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COMPARATIVE ANALYSIS OF RENEWABLE ENERGY SOURSES IN THE SELECTED EUROPEAN COUNTRIES

SROVNÁVACÍ ANALÝZA OBNOVITELNÝCH ZDROJŮ ENERGIE VE VYBRANÝCH EVROPSKÝCH ZEMÍCH

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1) Černoch, F., & Zapletalová, V. (2012). Energetická politika Evropské unie. Brno: Masarykova univerzita.
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ABSTRACT

The aim of this bachelor's thesis is to provide information about renewable sources of energy in Germany and the Czech Republic, mainly from the viewpoint of historical development, energy policy and utilization and potential of these technologies. After summarising the key events and treaties, which have a direct influence on the development of renewable energy, the thesis analyses the energy issue in Germany including its transformation of an energy sector called the Energiewende. The same methodology is used in an analysis of the renewable energy sources in the Czech Republic, including the comparison of the financial support of renewable sources in both countries. The thesis concludes with a chapter about impacts and potential consequences of the German energy transition on the Czech energy sector.

KEY WORDS

renewable sources of energy, Kyoto Protocol, Energiewende, energy policy, wind power, solar power, biomass, hydropower, potential of renewable sources of energy

ABSTRAKT

Cílem této bakalářské práce je poskytnout informace o obnovitelných zdrojích energie v Německu a v České republice, a to zejména z pohledu historického vývoje, energetické politiky, využití a možností dalšího rozvoje těchto technologií. Po shrnutí klíčových událostí a smluv s přímým vlivem na obnovitelné zdroje, práce analyzuje danou problematiku v Německu včetně energetické transformace této země, nazvané Energiewende. Stejná metodologie je použita při analýze obnovitelných zdrojů energie v České republice včetně srovnání finanční podpory obnovitelných zdrojů v obou zemích. Práce je zakončena kapitolou o vlivu, dopadech a možných důsledcích německé energetické přeměny na energetický sektor České republiky.

KLÍČOVÁ SLOVA

obnovitelné zdroje energie, Kjótský protokol, Energiewende, energetická politika, větrná energie, solární energie, energie z biomasy, vodní energie, potenciál obnovitelných zdrojů energie

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V Brně dne ....

(podpis autora)

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1 INTRODUCTION

Renewable sources of energy (in the form of traditional biomass, wind, water, etc.) have been used by mankind for thousands of years and prior to the development of coal, crude oil, natural gas and other types of non-renewable energy sources, renewables had covered the overwhelming majority of all the energy used by the human race. Nonetheless, since the beginning of the "Age of Oil", renewable sources of energy have been almost fully replaced by fossil fuels in developed countries. The events in 1973 and 1979 known as the "oil crisis" and the "energy crisis," have indicated that renewable sources of energy, though comprising a minority in the World's produced energy at a time, may perhaps represent a necessity to assure the energy security and sustainable development of modern countries. Furthermore, using renewable sources of energy as an alternative to extensively exploit fossil fuels on the global scale has been increasingly perceived as a long-term solution as far as environmental sustainability is concerned.

In the second chapter, this bachelor's thesis aims to discuss the issues of renewable energy sources within the context of energy policy, outlining the key policies of the European Union, alongside with international treaties with a direct impact on renewable sources of energy and their use.

The third chapter of this thesis focuses on Germany – a very interesting country for analysis as one of the leading countries in this area and the country within a transformation of its energy sector to alternative sources of energy. Germany is analysed from the viewpoint of the modern development of its energy sector, alongside with its energy policy. This chapter includes goals of the Energiewende and proceeds with the evaluation of Germany's use of renewable sources with respect to goals of their energy transformation plan. The conditions and potential for the development of renewable sources in Germany with perspectives in the prominent renewable technologies in this country are also included in this chapter.

The aim of the fourth chapter is to use the same methodology as in the third chapter to provide the analysis of renewables in the Czech Republic, including comparison with Germany, also from the viewpoint of financial support of these technologies in both countries.

The fifth chapter evaluates impacts of the German transition on the Czech energy system as the Energiewende already has impacts on the price of electricity and stability of the grid in both Germany and the Czech Republic. It also influences many other aspects of power production and distribution in this country, including its energy policy and safety, alongside with the future shaping of the Czech energy strategy.

2 RENEWABLE SOURCES OF ENERGY AND THE ENVIRONMENTAL DIMENSION OF THE EU

In the 1950s, most of the European countries were highly dependent on importing of crude oil, predominantly from the Near East, as a result of the fact that the prices of oil were at a rather low level. Furthermore, world's economy was experiencing an exponential growth between the 1950s and 1970s and consequently, the demand for fossil fuels of all kinds was increasing, as we can observe from the following table 1:

Table 1. *Import of natural gas and gas products in years 1955-1973, in mmt.*

	1955	**1960**	**1965**	**1970**	**1973**
USA	45	85	116	160	305
OECD - Europe	12	30	89	211	292
Western Germany	7	26	68	118	139
Britain	31	50	76	106	117
Italy	12	21	49	83	97
France	20	27	52	96	130
Worldwide	300	456	759	1263	1656

Adapted from Černoch and Zapletalová (2014).

This prominent dependency on importing of fossil fuels, alongside with growing tendencies of using oil as an instrument of political influence and the outburst of the Yom Kippur War, resulted in the first "oil crisis" in 1973. The oil embargo on the western countries and the consequent insufficiency of this resource in Europe had a dramatic effect on the Western economy. For example in Germany, a three-week ban on driving vehicles had to be ordered, and in the United Kingdom, miners had shifts only 3 times a week and without being paid for overtime (Černoch & Zapletalová, 2014).

The dependency on importing of oil from undiversified suppliers has been ever since observed as a significant threat to ensuring the energy security of a country and consequently, renewable sources of energy were obtaining higher importance as a secure source of energy, whilst not being fully dependant on import from other countries.

2.1 Important treaties for renewable sources and the environmental dimension of European energy policy

2.1.1 International Panel on Climate Change

Simultaneously with gradually increasing fear of unstable import of fossil fuels and its consequences, the environmental aspects of burning oil and natural gas and their extraction were the emerging topics in the public opinion amongst the European citizens in the 1980s. The more systematic approach to lower the influence of the energy sector on the environment was established with the Intergovernmental Panel on Climate Change, IPCC, taking place in 1988. The main objective of this panel was to provide the politicians with scientific aspects and the interpretation of information about the impacts on the climate. This was followed by an OSN conference about the climate and its development, held in Rio de Janeiro, later known as "The Earth Summit", leading to a non-obligatory agreement of 150 countries to lower their emissions of greenhouse gases. This agreement was validated in 1994 and led to a series of conferences. The conference of the eminent importance for the development of renewable energy sources was held in 1997 in Kyoto, Japan, and is known as "The Kyoto Protocol".

2.1.2 The Kyoto Protocol

In 1997, the third conference of the United Nations Framework Convention of Climate resulted in agreement upon concrete conditions for reduction of greenhouse emissions within signatory countries, a treaty known as "The Kyoto Protocol". According to Quaschning (2010), the treaty was ratified in 2005 and set targets for reduction of CO_2 and other various greenhouse gases recalculated as equivalents of CO_2, such as hydrofluorocarbons (HFC), sulphur hexafluoride (SF_6), perfluorinated compounds (PFC) or methane (CH_4).

Another significant aspect of the treaty was dividing signatory states into two groups within Annexes, while setting achievements for lowering (and in some cases even stabilising or even slightly increasing) greenhouse emissions in comparison with the situation in 1990. Quaschning (2010) mentions that the countries in Annex 1, including the Czech Republic, Germany, were bounded by the protocol to lower their emissions (18 and 22 % respectively), whereas countries from the other group, or Annex 2, were even allowed to increase their emissions (in comparison with the state of their emissions in 1990).

2.1.3 EU ETS

The Kyoto Protocol also included a mechanism of emission trading system, or ETS. This system allowed countries from Annex 1 to integrate various precautions to support the decrease of greenhouse emissions of countries from Annex 2, be it more efficient economically than investing into decreasing emissions on their own territory, obtaining so called „credits“. If a country from Annex 1 would do so, it was allowed to exchange these credits in order to obtain "allowances" to increase their own level of greenhouse emissions bounded by the Kyoto Protocol.

Renewable sources of energy naturally represented a significant factor in reducing greenhouse emissions, as for example for every kWh produced at any given location in Germany an equivalent of 600 grams of CO_2 is emitted into the atmosphere. A single 5 MW wind power plant at a suitable location would avoid 120,000 tons of CO_2, as it generates approximately 200 millions of kWh in its operational life (Quaschning 2010).

Various precautions were necessary also as far as the transportation sector was concerned, as the transportation sector accounts for a significant share of the final energy consumption[1] in most of the European countries. In order to establish stricter rules for achieving goals in reducing or preventing greenhouse gas emissions, the EU Climate and Energy Package was adopted in 2009.

2.1.4 EU ETS – Climate and Energy Package

This document, also known as the "20/20/20" plan, includes various targets to be reached by the European Union by 2020. Firstly, it sets target for reduction of greenhouse emissions by 20 % compared to 1990 level, varying slightly from country to country. Secondly, it aims for improvement in energy efficiency by 20 % and last, but not least, it involves the increased use of renewable sources, reaching 20 % share of gross final energy consumption by the year 2020. Furthermore, the share of renewable sources in transport

1 Final energy consumption is energy received and consumed after the transformation into other forms of energy (fuel, heat, electricity). Final consumption does not include the utilization of energy for non-energy purposes, self-consumption by power plants and losses (Quaschning, 2010).

sector shall be increased to 10 % (Goswami & Kreith, 2016).

In order to succeed in reaching rather ambitious goals mentioned above, members of the European Union had to adopt various technical and legislative measures, such as economical support of projects in the field of renewable sources of energy. In countries such as Germany, where the environmental and regional conditions for installing plants for renewable energy are not as favourable as in such countries as Norway (where 98 % of the final energy production is covered by renewable energy, with majority of hydro-power plants), research and development of efficient and also cost-effective technologies play a very important role.

As far as energy efficiency is concerned, renewable energy sources may be very beneficial in this area, as decentralised and local production of energy decreases losses of energy (mostly in the form of heat) that may be avoided this way. Furthermore, the Climate and Energy Package also emphasizes the necessity of increasing the share of renewable energy sources in the transport sector This may be achieved for example by utilising biofuels, or increasing the share of electromobility.

In the following chapter of this bachelor’s thesis, German energy model will be described considering its very serious approach towards not only reaching the goals set by the Kyoto Protocol and subsequent treaties, but even exceeding these achievements and become a “role model” in shifting to renewable sources of energy.

3 RENEWABLE SOURCES OF ENERGY IN GERMANY

Considering renewable sources of energy, Germany is a rather interesting country for further analysis, as the German energy sector was predominantly based on coal and nuclear energy in the beginning of the 1970s, but nowadays, this country is one of the world's leaders in renewable technology and installed power.

Before the 1980s, nuclear energy had a significant tradition and represented an environmentally clean and safe (in the form of supply of fuel) technology. Nevertheless, the events mentioned in the previous parts of this bachelor's thesis, alongside with two nuclear disasters in 1979 (Three Mile Island) and 1986 (Chernobyl), had substantial influence on alternating the current energy policy and the public opinion in Germany. Furthermore, these events triggered a growing ambition for renewable sources of energy to become a prominent source of energy and a replacement for nuclear energy. This plan for transforming the energy sector, called the Energiewende, had begun to culminate in 2011 after the last nuclear disaster in Fukushima Daichi (Japan), as the majority of German nuclear plants were closed and the renewables became a prominent and rapidly growing technology.

In the following chapters and subchapters, the topic of the Energiewende will be analysed in further detail from the viewpoint of its historical development, relevant German energy policies and last, but not least, the impact of this transmission on German economy will be analysed, alongside with the current use of renewables in Germany in general will be evaluated.

3.1 Modern history of renewable sources of energy in Germany

3.1.1. Energiewende and its development

Despite the fact that the term the “Energiewende” became more eminent only recently in 2010 after the latest nuclear disaster in Fukushima Daichi, it has been frequently used since the 1980’s. Until that period of time, Germany was highly focusing on nuclear energy and it was also a target of immense investments.

Černoch et al. (2015) mention that by the 1970’s, Germany had invested over 11 billion of marks into this technology and the energy capacity of this technology had contributed for 17 000 MW, but crises in 1973 and 1979, followed by the Chernobyl disaster in 1986 rapidly altered the public opinion in Germany and the first governmental support for renewable sources of energy emerged.

Černoch et al. (2015) also state that this support culminated in 1990 with the passing of the Grid Feed-in Law (StrEG), which obliged the operators of the grid to accept the electricity originating from renewable sources of energy at a certain minimum price and was hitherto followed by the German Renewable Energy Sources Act (EEG) in 2000, which calculated the support on the basis of the actual price of the technology. At this time, the topic of transforming the system of energy supply was already widely acknowledged by the German public and nuclear power plant operators. The transformation accelerated dramatically in 2011 when it was decided that seven of the oldest nuclear power plants had to be closed immediately and the remaining nuclear plants are to be closed within 2022.

Quaschning (2010) mentions that by 2020, renewable sources will have exceeded nuclear power in electricity production and by 2050, these sources will have already been a dominant source in covering the majority of electricity supply. In order to achieve this, Germany has presented the main goals of the Energiewende – a comprehensive Energy Concept comprising the roadmap of goals to be attained up to 2050.

3.1.2. Goals of the Energiewende

With the Energiewende, Germany aims to transform its energy sector and economy into one of the most energy-efficient and environmentally-friendly in the world. Naturally, renewable sources of energy play a crucial role in this plan, which corresponds to goals marked out in the EEG law, which are, according to Goswami & Kreith (2016), divided into the following three phases of operation:

- Phase One (2000-2009), focusing on scaling up of German generation of renewable energy. This process was followed by
- Phase Two (2009-2011), where the costs of solar photovoltaics and other various types of renewable sources were dramatically declining, finally resulting in
- Phase Three (2012), with increasingly competitive prices compared to traditional sources of electricity, and is therefore more viable for future investments. The goals of the Energiewende are depicted in the following table:

Table 2. *Status quo and main targets of the Energiewende.*

	2011	2020	2030	2040	2050
Greenhouse Gas Emissions					
GHG (against 1990)	-26.4 %	-40%	-55%	-70%	-80 to -95%
Efficiency					
primary energy use (against 2008)	-6%	-20%	–	–	-50%
electricity demand (against 2008)	-2.1%	-10%	–	–	-25%
heat in residential sector	n.a.	-20%	–	–	–
energy use in transport sector (against 2005)	-0.5%	-10%	–	–	-40%
Renewable Energy					
share in electricity consumption	20.3%	≥ 35%	≥ 50%	≥ 65%	≥ 80%
share in final energy use	12.1%	18%	30%	45%	60%

Reprinted from Agora Energiewende (2013).

It is important to mention that this comprehensive roadmap functions only as a guideline, although, as Goswami & Kreith (2016) mention, the implementation of the plan is monitored through monitoring reports and progress report, executed on an annual and three-year basis, with the public closely involved in its development.

3.2 Use of renewable sources of energy in Germany

Traditionally, German energy mix[2] has been based on nuclear energy and coal, but as we can observe from the following figure, since the 1990's, only renewable sources have been rising significantly in this country:

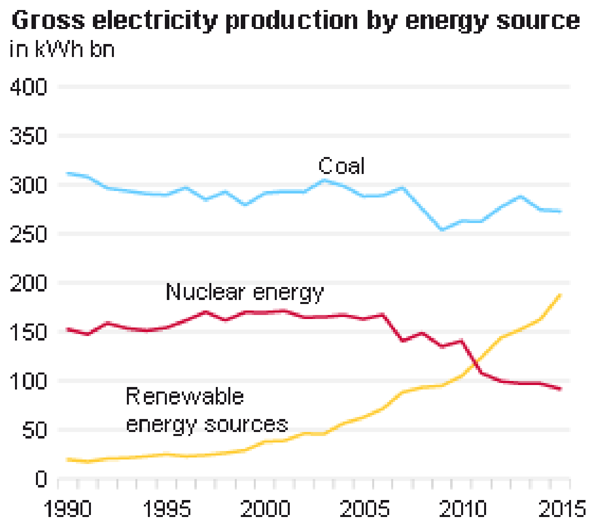

Figure 1. Gross electricity production by energy source in kWh bn.
Reprinted from www.destatis.de.

Figure 1 shows that while in 1990 renewables only accounted of 4 % share in gross electricity production, predominantly represented by hydro-power plants, this number rose up to 29 % in 2015. It is also clear that the nuclear energy share had been slowly decreasing until 2010, when the decrease accelerated even further and consequently, the total contribution to electricity production reached approximately a half of the its share in 1990.

The production of electricity from coal has, however, decreased only marginally. It is due to the fact that coal-fired power plants serve as a peak-load electricity source to avoid the imbalance in supply and demand on the grid, caused by variable supply of renewable sources of energy dependant on weather conditions and day-time, namely photovoltaics and wind power. Therefore, a flexible regulation of supply at the peak electricity demand and grid management are necessary in a system based on renewable sources of energy.

2 The energy mix of a country is a specific combination of various energy sources (renewable or non-renewable) it utilizes to meet its energy consumption needs (Černoch & Zapletalová, 2012).

The development of renewable sources of energy, alongside with individual share of various types of sources, can be observed from the following figure:

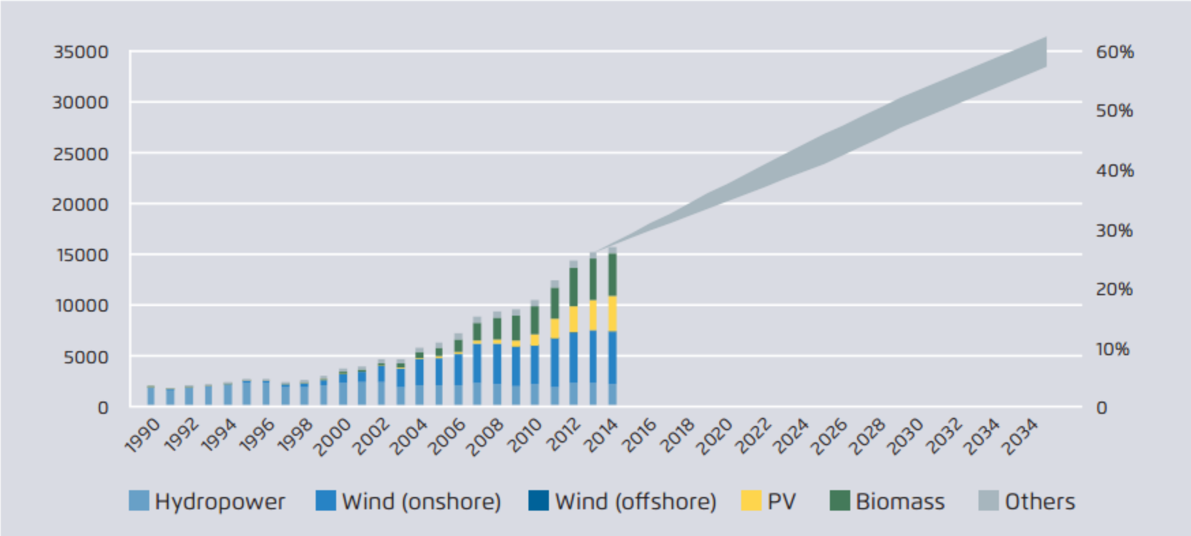

Figure 2. Electricity supply from renewable sources, 2000–2014, and prospective supply 2015-2020. Reprinted from Bayer (2015).

In Figure 2 we can see that while in 1990 hydro-power was the major renewable source of energy in Germany, in the following years its share in produced electricity stagnated. On the other hand, photovoltaics and wind-power plants became prominent from the viewpoint of produced electricity and there has also been a significant increase in electricity supply from biomass sources. This is due to the fact that the potential locations for building new hydro-power plants were largely depleted in Germany, and therefore no significant increase is expected in this area. On the other hand, photovoltaics and wind-power plants became prominent with regard to electricity production and there has also been a significant increase in electricity supply from biomass sources. Černoch et al. (2015) point out that there has been a rapid increase in installed capacity of photovoltaic panels (namely 11 GW between 2011-2013) and wind energy (5.6 GW in installed capacity in the same period of time), corresponding with the financial support determined in the EEG law and early depletion of potential new hydro-power sources. Authors also mention the fact that on a record-breaking day of 11 May 2014, renewable sources of energy have covered approximately 80 % of total electricity demand in Germany. It is important to mention that this value is not representative and the average value was approximately 25 % of total electricity consumption in 2014.

Some renewable sources of energy (wind and photovoltaics) are extensively dependant on weather conditions, daytime and climate conditions and therefore output of these sources fluctuates, as it can be seen in the following figure (see fig. 3).

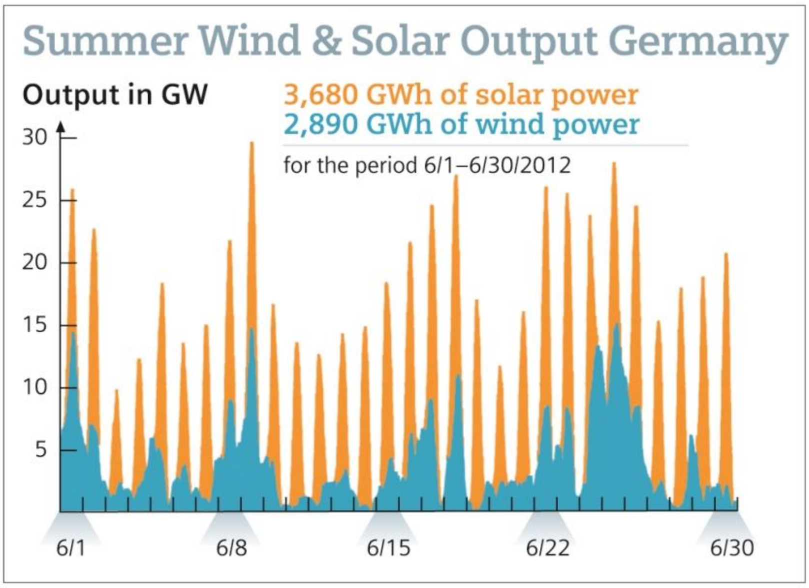

Figure 3. Summer wind and solar output Germany. Reprinted from Ruth (2014).

Even though these fluctuations can be predicted to some extent, they represent a certain issue for balancing supply and demand of electricity in order to avoid imbalance on the grid and consequent risk of blackouts and other technical issues. Černoch et al. (2015) mention two aspects of renewable sources of energy: *variability* and *uncertainty*. The second aspect is related to errors between the predicted amount of supplied energy (based on weather forecasts) and the actual supplied energy. This may have a negative effect on grid-stability not only in Germany, but also in the Czech Republic, due to potential overflows of electricity.

Authors of this text therefore expect a growing importance of energy sources which are flexible and simple to regulate, such as gas-fired and coal-fired power plants, alongside with improvements in grid-management and grid interconnection not only within Germany, but also between other countries in the EU.

3.2.1. Use of renewable sources of energy in Germany (by source)

3.2.1.1 Wind power

As far as total installed wind power is concerned, Germany is the leader in Europe, with 31,300 megawatts of total installed capacity in 2012. Nevertheless, from the viewpoint of installed wind power per capita, Denmark exceeds Germany with 751 MW per million people (Shahan, 2013).

3.2.1.2 Solar power

According to Quaschning (2010), solar energy in Germany took off in 1990 with the project called "1,000 roofs", where eventually a total of 2,550 roofs were fitted with solar panels and the development of this technology accelerated even more rapidly with the EEG law. He also stresses the fact that in 1980, 85 % of solar panels were manufactured in the USA, but in 2005 this share already decreased to 10 % as Germany, alongside with Japan, had a major share of produced solar panels.

Goswami and Kreith (2016) note that in 2012, Germany had 32,600 megawatts of installed capacity in photovoltaic systems, meaning Germany had the highest installed capacity in the world. Nevertheless, more energy was produced by bioenergy that year, as almost 7,600 MW installed in this source have produced more energy, largely due to the difference in utilization factor[3].

3.2.1.3 Biomass

Goswami and Kreith (2016) state that in 2012, biomass produced 43.5 TW h from installed capacity of nearly 7,600 MW (photovoltaics produced 26.4 TW h). This technology is, however, viewed critically due to the harmful environmental aspects, as burning biomass is a carbon-neutral technology (as approximately an equal amount of emissions is produced as is decreased while the biomass products are grown). According Suzuki (n.d.), in Europe, Finland and Sweden are the leaders in this technology.

[3] Utilization factor refers to the ratio of the time that a source of energy is in use to the total time that it could be potentially used (Quaschning, 2010).

3.2.1.4 Hydropower sources

Hydropower sources comprise 5,600 MW of installed capacity in Germany, with the largest hydropower plants located on the Rhine. According to Quaschning (2010), many of the oldest power plants are being modernized, enlarging electricity production and efficiency of the given power plant. Some types of hydro-power plants even provide a possibility of accumulation or regulation of electrical energy and have an important stabilization function in the system. In contrast with Germany, Norway had almost six times larger installed capacity, as it had 30.57 GW of electricity produced by this renewable source of energy, also being the largest producer in Europe (Word hydropower statistics, 2015).

3.3 Conditions and potential for the development of renewable sources in Germany

Quaschning (2010) mentions that as ideal locations for onshore wind turbines and wind parks are already substantially used, the offshore locations in the North and Baltic seas are ideal for new constructions. He also states that wind power is expected to cover 25-30 % of electricity consumption in Germany and that until 2030, approximately 30,000 MW of capacity is expected to be installed in offshore wind parks, located in the North and Baltic Seas.

Offshore wind parks are located 30-100 kilometres far from the coast. They are built 20-50 meters below sea level, and therefore they are more expensive to build than onshore wind turbines. The advantage of this technology is utilization of optimal wind conditions and only a few restrictions considering its location, as for example in the Czech Republic, where suitable locations for new wind-turbines (with an appropriate average speed of wind which is available at a certain altitude) commonly correspond with protected areas, and therefore are limited to some extent.

Solar energy has become more competitive, mainly due to the technological development alongside with mass-scale production, and has a significant influence on German export and economy. Quaschning (2010) argues that despite the fact that the conditions for solar panels and solar power plants are not as convenient as in other European countries (such as Portugal, Spain and Italy), German solar industry is still dramatically increasing not only as far as installed power is concerned, but also in terms of the employment rate and export of components.

Goswami and Kreith (2016) emphasize that geothermal energy, both used for heat and electricity production, exhibit a large technical potential. Nevertheless, due to high costs and other technical issues, this technology was still in a minority in Germany in 2012, with only 7 TWh in heat provision and insignificant installed capacity for electricity production.

4 RENEWABLE SOURCES OF ENERGY IN THE CZECH REPUBLIC

In contrast with Germany, the Czech Republic chose a less dramatic approach towards renewable sources of energy. Support of nuclear energy remains stable in this country, as this zero-carbon[4] source is, according to the State Energy Policy update in 2015, which, according to Budín (2015), is planned to cover approximately a half of the Czech energy production and renewable sources having a complementary character in the Czech energy mix in the next decades.

Nevertheless, with respect to targets of the 20/20/20 plan of the European Union, Czech Republic agreed to increase the share of renewable sources of energy in the next years, which is associated with financial support of the producers through various economical instruments, such as feed-in tariffs[5] or other electricity price guarantees. The legislature related to this subject, the Czech energy policy and meeting of the targets marked out by the European Union will also be a significant part of this chapter.

Meeting of these strategic achievements highly depends on actual share of renewables of the given country, alongside with potential of the technology in the given climatic conditions. Environmental conditions such as preservation of natural reservations are also very important as far as building of new power plants is concerned and last but not least, the economic aspect is not to be omitted. These aspects will be discussed in subchapters 4.3 and 4.4.

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4 A zero-carbon source is a source that produces no carbon emissions (Quaschning, 2010).

5 Feed-in tariff (or FiT) is a mechanism of a long-term financial support based on the cost of electricity generation of a given technology (Goswami and Kreith, 2016).

4.1 Modern history of renewable sources of energy in the Czech Republic

4.1.1 Hydropower

As far as producing electricity from renewable sources is concerned, hydropower has the longest tradition in this country. The oldest power plant of this type was built in 1888 and a number of Czech hydropower plants have been producing power since the first half of the 20th century, which has had a significant impact on the electrification of this country.

Bouška (2016) chronologically divides the history of this renewable source into the three time periods:

I the period prior to 1950,
II the period between 1950 and 1980,
III the period between 1980 and 2013.

According to the author, the first period **I** (prior to 1950) can be characterised as a period with a rapid development of small hydropower (up to 10MW of installed power), motivated by increased energy demands and consumption in between World Wars I and II. In the 1930s, there were a total of 11,785 hydropower structures, with total installed power over 50 MW.

In the same period of time, the first large hydropower structures (with installed power over 10MW) were built, alongside with the improvement of overall efficiency of the current structures. After World War II, the total installed power of hydropower plants reached 336.2 MW, despite the fact that numerous older small hydropower structures were closed for rentability reasons (in comparison with coal-fired power plants).

The period **II** was typical of constructing large hydropower units, especially on so called "Vltava Cascade" – a complex of mostly reservoir power plants on the Vltava river, which accounted for an impressive amount of 750 MW of installed capacity in 1961. Nevertheless, the amount of convenient locations for building new small and large hydropower units was largely depleted in the 1970s. Therefore, the construction of new hydropower plants in the Czech Republic focused on building pumped-storage power plants, such as Dalešice and Dlouhé Stráně, completed in 1978 and 1996 respectively.

In the following period **III**, the trend of further construction of new large hydropower units was replaced with modernisation of the older power plants and units. As far as building new small hydropower plants is concerned, there was an impulse in the form of support on the basis of a new legislature in 1989, followed by price support of renewable sources of energy in general at the beginning of the 21st century. Bouška (2016) mentions that the total installed capacity of small and large hydropower plants reached 1,083 MW (without pumped-storage plants) in 2013.

4.1.2 Wind and solar power

After the Oil Crises in the 1970s described in the previous chapters, many European countries started exploring the potential of other renewable sources of energy, such as wind and solar power. The beginning of using wind power for electricity production in this country dates back to the 1980s and 1990s, where, as Česká společnost pro větrnou energii (n.d.) describes, numerous power plants of this type were constructed. As far as technology is concerned, these pioneering Czech wind power plants were not technologically advanced. Moreover, they were built in inadequate locations and consequently had to be decommissioned. However, with the increased support of renewable energy, in particular through the Act on Support for the Use of Renewable Sources of Energy (Act No. 180/2005 Coll.), newly built power plants were more reliable and technologically advanced. Bouška (2015) points out that between 1994 and 2013, sixty-six new wind power plant were built, with the total installed capacity of 270 MW and nominal powers of individual power plants ranging from hundreds of kilowatts to even 2 to 3 MW.

By the end of the millennium, solar power had started to emerge as another source of renewable energy in this country. Bouška (2015) highlights that the first Czech solar power Mravenečník plant was built in 1997 and with 10 kW of installed power it had been producing electricity for 5 years, until 2002. The Act highly influenced the consequent rapid development of solar power plants installed in years 2008 and 2010, which was a topic of great controversy in the Czech Republic.

Divišová (2013) points out the problematic aspects of this so called “Solar Boom” in this country caused by insufficient flexibility of adjusting financial support for producers of solar energy. Due to dramatically decreased expenses for investing into installing new and more efficient solar panels, there was an immense increase in total installed capacity in solar power between 2009 and 2010, with 425 MW of new installed capacity in 2009 and almost 1500 MW in 2010. As the amount of photovoltaic power plants reached two times higher values than expected by the legislature, expenses for the support negatively influenced the electricity price for customers. Furthermore, the disproportionately high guaranteed support for the new power plants had been expected to be preserved until approximately 2030, which consequently burdens the national budget. The legislature has altered since, and in particular new large photovoltaic power plants are not widely supported. The status quo of the support of renewables will be discussed in the subchapter 4.2.

4.1.3 Biomass

Modern and technologically advanced ways of using biomass sources for electricity and heat production do not have an extensive history in this country, as the first attempts to build a power plant of this type, according to Skupina ČEZ (n.d), date back to 1995, when the supplied power of the decommissioned coal-fired power plant Tušimice I had to be replaced by new sources of energy. The first project with a fluid boiler for combined incineration of coal and biomass was completed in 1999 with the opening of a new technological block for burning biomass in Hodonín, which was followed by similar technological updates of cogeneration plants in Tisová, Poříčí, Ledvice and Dvůr Králové.

4.2 Financial support of renewables in the Czech Republic

With entering the EU in 2004, the Czech Republic agreed to reach a certain share of renewable sources of energy on total gross consumption. According to Goswami and Kreith (2016), the original target for this country was 8 % of final gross consumption by 2010, followed by a total of 13 % by 2020. Reaching these values is enabled through various types of financial support of renewable energy projects, while the price regulation of the support not being incorporated in the legislature is under the patronage of the Energy Regulatory Office (ERÚ).

4.2.1 Types of financial support for renewable sources of energy

There are generally two types of financial support for renewables in the Czech Republic – feed-in tariffs and the so called "green bonuses". The feed-in-tariff, (FiT), with a fixed price guarantee for longer periods of time (usually twenty years) and privileged offtake of the renewable energy sources by grid operators. The level of support is usually calculated on the basis of the construction and operation expenses of the given technology. From the viewpoint of new photovoltaic power plants built after 2014, the support has been cancelled and, as stated in Divišová (2013), the focus of the support has shifted onto small household photovoltaic systems.

The green bonus, originally incorporated in the Act No. 180/2005 Coll. (nowadays 165/2012 Coll.) is paid on top of the market price on a one-year basis with the price level updated by the ERÚ. This bonus is targeted on the producers who mostly consume the electrical energy of their own production and sell only an insignificant part of the electricity production.

Another way of supporting the development of renewable sources of energy is provided by the program called "Zelená úsporám". This governmental program is providing support via covering a part of investment expenses into renewable technologies of households or municipal buildings. In 2013, the program was updated to Nová zelená úsporám (2015), which predominantly focuses on "off-grid" systems up to 10 kW of installed capacity. Majling (2015) adds that the current project NZÚ is funded with sold emission allowances, with up to 27 billion CZK to be derived from the fund and invested within 2021.

4.2.2 Comparison of the Czech and German support for renewables

The previous chapters of this thesis indicate that the support for dramatic development of renewables, especially larger photovoltaic plants, has a decreasing tendency in the Czech Republic. In an interview with Klimičová (2016), a senior energy expert Alois Míka compares the Czech and German support of renewables, arguing that while the Czech financial support has been only limited since 2014, Germany innovates its system of support to a form of an auction instead of fixed prices for wind and solar energy, maintaining its stable support of a further development of renewables. Another significant difference lies, according to Míka (as cited in Klimovičová, 2016), in the unstable business environment, legislature and fluctuating political support of the Czech government.

4.3 Use of renewable sources of energy in the Czech Republic

In 2011, the Czech Republic had already reached the indicative target of a 13 % share of renewable sources of energy in gross final energy consumption by 2020. This outcome was mainly due to an immense increase in installed capacity in the photovoltaic power plants, accompanied by a significant increase in renewable energy share in a sector of heating and cooling, predominantly with utilization of biomass and cogeneration units in this country. The values can be observed from the following figure:

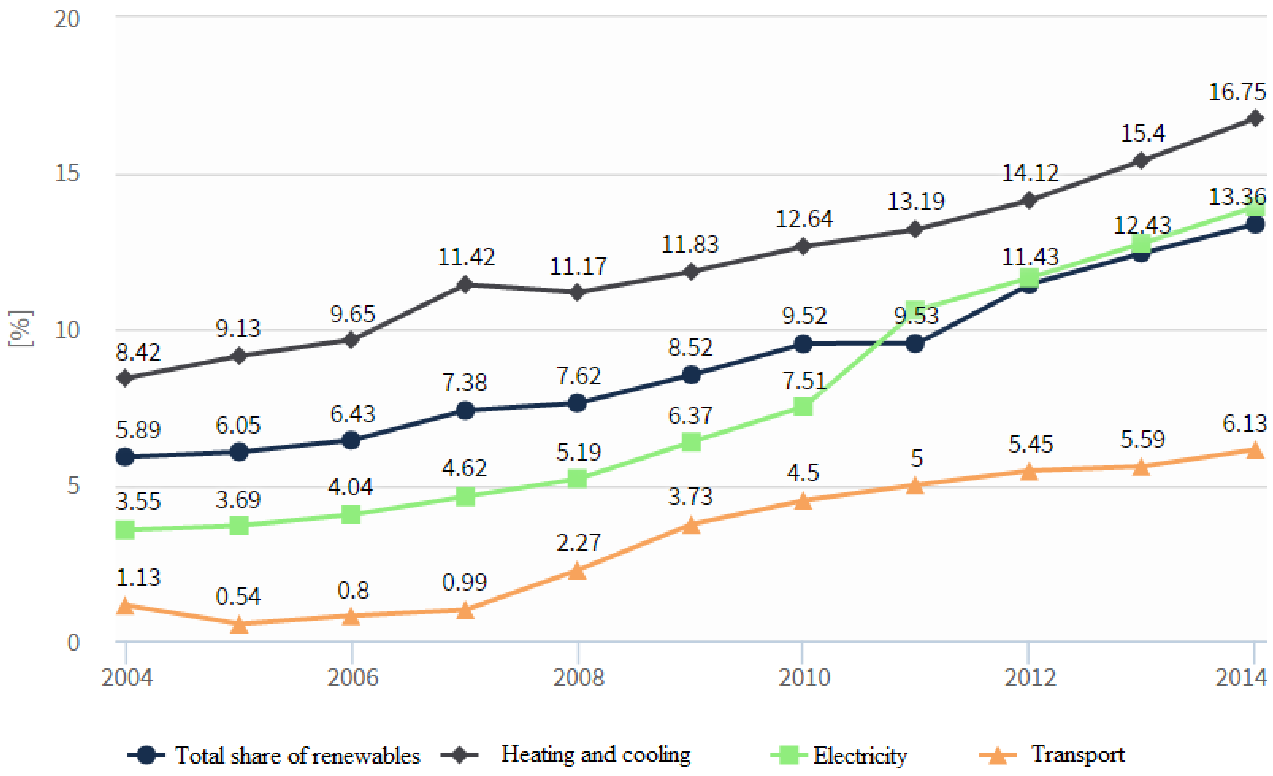

Figure 4. Share of renewable sources of energy on total gross energy consumption. Reprinted from oEnergetice.cz (2014).

The individual shares of various sources, as well as their function in the Czech energy mix will be evaluated in the following subchapters of this thesis. The sources have been ordered from the viewpoint of final energy production for comparison with Germany, however, wind power represents only a minor share in the Czech energy mix.

4.3.1 Use of renewable sources of energy in the Czech Republic (by source)

The electricity production (in percentage) of individual Czech renewable energy sources is illustrated in Figure 5. The figure shows that in 2013, biomass surpassed hydropower in electricity production. It also indicates that utilization of solar power decreased immensely between 2010 and 2011, as its share increased from 0.34 % of total electricity production in 2010 to 2.15 % in 2012. Wind power represents only a minority of renewable electricity production in the Czech Republic, as it accounted for only a half percent of the total electricity production in 2014.

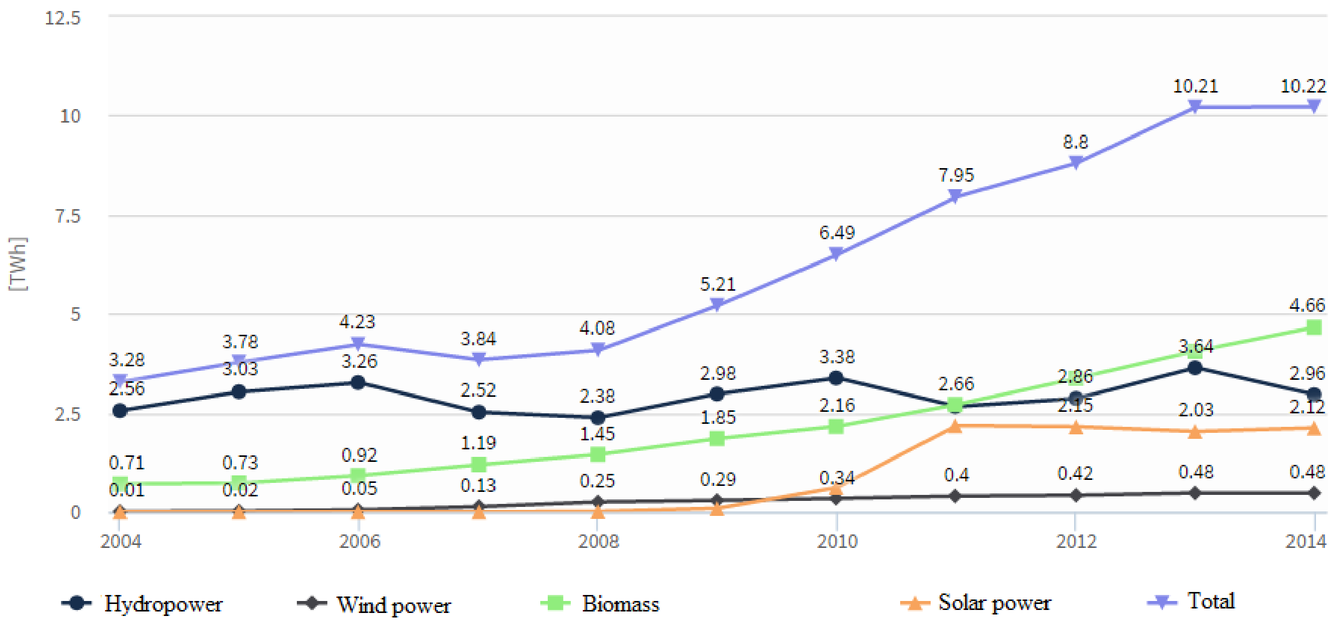

Figure 5. Electricity production of renewable energy sources.

Reprinted from oEnergetice.cz (2014).

4.3.1.1 Biomass

In the Czech Republic, biomass has a significant use in both electricity production and heating in households and urban areas. Vobořil (2017) highlights the increased utilization of biomass sources in this country, as incineration of wood products, municipal waste and other plant-based materials produced over 2 TWh of electrical energy in 2015. This renewable source also covered almost one tenth of the total heat production in the Czech Republic. Goswami and Kreith (2016) emphasize the rapid increase in utilization of efficient cogeneration units near the urban areas as a part of a trend with the support of decentralized energy in this country.

4.3.1.2 Hydropower

Despite the fact that hydropower plants are amongst the oldest Czech sources of electrical energy, they still play a significant role in energy mix of this country. Vobořil (2016) summarizes that there are currently 9 large hydropower plants (with installed power over 10 MW), with a total of 753 MW of installed power. With reservoir power plants such as Orlík (364 MW), Slapy (144 MW), Kamík (40 MW), or Štechovice I (22,5 MW), the majority of large Czech hydropower plants are located on the Vltava river.

The river conditions in the Czech Republic are more favourable for building of small hydropower units. Totally, there are 1,614 small hydropower units reaching approximately a half of the installed power in large hydropower units, with the total installed power of 348 MW.

Vobořil (2016) also stresses the importance of modern pumped storage hydropower plants, such as Dlouhé Stráně, Dalešice or Štechovice II, for the stability of the grid. The installed power in this technology (1,175 MW in total) and its power production are not included in values for reaching of the targets of the EU, as this type of hydropower plant usually operates in the regulation mode, where it consumes more energy than it produces. In the regulation mode, pumped storage power plants produce reactive power and create reserves that significantly compensate fluctuations caused for example by variable output of other renewable energy sources, such as solar or wind power plants. Alongside with reservoir power plants, pumped storage plants are also very efficient as a system for accumulation of energy, as they enable accumulation of surplus low-cost electricity in the off-peak, which can be consumed in the peak-load intervals when there is a high demand for electricity supply.

4.3.1.3 Solar power

The installed power in photovoltaics substantially increased with the “Solar Boom” explained in the previous parts of this thesis. Bouška (2015) notes that the total installed power in this technology was 2,074 MW in 2015, which represented almost a 10 % share in total installed power in the Czech Republic. Nevertheless, the share in total electricity production of this source reached only 2.7 %, as the utilization factor of solar power plants is significantly lower in comparison with sources such as nuclear power or hydropower plants. Bouška (2015) also remarks that the majority of the largest photovoltaic power plants in the Czech Republic were installed between 2009 and 2011, when new larger photovoltaic units were supported. Nowadays, the new installations are predominantly small photovoltaic units for household electricity or heat production.

4.3.1.4 Wind power

In comparison with Germany, where installed power of wind power plants exceeds 30,000 MW, Czech wind power represents only a minor share in the total electricity production. Vobořil (2015) summarizes the total installed power and production of this renewable source in this country, stating that there were 75 wind power plants in operation in 2014, producing nearly 0.5 TWh of electric energy, which represented 0.55 % of the total share of electricity production in the Czech Republic. The largest wind farm, Kryštofovy hamry – Přísečnice, with 21 turbines and total installed power of 42 MW, is located in the Ústecký region.

4.4 Conditions and potential for the development of renewable sources in the Czech Republic

Due to its geographic and climatic conditions, the Czech Republic belongs to the countries, which have little potential for further increase in renewable energy sources at the status quo of their technological progress. Nevertheless, a certain level of potential increase is yet available in some of the renewable sources, which is recognised also by Budín (2015), who points out that the updated State Energy Policy suggests two times higher share of renewable energy sources in the Czech energy mix by 2040 even with an expected increase in power demands of this country. The potential for further development of the individual renewable sources in the Czech Republic is to be evaluated in the following subchapters.

4.4.1 Hydropower

Since many of the large Czech rivers have their springs in this country, the hydropower conditions are favourable for small power plants rather than large hydropower units. Motlík et al. (2007) mentions that while favourable locations for new large hydropower plants have already been widely exploited, the majority of potential locations for new hydropower units are concentrated on small rivers with a low flow rate and river head.

However, these locations do not provide significant hydrological conditions for the future investments to be viable. Motlík et al. (2007) suggest the opportunity of a technological improvement of the older Czech hydropower units, as numerous power plants currently operated could be reconstructed with installing modern technology, consequently improving overall efficiency of some hydropower plants by approximately 10-20 %. Vobořil (2016) points out that there is also a future opportunity of potentially transforming former mining sites into pumped-storage hydropower plants, as there is already an experimental power plant constructed on the site of Jeremenko mine in Ostrava. Nevertheless, hydropower represents only insignificant potential for the future development of renewable energy sources in this country.

4.4.2 Biomass

Biomass is recognised in Státní energetická koncepce České republiky (2015) as a renewable source with the largest potential in the Czech Republic. It suggests significant energy potential in heating, electricity production and transport sectors with increased utilization of industrial and municipal waste, unused arable land for energy crop production and biogas production. According to this concept for the future development in this country, electricity production of biomass sources could gradually increase to over 4.5 TWh by 2040, alongside with 4.2 TWh produced with utilization of biogas stations. However, it is important to consider environmental aspects alongside with sustainability of biomass production such as the local character of biomass energy consumption. Furthermore, impacts on soil quality and potential food production should be considered in a further increase in biomass energy utilization in the Czech Republic.

4.4.3 Solar power

The solar power development has stagnated since the controversial "Solar Boom", as support for larger photovoltaic power plants was substantially limited in 2014. However, with the new support program Nová Zelená Úsporám, there is a growing number of household photovoltaic systems for heating and electricity production. Solární asociace (2017) observes that in 2016, 540 projects with total installed power of 4,833 kW were supported and completed. It also estimates that potentially up to 2,000 MW of installed power could be reached with new household photovoltaic units and additional 5,100 MW by installing solar panels on rooftops of stores or factories, which would provide over 7 TWh of additional renewable electrical energy.

4.4.4 Wind power

Unlike countries with an access to the seashore, such as Germany or Denmark, favourable locations for new wind power plants and farms in the Czech Republic are merely highland locations above 600 meters above the sea level, alongside with the mountain ranges in the northern part of the country. However, as Motlík et al. (2007) argue, a significant part of potential locations with a suitable wind speed and other technical parameters have already been exploited, as there are restrictions upon the construction of wind power plants in protected areas such as landscape parks. Bouška (n.d.) remarks that there are only approximately 15 to 20 % of suitable locations remaining. Furthermore, with the current legislature and territorial requirements, alongside with the public opinion and other aspects, new wind power plant projects will have to overcome various difficulties. Therefore, in contrary to the situation in Germany, wind power will probably represent only a minor part of electricity production in the Czech energy mix.

4.4.5 Geothermal power

Despite the fact that in 2017, there are no geothermal power plants in this country yet, this source of renewable energy represents certain future possibilities, although the geological conditions are not as favourable as in Iceland or Italy. Rozsypalová (2017) mentions that there is a geothermal energy project planned in Litoměřice. The project in cooperation with German town Dresden includes plans for the potential construction of a HDR (Hot Dry Rock) cogeneration power plant for the production of heat and electricity from geothermal energy with drilling to a 5-kilometer depth. Státní energetická koncepce České republiky (2015) recognizes the future potential utilization of geothermal energy for household heating in this country, depending on economic aspects and demands for this type of household heating solution.

5 IMPACTS OF THE ENERGIEWENDE ON THE CZECH ENERGY SECTOR

As neighbouring countries, Germany and the Czech Republic have certain impacts on each other, especially as far as the energy sector is concerned. The German energy transition to renewables even further increases these impacts and has both direct and indirect consequences on the Czech energy sector. Černoch et al. (2015) explain three fundamental impacts of the Energiewende:

I unscheduled flows of electricity,
II price signals and volatility,
III incompatibility of the Czech energy strategy with the new market situation.

The unscheduled flows of electricity (**I**) are, according to the authors, predominantly caused by the unequal distribution of the production and consumption capacities. Černoch et al. (2015) point out that a significant part of the German power production is located on the North (with favourable conditions for off-shore wind power plants near the shore of the Baltic sea) alongside with a majority of power consumption in Germany located on the South. As a consequence, it is necessary to transfer a large amount of electricity over the domestic transmission network, which is not able to provide sufficient capacity to transport necessary volumes of electricity. This issue will have become even more prominent with the planned closure of nuclear power plants by 2022, as the majority of the German nuclear sources are located in the southern parts of this country. Therefore, when there is an increased power production of wind power plants, unscheduled overflows over the Czech border emerge. Furthermore, there is a growing export due to an increased production of electricity and its efficiency in Germany. Brož (2016) remarks that the Czech grid operator, ČEPS, has to install regulatory phase-shifting transformers in the proximity of the Czech-German borders to maintain the grid stability, which is endangered by overflows of electricity from Germany. Černoch et al. (2015) concludes by noting that ČEPS had to invest 60 million Czech crowns in order to increase the reserve capacity of the grid, while these investments reached almost three times the costs of remedial actions for the entire 2012 and 2013 years.

The Czech and German electricity markets are interconnected, so the Energiewende influences the prices of electricity. These price signals (**II**) then determine which sources will be profitable to construct or operate. Černoch et al. (2015) implies that conventional sources without flexible and quick regulation of power output, such as nuclear sources, are gradually pushed out of the market with the advent of renewables due to a decrease in economic efficiency. In the system with a larger share of weather-dependant renewables, as it was described in the subchapter **3.2**, there is a necessity of additional reserve capacity in the form of coal and gas power plants, resulting in surplus of energy sources, which is reflected in the lower level of the wholesale electricity price[6]. Furthermore, with the variable output of wind and solar power plants, the prices of electricity are volatile and with the low level of predictability, especially in the long-term business planning. Consequently, the viability of nuclear power plants on the interconnected market of Germany and the Czech Republic is questioned.

Last but not least, Černoch et al. (2015) consider the updated Czech energy policy as inconvenient, since it is not compatible with the new situation on the Czech market. The authors argue that incompatibility of the Czech energy (**III**) is caused by an exaggerated position of nuclear energy as a primary source of energy in the Czech energy mix by 2040. The Czech energy policy considers the completion of additional nuclear blocks in Temelín (2 x 1000 MW) with state price support as well as prolonged operational life of the power plant in Dukovany. However, the price signals observed by Černoch et al. (2015) reveal that there is a questionable viability of investments into construction of additional nuclear blocks in this country caused by underestimation of impacts of the German energy transition, which can potentially have significant consequences on the Czech economy.

6 A wholesale electricity price refers to the cost of electricity sold by a wholesaler with an additional charge after purchasing it from a producer on the electricity market (Goswami and Kreith, 2016).

6 CONCLUSION

The aim of this bachelor's thesis was to summarise the main information about renewable sources of energy with regard to European and international energy policy. Fundamental policies and treaties influencing the development of renewable sources were listed and evaluated in the second chapter after the brief introduction of the topic.

In the third chapter, renewable sources of energy in Germany were discussed, together with their historical background and modern development. It was followed by describing the transformation of German energy sector, called Energiewende, with the emphasis on its goals and development. In the second part of the last chapter, the use of renewable sources in Germany was examined, with statistical descriptions of the development of different sources of energy, also with respect to various technical aspects of production and consumption of electrical energy. The consequent part of the thesis evaluated the use of the selected sources of energy in contrast with the leading countries in Europe and their installed capacity of the given technology, followed by a brief evaluation of regional conditions and potential for further development.

The same methodology of analysis was used in the fourth chapter dealing with the Czech Republic. The history, use, conditions and potential for the development of renewable sources of energy in this country were evaluated. The two countries were also compared from the viewpoint of financial support of renewable technologies. However, a further analysis of impacts on the industry, such as manufacturing of components and an employment rate, alongside with other impacts on the economy of these countries, would be highly convenient for a broader perspective of the information provided in this thesis.

The last chapter was dedicated to the impacts of the Energiewende on various aspects of power production and distribution in the Czech Republic and their consequences. The chapter also pointed out the potential threats of the German energy transition to this country's energy strategy and safety.

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