Czech University of Life Sciences Prague
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Diploma Thesis

Economic evaluation of Czech energy mix

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DIPLOMA THESIS ASSIGNMENT

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Thesis title

Economic evaluation of Czech energy mix

Objectives of thesis

Compare energy production from economic and environmental standapoint of each energy source used in the Czech Republic. Based on the gained data using linear programming optimal energy mix is created that is suitable for the Czech Republic and economic evaluation is conducted.

Methodology

Literature: induction, deduction, synthesis

Analysis: linear programming, qualitative and quantitative data analysis

The proposed extent of the thesis

60 pages

Keywords

energy, emission, energy sources, sustainable development, evaluation, linear programming

Recommended information sources

CASTELLANO, Robert. Alternative energy technologies. [online] USA: Old City Publishing, Inc., 2012 ISBN 9782813000767

KARLOFF, Howard. Linear Programming. [online] Birkhäuser Boston., 2009 ISBN 9780817648435

RAJAN, G.G. Practical Energy Efficiency Optimization. [online] USA: PennWell Corporation., ISBN 1593700512

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Declaration

I declare that I have worked on the diploma thesis titled "Economic evaluation of Czech energy mix" by myself and I have used only the sources mentioned at the end of the thesis.

In Prague on _____

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I would like to express my gratitude to my supervisor Ing. Petr Procházka, MSc, Ph.D. for his useful suggestions and guiding through the process of composing the thesis.

Ekonomické vyhodnocení českého energetického mixu

Souhrn

Diplomová práce „Ekonomická evaluace českého energetického mixu“ se zabývá podílem jednotlivých zdrojů elektrické energie na celkovém energetickém mixu. Hlavním cílem práce je současný energetický mix zhodnotit z ekonomického a environmentálního hlediska. Na základě získaných dostupných dat práce poukazuje na základní problémy tohoto mixu, a to je především obrovský podíl uhelných elektráren a s tím spojené enormní množství emisí vypuštěných do ovzduší. Diplomová práce pomocí lineárního programování současný energetický mix optimalizuje a navrhuje tak optimální poměr vybraných energetických zdrojů jak z ekonomického tak i z environmentálního pohledu. Získaný výsledek snižuje celkové náklady na výrobu elektrické energie, bere v potaz podporu obnovitelných zdrojů a tím i dosažení zadaného cíle 13% podílu obnovitelných zdrojů na hrubé spotřebě elektřiny v roce 2020. Větší podíl obnovitelných zdrojů nahradí uhelné elektrárny, které budou sloužit jako doplňující energetický zdroj, což bude mít za následek snížení emisí.

Klíčová slova: energie, emise, zdroje energie, lineární programování, obnovitelné zdroje, udržitelný rozvoj, vyhodnocení, elektřina, energetický mix

Economic evaluation of Czech energy mix

Summary

The diploma thesis "Economic evaluation of Czech energy mix" focuses on the proportion of individual sources of electric energy in the total energy mix. The main objective is to evaluate the current energy mix from an economic and environmental point of view. Based on the available data, the thesis points to the basic problems of the mix, and it is especially huge proportion of coal power plants and the associated enormous amount of emissions released into the air. The diploma thesis optimizes the current energy mix by using linear programming and suggests the optimal ratio of the selected energy sources both from an economic and from an environmental perspective. The result obtained lowers the total cost of electricity production, taking into account the promotion of renewable resources and thus achieving the specified target of a 13% share of renewables in gross electricity consumption in 2020. A greater proportion of renewable energy sources will replace coal power plants, which will serve as an additional energy source, which will result in reduced emissions.

Keywords: energy, emission, energy sources, linear programming, renewable resources, sustainable development, evaluation, electricity, energy mix

Table of content

List of abbreviations

CSVE - Czech Society for Wind Energy

CVUT – Czech technical university in Prague

CZK – Czech crowns

EU - European Union

ERO - Energy Regulatory Office

GWh – Gigawatt hour

kV – Kilovolt

MPO – The Ministry of Industry and Trade

MWh – Megawatt hour

RER - Renewable energy resources

SEC - State Energy Policy

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1 Introduction

A stable and balanced energy mix is a prerequisite for the functioning of the economy of every developed country. Recent years have represented a period of dramatic changes for the field of energy. The previously stable industry with relatively long persistence had to cope with several significant factors. One of these factors was gradual subsidy of fossil fuels, whose place began to be taken by renewable energy resources. The main reason for this decline was mainly the reduction of the amount of emissions released into the air during energy production and the subsequent production of electricity. Countries around the world began to struggle with this problem and started to adapt to a new trend in the form of renewable resources.

The Czech Republic, of course, was no exception, and after joining the European Union it has to adapt to the legislative action which sets a certain percentage share to the individual member states that have to be represented by renewables in the gross electricity consumption. The limit for the Czech Republic was established at 8% share by 2010. This goal had been the main driving force for the development of the renewable sector in the Czech Republic that has triggered a wave of incredible support and setting of high purchase prices from these resources.

The photovoltaic sector was definitely hit the most by the support system, which was then created. Production of electricity from the sun has a high potential and in our conditions can be, especially in the eastern Moravia, effectively used. Since 2009, the purchase prices of electricity produced from photovoltaic panels started to grow year after year, which led to the so-called "solar boom" that occurred in our country by the end of year 2009.
The favourable conditions, which were created, attracted also foreign investors to the Czech Republic who took advantage of these conditions, and therefore, this country had built many photovoltaic power plants currently owned by investors from abroad.

The government intervened in 2013 when it was forced to adopt a law that significantly limited the support of the photovoltaic field, also due to the fact that this strong support of

renewable energy sources was negatively reflected in the prices of electricity for the final consumers who had to pay increasing contributions to these resources year after year.
The coal power plants represent over 50% of the current energy mix of the Czech Republic. It produces over 44,000 GWh of electricity in year. This enormous electricity production is also accompanied by an enormous amount of emissions released into the atmosphere during this production, and since the Czech Republic is among the countries, which are mindful of environmental aspects in the energy sector, it is necessary to modify the current energy mix, improve it and make it optimal for the Czech Republic.

The term "optimal energy mix" refers to a model that takes into account not only the environmental aspects, meaning a significant reduction of emission production, but also an optimal solution from an economic standpoint. It shows a mix of electricity sources that takes into account the stability of the production as well as the resultant cost of production.

2 Goals and Methodology

Hypothesis:

H1: The energy mix for the Czech Republic is optimal.

H2: Finding the model of optimal energy mix for the Czech Republic will reduce emissions and improve economic outcomes of electricity producers.

H3: The right combination of the use of selected sources in the energy mix reduces the cost of generating electricity together with its price.

2.1 Goals

The goal of the thesis is to compare energy production of each chosen energy resource in the Czech Republic. After evaluation of the current energy mix, based on the gained data by use of a linear programming tool the main objective is to create an optimal energy mix suitable for the Czech Republic and provide economic evaluation.

2.2 Methodology

The methods of induction, synthesis and deduction were used for the creation of the theoretical part.

The analytical part is based on quantitative and qualitative data analysis. The required data was gathered from publicly accessible sites of the Energy Regulatory Office. Linear programming, a publicly available tool, was used for the creation of the optimal energy mix. By using the simplex algorithm and mathematical optimization a set of individual energies that satisfy the conditions of the optimal mix is created. 6 main energy sources used in our country were selected for the optimal energy mix equation – photovoltaics, wind, water, coal power plants, nuclear power plants and biogas. Each source is evaluated in economic terms and in relation to energy legislation.

An optimal energy mix is created based on the analysis of the collected data with a positive economic effect, which will also take into account environmental aspects. At the end, the comparative method is used to compare the current and newly created optimal energy mix.

3 Literature Review

3.1 Energy

Energy is an essential industry which involves dynamics, great responsibility and respect. The 21st century is built on energy, it surrounds us every day and the world today can hardly imagine life without it. Because of its significance it is crucial that this field is stable with clearly defined rules. The stability itself plays a major role in the energy sector, especially in power transmission, and even though the European energy policy has identified a number of rules relating to security of supply, environmental protection and sustainable economic growth and stability issues quite often represents a big problem.[1]

Energy is a discipline that has undergone a huge development in all regions of the world in recent decades. States were forced to seek new sources of raw materials, thus causing to diversify the energy mix and adapting to more efficient standards both in the transmission and consumption of energy. European utilities, as one of the few, places strong emphasis on environmental requirements.[2]

The energy industry of the Czech Republic includes mainly the acquisition and distribution of all forms of energy, along with mining and utilization of energy resources such as coal, oil and natural gas. The production and distribution of electricity has the most important position in the energy industry.[3]

The states of the European Union, along with the Czech Republic, tend to reduce the impact of human activity on the environment.[4]

Since 2004, the Czech Republic contributes to increasing the use of renewable energy sources, especially solar power, wind power and biomass.

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[1] ORÁLEK, Petr. *Energy outlook 2013.* [online]. CR: Economia, a.s., 2013 [Accessed on 3.1.2016] Available from: http://www.cez.cz/edee/content/file/pro-media-2013/12-prosinec/energy-outlook-2013.pdf

[2] STREJČEK, Petr. *Česká a evropská energetika v roce 2014.* [online]. 30.2.2014 [Accessed on 12.1.2016]. ISSN 1801-4399. Available from: http://energetika.tzb-info.cz/11019-ceska-a-evropska-energetika-v-roce-2014

[3] JENERÁLOVÁ, Ivana. *Enrgetický průmysl ČR.* [online]. 6.11.2011 [cit. 12.1.2016]. Available from: http://www.czech.cz/cz/Podnikani/Ekonomicka-fakta/Energeticky-prumysl-CR

[4] FEREŠ, Jaroslav, HORATIUS, David. *Možnosti využití obnovitelných zdrojů energie v České republice.* [online]. 2007 [cit. 10.11.2015]. Available at: http://www.cenia.cz/web/www/cenia-akt-tema.nsf/$pid/MZPMSFOFVRTC

Total energy consumption is growing rapidly, along with CO2 production. Energy consumption depends on:

- Population growth
- Industrial development and utilization of industrial technologies
- The growth of civilization and quality of life due to globalization[5]

How much energy is actually produced by each source is represented by the value of annual electricity production, which takes into account real conditions.[6]

3.1.1 Energy resources

Energy is included in everything that is happening on Earth, and is used in transport or biological systems, so it is important to be aware of its significance in matters of world nations.[7] It is defined as "*ability to perform work and is available for us in various forms and from many different sources.*"[8] Energy resources can be divided into primary and secondary. The primary energy resources include natural resources, meaning those that are not transformed by humans. These resources can be further divided into renewable and non-renewable. The secondary energy resources include sources that originated from human activities. These include: municipal waste, recuperation of oil, landfill gas or waste heat.[9]

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[5] NENADÁLOVÁ, Lucie. *Hodnocení energetického komplexu na životní prostředí.* [online]. [Accessed on 10.10.2015]. Available from: http://www.odpadoveforum.cz/DVD/dokumenty/prispevky/317.pdf

[6] MACHALA, Zdeněk, PAPAJANOVSKÝ, Jan. *Energetika České republiky: EKONOMICKÝ VÝHLED DO ROKU 2050.* [online]. 2014 [cit. 10.11.2015]. Available at: https://socv2.nidv.cz/archiv36/getWork/hash/1a5ad36a-aa31-11e3-98b3-faa932cbcfda

[7] BROWN, E. Charles. *World Energy Resources.* [online]. GE: Springer-Verlag Berlin Heidelberg, 2002. ISBN 3-540-42634-5. Available from: https://books.google.cz/books?id=WLC7CdLOZosC&printsec=frontcover&dq=energy+sources&hl=cs&sa=X&redir_esc=y#v=onepage&q=energy%20sources&f=false

[8] BROWN, E. Charles. *World Energy Resources.* [online]. GE: Springer-Verlag Berlin Heidelberg, 2002. ISBN 3-540-42634-5. Available from: https://books.google.cz/books?id=WLC7CdLOZosC&printsec=frontcover&dq=energy+sources&hl=cs&sa=X&redir_esc=y#v=onepage&q=energy%20sources&f=false

[9] MATĚJŮ, Dalibor. *Obnovitelné zdroje energie v energetickém mixu.* [online]. 18.3.2014 [cit. 2.12.2015]. ISSN 1801-4399 Available at: http://energetika.tzb-info.cz/9668-energetika-vybrane-pojmy-i

3.1.1.1 Non-renewable resources

Renewable energy resources are those resources which are not infinite, which is caused by their faster consummation than renewal. The efficiency of our use of these resources depends on when they will completely run out. Non-renewable energy resources include fossil fuels, coal, oil and natural gas.[10]

Coal

The Czech Republic ranks among the countries with significant reserves of lignite and coal, which in the past represented the traditional source of fuel for the Czech Electricity and Czech heating industry. Now heating industry is the field in which, immediately after the production from coal power plants, coal is used the most. More than one third of the total heat in the Czech Republic is produced from the coal. Coal is a domestic source for the country, which significantly reduces dependence on imports of energy commodities from abroad.[11]

The Czech Republic was always self-sufficient and independent of imports thanks to sufficient supplies of coal. 40% of all coal mined in the Czech Republic is intended for energy purposes. There are two main power plants involved in energy consumption of coal, power plants Dětmarovice and Vitkovice. Dětmarovice power plant poses with its installed capacity of 800 MWh and is one of the most important sources of electricity in northern Moravia.[12]

Nuclear energy

The use of nuclear energy is becoming an essential part of the energy mix for most developed countries, along with the Czech Republic. Nowadays, it is expected that nuclear power will significantly influence the future development of the economy. Currently there

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[10] *Neobnovitelné zdroje energie.* [online]. [cit. 10.10.2015] Available at: http://www.snizujeme.cz/slovnik/neobnovitelne-zdroje-energie/

[11] TROJÁNEK, Vladimír. *Energetická bezpečnost ČR a budoucnost energetické politiky EU.* [online]. CR: Ústav mezinárodních vztahů , v. v. i., 2011. ISBN 978-80-87558-02-7. Available at: https://books.google.cz/books?id=EhWFBwAAQBAJ&pg=PA83&lpg=PA83&dq=energetick%C3%BD+mix+%C4%8Dr&source=bl&ots=WHieQbL5Jb&sig=AHEdN90ZbjsVhPq3FBsOWuJrwd4&hl=cs&sa=X&ved=0ahUKEwjNxbbhn_7JAhUFWSwKHbwQAUA4FBDoAQgyMAM#v=onepage&q=energetick%C3%BD%20mix%20%C4%8Dr&f=false

[12] MAJLING, Eduard. *Těžba a spotřeba černého uhlí v ČR.* [online]. 27.6.2015 [Accessed on 10.11.2015]. Available at: http://oenergetice.cz/elektrina/tezba-cerneho-uhli-v-cr/

is not better source of energy that would cover the growing energy requirements and thus does not contribute to environmental degradation.[13]

Nuclear power plants are one of the types of steam power plants. They use the same manner for converting thermal energy into electric energy as in coal power plants, but unlike coal power plants, nuclear power plants produce no greenhouse gases or other harmful substances discharged into air, they release only steam.
Nuclear power plants have high installed output and from the economic point of view they are preferred due to their low production costs. On the other hand, they have a high acquisition cost and long payback period. There are two operating nuclear power plants in the Czech Republic, Temelin and Dukovany.[14]

3.1.1.2 Renewable resources

In the conditions of the Czech Republic, we count as renewable energy resources water power plants, wind power plants, solar (photovoltaic) power plants, biomass, biogas, geothermal energy and liquid biofuels. In the Czech Republic, however, renewables can be taken only as a supplement to conventional resources. Production from these sources is difficult to estimate, therefore there is a risk of overloading the capacity of the Czech transmission network.[15]

Regarding the use of renewable energy resources in our country, the key point for the Czech Republic was entrance into the European Union in 2004. This entrance brought along certain obligations based on principles of a coordinated EU energy policy.[16]

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[13] CEZ.CZ. *Jaderná energetika v České republice.* [online]. [Accessed on 12.11.2015]. Available at: http://www.cez.cz/cs/vyroba-elektriny/jaderna-energetika/je-v-cr.html

[14] MACHALA, Zdeněk, PAPAJANOVSKÝ, Jan. *Energetika České republiky: EKONOMICKÝ VÝHLED DO ROKU 2050.* [online]. 2014 [cit. 10.11.2015]. Available at: https://socv2.nidv.cz/archiv36/getWork/hash/1a5ad36a-aa31-11e3-98b3-faa932cbcfda

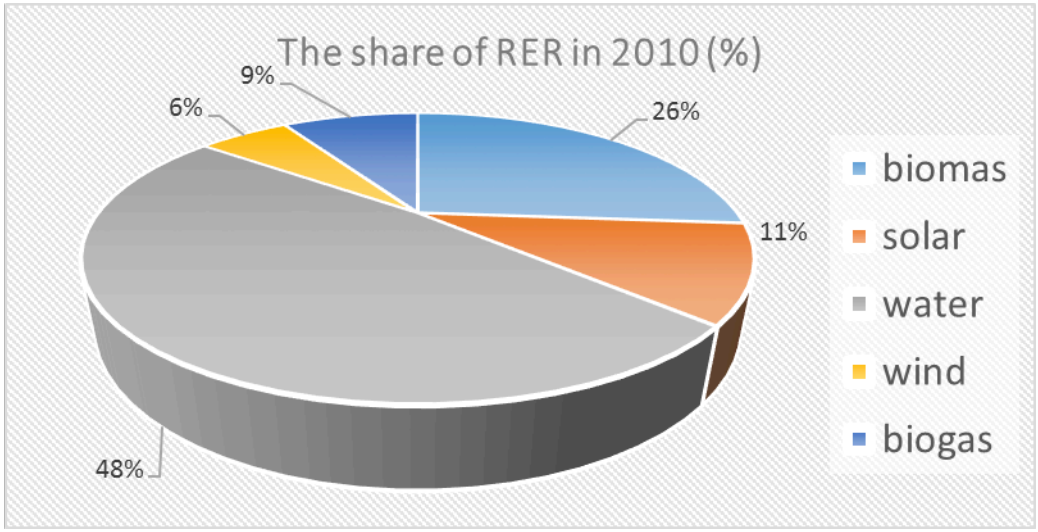
[15] CEZ.CZ. *Energie z obnovitelných zdrojů.* [online]. [Accessed on 12.11.2015]. Available at: http://www.cez.cz/cs/vyroba-elektriny/obnovitelne-zdroje.html

[16] COLL. OF AUTHORS. *Obnovitelné zdroje energie a možnosti jejich uplatnění v České republice.* [online]. CR: ČEZ, a.s., 2007 [Accessed on 10.10.2015]. Available at: http://www.cez.cz/edee/content/file/energie-a-zivotni-prostredi/oze-cr-all-17-01-obalka-in.pdf

The main law regarding to the use of renewable energy resources, Act 180/2005 Coll., gives obligation to ERO to provide regular annual evaluation of the share of renewable electricity in gross electricity consumption in the previous calendar year, together with publishing of economic impact of renewable electricity generation on the final price of electricity for final consumers in the upcoming calendar year.[17]

With the accession to the EU, the Czech Republic reached its given aim to achieve 8% share of renewable energy in gross electricity consumption. The Czech Republic fulfilled this objective with 8.24%. The following chart shows the share of individual and widely used renewable resources in the Czech Republic in 2010. It is seen that the biggest contribution in meeting the target had hydropower, which accounted for nearly 50%, the second mostly used renewable resource was biomass.

Graph 1: The share of renewable energy resources on total energy generation in 2010



Source: ČVUT (2011)[18]

The use of renewable energy resources has many advantages, but these are very difficult to be quantified by money. Among the most important advantages of renewable resources is

[17] COLL. OF AUTHORS. *Obnovitelné zdroje energie a možnosti jejich uplatnění v České republice.* [online]. CR: ČEZ, a.s., 2007 [Accessed on 10.10.2015]. Available at: http://www.cez.cz/edee/content/file/energie-a-zivotni-prostredi/oze-cr-all-17-01-obalka-in.pdf

[18] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

definitely more favourable impact on environmental. These are resources with significantly lower level of pollution and elimination of greenhouse gases into the atmosphere.

Also, the risk of accidents is noticeably smaller. From an economic perspective, the development of renewables helps to increase energy self-sufficiency of communities, regions and even countries. Along with this, there is an increase in job opportunities and overall economic development in the regions.[19]

Parameters of economic evaluation

When assessing the economic efficiency of investments of renewable resource, it is important to consider some essential parameters.

- **Payback period**

The payback period is essential benchmark of efficiency. The overall result of simple payback period on investment is achieved by dividing the net income. Conversely real payback period determines the return for actual economic conditions. The method of financing is mainly taken into account.

- **Internal rate of return**

It is a statement of return on investment. It works on the same principle as interest in the bank.

- **Net present value**

This indicator reflects the true value of the investment at the end of the economic life. Summed up with all proceeds lifetime, after deducting the initial investment and the reduction due to discounting. If the net present value is negative, it means that the project is in a loss.[20]

- **Cash flow**

Cash flow is usually expressed as a graph. From this graph it is seen how much money the project earns each year and how much it consumes. For investors, this is a significant

[19] Coll. of authors. *Obnovitelné zdroje energie – Ekonomika a možnosti podpory.* [online]. CR: Ministerstvo životního Prostředí, 2009 [2.1.2016]. ISBN 978-80-7212-519-7 Available at: http://biom.cz/upload/6e01d6d4c4835ec93cda508772f3bf6e/oze_ekonomika.pdf

[20] Coll. of authors. *Obnovitelné zdroje energie – Ekonomika a možnosti podpory.* [online]. CR: Ministerstvo životního Prostředí, 2009 [2.1.2016]. ISBN 978-80-7212-519-7 Available at: http://biom.cz/upload/6e01d6d4c4835ec93cda508772f3bf6e/oze_ekonomika.pdf

indicator because the chart can also represent the ability to repay the loan or payment of one-time expenses.[21]

Photovoltaic power plants

The Sun and its radiation supplies the Earth's with energy 15000 times bigger than humanity will be able to consume in a real time. This represents a huge potential in the field of renewable energies, together with the scope for environmentally acceptable and economically less demanding way of using solar energy. The use of this energy in family houses is mainly for the purpose of production and subsequent delivery of electricity to the grid. The process of converting solar energy into electricity is called photovoltaics.[22]

Gaining electricity from the Sun using photovoltaic panels is a discipline that developed very dynamically in recent years in the Czech Republic. In mid-2009 over 2 000 solar power plants were built in the Czech Republic, which resulted in the so-called solar boom that occurred in the country and led to an enormous increase in the use of photovoltaics. The state began to absurdly support photovoltaics sector and contributions to photovoltaics grew from year to year. This was negatively reflected in electricity prices for final consumers, especially households. But solar boom had also its advantages in terms of the share of renewables in gross electricity consumption.

This consumption in 2008 rose to 5.2%, and namely solar boom contributed to the fact that in 2012 this value had already climbed to 11.6%.[23]

The most appealing thing about photovoltaic power plants was their economic benefit. What investors valued the most was the law guaranteed purchase price and the time of purchase. In this position, the power plant owner should have a secure income for the next 20 years.

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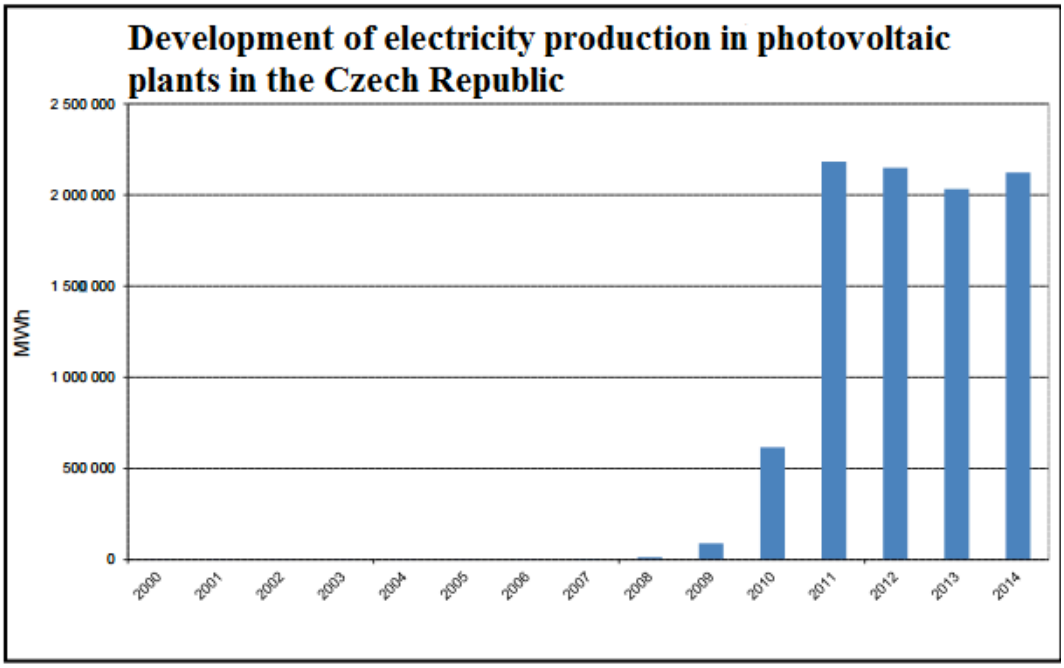
[21] Coll. of authors. *Obnovitelné zdroje energie – Ekonomika a možnosti podpory.* [online]. CR: Ministerstvo životního Prostředí, 2009 [2.1.2016]. ISBN 978-80-7212-519-7 Available at: http://biom.cz/upload/6e01d6d4c4835ec93cda508772f3bf6e/oze_ekonomika.pdf

[22] *Fotovoltaické systémy.* [online]. [Accessed on 12.11.2015]. Available at: http://www.fotovoltaicke-systemy.info/

[23] BUDÍN, Jan. *Žebříček deseti evropských států s největším podílem OZE.* [online]. 16.4.2015 [Accessed on 3.12.2015]. Available from: http://oenergetice.cz/obnovitelne-zdroje/zebricek-deseti-evropskych-statu-s-nejvetsim-podilem-oze/

Likewise, the investment costs were not challenging, they matched the size of the device. But currently the construction of massive solar power plants with high installed power capacity represents the problem of electricity distribution, in contrary it is convenient for smaller generators located on the roof of a house, for which such connection does not represent any problem.[24]

Graph 2: Development of electricity production in photovoltaic plants in the Czech Republic.



Source: MPO[25]

Wind power plants

The biggest advantage of wind energy is that it can be painlessly converted to the desired and universally usable electricity. As wind increases with the cube of the speed of the air, it is evident that even a slight change in the wind speed is significantly reflected in the quantity of electricity obtained. Therefore, it is essential to correctly determine the wind speed in the area before the final decision to build a wind power plant.

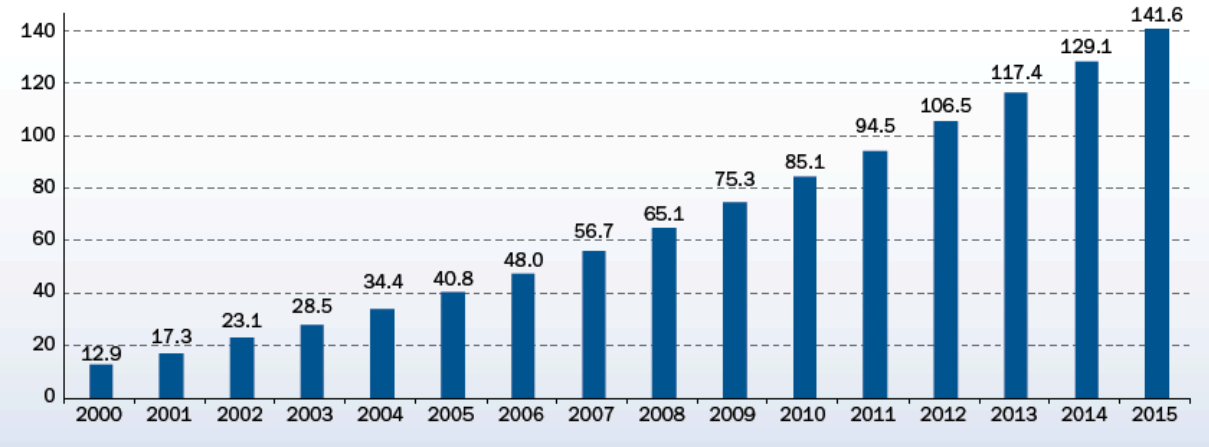
[24] *Příklad ekonomiky fotovoltaické elektrárny*. [online]. © 2008 EkoWATT [Accessed on 10.10.2015]. Available at: http://fotovoltaika.ekowatt.cz/priklad.php

[25] *Vývoj v produkci elektřiny z fotovoltaických elektráren v České republice.* [online]. Data available from: MPO (2000-2007), ERO (2008-)

The number of suitable locations in the Czech Republic is unfortunately limited because of several factors. It is a nature protection interests, the resistance of regional authorities, and also the meet of the necessary technical and legal regulations.[26] Likewise, weather conditions for Czech Republic are not favourable for greater use of wind energy.

The use of wind power plants also represents some disadvantages and risks for the transmission system. Irregularity, randomness and poor predictability of the strength and direction of the wind causes that these power plants can work only at certain times during the year, in the Czech Republic it is not more than 20% of the year. So build capacity is not fully used which is causing both economic losses and also problems in regulation in the transmission system.[27]

Graph 3: Cumulative wind power installations in the EU (GW)



Source: CSVE (2013)[28]

[26] Coll. of authors. *Obnovitelné zdroje energie – Ekonomika a možnosti podpory.* [online]. CR: Ministerstvo životního Prostředí, 2009 [2.1.2016]. ISBN 978-80-7212-519-7 Available at: http://biom.cz/upload/6e01d6d4c4835ec93cda508772f3bf6e/oze_ekonomika.pdf

[27] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

[28] *Celková výše instalovaného výkonu větrných elektráren v EU v letech 2000 – 2015.* [online]. © 2013 Česká společnost pro větrnou energii. Available from: http://www.csve.cz/clanky/vte-v-evrope/282

Water power plants

The status of hydroelectric power plants among renewable sources is privileged. They contribute to the total production from renewable sources over 80% worldwide, and their share in the Czech Republic was not endangered nor by significant solar boom that hit our country in recent years. This renewable resource represents several advantages, particularly the ability of rapid start up and shutdown, therefore it is used by the transmission system as rapid supplementary source of energy in the event of failure of another source, therefore they are greatly contributing to the stability of our transmission system.[29]

Their importance in the Czech Republic is not in the volume of electricity production, but in their unique and specific ability to respond promptly to the immediate need for electricity in the transmission system. Hydroelectric power plants also have high efficiency of conversion of mechanical energy to electrical energy and pollute the surrounding air minimally. They represent a relatively cheap source of electricity that our country uses mainly during peak demand.[30]

Biomass

"*Biomass is a material of biological origin of non-fossil nature, which usually comes from plant breeding, breeding animals, production of organic origin, and other organic wastes*."[31]

Electricity generation from biomass is an economically attractive technology for combined heat and power generation. One of the alternatives is the use of biomass as a renewable resource.[32]

The use of biomass as a renewable resource of energy has a significant importance in terms of energy. As a source it has high energy potential of centralized energy production.[33]

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[29] ORÁLEK, Petr. *Energy outlook 2013.* [online]. CR: Economia, a.s., 2013 [Accessed on 3.1.2016] Available from: http://www.cez.cz/edee/content/file/pro-media-2013/12-prosinec/energy-outlook-2013.pdf

[30] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

[31] Pastorek, Z. *Biomasa – obnovitelný zdroj energie.* FCC Public: 2004, 288 s. [Accessed on 10.11.2015]. ISBN: 80-86534-06-5

[32] *Technologie pro zpracování biomasy.* [online]. ©2016 Czechproduct.cz.s.r.o. [Accessed on 9.10.2015]. Available from: http://www.contechin.eu/3625/vyroba-el-energie-z-biomasy/

Energy use of biomass represents an incineration of plant and woody material along with non-renewable fuels to produce electricity or heat. Biomass is usually divided into several categories:

- Firewood
- Wood waste, sawdust, bark, wood chips, forest residues after mining
- Plant Materials
- Briquettes and pellets
- Cellulosic liquor
- Liquid biofuels[34]

Biogas

In former times the biogas power plants were built especially for the purpose of settling the problem of waste, where energy production was not the main function and the feedstock was free. Nowadays, it does not work like that anymore. Feedstock for biogas power plants is often corn or other biomass used in agriculture. This will automatically increase the cost of the raw materials, especially when shipping costs is added.

To avoid compromising the economics of investment, there is need to determine the potential of the available biomass. Economy of operation of biogas power plants can be strengthened, for example by selling heat that is partly used in the process. For this reason, it is efficient to build a biogas power plant close to residential neighbourhoods, where the heat could be sold.[35]

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[33] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

[34] BUFKA, Aleš, ROSECKÝ, Daniel. *Obnovitelné zdroje energie v roce 2014.* [online]. Ministerstvo Průmyslu a Obchodu, 12.1.2016. Available from: file:///C:/Users/Nat%C3%A1lia/Downloads/priloha001%20(2).pdf

[35] Coll. of authors. *Obnovitelné zdroje energie – Ekonomika a možnosti podpory.* [online]. CR: Ministerstvo životního Prostředí, 2009 [2.1.2016]. ISBN 978-80-7212-519-7 Available at: http://biom.cz/upload/6e01d6d4c4835ec93cda508772f3bf6e/oze_ekonomika.pdf

3.2 Transmission system of the Czech Republic

The electric transmission system is an interconnected system of devices that are designed to ensure the transmission of electricity from producers to individual users, households. This distribution is called the electric power distribution. The whole system is created by the backbone of electricity transmission and provides transmission over great distances and in large volumes.[36]

The transmission system of the Czech Republic is one of the integral part of the European interconnected electricity grid.[37] When electrical energy had begun to be industrially used, it was generally used locally and for own use, so there was no need to build a distribution or transmission system. Along with the emergence of the first public power plants in the first decade of the last century, also timing systems started to emerge. Distribution system providing electricity to individual customers, both industrial and municipal, is build up on transmission system. This system has mostly distribution or radial character.[38]
In 1919 "Law on continuous electrification of the country" was published, which was also the impetus for the construction of the grid in the form it has today.

Brochure of 1924 issued by the Provincial Office on the cultivation of trades characterized the main features of the emerging transmission system: "*The task of continuing electrification is to build on the territory of the Czechoslovak state the closed chain of large power plants established on sources of natural energy, that is, both on mines, both on large hydro powers in a way it allows, by working to a common network, economical distribution of electrical energy in sufficient quantities throughout the state*."[39]

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[36] http://www.gvp.cz/~vondrackova/fyzika/3.E-%20refer%C3%A1ty%20-elektromagnetismus/03-P%C5%99enosov%C3%A1%20soustava%20energetiky-Bed%C5%99ich09.pdf

[37] HONIŠ, René, and coll. *Přenosová soustava České republiky.* [online]. Vsoké učení technické v Brně, ISBN 978-80-905392-3-5. Available from: http://partnerstvi-energetiky.msek.cz/wp-content/uploads/2013/01/01-Prenosova-soustava-Ceske-republiky.pdf

[38] Máslo, Karel. *Řízení a stabilita elektrizační soustavy,* Asociace energetických manažerů 2013, https://www.powerwiki.cz/attach/PrilohyVyuka/%C5%98%C3%ADzen%C3%AD%20a%20stabilita%20elektriza%C4%8Dn%C3%AD%20soustavy.pdf

[39] CEPS,a.s. [online]. © ČEPS,a.s., 2016. Available from: https://www.ceps.cz/CZE/Cinnosti/Technicka-infrastruktura/Stranky/Default.aspx

The main part of transmission grid consists of 400 kV. Routes 220 kV are also located there, they serve as a backup and additional guidance. Electricity transmission network is used to distribute power from large power plants to the whole Czech Republic, and is part of the international connection of Europe.[40]

The transmission system of the Czech Republic is historically designed in a way to be able to allow and solve transport of a large amount of electricity from the various resources of electrical power through the transmission and distribution systems to end users. Renewable energy resources represent an installed capacity of up to approximately ten megawatts, depending on the type of renewable energy resource. Due to their installed power and other operational and technical issues, they are connected to the pipelines either directly or via consumer installation.[41]

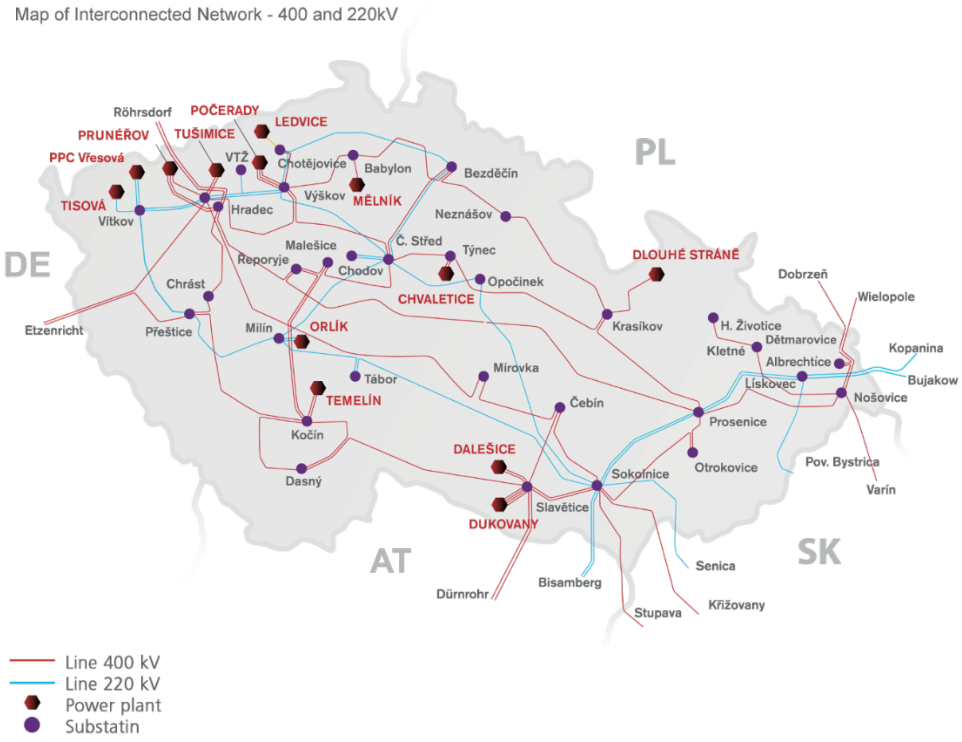
Connection and operation of individual renewable energy sources into the transmission system affects the quality of electricity supplied to end consumers. Each source connected to the transmission system is able, depending on its performance, either increase or decrease the voltage at the connection point and thus the size of the total distribution of voltage in the individual network nodes. For distributor of the transmission system, it is essential that the operation of renewable energy resources in parallel with the transmission system do not worsen the quality of voltage above permissible limit.[42]

[40] CEPS,a.s. [online]. © ČEPS,a.s., 2016. Available from: https://www.ceps.cz/CZE/Cinnosti/Technicka-infrastruktura/Stranky/Default.aspx

[41] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

[42] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

Picture 1: Transmission system data



Source: CEPS, a.s. (2015)[43]

3.2.1 The balance of the energy mix and the stability of production

While trying to ensure reliable, secure and environmentally friendly energy supply for the needs of the population but also the Czech economy at competitive and affordable prices, it is beyond the need to focus on one of the main priorities and this is a balanced energy mix. Balance of the energy mix is a cornerstone for the stability of the grid of the country and the fulfilment of responsible imports of electricity to customers.

It regards: "*balanced mix of primary energy sources and electricity production resources based on its broad portfolio, effective utilization of all available domestic energy resources*

[43]CEPS, a.s. [online] available at: https://www.ceps.cz/ENG/Cinnosti/Technicka-infrastruktura/Pages/Udaje-o-PS.aspx

and maintain the power balance surplus of EC with ample reserves. Maintaining strategic reserves of available domestic energy forms."[44]

3.2.2 Fluctuations in production and the role of CEPS in solving this problem

The transmission system of the Czech Republic must also face several threats from neighbouring transmission systems. The biggest one represents the transmission network in Germany, because of it, the Czech transmission system faced strong overload in 2009 and even teetered on the edge of safe operation. The main reason was mainly an enormous wind energy in northern Germany.[45]
Country managed to stabilize the situation, but northern neighbours utilize wind energy in large numbers, and therefore CEPS has to still count on a huge threat of the flow of energy from Germany to the Czech transmission system.

Another factor which burdens the transmission system of the Czech Republic is the amount of electricity that flows through the country into neighbouring countries. Germany uses mainly Czech transmission system to transfer power from the northern part of the Germany further to the south to Bavaria. All these costs, which are needed to cover the losses incurred by the electricity transmission, must be financed by the CEPS. So far, there is no mechanism which would compensated costs induced in these situations as well as the costs of induced investments in the development of networks of individual operators.[46]
The operator of the Czech transmission system had to face high and repeated onslaught of electricity from Germany in 2014/2015.

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[44] *Aktualizace státní energetické koncepce České republiky.* [online]. Prague 2014 © Copyright 2005 MPO [Accessed on 11.11.2015]. Available from: http://www.strukturalni-fondy.cz/getmedia/85476420-5469-46ab-a19f-51a0c97eae8d/AKTUALIZACE-STATNI-ENERGETICKE-KONCEPCE-CR.pdf?ext=.pdf

[45] *Německé větry – hrozba pro české přenosové soustavy.* [online]. © 2014 – 2016 – FCC Public s.r.o. [Accessed on 9.10.2015]. Available from: http://www.odbornecasopisy.cz/elektro/casopis/tema/nemecke-vetry-hrozba-pro-ceske-prenosove-soustavy--10222

[46] *Německé větry – hrozba pro české přenosové soustavy.* [online]. © 2014 – 2016 – FCC Public s.r.o. [Accessed on 9.10.2015]. Available from: http://www.odbornecasopisy.cz/elektro/casopis/tema/nemecke-vetry-hrozba-pro-ceske-prenosove-soustavy--10222

The company states that the main cause of these problems is the promotion of renewable energy sources, decommissioning of nuclear power plants in Germany and the unified German-Austrian zone that behaves as between their countries was no capacity constraints. Approximately 3,400 MW of electricity flowed over the Czech Republic to the south only at the end of 2014, compared to installed capacity of Temelin (our largest nuclear power plant) is about 2,200 MW.

CEPS published the total cost to extraordinary measures to more than 60 million CZK.[47]In 2015, the transit of electricity from Germany through the Czech Republic was on its record, it grew by 40%. CEPS states that the burden of the Czech transmission network has a negative impact both on the operational safety and it also increases losses in the domestic system. Last year, these losses accounted for 1,007 GWh, which represents about 20% more than in 2014.[48]

3.2.3 Czech Republic's energy balance

Energy balance of the Czech Republic is based on burning fossil fuels, especially coal. Even though the share of coal in the energy mix and electricity production gradually decreases, its representation is still significant.[49]

In addition to the rules that are dictated by the European Union energy sector, the key document determining the future of the National Energy is the National Energy Policy. The effort of the Energy Policy is to provide a stable business environment, which will provide investors with some certainty of investment into new sources.[50]

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[47] ČTK. *Nápory energie z Německa stály ČEPS přes 60 milionů.* [online]. Copyright 2016 Mladá fronta a. s. [Accessed on 10.11.2015]. Available from: http://zpravy.e15.cz/byznys/prumysl-a-energetika/napory-energie-z-nemecka-staly-ceps-pres-60-milionu-1159555

[48] *Česko trápí rostoucí nápor elektřiny z Německa.* [online]. 5.2.2016 Copyright © 2003–2016 Borgis, a.s. © Copyright © 2016. [Accessed on 20.2.2016]. Available from: http://www.novinky.cz/ekonomika/393935-cesko-trapi-rostouci-napor-elektriny-z-nemecka.html

[49] NENADÁLOVÁ, Lucie. *Hodnocení energetického komplexu na životní prostředí.* [online]. [Accessed on 10.10.2015]. Available from: http://www.odpadoveforum.cz/DVD/dokumenty/prispevky/317.pdf

[50] ORÁLEK, Petr. *Energy outlook 2013.* [online]. CR: Economia, a.s., 2013 [Accessed on 3.1.2016] Available from: http://www.cez.cz/edee/content/file/pro-media-2013/12-prosinec/energy-outlook-2013.pdf

In the energy sector, and especially in the field of electricity, the Czech Republic needs to maintain a high degree of independence along with the position to continue to provide the necessary partner for the neighbouring countries. This ensures a strong negotiating position to promote domestic energy policy.

3.3 Legislative measures

Power is the backbone of the national economy. Its effective functioning is a prerequisite for successful development and growth of the quality of life of the society in every country. Accessible, safe and affordable energy is one of the basic conditions for the functioning of a democratic society. Functioning energy sector is an essential condition for national security. For the creation of a relatively stable environment for the development of the energy sector is therefore responsible state.[51]

Essential part of the economic policy of the Czech Republic includes the State Energy Policy. It is the basic document for setting energy policy, the use of primary energy sources and the promotion of renewable energy sources. SEP is an expression of state responsibility for creating conditions for reliable and permanently safe supplies of energy at affordable prices and for creating conditions for its effective use, which will not endanger the environment and will comply with the principles of sustainable development. This legal responsibility is fulfilled by state by establishing the legislative framework and rules for the operation and development of energy sector.[52]

The obligation to draw up the National Energy Policy is set for by law no. 406/2000 on energy management, which establishes the concept of regional energy policy for each region. State energy concept is developed by the Ministry of Industry and Trade and the document is subsequently approved by the government.[53]

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[51] *Energetická politika České republiky.* Energetická politika, vládní dokument. [online]. 12.1.2000. [Accessed on 20.1.2016]. Available from: http://www.eis.cz/dokumenty/153_5_0_12005-10-30_13-51-58.htm

[52] *Energetická politika České republiky.* Energetická politika, vládní dokument. [online]. 12.1.2000. [Accessed on 20.1.2016]. Available from: http://www.eis.cz/dokumenty/153_5_0_12005-10-30_13-51-58.htm

[53] *ZÁKON 406/2000 SB. O HOSPODAŘENÍ ENERGIÍ.* [online]. © MPO 2008. [Accessed on 20.1.2016]. Available from: https://www.mpo-efekt.cz/cz/legislativa/zakony-a-vyhlasky/zakon-406-2000

3.3.1 State Energy Policy of 2004

First State Energy Concept was approved by Government in Resolution no. 211 in March 2004. Concept defines the priorities and objectives of the Czech Republic in the energy sector and describes specific instruments of implementation of energy policy. It also includes outlook to 2030.[54] When selecting priorities, objectives and set of instruments, the State Energy Policy was respected from energy, environmental, economic and social viewpoints.

Government has identified three basic priorities and four main objectives of energy policy in the State Energy Policy, including the instruments for their implementation.

Basic priorities of the SEP:

- The maximum independence of the Czech Republic on foreign sources of energy, energy resources from risky areas, and reliability of supplies of foreign resources
- Maximum security of energy sources, including nuclear safety, the reliability of all types of energy efficient and decentralized energy systems
- Maximum sustainable development with emphasis on environmental protection, economic and social dimensions of development[55]

The main objectives set by the SEP:

- Maximising energy efficiency
- Ensuring effective amount and structure of consumption of primary energy sources
- Provision of maximum environmental friendliness
- Completing the transformation and liberalization of the energy sector[56]

In 2009, the Ministry of Industry was preparing an update of the SEP, which responded mainly to the partial liberalization of the energy sector and worked out the situation in the Czech Republic with regard to developments in Central Europe more into detail. However, the complete proposal of the SEP has not been approved.

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[54] *Státní energetická koncepce ČR.* Ministerstvo Průmyslu a Obchodu. [online]. 10.5.2010 © Copyright 2005 MPO. [Accessed on 10.2.2016]. Available from: http://www.mpo.cz/dokument5903.html

[55] *Státní energetická koncepce České republiky.* Ministerstvo Průmyslu a Obchodu. [online]. 10.3.2004 © Copyright 2005 MPO. [Accessed on 12.2.2016]. Available from: http://www.mpo.cz/dokument5903.html

[56] *Státní energetická koncepce České republiky.* Ministerstvo Průmyslu a Obchodu. [online]. 10.3.2004 © Copyright 2005 MPO. [Accessed on 12.2.2016]. Available from: http://www.mpo.cz/dokument5903.html

3.3.2 Update of the SEP in 2015

Still valid National Energy Policy of 2004 was in many ways overcome in the following years and did not reflect the number of events that have occurred in the energy sector and in the European economy. For example the Czech Republic's entry into the EU, energy market liberalization, newly formulated climate and energy policy of the EU, gradually aging production mix, lack of generational renewal energy and technical experts, market distortions and last but not least, the dynamic development of the energy policy in other European countries.

Even with regard to meeting of European targets, the update had to be admitted. This occurred in 2015, when update of the State Energy Policy was approved by government on 18 May 2015. This is a key national strategic document in the field of energy, which gives strategic task for the development of Czech energy for another 25 years.[57]

The SEP builds on the natural comparative advantages of the Czech Republic, which are given by the option to use different types of energy sources within the limited natural potential and economic characteristics of the state. "*The main mission of the National Energy Policy is to provide reliable, safe and environmentally friendly energy supply for the needs of the population and economy of the Czech Republic, at competitive and affordable prices under standard conditions. It must also ensure uninterrupted power supply in emergency situations to the extent necessary for the functioning of the main components of the state and the survival of the population."*[58]

Finally, its objective is also to ensure a stable and predictable business environment, efficient government and adequate and secure energy infrastructure. State takes responsibility for the long-term direction of the energy sector through this concept.

Updated State Energy Policy also identifies the mechanisms that ensures national security in energy supply. It proposes especially greater diversification of resources and interest in

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[57] *Aktualizace státní energetické koncepce České republiky.* [online]. Prague 2014 © Copyright 2005 MPO [Accessed on 11.11.2015]. Available from: http://www.strukturalni-fondy.cz/getmedia/85476420-5469-46ab-a19f-51a0c97eae8d/AKTUALIZACE-STATNI-ENERGETICKE-KONCEPCE-CR.pdf?ext=.pdf

[58] *Vývoj a struktura hrubé produkce elektřiny.* [online]. 6.8.2015. © Copyright 2005 MPO [Accessed on 10.2.2016]. Available from: http://www.mpo.cz/dokument158059.html

maintaining the existing full independence in the supply of heat and electricity, but no significant exports of energy produced. This can be achieved only by further development of nuclear energy in the Czech Republic. This issue is analysed more into detail by the National Action Plan on Nuclear Energy, which immediately follows the Updated State Energy Policy.[59]

The main reason for the approval of the State Energy Policy is a need to clearly articulate priorities and strategic objectives of the state within the energy sector and provide investors, citizens and government by stability in today's turbulent and dynamic time.
Updating the State Energy Policy predicts increase of the share of renewable energy resources (RER), nuclear fuel, natural gas, and the group of "other fuels" in the structure of primary energy sources. Exported surplus of electricity is predicted to fall.[60]

Aims of the Updated State Energy Policy

Energy of the Czech Republic has three main strategic objectives in the European context:

Energy security

- Security of supply = It is mainly about ensuring the necessary energy supply for consumers both in normal operation and also in case of sudden change in external conditions in the context of the EU.
- Fault Tolerance[61]

Competitiveness

- Competitive prices for industry = Final energy prices in comparison with comparable countries in the region and other direct competitors.
- Social acceptability of energy costs for households[62]

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[59] *Aktualizace státní energetické koncepce České republiky.* [online]. Prague 2014 © Copyright 2005 MPO [Accessed on 11.11.2015]. Available from: http://www.strukturalni-fondy.cz/getmedia/85476420-5469-46ab-a19f-51a0c97eae8d/AKTUALIZACE-STATNI-ENERGETICKE-KONCEPCE-CR.pdf?ext=.pdf

[60] *Státní energetická koncepce.* [online]. 6.8.2015. © Copyright 2005 MPO [Accessed on 10.2.2016]. Available from: http://www.mpo.cz/dokument158059.html

[61] SÁDLO, Jan. *Energetické cíle ČR v evropském kontextu.* [online]. Ministerstvo Průmyslu a Obchodu. [Accessed on 22.12.2015]. Available from: http://www.odbornecasopisy.cz/data-ftp-user/konference/2015/AMPER_EproB_XIV/01-Energeticke_cile_CR%20v%20evropskem_kontextu.pdf

Sustainability

- Impact on the environment
- The sustainability of the supply of primary sources
- Financing energy system
- Human Resources[63]

These three basic objectives re based on EU's energy strategy and aims to fulfil the mission of the State Energy Policy and to achieve long-term vision of the Czech energy.[64] Updated SEP therefore assume that the Czech energy sector will be secure, cost-competitive and sustainable in 2040.

Concept identifies five strategic priorities, to contribute to achieving top goals:

- **A balanced energy mix** - a balanced mix of primary energy sources and electricity production based on its broad portfolio, effective utilization of all available domestic energy resources, maintaining the power balance surplus EC with plenty of available reserves and maintaining strategic reserves of domestic forms of energy.[65]
- **Savings and Efficiency** - increasing the energy efficiency of the national economy.
- **Infrastructure and International Cooperation** - Development of the network infrastructure of the Czech Republic in the countries of Central Europe together with strengthening international cooperation and integration of the electricity and gas markets in the region.

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[62] SÁDLO, Jan. *Energetické cíle ČR v evropském kontextu.* [online]. Ministerstvo Průmyslu a Obchodu. [Accessed on 22.12.2015]. Available from: http://www.odbornecasopisy.cz/data-ftp-user/konference/2015/AMPER_EproB_XIV/01-Energeticke_cile_CR%20v%20evropskem_kontextu.pdf

[63] SÁDLO, Jan. *Energetické cíle ČR v evropském kontextu.* [online]. Ministerstvo Průmyslu a Obchodu. [Accessed on 22.12.2015]. Available from: http://www.odbornecasopisy.cz/data-ftp-user/konference/2015/AMPER_EproB_XIV/01-Energeticke_cile_CR%20v%20evropskem_kontextu.pdf

[64] *Aktualizace státní energetické koncepce České republiky.* [online]. Prague 2014 © Copyright 2005 MPO [Accessed on 11.11.2015]. Available from: http://www.strukturalni-fondy.cz/getmedia/85476420-5469-46ab-a19f-51a0c97eae8d/AKTUALIZACE-STATNI-ENERGETICKE-KONCEPCE-CR.pdf?ext=.pdf

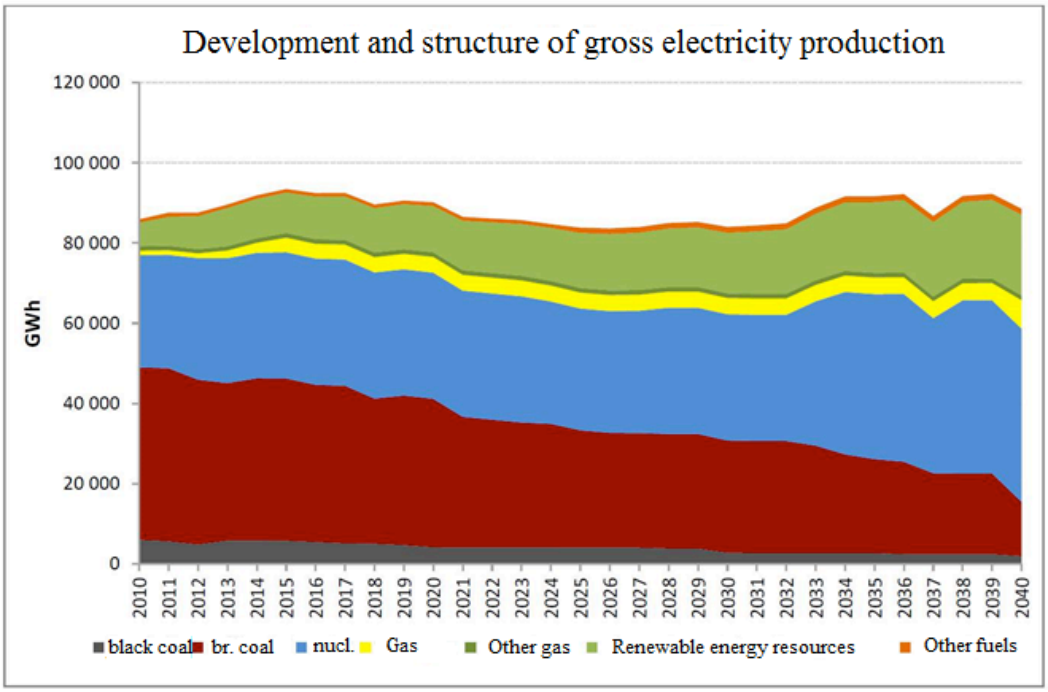
[65] SÁDLO, Jan. *Energetické cíle ČR v evropském kontextu.* [online]. Ministerstvo Průmyslu a Obchodu. [Accessed on 22.12.2015]. Available from: http://www.odbornecasopisy.cz/data-ftp-user/konference/2015/AMPER_EproB_XIV/01-Energeticke_cile_CR%20v%20evropskem_kontextu.pdf

- **Research, development and innovation** – support of research, development and innovation to ensure the competitiveness of the Czech energy sector and the promotion of education.[66]

- **Energy security** - increasing energy security and the resilience of the Czech Republic and strengthening the capabilities necessary to ensure supply in the event of cumulation of disorders.[67]

By approval of the Updated version of the State Energy Policy the Czech Republic clearly confirms that it intends to meet its obligations arising from the directive on security of supply and ensure that investment in the energy sector and related sectors to ensure a reliable supply of energy at competitive prices.

Graph 4: Development and structure of gross electricity production



Source: MPO (2015)[68]

[66] SÁDLO, Jan. *Energetické cíle ČR v evropském kontextu.* [online]. Ministerstvo Průmyslu a Obchodu. [Accessed on 22.12.2015]. Available from: http://www.odbornecasopisy.cz/data-ftp-user/konference/2015/AMPER_EproB_XIV/01-Energeticke_cile_CR%20v%20evropskem_kontextu.pdf

[67] SÁDLO, Jan. *Energetické cíle ČR v evropském kontextu.* [online]. Ministerstvo Průmyslu a Obchodu. [Accessed on 22.12.2015]. Available from: http://www.odbornecasopisy.cz/data-ftp-user/konference/2015/AMPER_EproB_XIV/01-Energeticke_cile_CR%20v%20evropskem_kontextu.pdf

[68] *Státní energetická koncepce.* [online]. 6.8.2015. © Copyright 2005 MPO [Accessed on 10.2.2016]. Available from: http://www.mpo.cz/dokument158059.html

The graph shows the evolution of the electricity sector, as it is assumed by the updated State Energy Policy. The share of nuclear and renewable sources is expected to grow, while coal resources should gradually reduce its stake. Nuclear power should thus in 2040 produce almost 50% of electricity and about 23% of electricity should be gained from renewable and secondary sources. It means that the Czech electricity would be almost three quarters of emission-free this year. The remaining quarter will by represented largely by coal, supplemented by gas and other sources, forming a bit more than 10% of production.

3.3.3 National Action Plan on Nuclear Energy

In connection with the approved Update of the State Energy Policy in June 2015, the government approved the National Action Plan on Nuclear Energy.
It was prepared by the Ministry of Industry and Trade in collaboration with the Ministry of Finance. It describes the options for further development of nuclear energy in the Czech Republic. Nuclear energy is going to play important role along with renewables in the future energy mix with a decreasing share of fossil fuels.[69]

Government considers it necessary to initiate preparations for the construction of one nuclear unit in Dukovany and one block at Temelín in order to ensure energy self-sufficiency and security of the State. It also envisages the possibility of extension for two blocks in both locations.
Due to the high degree of uncertainty about the future situation in the electricity market, document contains recommendations to continue the process of preparation and construction of a new nuclear power plant in two phases. "*The first phase is crucial for the country to keep all of the necessary capacity for future development of new sources, which means it is necessary to immediately continue the preparatory work leading to the construction. In the second stage there should be assessed whether the market situation has stabilized and it is possible to build new sources on a commercial basis, or whether*

[69] *Vláda schválila Národní akční plán jaderné energetiky.* [online]. 3.6.2015 Vláda ČR (c) 2009-2016. [Accessed on 10.2.2016]. Available from: http://www.vlada.cz/cz/media-centrum/aktualne/vlada-schvalila-narodni-akcni-plan-jaderne-energetiky-131166/

market distortions persist and new nuclear plants cannot be built without the provision of government guarantees."[70]

In this case state should decide whether and in what form it will provide a guarantee to the investor. Decisions must be made at the latest before issuing a building permit, which is believed to correspond to the period around the year 2025.[71]

One of the priority tasks of the National Action Plan on Nuclear Energy was also identifying potential investment and business models allowing the construction of a new nuclear source. In this regard there were presented and analysed in detail three possible variants that are able to be realized in the Czech Republic:

1. Investments provided by owners and operators of existing nuclear power plants by the company ČEZ, a. s.
2. Investments by a private investor consortium, meaning the association of investors in order to achieve certain goals
3. Direct construction provided by the state by newly established state-owned enterprise[72]

Material of National Action Plan on Nuclear Energy will be followed by the presentation of the study of a particular method of construction of new nuclear units in the Czech Republic with the business investment model and other necessary steps to ensure the construction with respect to the chosen model. This study should be submitted to the Government of the Czech Republic by 31. 12. 2015.[73]

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[70] *Vláda schválila Národní akční plán jaderné energetiky.* [online]. 3.6.2015 Vláda ČR (c) 2009-2016. [Accessed on 10.2.2016]. Available from: http://www.vlada.cz/cz/media-centrum/aktualne/vlada-schvalila-narodni-akcni-plan-jaderne-energetiky-131166/

[71] *Vláda schválila Národní akční plán jaderné energetiky.* [online]. 3.6.2015 Vláda ČR (c) 2009-2016. [Accessed on 10.2.2016]. Available from: http://www.vlada.cz/cz/media-centrum/aktualne/vlada-schvalila-narodni-akcni-plan-jaderne-energetiky-131166/

[72] *Vláda schválila Národní akční plán jaderné energetiky.* [online]. 3.6.2015 Vláda ČR (c) 2009-2016. [Accessed on 10.2.2016]. Available from: http://www.vlada.cz/cz/media-centrum/aktualne/vlada-schvalila-narodni-akcni-plan-jaderne-energetiky-131166/

[73] *Vláda schválila Národní akční plán jaderné energetiky.* [online]. 3.6.2015 Vláda ČR (c) 2009-2016. [Accessed on 10.2.2016]. Available from: http://www.vlada.cz/cz/media-centrum/aktualne/vlada-schvalila-narodni-akcni-plan-jaderne-energetiky-131166/

4 Practical Part

4.1 Energy mix

Each state uses the available energy resources to meet its energy needs, and each country uses these resources in a different proportion. We call this **energy mix**, it is "*an arbitrary proportion of primary and secondary sources of energy in electricity production*."[74] These values vary between countries, but 80% of the energy mix worldwide is represented by fossil fuels.

The very term energy mix tells how is the final energy consumption in a given geographic area divided by primary energy resources. It includes both fossil fuels and nuclear energy, waste and many renewable energy sources. These primary sources generate electricity, provide fuel for transportation and provide heat and cooling of residential and industrial buildings.

In the past, the formation of energy mix depended on the availability of primary energy sources while minimizing import dependence. In the last century, energy production did not take into account the environment, which reached a critical state in the second half of the last century in the field of coal power plants.

The structure of the energy mix depends on:

- Availability of funds on country's territory or on the possibility of their imports.
- The amount and type of energy that must be met.
- Policy decisions determined by historical, social, demographic, environmental and geopolitical factors.[75]

Historically, the basic source for electricity production constituted coal. The strategic role of this energy resource has been considerably limiting in recent years, certainly the main contribution was the decision of the European Union to reduce emissions in Europe. Coal is often replaced by core or gas.[76]

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[74] MATĚJŮ, Dalibor. *Obnovitelné zdroje energie v energetickém mixu.* [online]. 18.3.2014 [cit. 2.12.2015]. ISSN 1801-4399 Available at: http://energetika.tzb-info.cz/9668-energetika-vybrane-pojmy-i

[75] *About the Energy Mix.* [online]. 3.7.2015 © THINKSTOCK. [Accessed on 5.12.2015]. Available from: http://www.planete-energies.com/en/medias/close/about-energy-mix

[76] ORÁLEK, Petr. *Energy outlook 2013.* [online]. CR: Economia, a.s., 2013 [Accessed on 3.1.2016] Available from: http://www.cez.cz/edee/content/file/pro-media-2013/12-prosinec/energy-outlook-2013.pdf

4.1.1 Energy mix of the EU

The original energy mix of Europe relied mainly on coal power plants in recent years, they were also covering most of the consumption. A significant turning point came at the turn of the millennium when the EU committed itself in Kyoto to reduce greenhouse gas emissions. This decision represented a major step for the EU, it was a transition to environmentally clean fuels and especially renewable energy resources. Many European countries, including the Czech Republic, provided generous support to renewables, which began with changes in the energy mix across the EU and its individual members. The share of the installed output of coal power plants decreased by 3% between 2000 and 2012. In 2011, for over 70% of installed output was presented by newly launched wind power plants and especially solar power plants in Europe.[77]

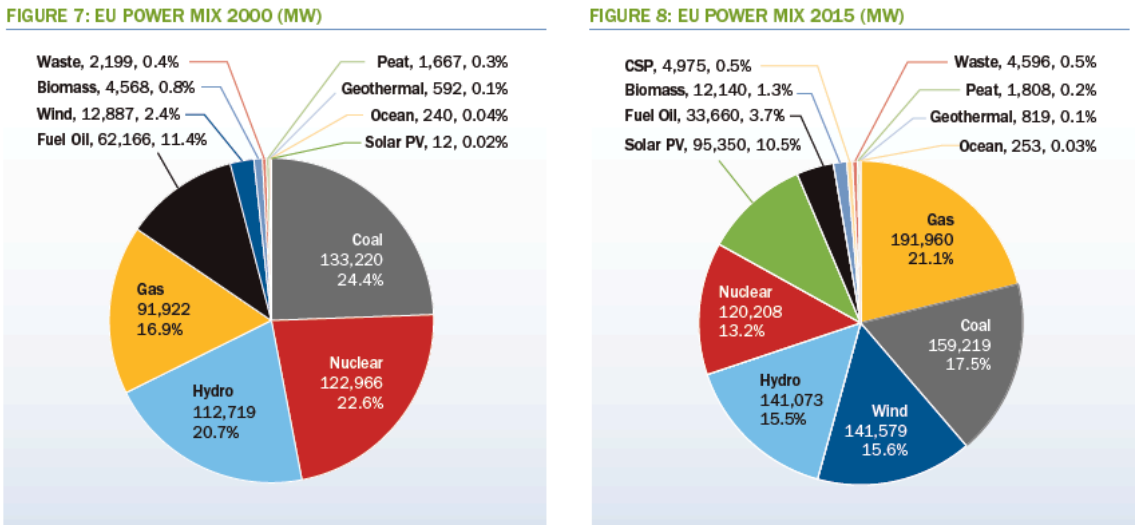
The European Union has set a goal of reducing greenhouse gases by at least 80% by 2050. In order to meet this goal, it is necessary to significantly reduce the use of highly polluting fuels, especially oil and coal. According to the resolution on the Energy Roadmap 2050, which was accepted by the European Parliament on March 14, the key aspects of the transition to low-carbon energy are higher share of renewable energy resources and increase of energy efficiency.[78]

The following graphs show the application of subsequent policies aimed at environmental sources of electricity. The largest increase is noticeable in the area of renewable energy, photovoltaics in particular, which from 0.02% in 2000 rose to 10.5% in 2015. Another renewables, now a major in the EU, has become a wind energy with 15.6%. Charts clearly confirm the retreat of fossil fuels, particularly coal and fuel oils. The share of coal in the energy mix decreased to 17.5%.

[77] ORÁLEK, Petr. *Energy outlook 2013.* [online]. CR: Economia, a.s., 2013 [Accessed on 3.1.2016] Available from: http://www.cez.cz/edee/content/file/pro-media-2013/12-prosinec/energy-outlook-2013.pdf

[78] *Energetický mix.* [online]. 21.3.2013 Evropský parlament Zpravodajství. [Accessed on 10.1.2016]. Available from: http://www.europarl.europa.eu/news/cs/news-room/20130318STO06602/Jak-by-m%C4%9Bl-vypadat-energetick%C3%BD-mix-budoucnosti

Graph 5: Comparison of energy mix of the EU in 2000 and in 2015



Source: CSVE (2015)[79]

4.1.2 Energy mix of the Czech Republic

Czech energy market is a part of the European market which is currently, on a global scale, the largest regional market and also the largest energy importer.[80]

"*Czech Republic has the right to determine such own energy mix which considers appropriate, but must take into account its neighbours, to cooperate with them and have a readable energy policy. Czech Energy aims to become a competent part of a common energy market.*"[81]

There has been a long-term structural alterations of energy in the Czech Republic and it leads to gradual changes in the national energy mix. "*Since 1993 there has been a significant decline in electricity production from coal in favour of electricity production from nuclear power plants and renewable resources. It is a consequence of the boom of solar power from 2010 to 2012 and the subsequent development of electricity generation*

[79] *Srovnání evropského energetického mixu v roce 2000 a 2015 (v MW).* [online]. Available from: http://www.csve.cz/clanky/vte-v-evrope/282

[80] *Aktualizace státní energetické koncepce České republiky.* [online]. Prague 2014 © Copyright 2005 MPO [Accessed on 11.11.2015]. Available from: http://www.strukturalni-fondy.cz/getmedia/85476420-5469-46ab-a19f-51a0c97eae8d/AKTUALIZACE-STATNI-ENERGETICKE-KONCEPCE-CR.pdf?ext=.pdf

[81] *Energetická bezpečnost ČR – Surovinová bezpečnost: Poradíme si s rostoucí energetickou závislostí ČR?* [online]. 2.12.2015. [Accessed on 15.1.2016]. Available from: http://www.adtt.cz/wp/2015/12/02/energeticka-bezpecnost-cr-surovinova-bezpecnost-poradime-si-s-rostouci-energetickou-zavislosti-cr/

using biomass and biogas. These three named resources for electricity production grew from almost zero in 1993 to almost 7% in 2013."[82]

Primarily renewable sources have their strong position in balanced energy mix of the Czech Republic. Nowadays, science and technology come with new opportunities to increase the efficiency of the utilization of these resources. Use of renewable sources in the Czech Republic has grown from year to year over the past decade, and the largest share is still represented by hydro power plants along with photovoltaics.[83]

Potential of the renewable energy resources in the Czech Republic

In terms of sustainable development, renewable energy sources represent the only way. Their potential was estimated many times in the past in the Czech Republic, and in 2003 in-depth research was carried out, which was accompanied by a proper economic evaluation.

The main purpose of the research was to provide authoritative data for the preparation of the State Energy Policy and also to the draft of the law on the promotion of renewable energy sources. Potential has been studied in five basic resources of renewable energy: solar, biomass, hydropower, wind and geothermal energy. Each resource represents the specific possibility of its use and thus exploring its potential. Exploring the potential was divided into the categories of technical, usable, accessible and economic potential.[84]

The main thing that limits the potential of the use of renewables are the natural conditions of the Czech Republic, meaning conditions of climate, soil and geology.

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[82] SOLARNINOVINKY.CZ,ČSU. *Energetický mix v ČR: Dochází k výrazným proměnám ve prospěch výroby elektřiny z jádra a OZE.* [online]. 30.10.2014 © Copyright SolátníNovinky.cz. [Accessed on 10.1.2016]. Available from: http://www.solarninovinky.cz/?zpravy/2014103001/energeticky-mix-v-cr-dochazi-k-vyraznym-promenam-ve-prospech-vyroby-elektriny-z-jadra-a-oze#.Vu8HI-LhDIV

[83] CEZ.CZ. *Obnovitelné zdroje energie a skupina ČEZ.* [online]. ČEZ,a.s.Duhová 2/1444. [Accessed on 20.1.2016]. Available from: http://www.cez.cz/edee/content/file/pro-media-2012/03-brezen/obnovitelne-zdroje-energie-a-skupina-cez.pdf

[84] *Infromace o potenciálu obnovitelných zdrojů energie v ČR.* [online]. CZ Biom, ÚFA, CityPlan, spol. s r.o. [Accessed on 10.1.2016]. Available from: http://www.3zemi.cz/docs/energiepotencial2050.pdf

- Wind energy potential is mainly limited by the landscape relief, which defines the major locations in terms of wind especially in the north of the territory, in the Ore Mountains and Highlands. Another limiting factor is the type of protected natural areas of national parks, protected areas, zones of military radar and more.

- Solar energy potential is limited by the climatic conditions of the Czech Republic. When it comes to solar energy it is primarily about meteorology latitude. Likewise, the protection of agricultural land excludes systematic utilization of such land for photovoltaic sources. This potential is thus given the expected parameters, for example the effectiveness of new technologies, or the range of flat roofs.[85]

- The potential for using biogas represents biodegradable waste, for example, plant residues, waste from gardens or droppings from livestock. The most common way of using biogas in the Czech Republic is the CHP. Electricity generation from biogas in cogeneration with heat in the Czech Republic is supported by Act no. 180/2005 Coll. with guaranteed purchase prices and green bonuses for the purchase of electricity.[86]

The following chart represents the energy mix for the Czech Republic in 2010. When it comes to the supply of electricity, the Czech Republic had 130% self-sufficiency in this area. Although 2010 was a period of so called solar boom, so far it was not projected significantly in the real picture of the energy mix of the Czech Republic, since the boom peaked just at the end of this year. This was determined by adjusting the purchase prices of the resources by the end of this year, and therefore the largest sources were finished by the end of the year, to be able to run by the end of this year and reach the competitive grants.

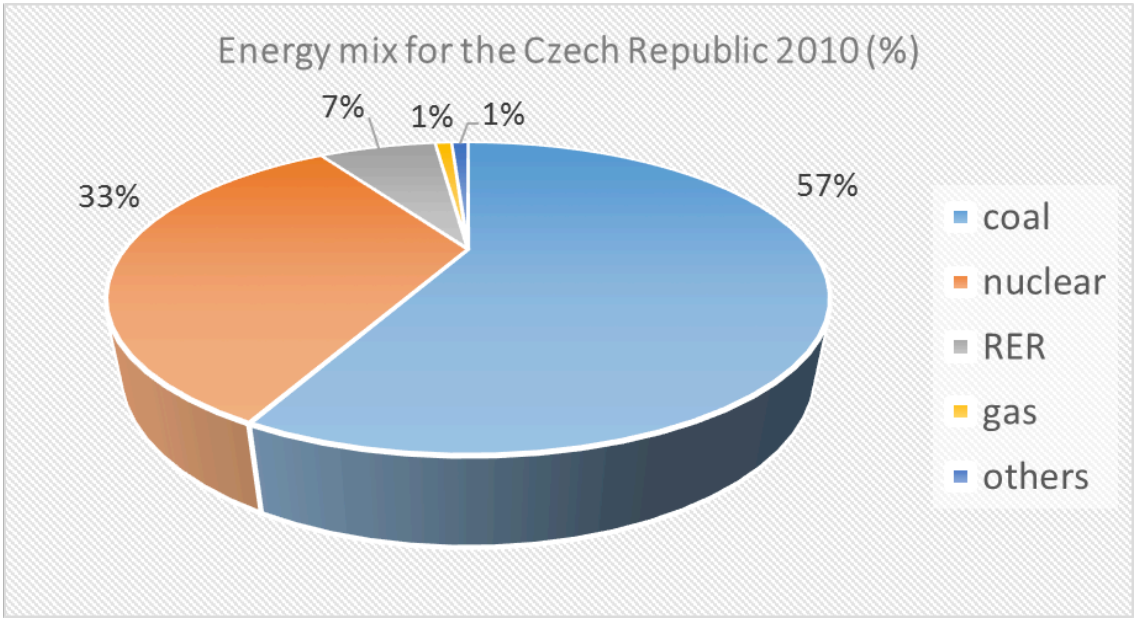
This chart demonstrates the energy mix with still high share of fossil fuels, particularly coal, which represented for almost 60% of the total energy mix, which was of course

[85] *Aktualizace státní energetické koncepce České republiky.* [online]. Prague 2014 © Copyright 2005 MPO [Accessed on 11.11.2015]. Available from: http://www.strukturalni-fondy.cz/getmedia/85476420-5469-46ab-a19f-51a0c97eae8d/AKTUALIZACE-STATNI-ENERGETICKE-KONCEPCE-CR.pdf?ext=.pdf

[86] NOVOTNÝ, Petr. *Historie a perspektivy OZE – bioplyn.* [online]. 4.5.2009 © Copyright Topinfo s.r.o. 2001-2016. [Accessed on 10.11.2015]. Available from: http://oze.tzb-info.cz/biomasa/5610-historie-a-perspektivy-oze-bioplyn

reflected in production of greenhouse gases. Mainly the subsidy policy of renewable resources should change quite significantly the energy mix in the future.

Graph 6: Energy mix of the Czech Republic in 2010



Source: MPO (2014)[87]

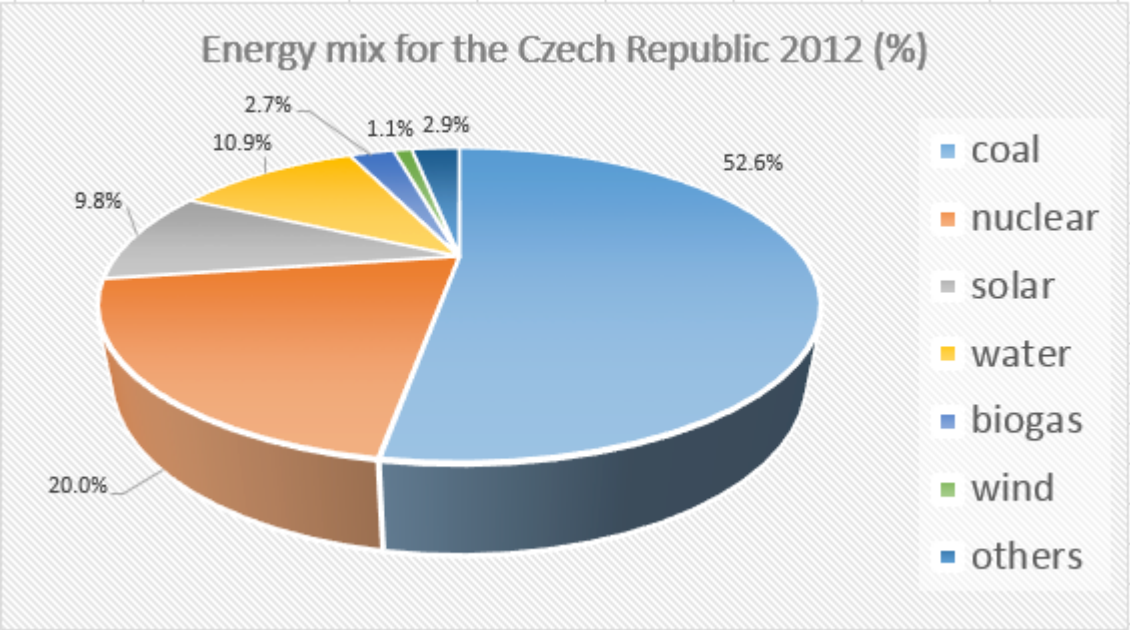
In 2012, there is a clear effect of a national policy to promote renewables. Gradually, there is a large decline in the use of fossil fuels and renewables are becoming an important part of the energy mix of the Czech Republic.

The year 2012 represented a year of very favourable purchase prices in the field of photovoltaics, which encouraged massive investment in this segment. At the same time it was a year of the massive onset of a new energy resource, biogas. Not only is this promising energy resource, but also it is one of the most stable sources of energy, which is essential for the national transmission system.

A visible decline of electricity generation from nuclear power plants on the graph represents the fact that these power plants produce the constant amount of electricity, on the contrary, mainly RER dramatically increase production and therefore percentage share of the core decreases throughout the energy mix.

[87] *Budoucnost energetické politiky České republiky.* [online]. 2014. Data available from: http://www.mpo.cz/, self-edited

Graph 7: Energy mix of the Czech Republic in 2012



Source: ERO (2015)[88]

The next chart demonstrates the energy mix of the Czech Republic for the year 2014. The chart clearly shows that half of the energy mix of the country is represented by the coal power plants. The second most frequently used source is nuclear power, and then renewable resources. Economically, it is a mix quite optimal. Currently, coal prices are at historic lows, so its use is not so expensive. The current energy mix is also stable as coal and nuclear power plants are among the most stable resources of energy.

[88] *Hodnocení energetického komplexu na životní prostředí.* [online]. Data available from: www.eru.cz, self-edited

Graph 8: Historical and current price of coal in the Czech Republic

Source: Kurzy (2016)[89]

But the energy mix is not optimal from an environmental perspective. Half of the mix is represented by a power source that burdens the atmosphere the most. From an ecological point of view it would be necessary to reduce the number of coal power plants in the Czech Republic and replace them with more environmentally compatible sources. Effect of coal power plants on the environment itself begins with production, which heavily influences the biosphere by eliminating all forms of flora and fauna.

Pedosphere is completely disrupted by coal mining and hydrology is affected by the water system. Extraction disrupts air which escapes into the atmosphere, emission of gases and vapours. Currently three technologies for CO2 removal are developed: oxy-fuel combustion, CO2 separation before combustion and removal of CO2 from flue gas - in the Czech Republic, yet none of these technologies is used.[90]

Policy of the support of renewable resources was fully manifested this year, as is seen dramatic onset of these sources in the total energy mix. Since 2010, utilization of coal resources decreased by almost 10%, but their use is still at a high level and the goal should be to reduce this source. Biomass power plants recorded a significant increase in 2014 with

[89] *Kurzy měn, akcie, komodity, online zpravodajství.* [online]. 2016. Available from: www.kurzy.cz
[90] http://www.odpadoveforum.cz/DVD/dokumenty/prispevky/317.pdf

21% contribution on green electricity production. Photovoltaic power plants and biogas stations also recorded an increase over the previous year, by 4% and by 14.5%.[91]

In 2014 a total of 86 billion KWh of electricity was produced in the Czech Republic, of which 69.7 was consumed, and 16.3 was exported. Amount of exported electricity was greater than was the whole year production of Temelín power plant.

From an economic point of view is primarily important the cost of producing energy from various energy sources.

These costs mainly consist of three main categories:

- Capital expenditures, including costs of waste processing and decommissioning after operation
- Fuel price
- Other factors such as operation and maintenance, insurance and the actual energy consumption

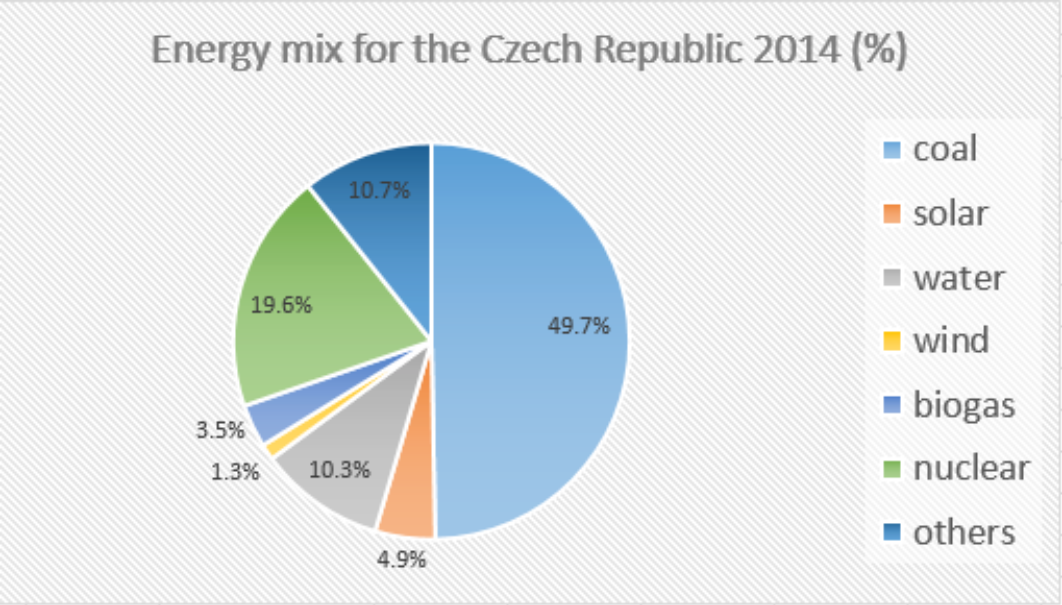
If we divide the total energy produced and the value of operational costs, we get production cost per 1 KWh.

The lowest costs of producing electricity represents nuclear energy, its production costs per 1 KWh are 0.926 CZK.

While the most expensive item is biogas, where the cost of production cost per 1 KWh is 3.1 CZK, it is caused by the fact that biogas power plant consumes 20-25% of its production to its own operations, which also reduces its effectiveness. This type of power plant improves its financial results using waste heat, of which there is plenty. This means that this source of electrical energy, under certain conditions, may represent high profitability.

[91] http://oenergetice.cz/obnovitelne-zdroje/vyroba-elektriny-z-obnovitelnych-zdroju-v-lonskem-roce-poklesla/

Graph 9: Energy mix of the Czech Republic in 2014



Source: Energostat (2015)[92]

With renewable energy is also closely related the issues related to energy prices. The state has an obligation to purchase priority all electricity generated from renewable sources. That is also why consumers of electricity pay item contribution to renewable energy sources during their procurement. The share of electricity from renewable energy sources in total energy consumption affects the final price of electricity. It is one of the main tools to promote renewables.[93]

Since 2006, the price of electricity is divided into two parts, regulated part and non-regulated part. Regulated part of electricity involves payment for transportation of electricity to final customers and is determined by the ERO. The part of the regulated electricity price includes the cost of supporting the purchase of electricity from renewable sources. The Czech Republic accession into the EU makes the country committed to

[92] *Energostat, Energetika v ČR a EU.* [online]. 2015. Data available from: http://energostat.cz/elektrina.html, self-edited

[93] CSEV.CZ. *Cena obnovitelné energie.* [online]. 2013 © ESF,CENIA,. [Accessed on 11.12.2015]. Available from: http://www.vitejtenazemi.cz/cenia/index.php?p=cena_obnovitelne_energie&site=energie

support this type of production with regard to its ecological benefits. Non-regulated part of the electricity price represents a payment for the own consumed energy.[94]

In 2014, there was a significant reduction in the regulated part of the final price of electricity, mainly due to decrease in the most of the components of regulated part. The main reason for reduction in regulated prices of transmission and distribution of electricity represents a decrease in the market price of electricity, which positively affects the valuation losses in the transmission and distribution system and further annual fall economic indices.

It also has a favourable effect on the effective procurement of support services to ensure a balance in balance performance in the electricity system and the influence of the correction factor from previous years, which reduces the cost for system services provided by the company CEPS, a.s. All these factors caused about 10.8% reduction in the regulated part of the final price of electricity for households in 2014.[95]

In 2015 there was a decreased in business part as well as in regulated part of electricity prices. The business part represented 45% of the total price, the remainder being regulated price, which fell by 1.4% in 2015.[96]

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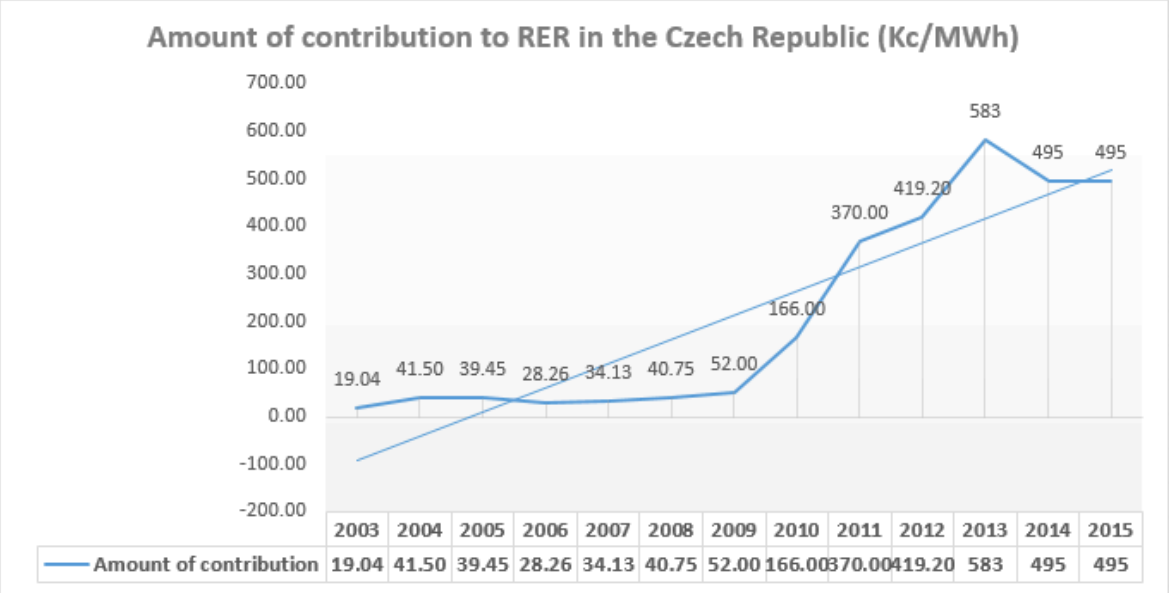
[94] CEZ.CZ. *Skladba ceny elektřiny.* [online]. Copyright 2016 ČEZ, a. s. [Accessed on 10.2.2016]. Available from: https://www.cez.cz/cs/sluzby-pro-zakazniky/ceny/elektrina/3.html

[95] *V roce 2014 klesnou regulované ceny elektřiny a plynu.* [online]. 29.11.2013 © 2013 CEMC. [Accessed on 10.2.2016]. Available from: http://www.tretiruka.cz/news/v-roce-2014-klesnou-regulovane-ceny-elektriny-a-plynu/

[96] FINANCE.CZ. *Elektřina opět zlevňuje. Kolik v roce 2015 ušetříte?* [online]. 9.12.2014 ISSN: 1213-4996 © Copyright 2016 ČTK. [Accessed on 20.2.2016]. Available from: http://www.financninoviny.cz/zpravy/elektrina-opet-zlevnuje-kolik-v-roce-2015-usetrite-/1156656

Graph 10: Amount of contribution to Renewable Energy Resources in the Czech Republic (CZK/MWh)



Source: ERO (2015)[97]

Support for renewables is of course important for their development and massive deployment, but in economic terms it is necessary to find such level of support in a way it was not an economic burden to customers and to avoid extremes as in 2013, when the amount of support for RER was at the level of 583 CZK/MWh, which was drastic to some customers. The main reason for such a massive growth of this support was the launch of the subsidy policy of thoughtless purchase prices, mainly photovoltaic resources.

The following table demonstrates evident development of purchase prices gap between photovoltaics and other renewable sources.

[97] *Cena obnovitelné energie.* [online]. Data from: eru.cz. Available from: http://www.vitejtenazemi.cz/cenia/index.php?p=cena_obnovitelne_energie&site=energie

Table 1: Comparison of purchase prices of electricity from renewable resources in the Czech Republic in CZK / KWh

Energy source	2007	2008	2009	2010	2011	2012	2013	2014	2015
photovoltaics	13.46	13.46	12.79	12.1	5.5	6.16	2.83	2.48	2.53
wind power plants	2.46	2.46	2.34	2.23	2.23	2.23	2.12	2.014	1.98
water power plants	2.93	2.6	2.7	3	3	3.19	3.23	3.23	3.23
biomass	3.37	4.21	4.49	4.58	4.58	4.58	3.73	3.335	3.263
biogas	3.04	3.9	4.12	4.12	4.12	4.12	3.55	4.12	3.04

Source: CSVE (2013)[98]

When creating an optimal energy mix for the Czech Republic, several parameters must be taken into account. Energy mix should be optimal both from the economic point of view and from the environmental. An increasingly important factor when planning the production of electricity remains the emissions that the European Union gradually decreases with its policy.

Optimal energy mix should be optimized in its relationship to the environment. The main assumption in creating an optimal energy mix will be reduction of the use of coal power plants and replacing them with renewable energy sources. In fact, over the past 20 years there has been a decline in the share of coal in the Czech installed capacity by nearly 30%.[99]

Of course it is not possible to shut down the use of coal power plants completely. Their operation is given historically in the country, and they are the essential source of energy in terms of stability. Since coal power plants constitute the most stable source of energy, it is also to be replaced by a stable source, in order to respect the balance of the energy mix. The most stable renewable energy resource is represented by hydroelectric power, but capacity utilization of hydro power plants in the Czech Republic has been already exhausted and it is not possible to expand this energy resource in a larger scale.

[98] *Vývoj výkupních cen větrné energie a ostatních obnovitelných zdrojů.* [online]. 2013 Data from: eru.cz. Available from: http://www.csve.cz/clanky/vyvoj-vykupnich-cen-vetrne-energie-a-ostatnich-obnovitelnych-zdroju/278

[99] ORÁLEK, Petr. *Energy outlook 2013.* [online]. CR: Economia, a.s., 2013 [Accessed on 3.1.2016] Available from: http://www.cez.cz/edee/content/file/pro-media-2013/12-prosinec/energy-outlook-2013.pdf

Picture 2: Scheme of the Vltava cascade hydropower power plants

Source: CVUT (2011)[100]

The second most stable renewable energy resource is biogas. In terms of stability of the transmission system and respect for the environment it would be optimal to replace coal power plants for biogas power plants. Biogas power plants definitely belong to the resources that pollute the air minimally, and combustion of biofuels is considered to be ecologically very valuable process. Another economic benefit of biogas combustion process is the fact that this process produces waste heat, which is used by these plants for other activities, thereby they are improving their financial results. This heat production is usually higher than the production of electricity. The share of heat obtained from cooling and exhaust gas heat is about 50:50.

Possibilities of using heat are following:

- heating of buildings in the immediate vicinity, particularly in the area of the farm
- deliveries to the central heating system and heating of residential buildings

[100] MASTNÝ, Petr and coll. *Obnovitelné zdroje elektrické energie.* [online]. CR: České vysoké učení technické v Praze, 2011. ISBN 978-80-01-04937-2. Available from: https://k315.feld.cvut.cz/CD_MPO/CVUT-2-OZE.pdf

- the need for the associated business operations

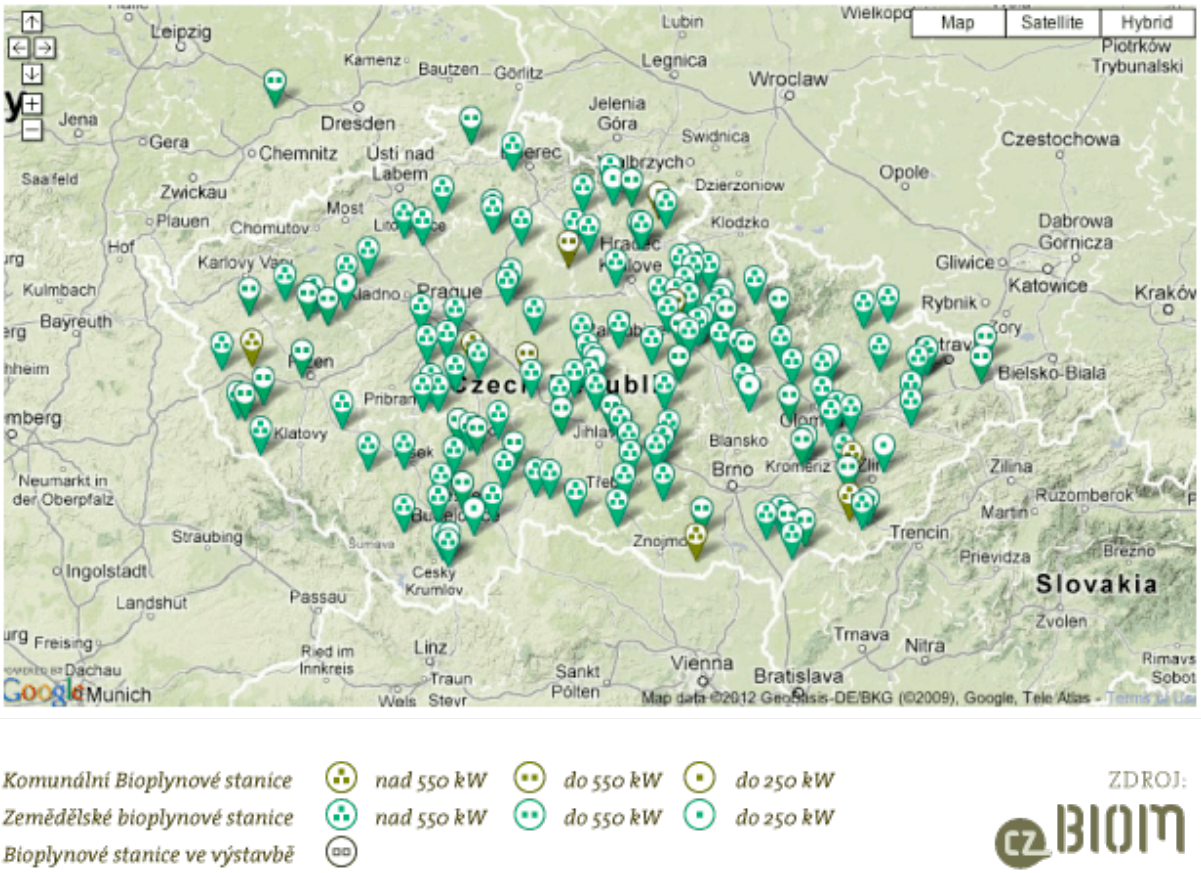
Implementation of some of these options is very individual, depending on the appropriate factors and thoroughly prepared project.[101]

The Czech Republic is a country that uses biogas in large numbers. Unfortunately, some of these power plants use crops commonly used in agriculture as feed, therefore there is a lack of these crops. The first option to solve this problem would be to grow more of these crops to be enough for biogas power plants as well as for economic purposes. But it is not allowed by photovoltaic power plants, which in our country are not only massive and with a small installed capacity, but are also standing on the surface that would otherwise be used for agriculture, such as arable land.

The present time offers the possibility of technological innovation, for example to build smaller photovoltaic panels with a greater installed capacity, that would free agricultural area which could be used for cultivation of crops needed for agriculture purposes. This would decrease such grain shortage and it could be used both in agriculture and biogas power plants, and the use of these power plants could greatly expand and would become a substitute of coal power plants.

[101] CZ Biom. *Využití odpadního tepla z výroby bioplynu.* [online]. 23.4.2014 ISSN: 1801-2655 © 2001-2009, CZ Biom. [Accessed on 26.12.2015]. Available from: biom.cz/cz/odborne-clanky/vyuziti-odpadniho-tepla-z-vyroby-bioplynu

Picture 3: Biogas power plants in the Czech Republic



Source: CZbiom (2012)[102]

Based on the research, the analysis showed that the current energy mix of the Czech Republic is not optimal. The cost of generating electricity is not that high since the biggest share in the energy mix is represented by the sources with relatively low costs of energy generation, but the most severe problem raising from such mix is the extremely high amount of emissions released to the atmosphere.

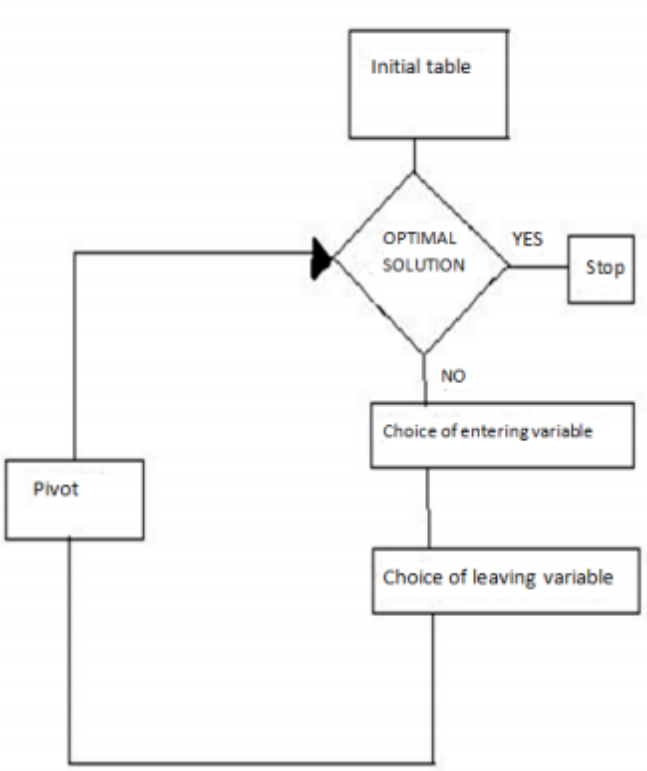
Coal power plants may be the stable energy resource convenient for the stability of the Czech transmission system, but the Czech Republic belongs between the states that have subscribed themselves to the mission of decreasing the amount of emissions in the air. For that purpose, it is necessary to come up with the optimal energy mix, which would be suitable for the Czech Republic both in economic and environmental way.

[102] *Bioplyn v ČR.* [online]. 2012. CZbiom. Available from: http://www.bioplynsezemice.cz/bioplyn

4.2 Optimization of the current energy mix with linear programming

For the purpose of the optimal energy mix creation, simplex method in linear programming tool is going to be used. Simplex method is the most suitable method for finding optimal solution for the given problem.

Picture 4: Finding an optimal solution for the given problem



Source: HEC Montreal[103]

Linear programming or linear optimization is a kind of mathematical programming discovered by the American mathematic George Dantzig in 1947. This is essentially a study of systems of inequalities and their solutions, then it comes to optimizing solutions under conditions determined by a system of inequalities.[104]

[103] *The steps of the simplex algorithm.* [online]. Available from: http://www.hec.ca/en/cam/help/topics/The_steps_of_the_simplex_algorithm.pdf

[104] SGALL, Jiří. *Úvod, problém lineárního programování.* [online]. 24.2.2012. [Accessed on 9.10.2015]. Available from: http://kam.mff.cuni.cz/~sgall/vyuka/OPT/opt12-1.pdf

The basic mathematical model consists of the objective function and constraints. "*Objective function and constraints are expressed by linear relations with constant coefficients for individual variables, and with constant right sides of restrictions system*."[105]

During the work on the model of linear programming it is necessary to determine what the result of the calculation is, meaning what are the different components and units in which they are presented. Then it is necessary to correctly formulate the objective equation along with their own constraints.

The goal of linear programming to find the optimal range of processes for compliance with the restrictions along with maximizing or minimizing the value criteria.

The generalised model of linear programme can be described as follows:

Picture 5: Generalised linear programme

$$
\begin{aligned}
\text{maximize} \quad & c_1x_1 + \ c_2x_2 + \cdots + \ c_nx_n \\
\text{subject to} \quad & a_{11}x_1 + a_{12}x_2 + \cdots + a_{1n}x_n \leq b_1 \\
& a_{21}x_1 + a_{22}x_2 + \cdots + a_{2n}x_n \leq b_2 \\
& \qquad\qquad \vdots \\
& a_{m1}x_1 + a_{m2}x_2 + \cdots + a_{mn}x_n \leq b_m \\
& x_1,\ x_2,\ \ldots\ x_n \geq \ 0.
\end{aligned}
$$

Source: Princeton (2001)[106]

The example demonstrates that objective function is to be maximised and is constrained by inequalities and the condition of non-negative decision variables. If the solution is satisfactory for all of the constraints, it is called feasible. In addition, it is optimal in case it attains the desired maximum. It is also possible that problem has no feasible solution, in which case it is called infeasible.

[105] FRIEBELOVÁ, Jana. *Lineární programování.* [online]. [Accessed on 9.10.2015]. Available from: http://www2.ef.jcu.cz/~jfrieb/rmp/data/teorie_oa/LINEARNI_PROGRAMOVANI.pdf

[106] VANDERBEI, J. Robert. *Linear Programming: Foundations and Extensions.* [online]. Princeton, NJ. 2001. Available from: https://support.dce.felk.cvut.cz/pub/hanzalek/_private/ref/Vanderbei_Linear_Programming.pdf

Standard maximization problem

A linear programming (LP) problem is called a **standard maximization problem** if:

- We are to find the maximum (not minimum) value of the objective function.
- All the decision variables x_1, x_2, ..., x_n are constrained to be non-negative.
- All further constraints have the form $bx_1 + bx_2 + .. + bx_n \leq c$ (and not $\geq$) with c nonnegative.[107]

In our optimisation problem, we are to minimize the objective function, so in our case it is not standard optimization problem. Such problem is called **problem with mixed constraints**.

Optimisation model

Selected resources

- u = solar power plants
- v = wind power plants
- w = water power plants
- x = coal power plants
- y = biogas power plants
- z = nuclear power plants

The basic objective function of the linear model indicates that the basic objective is to create an energy mix with a view to minimizing the cost of producing energy from selected energy sources. Among the constraints also emissions were included, with the aim that the amount of emissions produced from selected sources was less than the total amount of emissions produced in the Czech Republic.

[107] *The Simplex Method: Solving Standard Maximization Problems.* [online]. Copyright © 2010. [Accessed on 11.10.2015]. Available from: http://www.zweigmedia.com/RealWorld/tutorialsf4/framesSimplex.html

Optimisation equations:

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [I]

u + v + w + x + y + z => 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)[108]

The equations chosen for the optimization problem clearly demonstrates that the main aim of the linear programme is to find such energy mix, which would represent lower costs of electricity generation, together with the lower amount of emissions produced during this generation.

Total installed output of the proposed energy resources is set to be the same or higher. The installed output of power plants is always higher than the amount of power they actually provide to the transmission system, so that the balance of the transmission system is not threatened.

[108] Data available from: https://www.eru.cz/documents/10540/462820/Rocni_zprava_provoz_ES_2014.pdf/933fc41a-ad79-4282-8d0f-01eb25a63812

Creation of the first optimal scenario

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [II]

u + v + w + x + y + z >= 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3 (installed output)

Table 2

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
```

Solution:

Optimal Solution: c = 52918.1; u = 0, v = 0, w = 0, x = 0, y = 0, z = 57147

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

```
Tableau #1
u         v         w         x         y         z         s1        s2        s3
-c
1         1         1         1         1         1         -1        0         0
0         57147
0.03      0.011     0.016     0.86      0         0.009     0         1         0
0         38576500
2067.4    278.1     1080.4    10836.7   766       4290      0         0         -1
0         21920.3
2.12      1.339     1.85      1.89      3.1       0.926     0         0         0
1         0

Tableau #2
u              v              w              x              y              z
s1             s2             s3             -c
```

In the first proposed scenario the linear programme proposed an optimal solution in a way of using only nuclear power plants with total energy generation 57 147 GWh, and total costs of 52 918.1 CZK/GWh.

In practice, such energy mix is not applicable in the Czech Republic conditions. The Czech Republic uses two nuclear power plants, Temelín and Dukovany, and it is not possible these two power plants would represent all energy mix, since their share in the current energy mix is about 30%.

The proposed optimal energy mix ought to comprise renewable energy resources in order to ensure decrease of the amount of emissions released in the air from electricity generation, but also to fulfil the legislative measures given by the European Union to keep the 13% share of the renewables in the gross electricity consumption in 2020. For this reason, the purchase price from photovoltaics was increased, so that the return on investment from these power plants was 15 years.

The proposition of the nuclear energy is acceptable since this energy resource is going to be used largely in the Czech Republic. Based on the newly accepted Energy Policy from 2015, nuclear energy will be majorly represented in the future energy mix. It is expected to represent over 50% of the total energy mix, since it is not only the most stable energy resource used, but also two more blocks are going to be added into nuclear power plants which will also increase their installed output. Therefore in the next step, nuclear power plants production is reproached in order to give the programme possibilities to use also other energy resources in the optimal mix creation.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [III]

u + v + w + x + y + z => 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)

Z <= 5000

Table 3

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57 147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
z <= 5000
```

Solution:

Optimal Solution: c = 74454.8; u = 0, v = 52147, w = 0, x = 0, y = 0, z = 5000

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

Tableau #1

u	v	w	x	y	z	s1	s2	s3
s4	-c							
1	1	1	1	1	1	-1	0	0
0	0	57147						
0.03	0.011	0.016	0.86	0	0.009	0	1	0
0	0	38576500						
2067.4	278.1	1080.4	10836.7	766	4290	0	0	-1
0	0	21920.3						
0	0	0	0	0	1	0	0	0
1	0	5000						
2.12	1.339	1.85	1.89	3.1	0.926	0	0	0
0	1	0						

The reproached value was given to the nuclear power plants which in this energy mix produce 5 000 GWh. New energy resource proposed by the linear programming system are wind power plants with the production of 52 147 GWh.

Such result is clearly not optimal, and more importantly, not applicable as well. Given that the current yearly energy production from wind power plants is 476.5 GWh, it is not possible to increase their use to the proposed value over 52 000 GWh. The capacity of the use of wind power is strictly limited in the Czech Republic conditions. The amount of places where such power is able to be efficiently used is limited to the North part of the country to the Czech German borders. From all the renewables, wind energy is one of the most limited by the nature conditions.

When it comes to the costs of using wind power plants, it is not really economically demanding since they are mainly located closer to the point of consumption, and because electricity and transport networks usually require only minor adjustments, it significantly reduces the overall costs. But overall potential for meaningful construction of wind power plants in the Czech Republic is at a lower level.

Therefore, in the next step, the production of the nuclear power plants is reproached up to the limit of their current production, 30 324.9 GWh.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [IV]
u + v + w + x + y + z => 57 147 (electricity consumption)
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)
Z <= 30324.9

Table 4

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57 147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
z <= 30324.9
```

Solution:

Optimal Solution: c = 63995.6; u = 0, v = 26822.1, w = 0, x = 0, y = 0, z = 30324.9

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

```
Tableau #1
u         v         w         x         y         z         s1        s2        s3
s4        -c
1         1         1         1         1         1         -1        0         0
0         0         57147
0.03      0.011     0.016     0.86      0         0.009     0         1         0
0         0         38576500
2067.4    278.1     1080.4    10836.7   766       4290      0         0         -1
0         0         21920.3
0         0         0         0         0         1         0         0         0
1         0         30324.9
2.12      1.339     1.85      1.89      3.1       0.926     0         0         0
0         1         0
```

With the nuclear power plants production of 30 324.9 GWh, production of water power plants was decreased to 26 822.1 GWh. Such result is still not applicable and therefore wind power plants production is reproached to their current limit 476.5 GWh together with reproached value of nuclear power plants.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [V]

u + v + w + x + y + z => 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)

Z <= 30324.9

V <= 476.5

Table 5

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57 147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
z <= 30324.9
v <= 476.5
```

Solution:

Optimal Solution: c = 77458.3; u = 0, v = 476.5, w = 26345.6, x = 0, y = 0, z = 30324.9

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

```
Tableau #1
u         v         w         x         y         z         s1        s2        s3
s4        s5        -c
1         1         1         1         1         1         -1        0         0
0         0         0         57147
0.03      0.011     0.016     0.86      0         0.009     0         1         0
0         0         0         38576500
2067.4    278.1     1080.4    10836.7   766       4290      0         0         -1
0         0         0         21920.3
0         0         0         0         0         1         0         0         0
1         0         0         30324.9
0         1         0         0         0         0         0         0         0
0         1         0         476.5
2.12      1.339     1.85      1.89      3.1       0.926     0         0         0
```

The production of nuclear power plants remains the same, and the production of wind power plants equals their current production 476.5 GWh. The simplex method added new renewable resource to the proposed solution, water power plants with energy production of 26 345.6 GWh.

The current electricity production from water power plants represents 1 909.2 GWh. Since the capacity of the water resources in the Czech Republic is almost totally exhausted, it is clear that it is not possible to significantly increase production from water power plants. Actually, it is probably the most limited renewable energy resource in the Czech Republic conditions.

Therefore it is needed to reproach another value so the simplex method is able to look for another ways to optimise the energy mix. In the next simplex method, the total production from water and wind power plants is reproached up to the limit of their current production 2 385.7 GWh. The reproached value of the nuclear power plants and single wind power plants remains the same.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [VI]

u + v + w + x + y + z => 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)

Z <= 30324.9

V <= 476.5

V + W <= 2385.7

Table 6

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57 147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
z <= 30324.9
v <= 476.5
v + w <= 2385.7
```

Solution:

Optimal Solution: c = 78435.7; u = 0, v = 476.5, w = 1909.2, x = 24436.4, y = 0, z = 30324.9

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

```
Tableau #1
u         v         w         x         y         z         s1        s2        s3
s4        s5        s6        -c
1         1         1         1         1         1         -1        0         0
0         0         0         0         57147
0.03      0.011     0.016     0.86      0         0.009     0         1         0
0         0         0         0         38576500
2067.4    278.1     1080.4    10836.7   766       4290      0         0         -1
0         0         0         0         21920.3
0         0         0         0         0         1         0         0         0
1         0         0         0         30324.9
0         1         0         0         0         0         0         0         0
0         1         0         0         476.5
0         1         1         0         0         0         0         0         0
0         0         1         0         2385.7
```

The proposed production from the nuclear power plants and wind power plants remains the same as in the previous step. The electricity production from the water power plants was proposed by the system to the same level as it is currently in the Czech Republic.
The newly proposed result adds coal power plants into the solution with the production of 24 436.4 GWh. Such solution equals to the 20 000 decrease in the electricity production from the coal power plants, which is optimal from the environmental point of view and it corresponds to the assumption to decrease the total amount of emission produced in the air from energy generation.

Such result could be considered optimal. But two important renewables, photovoltaics and biogas, are not included in the proposed mix and therefore another value will be reproached in order to see whether simplex method will include these renewables or not.
The already reproached values remain the same, only one more is added in order to see whether the production from the proposed fossil fuels, nuclear power plants and coal power plants, will be slightly changed or if the programme will propose the same energy production from each source.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [VII]

u + v + w + x + y + z => 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)

Z <= 30324.9

V <= 476.5

V + W <= 2385.7

Z + X <= 40000

Table 7

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57 147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
z <= 30324.9
v <= 476.5
v + w <= 2385.7
z + x <= 40000
```

Solution:

Optimal Solution: c = 81830.8; u = 14761.3, v = 476.5, w = 1909.2, x = 9675.1, y = 0, z = 30324.9

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

Tableau #1

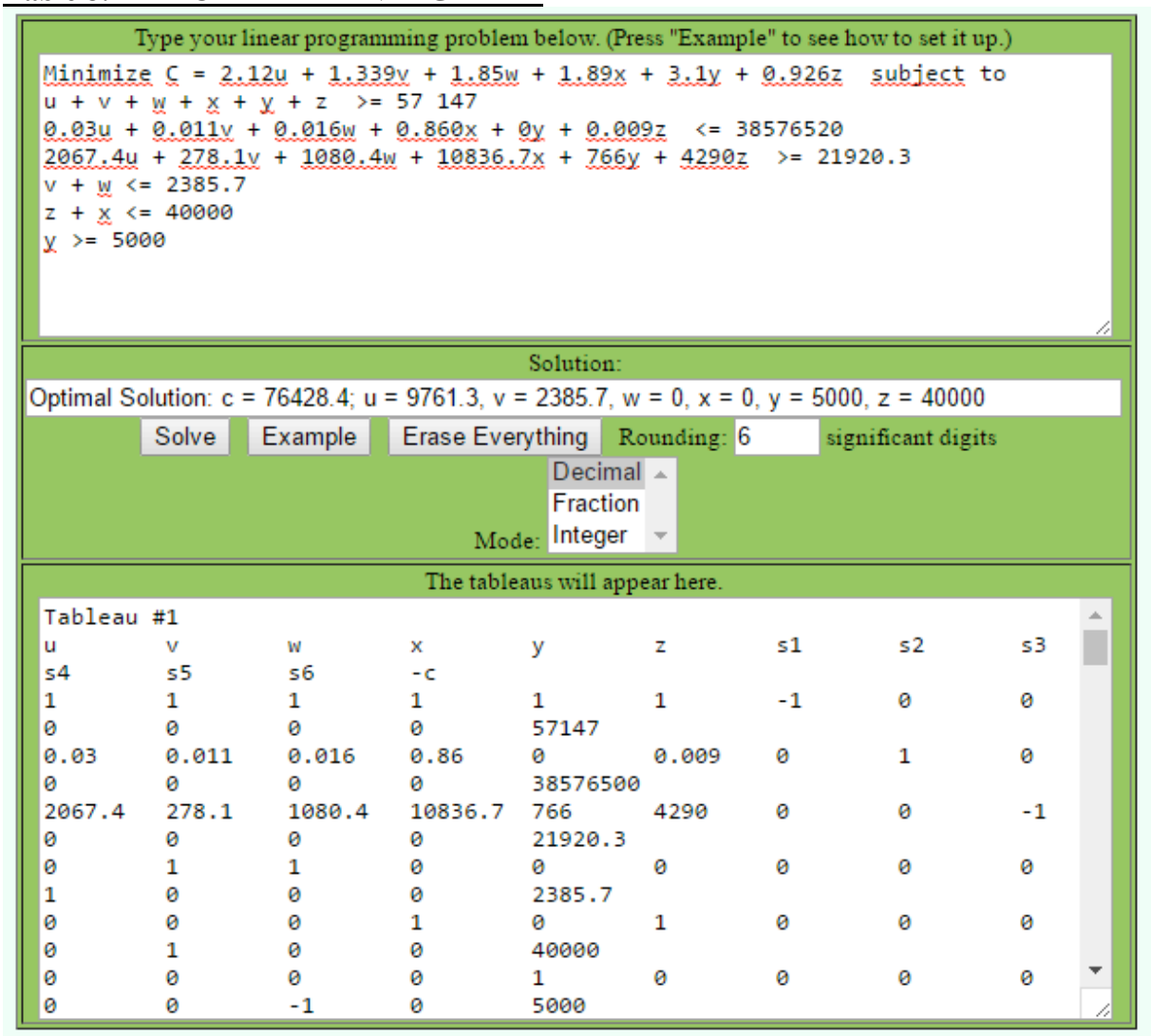
u	v	w	x	y	z	s1	s2	s3
s4	s5	s6	s7	-c				
1	1	1	1	1	1	-1	0	0
0	0	0	0	0	57147			
0.03	0.011	0.016	0.86	0	0.009	0	1	0
0	0	0	0	0	38576500			
2067.4	278.1	1080.4	10836.7	766	4290	0	0	-1
0	0	0	0	0	21920.3			
0	0	0	0	0	1	0	0	0
1	0	0	0	0	30324.9			
0	1	0	0	0	0	0	0	0
0	1	0	0	0	476.5			
0	1	1	0	0	0	0	0	0
0	0	1	0	0	2385.7			

After the last step, the linear programming tool gave 30 324.9 GWh production to nuclear power plants, and 9 675.1 GWh to coal power plants. Simplex method also proposed addition of the photovoltaics with the production of 14 761.3 GWh to the mix. The proposed costs of electricity generation would be 81 830.8 GWh.

Such energy mix is considered to be optimal, especially from the environmental point of view. Totally three renewables are involved, with total production of 17 147 GWh. But there is need to reproach one condition. Proposed energy mix does not count with biogas power plants, and since it is called to be "fuel of the future", it is necessary to include this energy resource into the mix.
The current biogas production is around 3 490 GWh, but since it will grow in the future the reproached condition is giving the limit up to 5 000 GWh.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [VIII]
u + v + w + x + y + z => 57 147 (electricity consumption)
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z =< 38576520 (emissions)
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z => 21920.3 (installed output)
V + W <= 2385.7
Z + X <= 40000
Y >= 5000

Table 8: THE OPTIMAL ENERGY MIX



The proposed optimal energy mix consists of the main resources represented by photovoltaics with the production of 9 761.3 GWh, wind power plants with 2 385.7 GWh, biogas with 5 000 GWh and nuclear power plants with the production of 40 000 GWh. The total electricity production from these main energy resources in the optimal energy mix equals to 57 147 GWh.

Of course, coal power plants together with water power plants will continue to operate as well, but their representation will be only as a support resources with significantly decreased energy production.

Creation of the second optimal scenario

In order to have ability to compare more variants, the second optimal solution was created with the same simplex method, but there was a focus on a different combination of resources in reproached conditions in the simplex method.

In the first step, all the equations are the same as in the first step of the previous variant.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [IX]

u + v + w + x + y + z >= 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3 (installed output)

Table 9

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z  subject to
u + v + w + x + y + z  >= 57147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z  <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z  >= 21920.3
```

Solution:

Optimal Solution: c = 52918.1; u = 0, v = 0, w = 0, x = 0, y = 0, z = 57147

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

```
Tableau #1
u         v         w         x         y         z         s1        s2        s3
-c
1         1         1         1         1         1         -1        0         0
0         57147
0.03      0.011     0.016     0.86      0         0.009     0         1         0
0         38576500
2067.4    278.1     1080.4    10836.7   766       4290      0         0         -1
0         21920.3
2.12      1.339     1.85      1.89      3.1       0.926     0         0         0
1         0

Tableau #2
u              v              w              x              y              z
s1             s2             s3             -c
```

In the next step, production from the proposed fossil fuels is reproached up to the limit 40 000 GWh. In this variant, the condition reproaching fossil fuels is included in the simplex method already in the second step, in order to see whether the linear programming again selects only nuclear power plants as in the first variant, or if the proposed value will be divided between nuclear energy and coal.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [X]

u + v + w + x + y + z >= 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520 (emissions)

2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3 (installed output)

X + Z = 40000

Table 10

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to
u + v + w + x + y + z >=57147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3
x + z = 40000
```

Solution:

Optimal Solution: c = 59999.8; u = 0, v = 17147, w = 0, x = 0, y = 0, z = 40000

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

```
Tableau #1
u        v        w        x        y        z        s1       s2       s3
s4       s5       -c
1        1        1        1        1        1        -1       0        0
0        0        0        57147
0.03     0.011    0.016    0.86     0        0.009    0        1        0
0        0        0        38576500
2067.4   278.1    1080.4   10836.7  766      4290     0        0        -1
0        0        0        21920.3
0        0        0        1        0        1        0        0        0
1        0        0        40000
0        0        0        1        0        1        0        0        0
0        -1       0        40000
2.12     1.339    1.85     1.89     3.1      0.926    0        0        0
```

The result of the second step also shows that simplex method allots all 40 000 GWh to nuclear power plants. Another energy resource proposed by the linear programme is wind power, with the production of 17 147 GWh.

Since the current production from the wind power plants is 476.5 GWh, such result is also not optimal. As in the first variant, it is needed to reproach another value regarding wind power plants. The new reproached value is limiting the energy production from the wind power plants up to their current capacity 476.5 GWh.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [XI]
u + v + w + x + y + z >= 57 147 (electricity consumption)
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520 (emissions)
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3 (installed output)
X + Z = 40000
V <= 476.5

Table 11

Type your linear programming problem below. (Press "Example" to see how to set it up.)

```
Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to
u + v + w + x + y + z >=57147
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3
x + z = 40000
v <= 476.5
```

Solution:

Optimal Solution: c = 68518.5; u = 0, v = 476.5, w = 16670.5, x = 0, y = 0, z = 40000

Solve | Example | Erase Everything | Rounding: 6 significant digits

Mode: Decimal / Fraction / Integer

The tableaus will appear here.

Tableau #1

u	v	w	x	y	z	s1	s2	s3
s4	s5	s6	-c					
1	1	1	1	1	1	-1	0	0
0	0	0	0	57147				
0.03	0.011	0.016	0.86	0	0.009	0	1	0
0	0	0	0	38576500				
2067.4	278.1	1080.4	10836.7	766	4290	0	0	-1
0	0	0	0	21920.3				
0	0	0	1	0	1	0	0	0
1	0	0	0	40000				
0	1	0	0	0	0	0	0	0
0	1	0	0	476.5				
0	0	0	1	0	1	0	0	0
0	0	-1	0	40000				

Third step gives the same production to nuclear power plants as in the previous step, and the production from the wind power plants is on their current level. The simplex method proposed the use of another renewable, water power plants with the production of 16 670 GWh.

As in the first variant, such proposed use of water power plants is not applicable in the Czech Republic conditions, therefore it is needed to add another reproached value setting the use of water and wind power plants up to their current limit.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [XII]

u + v + w + x + y + z >= 57 147 (electricity consumption)

0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520 (emissions)

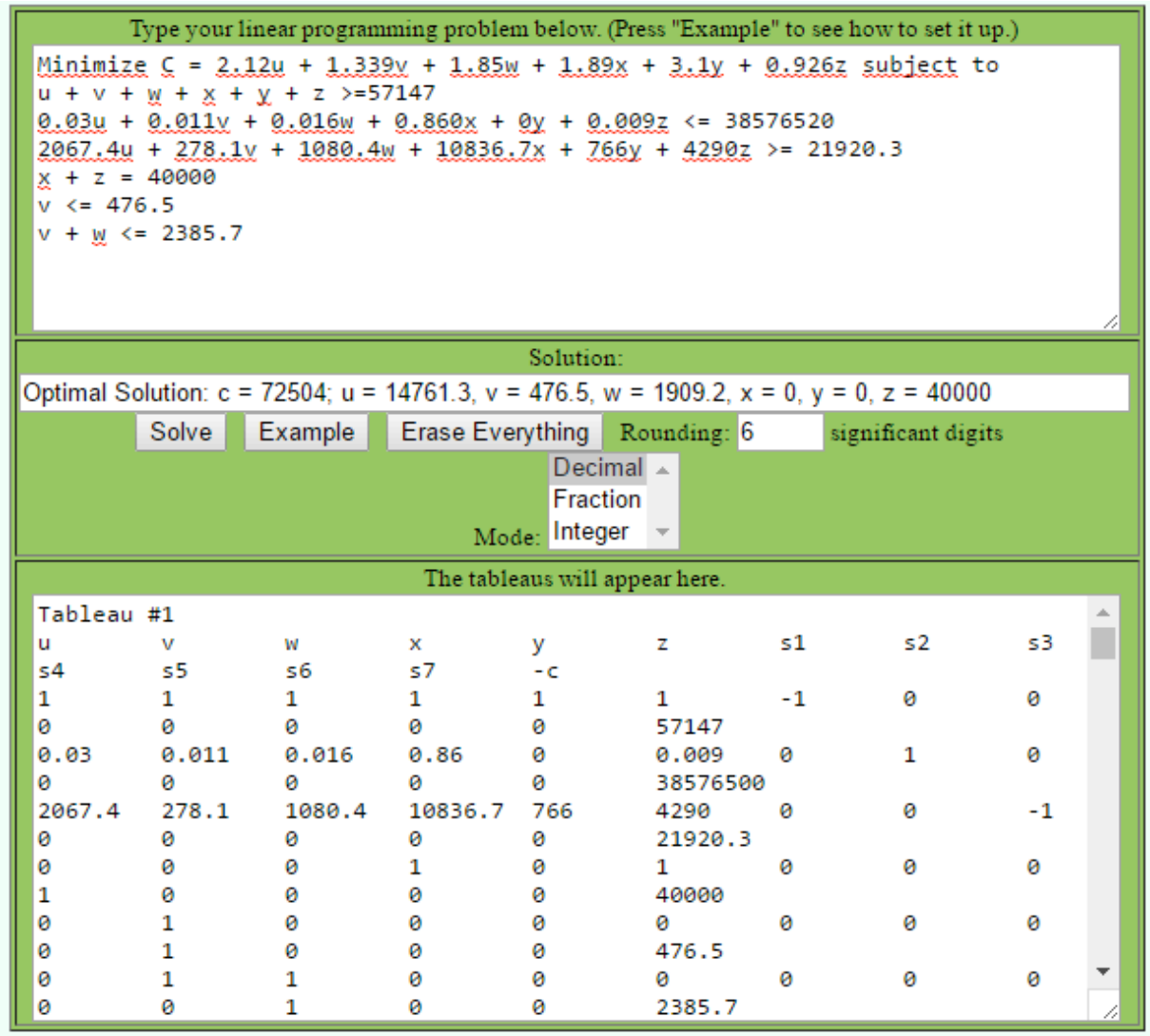
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3 (installed output)

X + Z = 40000

V <= 476.5

V + W <= 2385.7

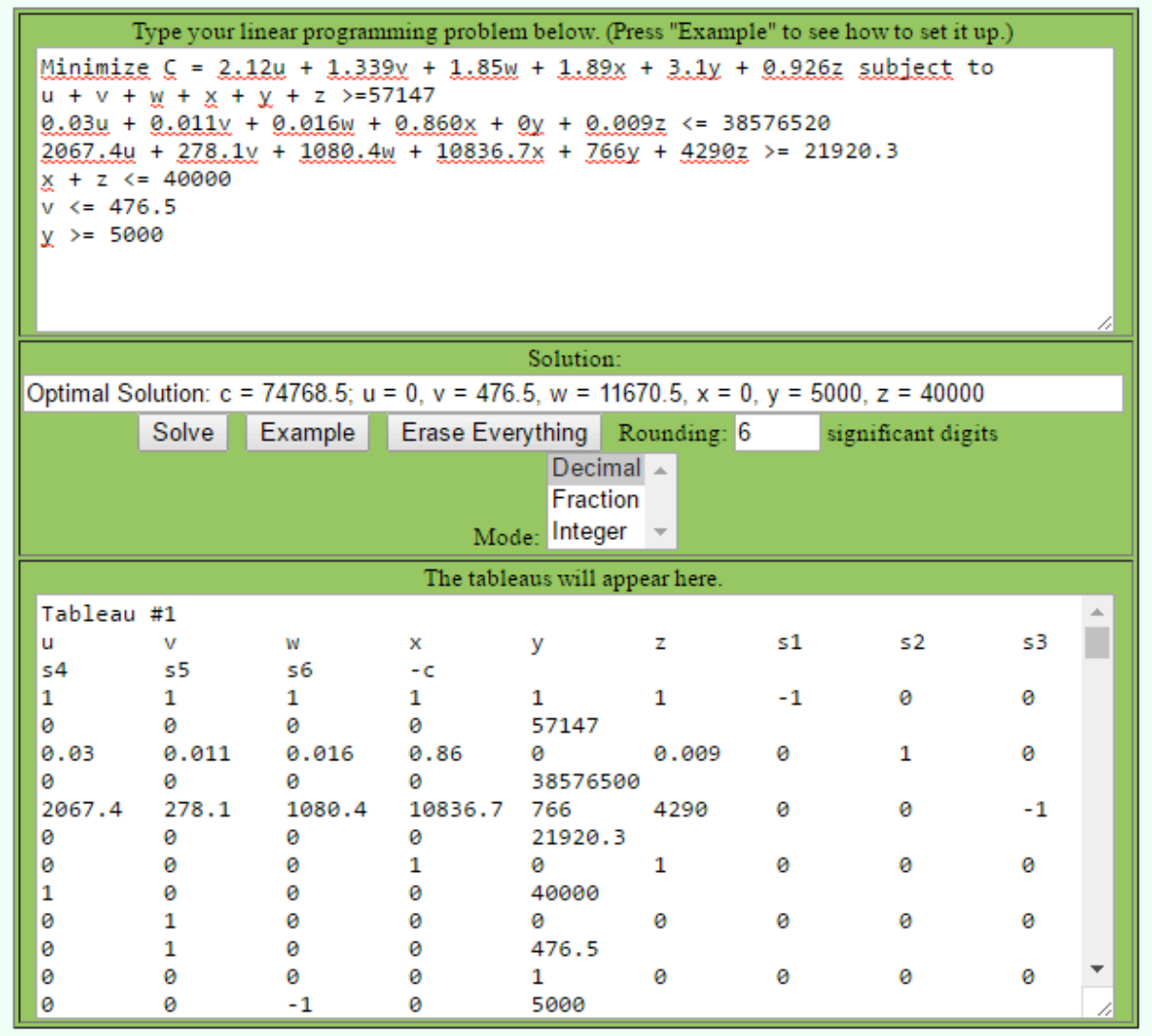
Table 12



The result of the third step adds photovoltaics with the production of 14 761.3 GWh. The production of nuclear power plants remains the same and amount of production from wind and water power plants equals their current production in the Czech Republic.
As well as at the end of the first variant, the proposed energy mix does not propose the use of biogas power plants in the solution. Therefore, there is need to reproach the use of biogas power plants, the value was set at the same level as in the first variant, 5 000 GWh.

Minimize C = 2.12u + 1.339v + 1.85w + 1.89x + 3.1y + 0.926z subject to [XIII]
u + v + w + x + y + z >= 57 147 (electricity consumption)
0.03u + 0.011v + 0.016w + 0.860x + 0y + 0.009z <= 38576520 (emissions)
2067.4u + 278.1v + 1080.4w + 10836.7x + 766y + 4290z >= 21920.3 (installed output)
X + Z = 40000
V <= 476.5
Y >= 5000

Table 13: THE OPTIMAL ENERGY MIX



The optimal energy mix in the second variant proposed four energy resources. The production from the nuclear power plants and biogas power plants is the same as in the first variant. Unlike the first proposed mix, this solution does not propose photovoltaics, but wind power plants with production of 476.5 GWh together with water power plants with production of 11 670.5 GWh. The total energy production from the main proposed energy resources in the second variant represent 57 147 GWh.

5 Results and discussion

The linear programming proposed two scenarios of the optimal energy mix suitable for the Czech Republic situation. In the first scenario, the combination of resources was represented by nuclear energy, photovoltaics, wind and biogas power plants.
In the second variant, the combination of resources was represented by nuclear energy, wind energy, water power plants and biogas power plants.

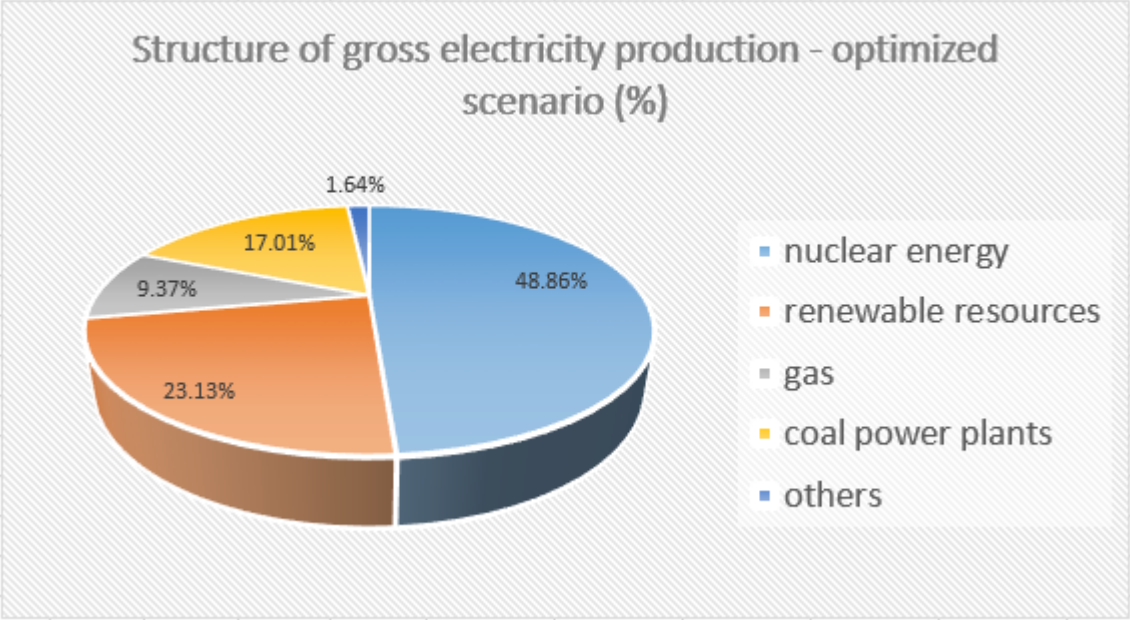
The creation of the optimal models of the energy mix answers to the first hypothesis, it means that the current energy mix for the Czech Republic is not optimal and the hypothesis is not confirmed.
The result proves the assumption that the share of coal power plants in connection to the total energy mix of the Czech Republic should be decreased. Lowering of the share of coal power plants will ensure significant decrease in the total emissions produced in the Czech Republic by electricity generation. From an economic perspective, current electricity production from coal power plants is favourable, due to recent sharp price forfeiture of the commodity - coal. The main goal should be to maximally reduce this source because it is the largest source of emissions in this sector.
This status confirms the second hypothesis, the recommended model dramatically reduces the production of electricity from coal, thereby significantly reduces emissions and prioritizes ecological resources of electricity that are also economically effective in terms of cost. This fact confirms the second part of the hypothesis of an increase in economic performance of producers of electricity.
The optimal energy mix that emerged from the linear programming method confirms the third hypothesis, because the mix recommends the cheapest energy sources, and the lower cost of producing electricity will be adequately reflected in the final price of electricity, which will also be lower.

The proposed energy mix is also correspondent to the energy mix created by the Czech government and Ministry of the Industry and Trade, which follows the plan for the year 2045. Based on this graph, it can be seen that the use of nuclear power plants is going to

increase significantly, almost up to the 50% of the total energy mix. In the proposed optimal mix, nuclear power plants represent even a 70% share.

The second biggest share belongs, as in the proposed energy mix, to renewable resources with a 23% share. The use of coal power plants is planned to decrease to 17% from the current 50%.

Graph 11: Optimized scenario of the Czech Energy mix by the Ministry of the Industry and Trade



Source: MPO (2014)[109]

The analysis clearly demonstrates that in order to optimize the current energy mix of the Czech Republic, it is necessary to decrease the use of coal power plants, and continue to use environmentally friendly and economically efficient energy resources, which are nuclear power plants in combination with renewable resources.

Based on the natural conditions of the Czech Republic, and also efficiency of the use of each energy resource used in the analysis, it is recommended by the author that the most optimal energy mix for the Czech Republic is represented by the first optimized scenario.

[109] *Doplňující analytický materiál k návrhu aktualizace Státní energetické koncepce.* [online]. 9.12.2014. Ministerstvo průmyslu a obchodu. Available from: https://www.email.cz/download/k/T1ogoYeXHbM94TV-Fw8WR7Nr3cPXjk744rxIvHhM2pOfMIsiQFDC6iIRZBsunXCnCyl8M3c/priloha004.pdf

6 Conclusion

The aim of the thesis was to analyse the current energy mix from the economic and environment stand point. Based on the analysis, it was presumed that the current energy mix may be improved from the economic point of view, and definitely ought to be optimized from the environmental standpoint.

The main problem found from the analysis was the enormous amount of emissions which are produced into the air from the activity of the energy sector. The energy resource causing this problem are coal power plants. These power plants are largely used in the Czech Republic and are improving energy self-efficiency of the country, therefore their use cannot be stopped. But it certainly can be optimized and decreased on such a level that it would not cause such a huge problem to the environment and their use would still be economically efficient.

Two optimized solutions were proposed with the use of the linear programming tool, both of them demonstrate the use of nuclear power plants accompanied by renewable resources. Both scenarios propose the use of biogas power plants and wind power plants, but the first solution added photovoltaics whereas the second chose water power plants.
The biggest representation in the proposed optimal energy mix belongs to nuclear energy. In the current energy mix, nuclear power plants supply the total electricity generation with 33%, in the proposed optimal scenario, their share increased up to 70%.

Such energy mix not only meets the vision and conception of the Czech government, which was adopted, but also the EU objectives of minimizing resources of electricity from fossil fuels to a minimum, and transfer mainly on renewable resources or on resources that have the least emissions – nuclear power plants. It is clear that coal power plants in certain small installed capacity will remain, but it will be only the latest that have a very complete desulfurization and filtering, and will probably remain as a strategic reserve in case of failure of nasal sources - nuclear power plants and renewable resources.

It can be assumed that even the technological level of the use of renewable resources will exceed in a few years, mainly in the sector of photovoltaics, as well as certain quality of production of turbines in the sector of wind and hydro energy, which will automatically increase the installed renewable capacity and will be able to further reduce the consumption of fossil fuels.

The thesis stated three research hypotheses:
H1: The energy mix for the Czech Republic is optimal.
H2: Finding the model of optimal energy mix for the Czech Republic will reduce emissions and improve economic outcomes of electricity producers.
H3: The right combination of the use of selected sources in the energy mix reduces the cost of generating electricity together with its price.

The creation of the optimal models of the energy mix answers to the first hypothesis, it means that the current energy mix for the Czech Republic is not optimal and the hypothesis is not confirmed.
The recommended model dramatically reduces the production of electricity from coal, thereby significantly reduces emissions and prioritizes ecological sources of electricity that are also economically effective in terms of cost. This fact confirms the second part of the hypothesis and economic performance of producers of electricity will increase.
The optimal energy mix that emerged from the linear programming method represents a confirmation of the third hypothesis, since the proposed mix recommends the cheapest energy resources, the lower cost of producing electricity will be adequately reflected in the final price of electricity, which will also be lower.

The use of the water energy cannot be increased any further in the Czech Republic's conditions, since the capacity of the water resources is almost fully used up. Based on the efficiency of the use of each resource in the Czech Republic conditions, and also given their installed output, it is therefore recommended by the author to use the first optimized energy mix.

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