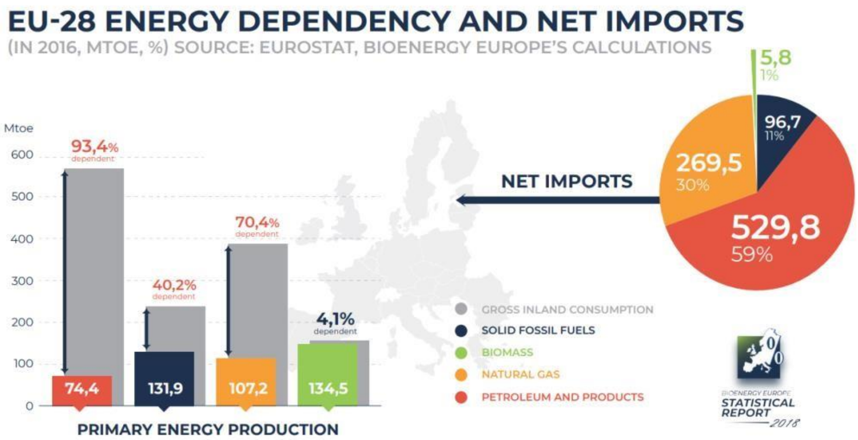

Fig. 23: EU-28 Dependency rate per fuel based on net imports, 2016
Source: Bioenergy 2018[82]

[70] European Commission, “Biomass.”

[81] “Peta4 – Heat Roadmap Europe.”

[71] Cristina Calderón et al., *Bioenergy Statistical Report 2018: Key Findings.*, 13

6.7.2.Environmental Impact

Bioenergy has significant advantages – even more, when it comes to energy security. As bioenergy is renewable and available in large quantities. However, there is growing public and scientific concern about the alteration of the environment regarding water quantities, soil erosions, loss of nitrogen as well as biodiversity. Although scientist highlight the fact, that environmental impacts do depend to a high degree on the sourcelocation chosen for bioenergy, as well as the management of the operation.[72]

6.8. Renewable Energy Sources Potential in EU-28

In general, the potential of RES in the 28 MS of the European Union is not covering the future demand. RES could only cover the final energy demand of 2016 by 40%. Therefore, there is the need to close the gap with a change of consumer behavior (30%) as well as an increase in the efficiency (70%) of the technology. Furthermore, to cover the demand other technologies besides energy efficiency, like energy storage, have to be developed. If those measures are not taken, RES are not an eligible alternative to conventional energy supply.[73]

Tab. 1: Potential of RES in Austria, Germany and the EU-28
Source: Günther Brauner[85]

TWh/a	Österreich		Deutschland		EU-28	
	2016	**2050**	**2016**	**2050**	**2016**	**2050**
Wasserkraft	39,3	42	20,6	22	340	500
Windenergie onshore	5,2	20	66,3	400	237	2000
Windenergie offshore	-	-	12,3	200	47	700
Photovoltaik	0,5	30	38,1	250	102	1500
Biomasse	2,5	20	50,8	60	169	300
Geothermie	0	0	0,16	20		60
Erneuerbare Elektrizität (EE)	**47,5**	**112**	**188,2**	**952**	**895**	**5060**
Endelektrizitätsbedarf	68	140	611	1200	3070	6200
% EE von Endelektrizitätsbedarf	70 %	80 %	31 %	79 %	29,2 %	82 %

Within the electricity sector of the RES, or shortly called “RES-E”, category, RES are increasingly capable. The next table shows the different categories of RES and their capacity within the electricity generation in the EU-28.

[72] Wu et al., “Bioenergy Production and Environmental Impacts,” 2–7.
[73] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*, 34.
[85] Brauner, 19.

Tab. 2: Total renewable electricity (RES-E) capacity and energy for all 27 European Union Member States

Source: [74]

		2005	2010	2015	2020	[%][a]	[%][b]	*Page*
Hydropower < 1MW	[GW]	2.7	2.9	3.1	3.4			*100*
	[TWh]	11.3	11.0	11.7	12.6			*103*
	[Mtoe]	1.0	0.9	1.0	1.1	1.0	0.4	-
Hydropower 1MW – 10 MW	[GW]	9.4	9.9	11.2	12.5			*100*
	[TWh]	34.0	34.1	36.6	40.3			*103*
	[Mtoe]	2.9	2.9	3.1	3.5	3.3	1.4	-
Hydropower >10MW	[GW]	101.4	99.1	104.6	112.4			*100*
	[TWh]	294.8	291.8	299.3	309.5			*103*
	[Mtoe]	25.3	25.1	25.7	26.6	25.4	10.8	-
Pumped storage hydropower	[GW]	23.4	28.1	32.0	39.5			*100*
	[TWh]	23.9	23.6	27.7	32.6			*103*
	[Mtoe]	2.1	2.0	2.4	2.8	n.a.	n.a.	-
Hydropower (subtotal excluding pumped storage)	[GW]	119.4	122.4	130.0	139.7			*100*
	[TWh]	340.9	342.7	354.0	369.3			*103*
	[Mtoe]	29.3	29.5	30.4	31.8	30.4	12.9	-
Geothermal	[GW]	0.7	0.8	1.0	1.6			*108*
	[TWh]	5.5	6.0	7.3	10.9			*110*
	[Mtoe]	0.5	0.5	0.6	0.9	0.9	0.4	-
Solar photovoltaic	[GW]	2.2	25.5	54.4	84.4			*118*
	[TWh]	1.5	20.1	51.8	83.4			*121*
	[Mtoe]	0.1	1.7	4.5	7.2	6.9	2.9	-
Concentrated solar power	[GW]	0.0	0.6	3.6	7.0			*118*
	[TWh]	0.0	1.2	9.0	20.0			*121*
	[Mtoe]	0.0	0.1	0.8	1.7	1.6	0.7	-
Solar (subtotal)	[GW]	2.2	26.1	58.0	91.4			*118*
	[TWh]	1.5	21.3	60.8	103.3			*121*
	[Mtoe]	0.1	1.8	5.2	8.9	8.5	3.6	-
Tidal, wave and ocean energy	[GW]	0.2	0.2	0.4	2.3			*126*
	[TWh]	0.5	0.5	0.9	6.5			*128*
	[Mtoe]	0.0	0.0	0.1	0.6	0.5	0.2	-
Onshore wind	[GW]	39.8	82.2	126.7	168.8			*136*
	[TWh]	66.9	155.5	257.7	351.8			*139*
	[Mtoe]	5.7	13.4	22.2	30.2	28.9	12.3	-
Offshore wind	[GW]	0.7	2.6	15.6	44.2			*136*
	[TWh]	1.9	8.7	49.9	142.5			*139*
	[Mtoe]	0.2	0.7	4.3	12.2	11.7	5.0	-
Wind power (subtotal)	[GW]	40.4	84.9	143.2	213.6			*136*
	[TWh]	70.4	164.6	309.2	494.8			*139*
	[Mtoe]	6.1	14.1	26.6	42.5	40.7	17.3	-
Solid biomass	[GW]	10.6	14.4	20.8	27.7			*146*
	[TWh]	55.1	76.8	113.8	154.9			*149*
	[Mtoe]	4.7	6.6	9.8	13.3	12.7	5.4	-
Biogas	[GW]	2.7	5.4	7.9	11.2			*146*
	[TWh]	12.5	28.7	43.9	64.0			*149*
	[Mtoe]	1.1	2.5	3.8	5.5	5.3	2.2	-
Bioliquids	[GW]	0.4	1.0	1.4	1.7			*146*
	[TWh]	1.5	8.6	10.9	12.7			*149*
	[Mtoe]	0.1	0.7	0.9	1.1	1.0	0.4	-
Biomass (subtotal)	[GW]	15.7	22.6	32.4	43.6			*146*
	[TWh]	60.2	103.7	169.0	232.0			*149*
	[Mtoe]	5.2	8.9	14.5	19.9	19.1	8.1	-
Total renewable electricity	[TWh]	479.0	638.7	901.2	1216.8			-
	[Mtoe]	41.2	54.9	77.5	104.6	100.0	42.5	-

'Pumped storage hydropower' has not been considered in the values for totals and subtotals
[a] The percentage refers to the share of the individual technologies in total renewable electricity in the year 2020
[b] The percentage refers to the share of the individual technologies in total renewable energy (electricity, heating and cooling and transport) in the year 2020

74 Beurskens, Hekkenberg, and Vethman, "Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States," 22.

7. RES and Energy Security through energy independence

7.1. Energy Security

Energy security has been defined various times and by different stakeholders and groups of interests. Hence, the interpretation of the term can vary quite significantly. The European Commission has defined Energy Security in the 1990 as *"the ability to ensure that future essential energy needs can be met, both by means of adequate domestic resources worked under economically acceptable conditions or maintained as strategic reserves, and by calling upon accessible and stable external sources supplemented where appropriate by strategic stocks"*[75]. More recently the Commission added the focus on the energy supply security of fossil fuels and gas.

Other institutions like the International Energy Agency (IAEA) kept the concept of Energy Security short: "*the uninterrupted availability of energy sources at an affordable price*"[76]. The report to the Trilateral Commission, which was born after the Gulf Crisis and hence the first Energy Security shock, resulted in a more academic and broader definition: "*Energy security has three faces. The first involves limiting vulnerability to disruption given rising dependence on imported oil from an unstable Middle East. The second, broader face is, over time, the provision of adequate supply for rising demand at reasonable prices—in effect, the reasonably smooth functioning over time of the international energy system. The third face of energy security is the energy-related environmental challenge (to operate within the constraints of 'sustainable development')*"[77]

In other words, the concept of Energy security is a very multidimensional one, Cherp and Jewell created an extension to the Trilateral Commission: Three aspects fulfill energy security: First, sovereignty. A state is only secure in the energy supply, if they can provide large parts on their own as threats of international relations may occur. The second aspect, robustness, regards the technology itself, how robust the technology, devices etc. are to adverse effects. The last point, resilience, is the built on the uncertainty factor, which should be reduced in order to guarantee energy security. All of the above-mentioned

75 Skinner, "Eurogulf: An EU-GCC Dialogue for Energy Stability and Sustainability," 23.
76 "What Is Energy Security?"
77 "TFR 48 - Maintaining Energy Security in a Global Context – The Trilateral Commission."

definitions grasp a different aspect of the energy security challenge: The EU's definition, which sheds light on the costs and needs, the Trilateral Commission, which firstly takes into account the environmental variable or Cherp and Jewell, who tried to identify the faces of risk in the technology itself, international relations and external threats.

7.2. Threats to Energy Security

The International Energy Agency (IEA) laid out three factors which are positively influenced by the deployment of RES:

- "market instabilities;
- technical system failures;
- and physical security threats including terrorism and extreme weather events."[78]

Market instabilities are created through general instabilities by political insecurities, (violent) conflicts and other destabilizing political or economic factors. Usually, political unrest is not affecting the end-user, due to major flexibility within the electricity markets. However, shortages may affect fossil fuel prices. The unbalanced distribution of fossil fuel is accelerating prize fluctuations, as only a few countries hold the main reserves of fossil fuels. The countries of the Organization for Economic and Co-operation and Development (OECD) are among the main consumers: "OECD countries only account for 7% while they consume close to 60% of the world total. Similarly, over half of global proven gas reserves are found in three countries: the Russian Federation (27%), Iran (15%), and Qatar (14%). OECD member countries account for only 8% of the total reserves but consume over 50% of the world total (BP, 2005). The concentration of fossil fuel resources is the most enduring energy security risk (IEA, 2007)."[91] The majority of the OECD are EU member states, to put this in numbers, 21 out of the 35 member states are the also members of the EU. In 2007, before the Ukrainian Crisis, the IEA already stated that a concentration of a fossil fuel would increase the threat to energy security, even though as the liberalization of the energy market could mitigate the graveness of the dependence.[79]

[78] Olz, "Contribution of Renewables to Energy Security," 7.
[91] Olz, 14.
[79] Olz, 20.

Technical system failures are caused by accidents or human errors. These mistakes can cause interruptions and initiate supply difficulties. They are graver, if they occur on big transmission grids, hence if a local grid is affected, the damage will be lower. Technology and a right maintenance can alleviate such threats.

Due to politically instability and the rise of terrorism of energy exporting countries, physical insecurities are becoming increasingly important in the public concern. In 2006, the G8 – an informal meeting group of the most powerful industry nations of the West – were holding a summit to highlight the importance of this aspect. Even though the final result might be similar to technical failures, which result in a cut of supply. Attacks on energy supply are inter alia attacks on power stations, oil and gas exploration sites, pipelines, stations as well as on individual transport such as transporters.[80]

	Electricity system and infrastructure	
Nature of risk	**National**	**Business**
Energy market instability	*	*
Technical failure	***	***
Physical security threat (including natural disasters)	***	**

*** High risk
** Medium risk
* Low risk
No star No perceived risk

Fig. 24: Perceived gravity of risks by category, economic and national perspective
Source: EIA 2006[94]

For this paper the most important model comes from the EU itself: The Joint Research Center (JRC) by the European Commission elaborated a multidimensional approach to the electricity security within the EU-28 with four dimensions:

- infrastructure,
- source,
- market and regulation, as well as
- geopolitical dimension

[80] Olz, 13–15.
[94] Olz, 24.

and its five properties:

- flexibility,
- adequacy,
- operational security,
- resilience and
- robustness

RES can contribute quite differently to each dimension and property.

7.3. Infrastructure Dimension – Grid, Storage and Transmission Lines

Regarding the infrastructural dimension, which contains operational security, adequacy as well as flexibility, new challenges emerge under the integration of RES into the grid. The grid is undoubtedly one of the main elements to ensure energy security within the EU. Without an efficient, secure and well-planned grid, the integration and advantages of renewables cannot guarantee the energy security. There are several challenges such as an expansion of the grid or the new flexibility or dynamics instead of the old-fashioned static of the grid. But on the other hand, there are certain characteristics that improve security, as RES increase the decentralization of electricity generation and hence make large scale failures less likely.

7.3.1. Operational Security: Grid

The grid is an overview-term for several components: "Overhead lines, cables, switchgears and transformers".[81] Because of the population density in Europe, only cables up to a capacity of 380-kV have been installed. Historically, the grid was only exhausted up to a 60%, but since RES are integrated, the process has become more dynamic. In case of emergency, there is a bottleneck management, which will handle the different loads, by managing and shutting off different power plants. This is a key element for operational security, which guarantees that the network is managed correctly in case of issues or disturbances.

As most RES will generate electricity further away from the end-consumer, the grid is the link between the consumer and producer. Apart from PV, which will be installed mainly

[81] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*, 107.

on buildings and therefore close to the consumer, the other RES, like off- and on-shore wind parks, will be installed further away from consumers. Right now, the legislation lays out a minimum 2,000 meters distance between areas of settlement and a wind park. 380 kV grids will be used to integrate large-scale wind parks, smaller wind parks will be integrated through a 220-kV grid. While 380-kV grids are used for transmission on a European level and the integration, transformation is needed to distribute it to the end-costumer. In that case, 220- to 110-kV grids are used. Additionally, to the capacity-question of the grid, there is the question of the transmission of cables or overhead lines. Both - the underground cable or the overhead line - have approximately the same capacity, depending on external influences like ground moisture or temperature of the area.

From a security perspective, the answer to this is clear. Both categories fight with the same initial problems as assembly failures, atmospheric influences, natural catastrophes and human error. Nevertheless, for the long-scale transmission the 380 kV overhead lines are the better choice, as they are easier to repair and hence, in case of failure, faster to get back on track.[82]

Tab. 3: Failure Rate and Non-Availability comparison cables and over headlines Sourc
e: Günther Brauner[97]

380-kV	Failure Rate [Per 100 km x a]	Average Repair Time	Non-Availability [h x a]
Overhead lines	0,353	2,94 h	1,04
Paper-Oil Cables	0,595	2-3 Months	1085
VPE Cables	0,7	2-3 Months	1278

The International Energy Agency (IEA) does point out that the more efficient overhead lines are more vulnerable to the third class of energy security risk "physical attacks and terrorism" than underground cables, but nevertheless the risk is classified as moderate.[83]

[82] Brauner, 107–14.
[97] Brauner, 132.
[83] Olz, "Contribution of Renewables to Energy Security," 35.

In general, the IEA welcomes RES and the technology behind it as they contribute to energy security through a decentralization of the grid (most of all with PV in house installed grids).

Furthermore, the European Union presented energy storage, as well as the promotion of smart grid as additional key factor in the integration of RES in the electricity grid.[84] These situations could lead to two possible developments: Either the super-grid within the EU will be established and expanded or the micro-grid will be introduced. The super-grid would be an international project, which requires enormous political unity and stability as both the project planning and the infrastructure of the material are fragile. An advantage of the super-grid would be that environmental impacts would be far enough away that the grid would be stabilized. Right now, the grid within the EU carries between 220- or 380-kV. Modernization efforts to establish the 380-kV grid fast, have been slowed down by legal procedures such as the environmental impact assessment.[85]

The micro-grid on the other hand holds valuable characteristics, that offer other qualities. One of the biggest advantages is, that the energy is generated and consumed at one location, which means no big investments in grids and no transmission infrastructure.[86]

7.3.2. Adequacy: Transmission Lines, Storage, Efficiency

Transmission lines are a key element to adequacy and hence energy security: Main stakeholders and institutions have pointed out, that in order to guarantee energy security, there is a need to interconnect certain regions with the Union. As the IEA elaborated, it is of utmost importance to install a cross-border transmission. As an example, the IEA presented the MS with the highest wind power-share Denmark, which installed modern interconnectors to Germany for both back-up in wind-low times and export in wind-intensive times.[87] Better interconnections between the Member States have to be developed, in the case that a surplus can be sent to another state - energy solidarity so to speak. The European Council already pledged to this key element within the Energy Union Package in 2015. 10% of each MS' installed electricity production capacity needs to be interconnected. This interconnection can be promoted by "the Connecting Europe

[84] Erbach, European Parliament, and Directorate-General for Parliamentary Research Services, *Promotion of Renewable Energy Sources in the EU*, 15.
[85] Brauner, *Energiesysteme*, 24–25.
[86] Brauner, 24–25.
[87] Olz, "Contribution of Renewables to Energy Security," 29.

Facility (CEF), the European Structural and Investment Funds (ESIF), the European Fund for Strategic Investment (EFSI) and private investors."[88]

However, there are certain barriers, which were identified. The main challenges were recognized at the weak connection between Great Britain, Ireland, the Iberian Insula and the Baltics to the European network. Main barriers are geographical obstacles like maritime borders or alpine regions. Further restrictions to an interconnection are different price levels of electricity as this creates an inability for an efficient trade.[8990]

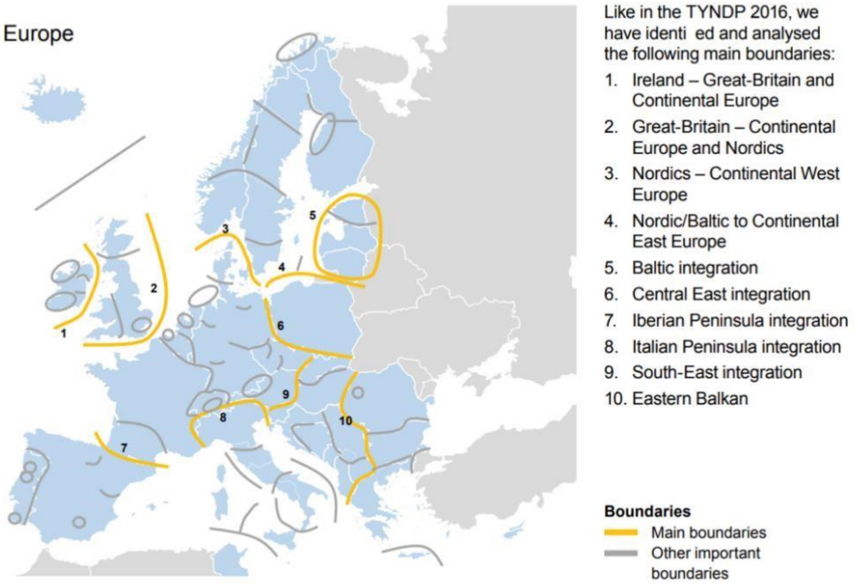

Fig. 25: Boundaries Europe, 2018
Source: TYNDP 2018[91]

[88] Erbach, European Parliament, and Directorate-General for Parliamentary Research Services, *Promotion of Renewable Energy Sources in the EU*, 15.
[89] ENTSO-E Report, *TYNDP 2018 Executive Report: Connecting Europe: Electricity 2025-2030-2040*,
[90] –25.
[91] ENTSO-E Report, 24.

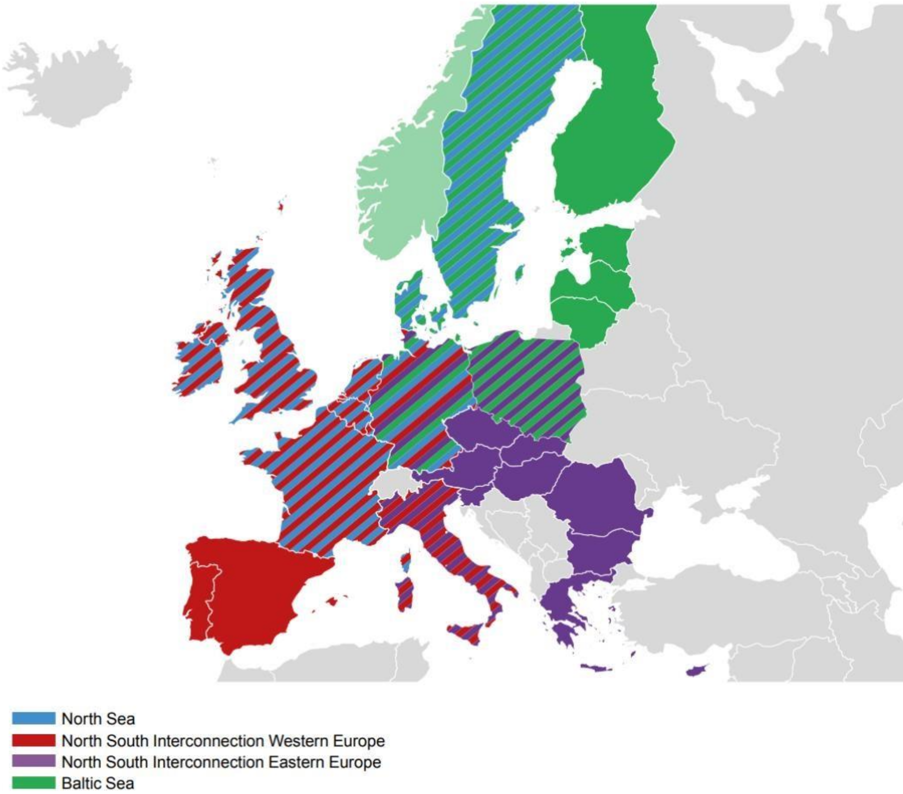

Fig. 26: Trans-European Networks for Energy (TEN-E) electricity priority corridors - Regional Groups Source: TYNPD, 2018[106]

7.4. Source Dimension

The Source Dimension aims to assess the capability of the energy system to guarantee access to the primary sources as well as the conversion of the resources to cover the total demand of electricity. Within this category RES can contribute with their natural characteristics. As laid out in the infrastructural dimension, RES have a great potential as their "fuel" is found everywhere. However, for the flexibility property, as RES bring challenges with their unpredictability and the possibility of overproduction phases followed by underproduction-phases is given. This creates on the one hand a broader energy generation mix and therefore a more solid robustness with weaker dependency on one energy source and dependency on energy imports, but on the other hand also a limited reliability.

7.4.1. Flexibility: Challenges through Variability and Partially Unpredictability

Flexibility "is the capability of the power system to cope with the short/mid-term variability of generation (like renewable energy) and demand so that the system is kept

[106] ENTSO-E Report, *TYNDP 2018 Executive Report: Connecting Europe: Electricity 2025-2030-2040*. 9.

in balance."[92] This property actually touches both the infrastructural - as well as the source - dimension, as the characteristics of RES (for example volatility) provoke grid adaptations to guarantee a balanced grid and hence energy security.

Within the RES category, there are some energy sources which are "dispatchable" or "variable"[93]. Biofuels or geothermal-power counts as dispatchable energy sources, while wind- or solar-power are considered as variable sources, as they are dependent on input of their environment. This poses a threat to the energy security as the grid integration is challenge by the characteristics brought by the variable RES: "noncontrollable variability, partially unpredictability and locational dependency".[94] These characteristics induce emerging challenges to the promoters and deployers of RES.

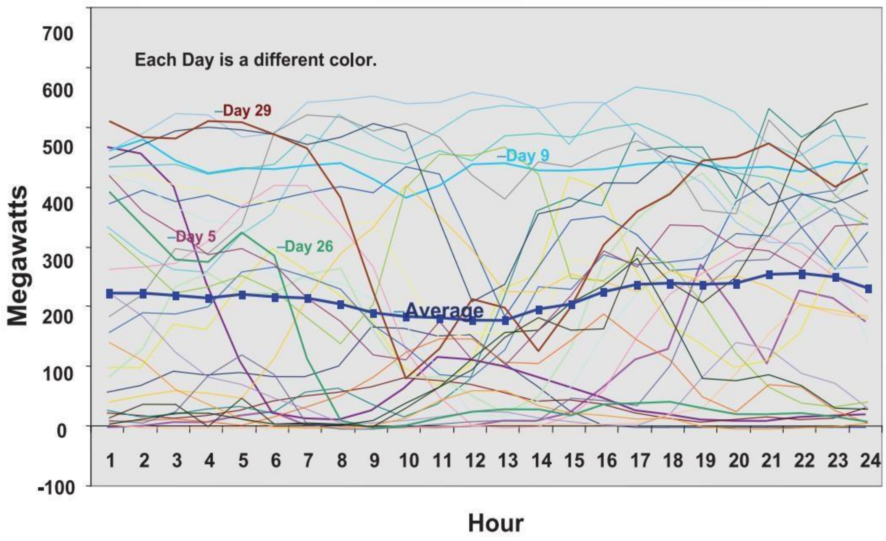

Fig. 27: Non-controllable variability, Hourly wind power output on 29 different days in April 2005 at the Tehachapi wind plant in California
Source: IEC[95]

[92] "Electricity Security in the EU: Features and Prospects | JRC Smart Electricity Systems and Interoperability."

[93] Erbach, European Parliament, and Directorate-General for Parliamentary Research Services, *Promotion of Renewable Energy Sources in the EU*, 14.

[94] IEC Market Strategy Board, *Grid Integration of Large-Capacity Renewable Energy Sources and Use of Large-Capacity Electrical Energy Storage*, 4.

[95] IEC Market Strategy Board, *Grid Integration of Large-Capacity Renewable Energy Sources and Use of Large-Capacity Electrical Energy Storage*.

Partially unpredictable behavior of the RES fuels – wind and solar light – is a different category and points out the uncertainties of forecasts. Scholars urge the need for more advancements in the field of forecasts and prediction technology. Another approach to solve this challenge are unit commitments. Unit commitments are schedules, which are elaborated in advance. If a gap between calculated demands and reality occurs, the difference is balanced by the grid operators. The third point is the geographical location of the RES is more limited in comparison to conventional fuels such as coal or oil. RES like wind- or solar power are generated at the location they are deployed. This means, the energy generation can be far away from the end-user, which means transmission losses and transmission costs.

Tab 4: Qualitative comparison of risks of electricity generation technologies
Source: IEA[96]

Technology	Plant capacity ranges (MW)	Lead time	Fuel cost as % of total generation costs[24]	Risk of fuel cost fluctuation	Variability	Rapid response rate use to level out peak demand for generation	Regulatory risk
Hydro	14 – 32000	Long	Nil	Nil	Low	Yes	High
Wind power	0.5 - 300	Short	Nil	Nil	High	No	Medium
Photovoltaics	0.01 - 10	Very short	Nil	Nil	High	No, except in hybrid systems and systems with expensive storage components	Low
Geothermal	0.1 - 200	Long	Nil	Nil	No	No	Low
Biomass including CHP	10 - 240	Medium	60%	Medium[25]	No	No	Low
Fuel cells	0.1 - 10	Very short	40%	Low	No	Yes	Low
Coal	150 - 900	Long	35%	Medium	No	Yes	High
CCGT	100 - 500	Short	75%	High	No	Yes	Low
Nuclear	700 - 1600	Long	10%	Low	No	No	High
Internal combustion engines	0.1 – 60	Very short	70%	Medium	No	Yes	Low

[24] At 10% discount rate - IEA/NEA (2005)
[25] A significant supply risk is the competition for the biomass resource – for energy uses, such as electricity, heat and transport, and for food, fibre and chemical production.

Non-controllable variability seeks to address the problem of changing wind velocity or variating UV-light, which affects the output of the RES. This variability, which is beyond human-control, is the opposite to what grid operators desire. Until nowadays, conventional power plants are the main players within the category of flexibility. But with the increasing integration of RES, new technologies have to be promoted and applied, as well as old technologies enhanced. A balanced and stable grid is only possible through different types of technology applications.

[96] Olz, "Contribution of Renewables to Energy Security," 34.

For wind turbines, one of these technologies is voltage control. This power control is available through "a built-in capability, a combination of switched capacitor banks and power electronic based transmission technologies such as static var compensator (SVC) and static synchronous compensator (STATCOM) equipment"[97] applicable for example for wind turbines. Other technologies for large-scale RES are fault ride through. As a RES integrated grid is exposed to larger voltage fluctuations, modifications to the control is added. Furthermore, primary frequency regulation, inertial responses or short-circuit current control help to keep a balanced grid. The short-circuit control limit the fault current to a level that does not exceed 150 % of the full load current. Integration of RES into a grid needs adaptation. Experts plead for a plant-focused approach, where communication tools, forecasting methods, monitoring systems and reactive power compensators are working effectively together.[113]

7.4.2. Adequacy: Enhancing efficiency and storage technologies

In terms of adequacy, the EU's potential for RES is limited. Nowadays, the electricity demand is only covered by approximately 40%. The rest of the demand would be needed to cut down (60%). How will this drastic decrease be possible to achieve? 70% of this reduced demand will be attributed to a shift in technology, the rest will be consumer behavior. Thus, this shift in technology is important for the achievement of the Renewables Energy Directive, as it makes the energy transition possible. In 2012 the EU has drafted another directive for this purpose. The legally binding targets set within the document have since been updated in 2018. By 2020 the EU member states are committing to a 20% energy efficiency rate, by 2030 an efficiency rate of 32,5% – with a possible shift upwards. These targets should be achieved with a series of policy suggestions, such as a national reduction of energy sales of 1,5%, a boost in building sector efficiency or a stringent eco- design for household machinery. As laid out before, the primary energy consumption as well as the final energy consumption has increased since 2014, hence the EU member states are currently 5.3% above the 2020 target and 3.3% (2017).

[97] IEC Market Strategy Board, *Grid Integration of Large-Capacity Renewable Energy Sources and Use of Large-Capacity Electrical Energy Storage*, 52. [113] IEC Market Strategy Board, 51–53.

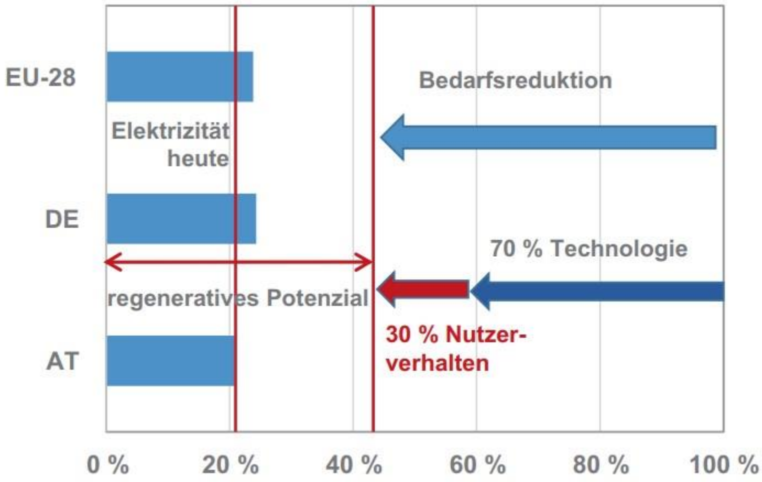

Fig. 28: Limits to RES potential and efficiency rates, Source:
Günther Brauner[98]

But not only the efficiency targets are important to implement the energy transition. As already mentioned, the variability of wind and solar-power as well as the partially unpredictability are a weakness of the climate-friendly technology, as the grid needs balanced out loads. PV and wind-energy generate less full load hours than fossil fuel plants but achieve a better performance per unit of energy. Thus, additional technology is needed to ease this challenge. Mobile and fast-responding technologies are desired to balance out fluctuations within the grid, as well as to maximize the harvest of energy, reduce the transmission and distribution losses. The storage facilities have following tasks:

- balancing of the grid
- gradient minimization
- load leveling
- peak shaving

The general trend for central storage is going towards pump storage, whereas buildings with integrated PV will tend to install accumulators.[115]

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[98] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*, 17.
[115] Brauner, 81– 89, 103 – 104.

7.5. Regulation and Market Dimension

Within the regulation and market dimension, “electricity security is assessed in terms of the power system and market capability to adequately fulfil their electricity delivery mission with a set of laws, rules, market arrangements and price schemes.”[99] Hence, we have to look at the adequacy of the market and the legal framework to achieve energy security through RES.

Empirical evidence shows that political interventions, positive legal provisions and market liberalization play a big role in achieving energy security through Renewable Energies.[100] A challenge that the EU is facing is on the one side the adaption of the electricity market design for RES and on the other hand creating and enhancing a legal framework to promote RES and to help their deployment.

Within the legal aspect, the overall strategy has been created as laid out in Chapter 10. On a smaller scale, the national action plans have been elaborated already in 2010, which implemented the international targets into national law.

7.5.1. Adequacy: Legal Procedures for RES deployment

Experts within the energy sector point out the fact, that the legal procedures for permissions for deployment of RES are still a burden, as they are postponing the process and thus slowing down the transition.[101] The legal context for the procedure, in most cases, is the so-called Environmental Impact Assessment, which was introduced through the Directive 2001/42/EC or “Strategic Environmental Assessment”– SEA Directive. Projects to deploy new sources of renewable energies can hence be under investigation for their potential environmental impacts before their national permission authorization.[102]

[99] “Electricity Security in the EU: Features and Prospects | JRC Smart Electricity Systems and Interoperability.”
[100] Valdés Lucas, Escribano Francés, and San Martín González, “Energy Security and Renewable Energy Deployment in the EU,” 1036.
[101] Brauner, *Systemeffizienz bei regenerativer Stromerzeugung*, 247.
[102] “Environmental Impact Assessment - Environment - European Commission.”

7.6. Geopolitical Dimension

The geopolitical dimension is all about the energy system and its capability to guarantee "availability of primary sources and/or cross-border electricity exchanges in case of economic or geopolitical constraints/stresses"[103]. The two properties affecting most these dimensions are the mid-term capability of the system to neglect external effects of disturbances and guarantee a certain performance level (resilience) and the long-term capability of the system to handle external constriction "originating outside the infrastructure dimension."[104]

7.6.1. Resilience and Robustness: RES contributing to a multi-faceted independence

As in the introduction stated, the EU is spending about 1 billion Euros per day for energy imports, accumulating a dependency rate of 51%, with high fluctuations between the member states inter alia Malta with a dependency rate of 99% or Denmark with 14%. Dependency is regarded as a vulnerability to energy security. As Europe has limited resources of conventional fuels, RES are offering a good alternative, as wind-, hydro-, biomass- and sun-power potential is present everywhere, even though the discrepancy of the potential within the EU territory is high (more detailed laid out in chapter 1). If more RES are deployed within the EU territory, the less dependent the EU will get from non-EU countries regarding energy imports. Additionally scholars argue that the more local the energy is produced, the more security is created: "[…] Sovereignty, as a domestic and decentralized energy supply, RES are less vulnerable to the use of energy as political weapon or to physical attacks."[105] Right now, the EU is importing from only a small amount of countries, inter alia Russia (31.9%), Norway (12.4%), Saudi Arabia (7.8%), Iraq (8.3%) or Kazakhstan (6.8%). If one of those suppliers cut their support, the EU is challenged to find a new provider. The longer the way of the energy import, the more exposure to physical attacks and sabotage are possible. Therefore, if the EU produces electricity within their own territory, is less likely to be put in this challenging.

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[103] "Electricity Security in the EU: Features and Prospects | JRC Smart Electricity Systems and Interoperability."

[104] "Electricity Security in the EU: Features and Prospects | JRC Smart Electricity Systems and Interoperability."

[105] Valdés Lucas, Escribano Francés, and San Martín González, "Energy Security and Renewable Energy Deployment in the EU," 1034.

RES have a positive side effect for another international level: RES contribute to the achievement of the goals, which were internationally agreed upon in the Kyoto Protocol or the Paris Agreement.

8. Summary

The deployment of RES create challenges to energy security, but furthermore enable unique advantages to energy security, such as energy independence from non-EU member states as well as energy security through an energy generation mix.

Within the dimensions and properties elaborated by the JRC, energy security through Renewable Energy Sources bring challenges on the one hand, but also opportunities and advantages on the other hand.

As RES come along with a certain volatility and unpredictability factor, the way we established grids for conventional fuels have to be adapted. The grid, furthermore, as the connection between producer and consumer and a vital key element for energy supply security, has to be modernized. But with new technologies these gaps can be closed, enabling a strong energy security through RES. Adequate storage and efficiency technologies contribute to the achievement. Transmission lines between the EU MS have to be expanded, to fulfill the solidarity the Union laid out in their various legal frameworks for the Energy Union. Overhead lines should be installed to guarantee supply security in case of failures as the repair time is significantly faster and the capacity higher. Grid management have to adapt to the new dynamic approach, which comes along with the integration of RES additional to conventional fuels. But even just building and deployment process needs to be more efficient and speeded up, to guarantee a functioning energy transition. Social acceptance needs to be enhanced, through mediation processes and a better understanding for the need of energy generation within the EU territory. Legal procedures, as experts urge, need to be harmonized for RES deployment and accelerated.

However, despite these challenges, which emerge under the deployment and integration of RES, there are undeniable advantages regarding energy security. The diversification of the energy generation creates less dependency towards one energy source. The different potentials within the EU are ought to be used strategically, to create a sustainable transition. The generation of energy within the EU territory help to reduce our enormous dependency rate of 53% on foreign countries and enable the reduction of the EU's daily 1 Billion Euro energy bill – which is even more important in the background of fast changing geopolitics and global instabilities. Thus, we are less exposed to external crisis and attacks, as well as international price fluctuations of fuels.

Experts are clear, that not all energy demand can be covered by RES, only 80% of the demand will be covered. However, the need for energy security and climate mitigation leads us undeniable to the deployment of Renewable Energies within the EU.

Tab. 5: Contribution and Challenges of RES to Electricity Security, Dimensions and Properties from JCR

Orange Bullet points = Challenges to Electricity Security

Black = Positive Contributions to Electricity Security

	Infrastructure Dimension	Source Dimension	Market and Regulation Dimension	Geopolitical Dimension
Operational Security	▪ Changing Management of Grid from static to dynamic	▪ Source Diversification creates less dependency on one source	▪ Dependent on new investments	
Flexibility	▪ Grid Adaption to Fluctuations of RES	▪ Energy Generation Mix increases ▪ Forecast Technologies improvement	▪ Social Acceptance, Legal procedures, establishing mediation processes	
Adequacy	▪ Storage Technologies ▪ Transmission Expansion	▪ Energy Efficiency ▪ Potential of RES: 80%	▪ New Business models for RES	
Resilience	▪ Grid Decentralization minimizes technical failures		▪ Less Fuel Price Volatility	▪ Less affected under crisis
Robustness	▪ RES infrastructure less delicate to external influences		▪ New economic opportunities	▪ Decreasing independence on energy imports ▪ Less vulnerable to terror attacks through energy generation dispersion

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