BRNO UNIVERSITY OF TECHNOLOGY

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FACULTY OF CIVIL ENGINEERING
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FAKULTA STAVEBNÍ
ÚSTAV TECHNICKÝCH ZAŘÍZENÍ BUDOV

# ENERGY MANAGEMENT STRATEGY FOR SUSTAINABLE REGIONAL DEVELOPMENT

DISERTATION THESIS
DISERTAČNÍ PRÁCE

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BRNO 2015

**ABSTRACT**

Energy Management strategy for sustainable regional development has been selected as the topic of my research due to the fact that energy demand alongside with energy dependency have been continuously growing from a long term perspective. Sustainable development is defined by three imperatives – energy efficiency, ecology and security. Review of the current state and analysis of historical trends in Energetics at global and regional level are covered in this research. Results of the Multi-Criteria Decision Analysis introduce a set of implications and recommendations for Energy Management strategy in the Czech Republic.



**KEYWORDS**

Energy Management, Sustainable development of the Czech Republic, Energy efficiency, Energy security, Ecology, Renewable Energy Sources, Smart Governance

**DECLARATION**

I declare that this thesis and the work presented in it are my own and have been generated by me as a result of my own original research. Where I have quoted from the work of the others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

Brno, 27.5.2015

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Ing. Martin Hrubý

**ACKNOWLEDGEMENTS**

At the first place, I would like to express my sincere thanks to the supervisor of my research, Associate Professor Ing. Jiří Hirš, CSc., providing me with all the help and professional support I required. I am also very grateful to my family and friends for their patience, flexibility and encouragement whenever it was desired.

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## INTRODUCTION

Energy demand is continuously growing alongside with quality of living and Energy Management represents one of the main challenges of today's world. Our dependency on primary energy sources has doubled over the past decades and some of those non-renewable might be depleted in future. Discovery of new technologies and energy sources change our traditional view on Energetics, where reliable and affordable energy supply represents a key aspect. Sustainability is essential for development of our civilization.

Defining right strategy is important for setting appropriate direction, baseline and decision making framework in order to meet determined objectives. Thus, Energy Management strategy for sustainable regional development has been selected as the topic for my research to address some of these questions.

In the first part of the research, I focus on current status review and analysis of trends in Energetics at global and regional level. This helps me to define alternatives and criteria for future analysis as well as forecast future development. The Czech Republic, as a member country of the European Union, is substantially influenced by policy and directives set by the European Commission. Based on that, national strategy should be more or less aligned with strategy of the EU, but it primarily should address national interests and respect local conditions. Overall energy production, distribution and consumption are assessed in order to identify research scope with alternatives and criteria for detailed analysis. As a result, particular renewable energy sources and Energy Management measures are selected for further evaluation based on their relevance with regard to sustainability.

The second part defines the goal of this research and methodology used. The main goal is divided into multiple objectives, while applied methodology is split into several phases. Hypotheses are formulated in this section too. Analytic Hierarchy Process was selected as the most appropriate type of Multi-Criteria Decision Analysis for evaluation.

In the main part of this thesis, I perform detailed analysis of selected alternatives and criteria. Alternatives are represented by selected renewable energy sources and Energy Management measures, specific criteria are defined by three imperatives associated with sustainable development – efficiency, ecology and security. This analysis is carried out for two scenarios. The first scenario reflects current state, where suitable technology for energy storage is not available, whereas the second one assumes that such storage will become available in near future. General observations are also covered in this chapter.

Results of the research based on conditions in the Czech Republic, including implications and recommendations of preferred alternatives, are presented in the concluding part of the thesis. I propose concrete solutions to be a part of Energy Management strategy for sustainable regional development and describe areas for future research. Results and methodology can be used by individual investors as well as policy makers as an input for conceptual planning and Energy Management governance at local and regional level.

**CURRENT STATE REVIEW**

# 1. TRENDS IN ENERGETICS

Trend of globalization in past decades impacts Energy Management along with many other aspects of our daily life. Energy concepts of individual households or enterprises are influenced not only by local environmental conditions, which predominated in the past, but more and more by global aspects impacting Energy Management at district, country and regional level, where these households and enterprises are situated. This means that alignment with global and regional conditions, proper understanding of national energy situation as well as historical trends are essential for evaluation of both current state and available options for improvement and strategic proposals. Therefore, next chapters describe trends in global and regional context, supplemented with regional and local strategies in the area of Energetics.

## 1.1. Global context

Energy as well as Primary Energy Sources (PES) are publicly traded commodities, meaning that the price is based on current demand/supply and driven by the global market. For example, shortage of coal in one part of the world can initiate price increase; likewise discovery of new oil/gas reserves would have the opposite effect. Volatile fuel costs then influence behavior of stakeholders in energy market.

Despite the fact that recent economic crisis in western markets impacted many countries and energy prices stagnated or declined, total energy consumption and supply of PES were growing globally. This growth was driven mainly by demographic and industrial development in emerging markets in Asia.

Statistics published by International Energy Agency[1] clearly demonstrate continuous growth of global energy demand and supply over the past decades. Both total final energy consumption as well as primary energy supply have doubled since 1970’s and fuel mix has changed slightly as illustrated in Figures 1 and 2.

Interesting observation resulting from these figures is that 6,106 Mtoe of primary energy was required to cover final consumption of 4,672 Mtoe in 1973. In 2012, it was 8,979 Mtoe of the energy demand covered from 13,371 Mtoe of primary energy produced. Therefore, calculated total energy efficiency in 1973 was at 76.5% compared to efficiency in 2012 at 67.2% only. Such trend indicates worseness of the situation during measured period and substantial potential to improve Energy Management globally.

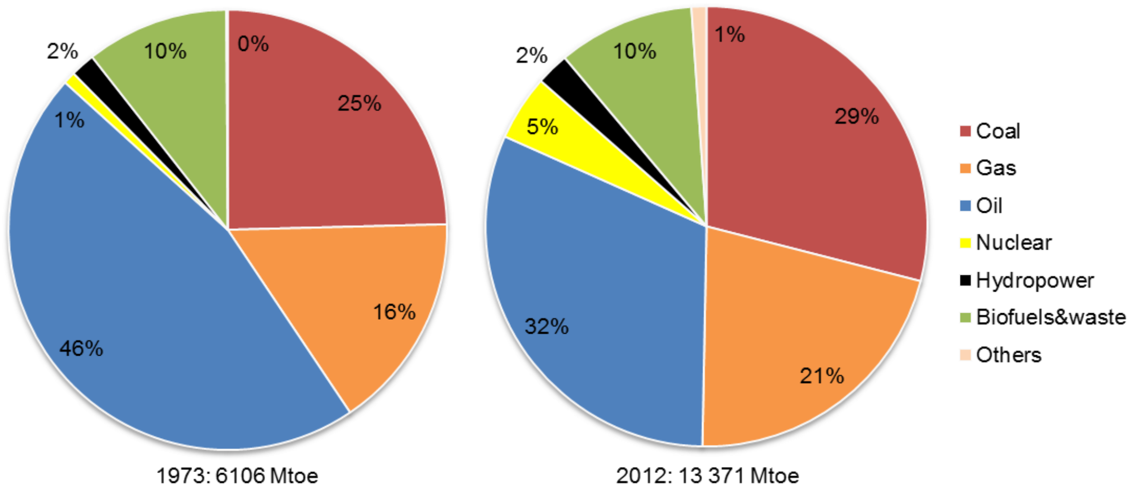


**Figure 1: World primary energy supply - fuel shares[1]**

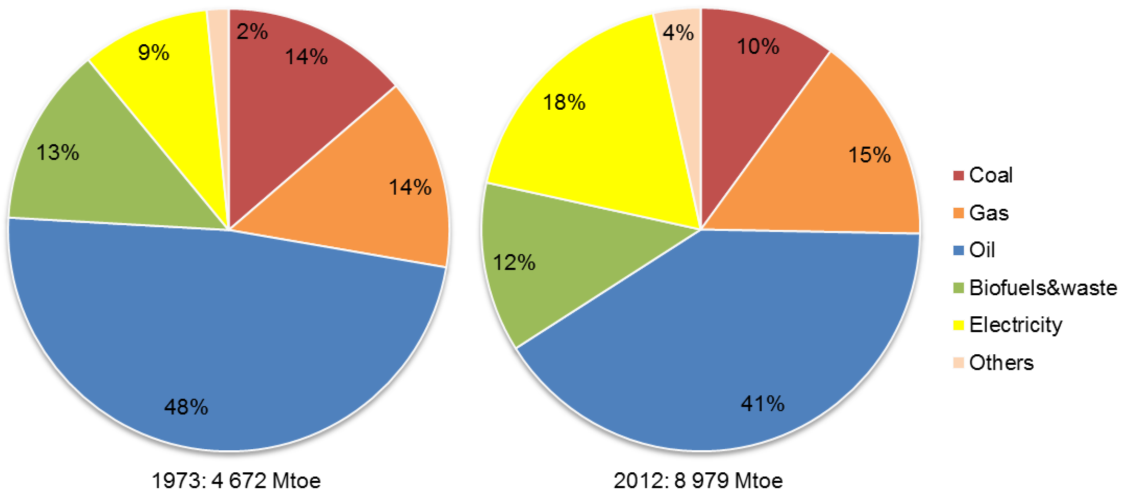


**Figure 2: World final consumption - fuel shares[1]**

Another important fact is related to subsidy policies used by governments to motivate producers and consumers to utilize desired sources of energy. It is well known fact that the recent boom in renewable energy sources in the past decade has been stimulated by subventions and public money encouraging investors to move from fossil fuels towards renewables. However, according to IAE statistics, governments spent globally USD 96.5 billion to support utilization of renewables in contrast with USD 548 billion spent to support fossil fuels including search for new deposits. Such discrepancy was mainly sponsored by countries exporting gas and oil from Middle East and Russia. It is assumed that higher investments into renewable technologies would make them more competitive compared to those conventionally used.

Forecast published by UNFPA[2] predicts that the world population will grow about 20% from now until 2050. This would increase energy consumption and demand for primary energy. Based on these assumptions, energy efficiency and utilization of renewable energy will be critical for sustainable development. In alignment with global trends, regional context is described in the following chapter.

### 1.2. Regional context

The Czech Republic as a member state of the EU is predominantly influenced from outside by other member countries and is obliged to adopt at local level assigned energy strategy and related legislation proposed by the European Commission. The internal EU market with integrated energy distribution networks and sufficient production capacity for sustainable operations is one of the priorities set by the European Commission. Standardization of norms and regulations across all member countries to liberalize gas and electricity markets, with emphasis on the environmental and security aspects, should guarantee open market and protection of final consumers. However, implementation of new regulations might result in opposite effect and slow down liberalization of energy market. Expansion of trans-European distribution networks for electricity, gas and oil transport should secure stable supply of resources for member countries, considering energy dependency of the EU, where more than 50% of PES have to be imported from other countries.[4]

Based on statistical figures published by the European Commission[3], pace of fuel consumption growth stagnated or slightly decreased in EU in past years, specifically from 1,804 Mtoe in 2007 to 1,666 Mtoe in 2013. This was caused mainly by economic crisis, but also due to the measures introduced by the European Commission and funding of initiatives supporting energy efficiency. Even though the number of final consumers has increased, operations and appliances used are more efficient. In the past two decades, the energy mix shifted from extreme dependency on fossil fuels to balanced energy mix including 20% of energy produced from RES. Price of electricity and gas for final consumers in EU grew around 25% and 35% respectively over the past five years and more households are facing a risk of energy poverty.[3] In this context, energy independence plays a key role in sustainable regional development.

### 1.3. Energy dependency

Energy independence is an important element of overall energy security. Due to the local conditions and availability of natural resources compared to economic maturity and GDP demandingness, the Czech Republic and the EU are dependent on external supply of PES. Available data from Eurostat show that the situation has stabilized over the past years due to implemented Energy Management policies as well as recent stagnation of economy. Energy dependency of the EU and the Czech Republic in terms of PES import/export are shown in Figures 3 and 4.

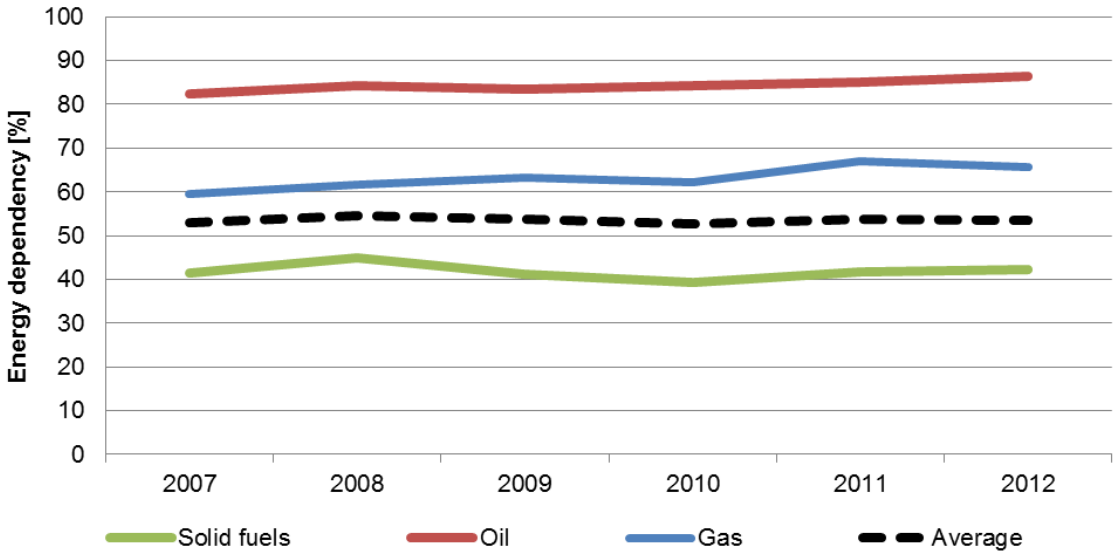


**Figure 3: Energy dependency of EU[4]**

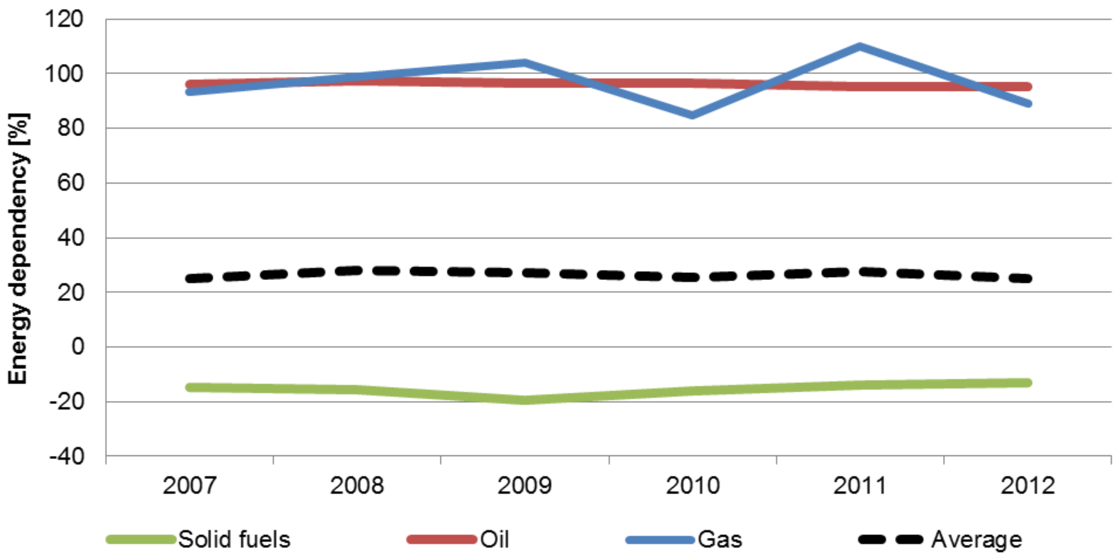


**Figure 4: Energy dependency of CZ[4]**

Energy dependency of the Czech Republic, with 26% of the inland consumed PES being imported in 2012 (whilst 15% of solid fuels have been exported), represents only about a half of the EU average dependency. In the EU, almost 54% of the consumed energy in 2012 was imported from outside, creating economic dependency on supplying countries, mainly the Russian Federation, Norway and Arabic countries.[1] It is logical that EU invests money to reduce overall energy consumption and supports utilization of Renewable Energy Sources (RES) in order to minimize dependency on external PES supply and ensure energy security.

In the context of the EU energy market, the Czech Republic was the third biggest exporter of electric energy in the past years with balance of 16.9 TWh sold to our neighbors in 2013[5]. However, more than 85% of this energy was produced from fossil or nuclear fuels and makes us dependent on the import of PES. Despite the fact that inland uranium reserves are sufficient to cover the whole domestic demand, technology for manufacturing fuel cells is not available in the Czech Republic but provided by the Russian Federation.

One of the positive trends since 1990's is that transformation of the national economy from heavy industry into more "knowledge based" brings significant reduction of the energy consumption per GDP. The ratio between PES and GDP has declined more than 35% since 1995. However, in comparison with rest of the EU, the Czech Republic still ranked as the eighth most energy demanding economy within the EU in 2012.[4] This means that the Czech economy still has a significant potential for improving its energy demandingness, ideally driven by increasing energy efficiency and implementing Energy Management measures.

| GDP energy intensity | 1995 | 2000 | 2005 | 2010 | 2011 | 2012 |
|---|---|---|---|---|---|---|
| GDP [billion CZK] | 2 328 | 2 550 | 3 116 | 3 557 | 3 622 | 3 585 |
| PES [PJ] | 1 749 | 1 657 | 1 856 | 1 852 | 1 768 | 1 740 |
| PES/GDP ratio | 0.75 | 0.65 | 0.6 | 0.52 | 0.49 | 0.49 |

**Table 1: Energy demandingness (intensity) of the national economy[6]**

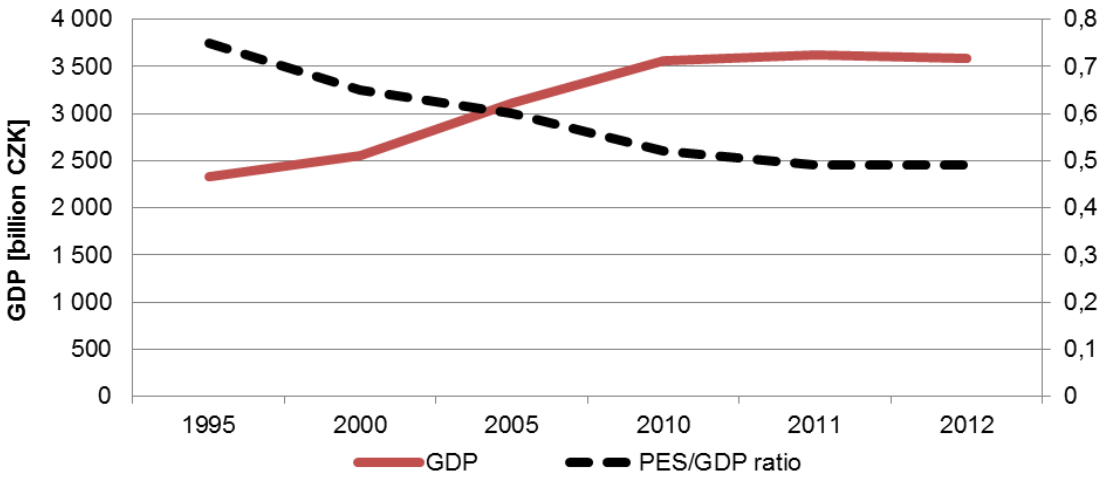


**Figure 5: Energy demandingness (intensity) of the national economy[6]**

The graph above illustrates decline of the GDP energy intensity in the past twenty years. This trend has slowed down recently due to the stagnating national economy. National Energy Policy[11] expects further reduction of GDP energy intensity as well as growing share of renewable energy on the total energy consumption. Implementation of energy saving measures across all sectors would further reduce energy intensity of national GDP.

### 1.4. EU strategy and 2020 roadmap

The European Commission set the energy targets in official paper called "Europe 2020"[7] published in 2010 and defines the EU growth strategy towards smart, sustainable and inclusive economy by 2020. Particularly "Energy 2020"[8] communication with associated legislation set key priorities for the upcoming years:

- reduce overall energy consumption
- establish internal energy market
- develop energy infrastructure and improve technologies
- protect consumers

The strategy explicitly defines one of the five main targets related to climate change and energy sustainability as follows:

"*Reduce greenhouse gas emissions by at least 20% compared to 1990 levels or by 30%, if the conditions are right; increase the share of renewable energy sources in our final energy consumption to 20%; and a 20% increase in energy efficiency*"[9]

This target can be achieved by fulfilling 2 objectives:

1. First objective is to reduce by 20% annual primary energy consumption of the EU. There have been several measures proposed by the European Commission in order to improve efficiency in all stages of the cycle - energy production and transformation, distribution and consumption. This includes for example mandatory product/building labelling with energy certificates and implementation of smart meters to encourage final consumers manage energy utilization more effectively.
2. Second objective is to achieve that at least 20% of the overall energy production is coming from RES with primary focus on power generation from wind, solar (thermal/photovoltaic), hydro, geothermal and biomass sources. This approach also helps to reduce amount of greenhouse emissions.

"The Europe 2020 Strategy" gives clear direction to the EU member states to redefine their energy mix by moving from fossil fuels to RES. The European Commission also set the minimum target for the Czech Republic having at least 13% of gross energy consumption coming from renewable sources. The National action plan set the target at 14% for the Czech Republic (vs. 13% committed to EU).[29] Recently announced EU strategy for 2030 expects reduction of greenhouse gasses by 40%, increased consumption from RES by 27% (almost double as of today) and improved efficiency by 27%, all compared to levels in 1990.[10] In alignment with EU goals, strategy for the Czech Republic is described in the next chapter.

## 1.5. Strategy for the Czech Republic

Energy production in the Czech Republic is dependent on availability of fossil fuels, where majority of electricity and heat generating plants use coal as a primary fuel. Solid distribution networks provide reliable energy supply to final consumers as well as transmission capacity to and from our neighbor countries. Despite the stable state, majority of the production facilities and distribution infrastructure is more than 40 years old and would require substantial investments into modernization. This is an opportunity to apply advanced technologies, improve energy efficiency, modify energy mix with lower impact on environment and strengthen energy security.

Strategic goals of the Czech Republic are derived from those set by the EU. However, considering national interests and opportunities given by historical trends and local conditions, described in National Energy Policy[11]. The three strategic goals are:

1. Secure energy supply to final consumers with respect to external factors such as resource supply cut-offs, outages or significant price fluctuations. Prompt restoration of energy supply for all types of energy is required in emergency cases.
2. Competitiveness of Energetics by provisioning reasonable energy prices to final consumers, comparable to those in neighbor countries
3. Sustainable development with positive impact on environment, availability of PES, financial stability of energy producers and population

Goals listed above can be reached by improving operational efficiency and implementation of savings in energy demanding sectors together with innovations ensuring competitiveness of national industry. Balanced mix of energy sources including renewables with sufficient reserves of local resources and further development of energy distribution infrastructure should be priorities for the Czech Republic in the upcoming decades. As a next step, suitable sources for energy production are assessed in the following section.

# 2. ENERGY PRODUCTION

Amounts of energy produced are dependent on demand and availability of resources. Based on growing trends in energy consumption described in previous chapter, optimization and diversification of energy production with respect to operational efficiency and resource availability is crucial for sustainable Energy Management.

Energy sources can be split into two main groups, those from fossil fuels and those that are relatively renewable. Although the definition of RES varies among experts, adopted interpretation for this research is “resources which can be continually replenished”. This includes biomass as well as other biofuels that can be re-produced in relatively short period of time, thus they are renewable.

Both renewable and non-renewable fuels are considered as PES until being converted in transformation processes. These are predominantly fossil fuels, but also nuclear and natural renewable sources that are freely available in nature. Initial breakdown of PES is following:

- Fossil fuels (coal, lignite, oil, natural gas)
- Nuclear fuels (uranium)
- Renewables (biomass, biogas, hydro, geothermal, wind and solar etc.)

PES can be obtained by various approaches such as mining (fossil fuels), utilizing natural energy potential (renewables) or simply imported in the form of primary energy. In majority of the cases, PES are combusted as a fuel in boilers, generating steam for electricity or heat production. Large facilities use boilers designed for specific, mostly conventional fuels such as coal, gas or oil. This dominance changed towards better utilization of waste and renewable fuels in the past years. The graph below illustrates shares in overall PES consumption in the Czech Republic for 2013 and underlines our dependency on imported non-renewable fuels as mentioned in Chapter 1.3.

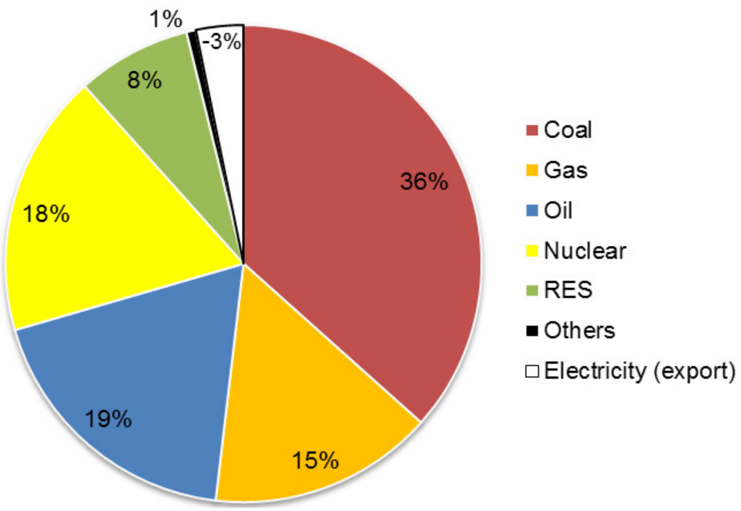


**Figure 6: Primary energy sources in CZ for 2013[12]**

Consumption share of coal being at 36% in 2013 across all sectors is even higher in case of electricity and heat production, reaching 60% of all PES. Furthermore, most of the obsolete coal combusting facilities reach end of their life and will require substantial investment to get them modernized in upcoming years. This offers a great opportunity to introduce more efficient and sustainable technologies. The National Energy Policy assumes that coal share in energy mix would decrease by 316.8 PJ until 2030, substituted mostly by gas and nuclear power growing by 224.8 PJ in annual energy production, accompanied by RES growing by 112.8 PJ of annual energy prodcution.[11,12]

The amount of PES required for energy production calculated with heating (calorific) value is important for the assessment of energy utilization efficiency. In case of nuclear and renewable fuels (hydro, wind, solar), efficiency calculation based on heating value of the material is unfeasible, thus amount of finally produced heat or electricity is considered instead. According to the Czech Statistical Office (CZSO)[6], utilization of PES is split almost constantly in 2:2:1 ratio over the past decade as follows:

- 40% for electricity and heat production
- 40% for final consumption
- 20% for transformation processes and transmission losses

Further analysis of the breakdown above will be covered in next chapters. This section will focus on electricity and heat generation, analyzing trends in installed power of production plants with detailed breakdown of RES. Renewable fuels, which are directly used for final consumption in Transportation sector, are not covered in the scope of the research. Their utilization in stationary facilities bounded to the region is very low. The next graph shows total energy produced in the Czech Republic including the one generated during transformation processes.

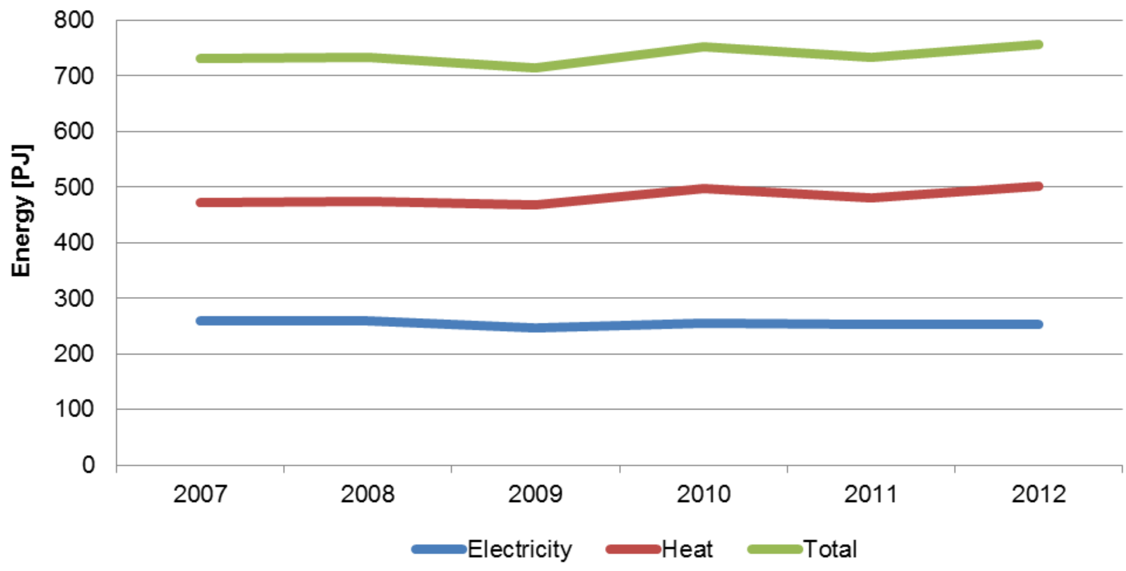


**Figure 7: Total energy production in CZ[6]**

On average, 482 PJ of heat and 255 PJ of electricity were produced during measured period, summing into 737 PJ of total energy production. Majority of this energy was consumed in the country and about 8% exported to neighbor countries.[5]

The Czech Republic is self-sufficient in electricity and heat production but most of the fuels except for coal have to be imported and create secondary energy dependency. According to National Energy Policy[11], up to 80% of heat production is covered by inland fuels, mostly coal. However, more than a half of heat production facilities operate inefficiently without using cogeneration technology.

Although comprehensive strategy for secure energy supply in the Czech Republic is currently missing, reserves of fossil fuels and distributed heat plants burning coal are able to operate in stand-alone emergency mode for several months.[11]

Following chapters describe available installed power for electricity and heat generation in the Czech Republic. Special attention is paid to sustainable resource management associated with renewable energy sources. Important fact to highlight is that from thermodynamic perspective, the energy quality of electricity, so called “exergy”, is about 2.6 times higher than quality of thermal energy. In very simplified assumption this means that 1 J of electricity could produce approximately 2.6 more work than 1 J of heat. Exergy becomes essential when selected attributes between electricity and heat are compared in subsequent chapters as well as later during detailed analysis of source efficiency in Chapter 5.4.

## 2.1. Installed power for electricity generation

Most of the electricity produced in the Czech Republic is coming from steam driven thermal power stations. These held about 52% share of the total installed power in 2013 and represented together with nuclear power stations with share about 20% vast majority of the total energy production. The graph below illustrates that installed power of RES has increased over the past years.

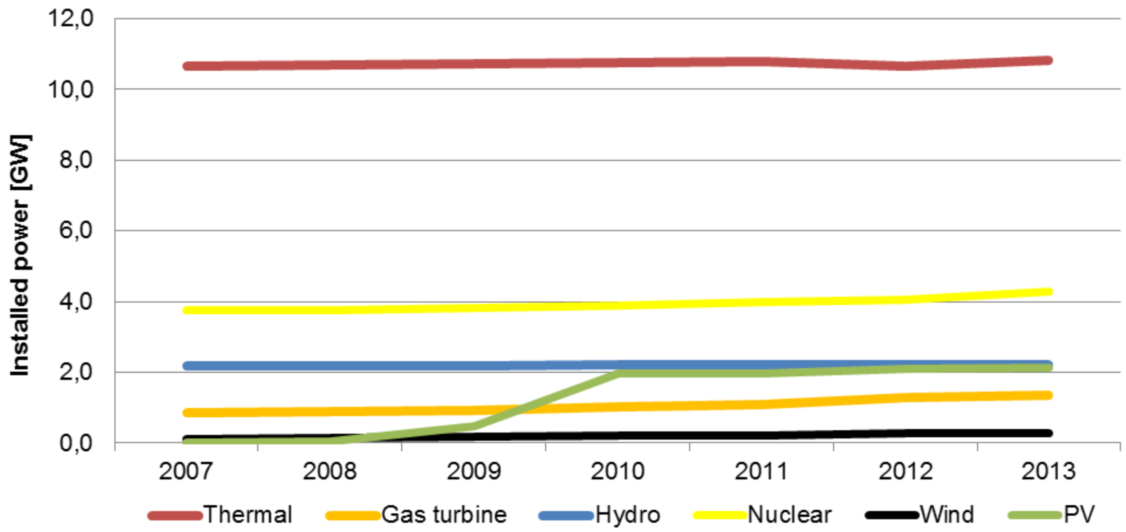


**Figure 8: Installed power for electricity generation in CZ[5]**

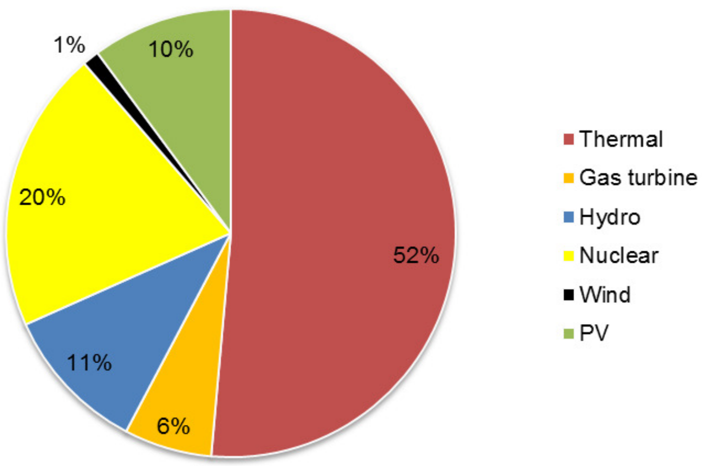


**Figure 9: Installed power for electricity generation in CZ for 2013**[5]

According to Figure 9, pure RES (represented by hydropower, wind power and PV) contributed by at least 22% to the total installed power for electricity generation in the Czech Republic for 2013. However, overall share of renewables in energy mix is higher due to the fact that many thermal and gas turbine power plants built or modernized in the past years can also combust renewable fuels as a primary or an alternative energy source.

## 2.2. Attainable installed power for heat generation

According to the CZSO[6] data, attainable capacity of installed heat producing boilers in power plants, heat generating plants and combined heat and power (CHP) plants was more than 50 GW in total for 2013.

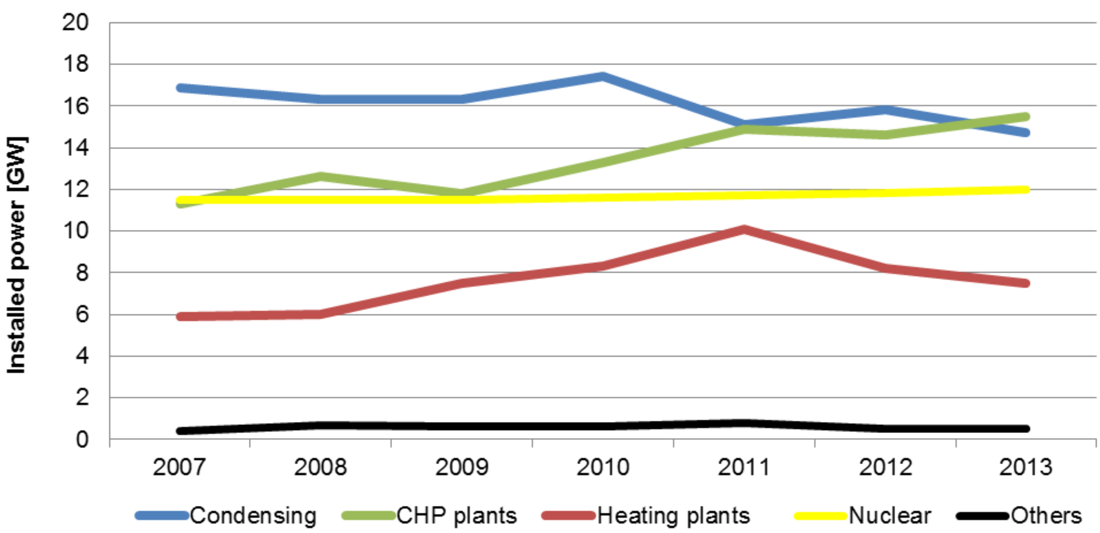


**Figure 10: Installed power for heat generation in CZ**[6]

Figure 10 demonstrates growing installed capacity of cogeneration facilities against condensing plants over the past years. In 2013, CHP represented 31% of attainable installed power, whilst condensing plants 29% of attainable power for heat generation as shown in Figure 11.

Important fact to highlight is that majority of the 12 GW of attainable installed capacity in two nuclear power plants Dukovany and Temelin is not supplied into the distribution grid for further utilization. According to Figure 11, this amount represents 24% of total attainable capacity for heat generation, which is not fully utilized and indicates an opportunity to supply recovered waste heat to nearby agglomerations. Comprehensive study would be required to assess feasibility of such initiative.

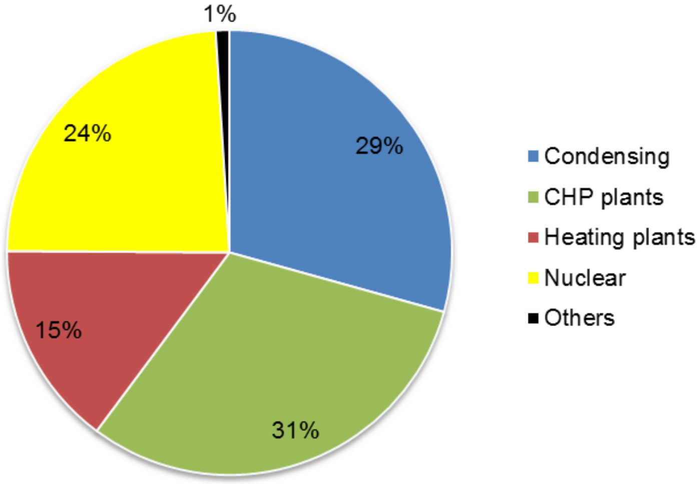


**Figure 11: Installed power for heat generation in CZ for 2013**[6]

Most of the heat production capacities use locally available brown coal for energy generation. On one hand this can positively stimulate competitiveness of the business, but on the other hand adversely impacts environment as stated in the National Energy Policy.[11]

The statistics presented by CZSO cover all energy produced in plants as well as consumption of fuels required for heat generation in transformation processes. In contrast, international methodologies used by Eurostat and OECD do not consider own consumption in their calculations.

From Chapter 2.3 onwards, renewable energy sources are described in order to provide comprehensive information about used technologies, recent trends in installed capacity, fuel mix and potential for future growth. Selected data from these chapters will be used later in detailed analysis delivered in Chapter 9.

## 2.3. Sustainable resource management

Sustainability at regional level is closely related to the natural environment of given country. Besides economic and social aspects, ecological elements like alternative energy sources and climate conditions lasting for hundreds of years are essential for sustainable planning and development of the region.

Despite the fact that renewables represent only 8.3% of total PES consumed today in the Czech Republic[12], it is expected that share of RES will grow in the future driven by EU energy policy. In most of the cases RES are less damaging to the environment than traditional fuels and remove dependency on external suppliers due to their long-term availability. Following RES were selected for further assessment:

- Biomass and Biogas
- Waste and Alternative Solid Fuels (ASF)
- Hydro energy
- Wind energy
- Solar energy (photovoltaics, solar heating systems)
- Geothermal energy and Heat pumps

Each of the RES listed above will be described more in details in one of the following chapters, evaluating current status, historical trends and potential for future growth. Main factors in decision making analysis such as environmental, economic and social attributes will be considered based on local conditions of the Czech Republic.

Nuclear power, with 338 PJ energy produced in 2013[12] and approximately 20% share of total electricity consumed in the Czech Republic (Figure 9), has specific position in the energy mix. Despite high initial investment costs, operations are relatively cheap. Possibility to store fuel cells for a longer period also creates strategic advantage. Uranium mined in the Czech Republic would cover all inland demand in a long-term perspective. However, technology to manufacture fuel cells is available in Russian Federation and makes us dependent on external supply. Considering strategic plan to reduce utilization of coal and oil fuels for energy production in upcoming decades, installation of additional nuclear blocks in existing power plants might cover transformation period until sufficient renewable capacity is available. Nuclear power generation is relatively sustainable and recovery of waste heat could supply densely populated agglomerations. The National Energy Policy counts with growing share of nuclear fuel in energy mix until 2040 and beyond, to the gradual exclusion of coal.

The following chapter provides basic overview of renewable energy sources in the Czech Republic, their position in overall energy mix as well as fuel/technology share.

## 2.4. Renewable energy mix

As of today, the biggest portion of the energy produced from RES comes from traditional sources used for many years, typically hydro energy and biomass. In the past decades, newer technologies like photovoltaics, wind energy or biogas were developed and their share has been growing. Detailed breakdown per energy resource is available in tables below:

| RES type | Gross prod. [GJ] | Share in RES | Share all sources |
|---|---:|---:|---:|
| Biomass total | 52 101 988 | 82.8% | 7.5% |
| Biomass households | 32 048 052 | 50.9% | 4.6% |
| Biomass commercial | 20 053 936 | 31.9% | 2.9% |
| - Wood logs, bark & chips | 10 527 138 | 16.7% | 1.5% |
| - Pulping liquor | 7 826 974 | 12.4% | 1.1% |
| - Crops | 687 438 | 1.1% | 0.1% |
| - Briquettes & pellets | 1 007 513 | 1.6% | 0.1% |
| - Others | 4 873 | 0.0% | 0.0% |
| Biogas total | 3 571 077 | 5.7% | 0.5% |
| - Water treatment plant | 749 688 | 1.2% | 0.1% |
| - Biogas plant | 2 724 264 | 4.3% | 0.4% |
| - Landfill gas | 97 125 | 0.2% | 0.0% |
| Waste and ASF | 3 194 366 | 5.1% | 0.4% |
| Heat pump | 3 431 036 | 5.5% | 0.5% |
| Solar thermal | 630 340 | 1.0% | 0.1% |
| **Total heat** | 62 928 806 | 100.0% | **9.0%** |

**Table 2: Heat production from RES in CZ for 2013**[13]

| RES type | Gross prod. [MWh] | Share in RES | Share all sources |
|---|---:|---:|---:|
| Hydropower | 2 734 740 | 29.4% | 3.1% |
| - SHP < 1 MW | 478 721 | 5.1% | 0.5% |
| - SHP 1-10 MW | 614 803 | 6.6% | 0.7% |
| - LHP ≥ 10 MW | 1 641 216 | 17.6% | 1.9% |
| Biomass total | 1 683 272 | 18.1% | 1.9% |
| - Wood logs, bark & chips | 788 160 | 8.5% | 0.9% |
| - Pulping liquor | 623 117 | 6.7% | 0.7% |
| - Crops | 104 445 | 1.1% | 0.1% |
| - Briquettes & pellets | 165 045 | 1.6% | 0.2% |
| - Others | 2 505 | 0.0% | 0.0% |
| Biogas total | 2 293 593 | 24.6% | 2.6% |
| - Water treatment plant | 99 006 | 1.1% | 0.1% |
| - Biogas plant | 2 083 546 | 22.4% | 2.4% |
| - Landfill gas | 111 041 | 1.2% | 0.1% |
| MSW+ASF | 83 946 | 0.9% | 0.1% |
| Wind power | 480 519 | 5.2% | 0.5% |
| Photovoltaics | 2 032 654 | 21.8% | 2.3% |
| **Total electricity** | 9 308 724 | 100.0% | **10.7%** |

**Table 3: Electricity production from RES in CZ for 2013**[13]

According to statistics provided by the Ministry of Industry and Trade (MIT)[13], there was about 9% of total gross domestic production of heat in the Czech Republic in 2013 coming from RES. Share of gross electricity produced from renewables was calculated at 10.7% differing from data provided by Energy Regulatory Office (ERO).[5] This was caused by various statistics reported biomass and biogas. Power plants utilizing renewable sources such as water, wind and photovoltaics produce solely electricity. Other RES like heat pumps or solar thermal systems are usually generating heat for local use only.

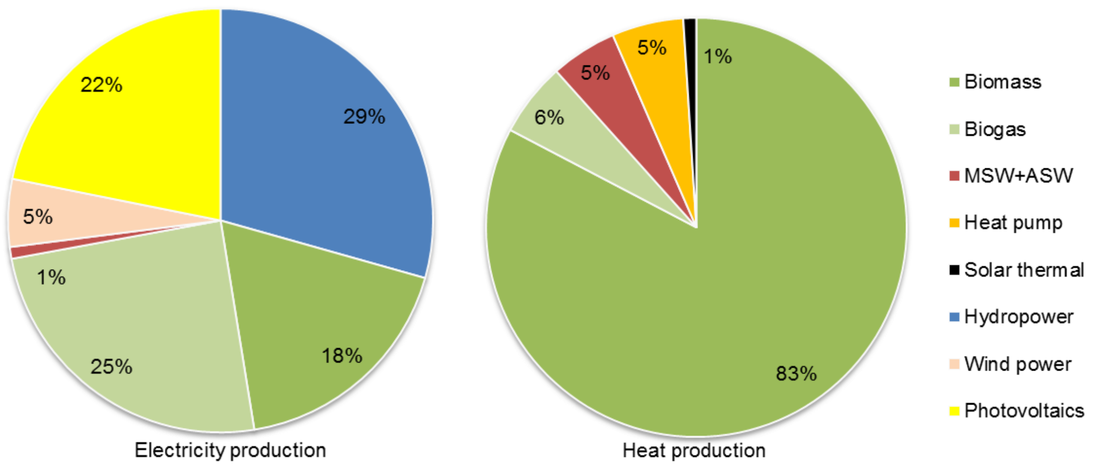


**Figure 12: RES electricity and heat production share in CZ for 2013[13]**

Biomass in solid or gas form produced from rural or urban feedstock represents about 43% of RES for electricity production and 89% for heat production respectively. These numbers underline that solid biomass is in fact the only RES broadly available and suitable for heat generation. Liquid form is rather used as fuel in Transportation sector and not for power generation in stationary applications, thus not considered in scope for analysis. Potential of geothermal and solar energy for centralized heat generation is very low in the conditions of the Czech Republic.

Investments into sustainable development and increasing share of RES in overall energy mix at regional scale requires very often engagement of local individuals during implementation, motivated by financial subsidies from the government. There was an obvious expansion of photovoltaic and wind power plants experienced in the past years because of EU subsidy policy. Recently, subsidy models have been reorienting from photovoltaic to biomass energy sources, with continuous support of cogeneration and reusing of waste heat.

Some of the RES have been removed from scope of this research. Due to the fact that there is no sea in the Central Europe, tidal facilities or offshore wind power plants are not operating in the Czech Republic and will not be covered in this thesis. In the following chapters, relevant energy sources are described in terms of technology pros/cons, installed capacity trends, current fuel mix and potential for future growth.

### 2.4.1. Biomass

Biomass in a solid form is the most frequent RES used for energy production in the Czech Republic. It is also the only alternative fuel broadly available for heat generation. Energy from solid biomass is obtained by combustion of biological material in the boiler, producing either heat directly or steam for electricity generation. Most common types of solid biomass are derived from wood, specific energy crops or as side products from other manufacturing processes. These are besides others:

- Wood logs
- Briquettes and pellets
- Bark & wood chips
- Sawdust and shavings
- Pulping liquor
- Crops (maize, corn cob, wheat straw etc.)

Usage of solid biomass for heating in households is not fully covered in studies published by MIT. Number of private energy sources such as boilers and heaters is not measured but only estimated. It is assumed that majority of the biomass used in households comes from wood (lumber and waste). Available statistics for heat production from biomass were collected by MIT directly by conducting surveys with facility operators.

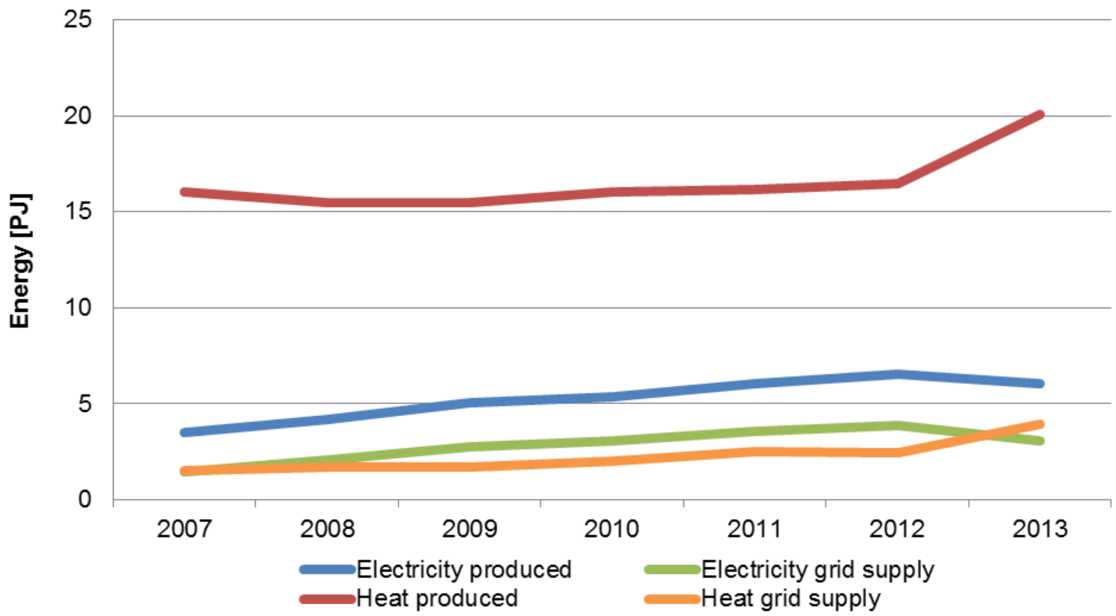


**Figure 13: Biomass heat and electricity production in CZ**[13]

In the past years, amount of electricity and heat produced from biomass was growing as shown in Figure 13. In average, about 54% of the produced electricity was supplied to the grid, compared to 14% of produced heat. However, percentage of energy sold to the distribution network grew as well. Most frequently used biomass fuels were bark and wooden chips with 47% and 50% share on production of electricity and heat respectively, followed by pulping liqueur with 37% and 39% shares for the same.

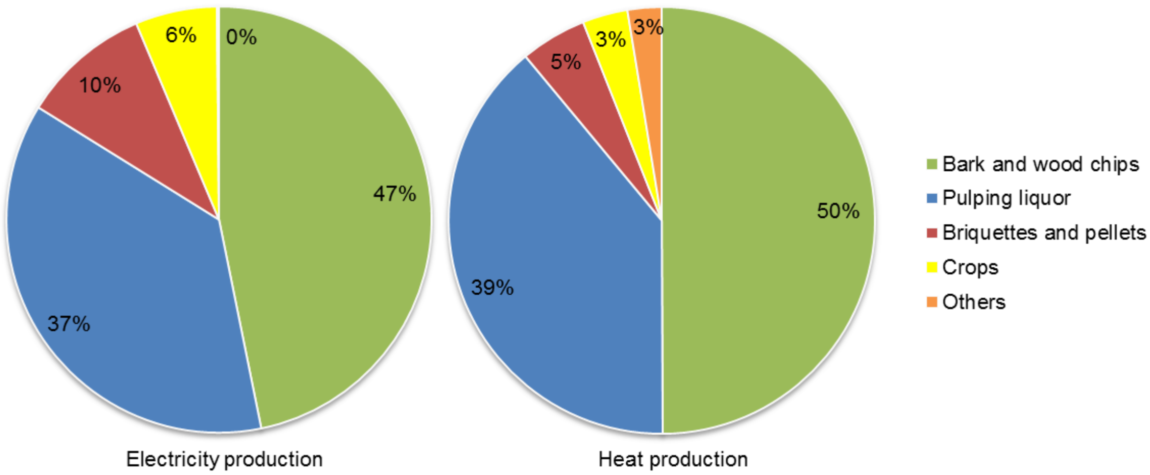


**Figure 14: Biomass electricity and heat production share in CZ for 2013[13]**

Total consumption of biomass fuels grew from 2.6 Mt to 3.8 Mt over the past years with converging trend between electricity and heat shares for most of the period.

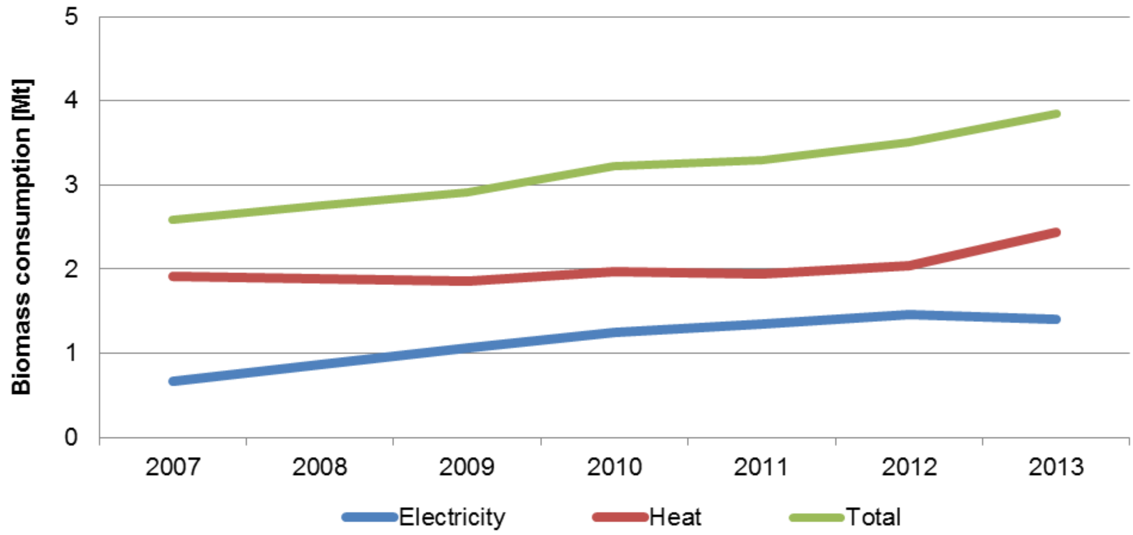


**Figure 15: Biomass consumption for energy production in CZ[13]**

Availability of biomass material and distance from the production plant are key factors for scaling and feasibility of the facility. Another important factor for selection of biomass as an energy source is specification of material energy potential. There were several studies carried out in the Czech Republic bringing different conclusions due to many variables and their complexity. Multiple assumptions and marginal conditions considered in calculations have impact on final results. Representative samples of biomass material with energy potential characteristics have been selected from EkoWATT[14] study published by former Czech Energy Agency under MIT as per tables below.

Purpose-grown energy crops require large amounts of land. Also proper balance between energy and food security has to be considered. Secondary utilization of waste biomass from agrarian, forestry or timber industry seems to be viable option, contributing to the overall RES mix. Overview of biomass fuels with basic characteristics is in the following tables:

| Type of biomass | Combustion heat [MJ/kg] | Optimal yield [t/ha] |
|---|---|---|
| Wheat straw | 14.0 | 5 |
| Rape straw | 13.5 | 6 |
| Fast growing wood plants | 12.0 | 12 |
| Annual plants | 14.5 | 20 |
| Energy crop | 15.0 | 25 |

**Table 4: Purpose-grown biomass[14]**

| Type of biomass | Combustion heat [MJ/kg] | Optimal yield [kg/sm] |
|---|---|---|
| Deciduous wood | 14.6 | 475 |
| Coniferous wood | 15.6 | 340 |
| Wheat straw | 15.5 | 120 |
| Corn straw | 14.4 | 100 |
| Flax straw | 16.9 | 140 |
| Rape straw | 16.0 | 100 |

**Table 5: Waste biomass[14]**

Table 4 shows that annual plants and energy crops have the best yield potential with relatively high heat of combustion factor around 15 MJ/kg, representing most efficient solid biomass fuel. The same applies to waste materials and side products in forestry and food processing industries shown in Table 5. Seasonal availability and forest lifecycle are key aspects to be considered during determining fuel mix from solid biomass. Utilization of biomass as a fuel is limited by production capacity of the land in given region, considering other benefits such as food provisioning.

Burning of organic material in biomass and biogas fuels creates air pollution (carbon and nitrogen x-oxides). Although such energy is considered as renewable, production is not fully ecological but described as “carbon neutral”. Biogas fuels as well as energy gained by combustion of organic waste will be covered in the next two chapters.

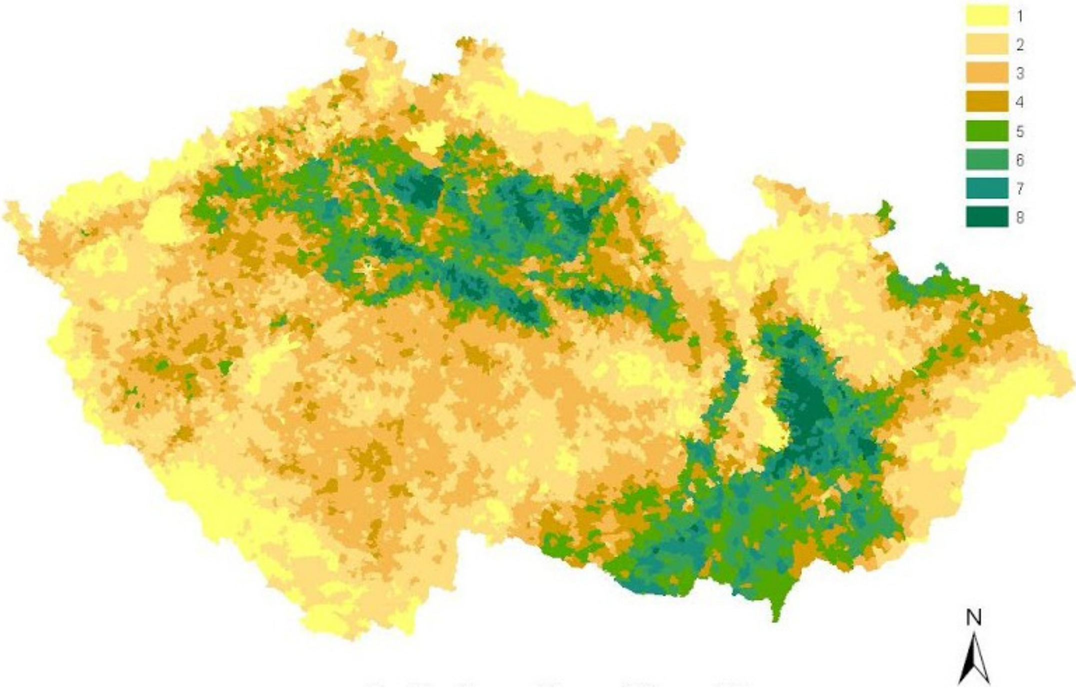


**Figure 16: Potential for purpose grown biomass[15]**

Figure 16 illustrates those regions in the Czech Republic with available biomass potential. Green color in lowlands represents agrarian areas with the highest potential for purpose-grown crops, utilized also in biogas plants. Yellow and amber colors show in most of the cases forested areas with solid biomass potential. This map demonstrates relatively even distribution of available biomass fuels across all regions.

Potential for biomass utilization is calculated with respect to food security of the Czech Republic. Land suitable for growing energy crops spans over 1.5 mil. hectares covering about 35% of agricultural soil. This represents technical potential of 13.3 mil. tons biomass used for 275 PJ of energy generation from energy crops. Economic potential considering food security is 41 PJ.[16] Together with additional 44.8 PJ available potential in forestry, biomass remains energy source with the highest potential among RES and positive impact on traditional rural regions. Total potential of 85.8 PJ is used in research analysis in Chapter 9.

Large CHP facilities and small heat plants are most suitable for effective utilization of biomass. Big amount of district heating systems and facilities burning coal will reach end of their life in the upcoming years, offering great opportunity for modernization in order to combust biomass in future.

### 2.4.2. Biogas

In biogas plants, solid/liquid biomass such as energy crops, food waste or sewage sludge is transformed by fermentation or anaerobic digestion into gas form and further used for electricity or heat production by combustion. In the Czech Republic, biogas technology is broadly used as a part of water treatment plants and landfills, mostly for own operational heat consumption in the facility. There is a rising trend in the construction of stand-alone biogas plants with combined heat and power generation supplying energy into surrounding districts. Big advantage of the biogas is that it can be transited to other locations with negligible transportation losses.

According to the SEVEn Energy[17] institute, 20-30% of the energy from biogas are consumed by the plant itself. Overall efficiency and net energy output of biogas plant depends on used technology and produced form of energy, represented by the following cases:

- 35% efficiency for electricity production without heat cogeneration
- 55% efficiency for electricity and heat production using cogeneration
- 75% efficiency for bio methane production

According to statistics from MIT[13], there is a trend of gradual growth in the area of biogas production in water treatment plants or landfills. At the same time, rapid growth of installed power and energy supply from stand-alone biogas plants was experienced. This was mainly driven by generous EU subsidy policy in the past years for both electricity and heat production from biogas.

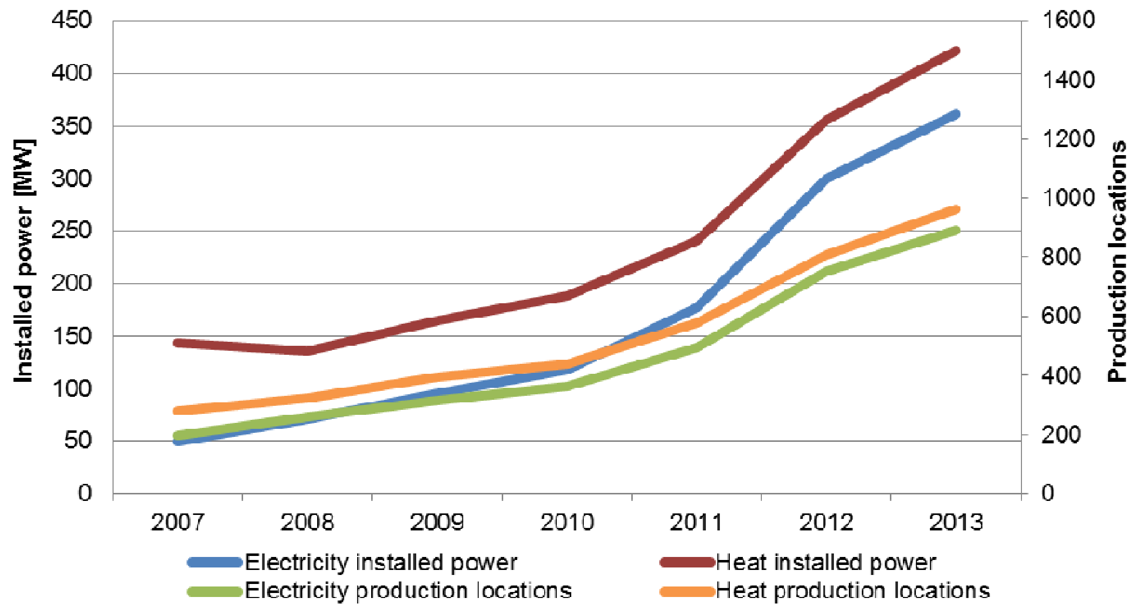


**Figure 17: Biogas heat and electricity production in CZ[13]**

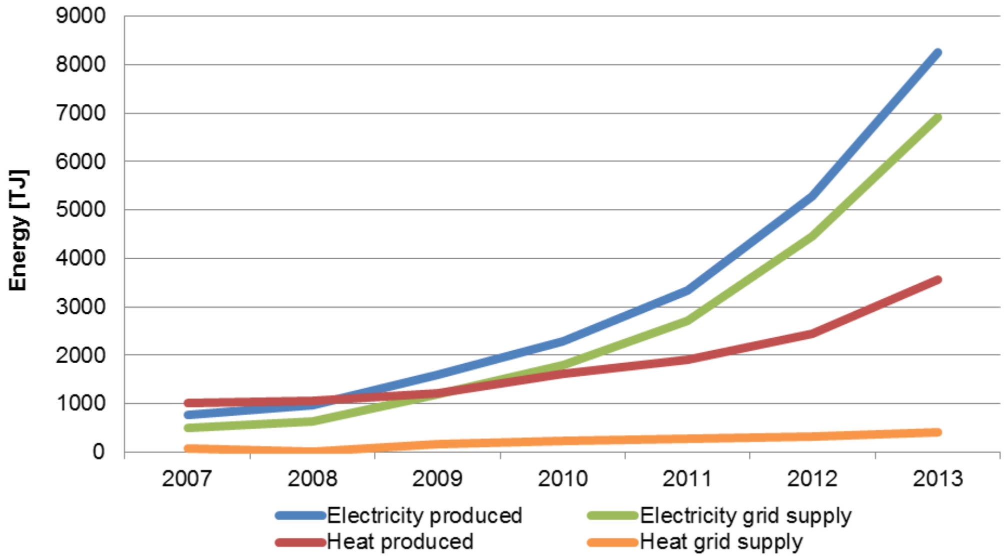


**Figure 18: Biogas electricity and heat production in CZ[13]**

Figures 17 and 18 demonstrate a strong growth of the biogas over the past years. The total number of production facilities as well as the total installed power for electricity and heat generation increased approximately four times during measured period. The amount of produced energy increased more than 6.5 times, followed by growing trend of energy supplied to the distribution grid. In the past decades, majority of the energy from biogas was generated as a side product in water treatment plants or landfills.

Situation has changed with rapid growth of new installations in the past years, in vast majority represented by stand-alone biogas plants. As shown in Figure 19, these new installations secured dominant shares of 91% and 76% for electricity and heat generation respectively, reducing share of formerly dominant sources to 9% and 24% respectively.

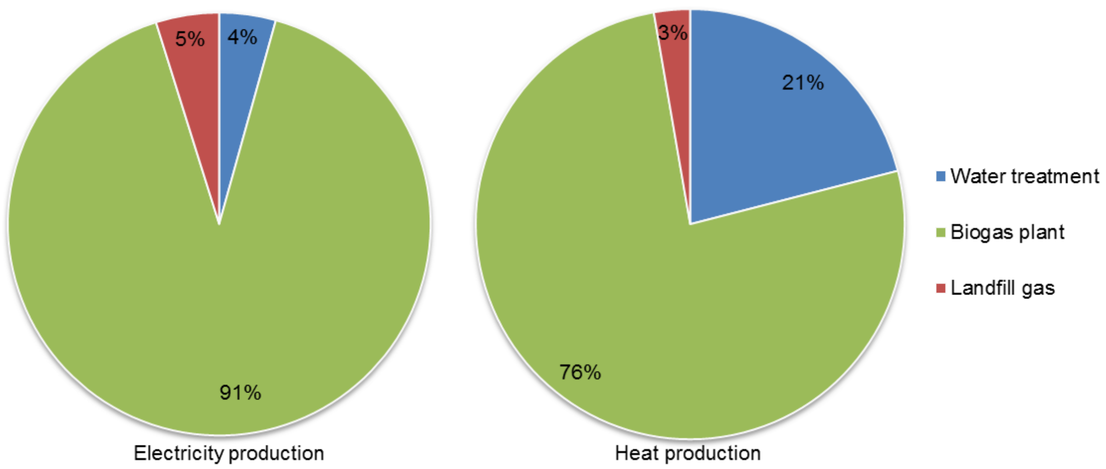


**Figure 19: Biogas electricity and heat production share in CZ for 2013[13]**

Disadvantage of the biogas, but very important one in comparison with all the other renewable fuels, is that biogas is an explosive material and strict safety regulations must be observed. Technical potential of utilizing biogas in the Czech Republic was calculated at 33 PJ, available potential around 16 PJ per.[16]

Furthermore, according to recent SAO report[18], many biogas facilities do not utilize full potential of waste heat as side product during electricity generation, offering potential for improvement.

### 2.4.3. Municipal solid waste and alternative solid fuels

Energy production from organic components of Industrial or Municipal Solid Waste (MSW) and Alternative Solid Fuels (ASF), generated by combustion in incineration plants, has low operating cost and in fact saves potential costs for waste disposal with positive impact on the environment. There is no comprehensive study available covering full potential of energy production from MSW and ASF. However, MIT data based on input from three major incineration plants in the Czech Republic and recommendation from EU published following statistics for further analysis:

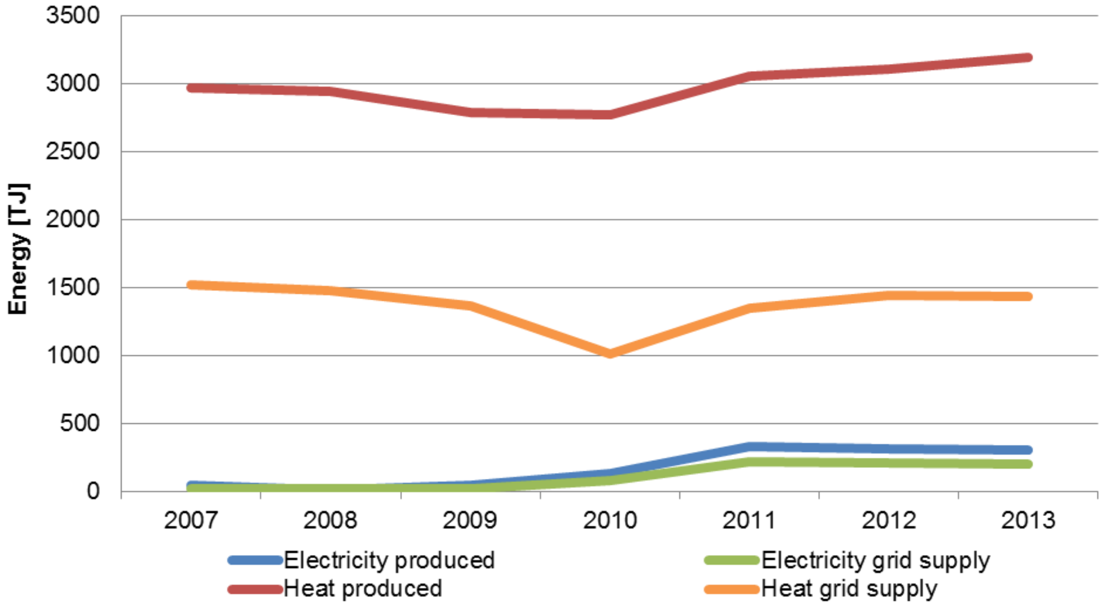


**Figure 20: MSW+ASF electricity and heat production in CZ[13]**

As shown in Figure 20, most of the municipal solid waste and alternative solid fuels are used for heat generation, representing about 90% share. There was 45% of produced heat and 66% of produced electricity sold to the distribution grid, with approximate split of the fuels 2/3 for MSW versus 1/3 for ASF used in 2013.


**Figure 21: MSW+ASF consumption for energy production in CZ[13]**

MIT estimates that 4 million tons of wastes are produced annually in the Czech Republic, where up to 60% are biologically decomposable components considered as RES. Comparing to the numbers in graphs above, only 10% of the waste is utilized for energy production. According to National Energy Policy[11], the national target for 2040 counts with 80% utilization of waste potential for energy production. Inspiration could be found in Switzerland where landfill waste disposal is entirely forbidden. This directive increased attractiveness of combustion in incineration plants and production of heat in combined heat and power (CHP) plants.

There are currently three incineration plants operating in the Czech Republic with capacity to absorb up to 654 kt of waste every year. All of them supply energy to the distribution grid, but their potential is not fully utilized according to Figure 21. Other four incineration plants are planned to be built in near future. The EU regulations set challenging target to reduce amount of biologically decomposable waste stored in landfills by 65% between 1995 and 2016. Based on figures reported by MIT in 2014, this commitment will not be fulfilled by the Czech Republic and represents huge potential for future improvement. Some of the EU countries do not dispose waste at landfills at all or only in limited amounts. There are four additional incineration plants under construction or planned to be built in the Czech Republic with aggregated capacity over 500 kt/year. This potential would bring us to the point, where around 30% of waste were utilized for energy production. However, these are blocked by ecological institutions due to negative impact on the environment.

#### 2.4.4. Hydro power plants

Energy in hydro power plants is produced by falling or running water through mills/turbines generating electricity. Power made in four pumped-storage plants with total installed power of 1.2 GW is not considered in data analysis from MIT available below. However it is covered in overall ERO[5] and EU[4] statistics used for assessment of energy production from RES. Flexibility of pumped-storage plants provides opportunity for energy "accumulation" during off-peak period and reuse during peak demand. Hydro power plants can be divided into three categories based on power output, calculated according to methodology provided by the European Commission:

- Small Hydro power plant (SHP) with installed power < 1 MW
- Small Hydro power plant (SHP) with installed power 1-10 MW
- Large Hydro power plant (LHP) with installed power > 10 MW

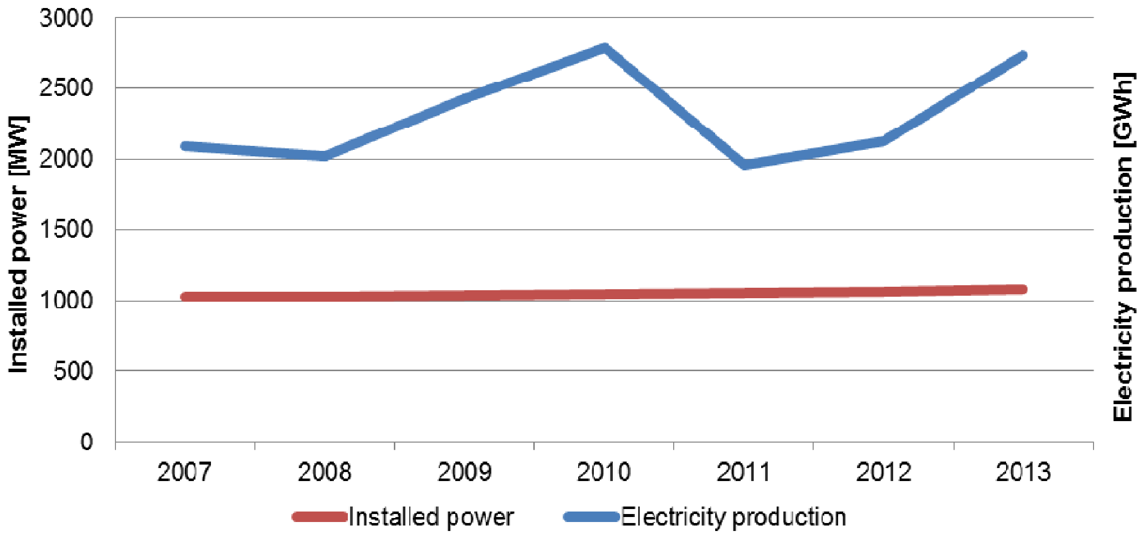


**Figure 22: Hydro power plant energy production in CZ[13]**

Total installed power has grown slightly in the past years due to construction of small hydro power plants as per Figure 22. LHPs represent 70% of the total installed power and hold a 60% share in the total energy production. As of today, most of the available hydropower potential in the Czech Republic is already utilized and construction of new power plants with capacity greater than 10 MW would require extensive landscape intervention. Additional potential of 1.1 GW installed power would generate 2.3 TWh of new energy but more than 80% of it is available in already utilized locations. This gives us approximately 450 GWh of available potential for new SHP construction including repowering of existing plants.[16]

### 2.4.5. Wind power plants

Generating energy from wind in the Czech Republic is suitable in limited number of areas where velocity of the wind is relatively high and constant. This is predominantly in mountains and usually within protected natural areas. Operating requirements of the wind power plants are relatively low. However, irregular energy production dependent on weather conditions does not ensure reliable supply and even small change in the velocity has a big impact on the power produced. Besides that, propellers and turbines are designed for specific range of air velocity where too little wind does not initiate turning (cut-in velocity) and too much wind can destroy the engine (cut-off velocity). Assessment of feasibility to build the wind power plant is rather theoretical, based on reference values (air velocity and density), measured in given location and simulations of propeller variables (area, inclination).

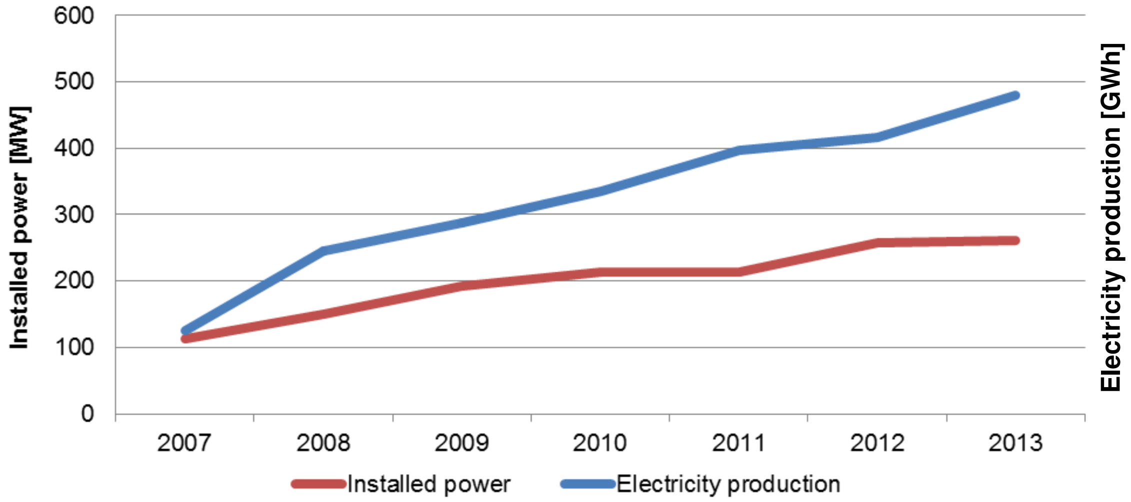


**Figure 23: Wind power plant energy production in CZ**[13]

Figure 23 above shows stable growth of wind power in the past years, resulting in 262 MW of installed capacity in 2013 and generating 480.6 GWh electricity. In majority of the cases, these are wind farms with horizontal-axis wind turbines supplying power to distribution grid. There are around sixty wind power plants operating in the Czech Republic nowadays, where only five of them have installed power greater than 10 MW.

Potential for expanding wind power generation in the Czech Republic is debatable. Multiple sources consider minimum velocity of 7.5 m/s economically feasible. From this perspectives, suitable locations for construction of wind power plants in the Czech Republic are mainly in mountainous border areas and inland highlands where the measured wind velocity is 7.5 m/s and higher. The map provided by Academy of Sciences in Figure 24 illustrates areas suitable for construction of wind power plants.

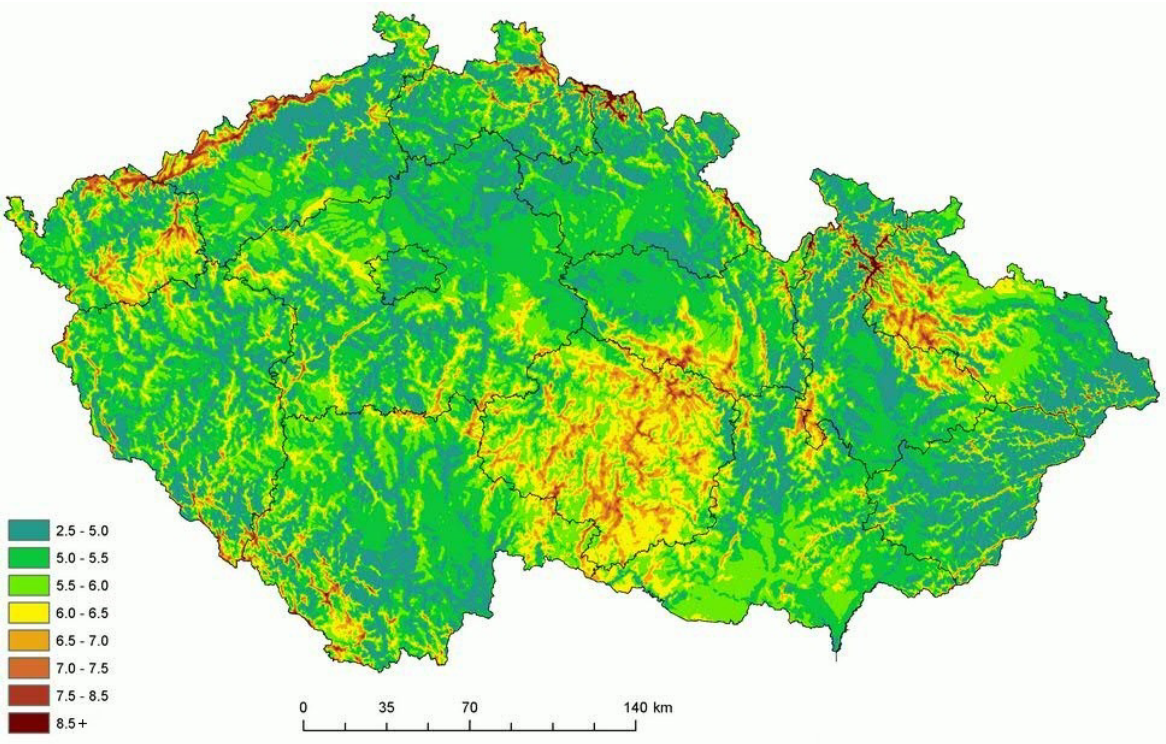


**Figure 24: Wind intensity in CZ[19]**

The outlook published in 2005 estimated technical potential for wind energy in the Czech Republic at 11 GW of installed power generating 16.3 TWh per year. Available potential was calculated around 3 GW with output 4 TWh per year[16]. Although the wind power plants can be easily dismantled, available potential might not be fully utilized due to drastic aesthetic impact of onshore wind farms on landscape.

### 2.4.6. Photovoltaic power plants

Photocells, basic component of PV power plants, convert solar energy directly into DC electricity. This is transformed into AC electricity in invertors and ready for supply into distribution grid. Production is dependent on intensity and duration of the sunlight so energy supply is not stable and fluctuates during the day. Solar energy from sun passes through the atmosphere and reaches the surface with peak solar radiation about 1 kW/m2 equivalent to average daily solar insolation. Photovoltaics became more cost effective in the past decade due to significant investments into research and development, but it was still not enough to ensure their competitiveness without subsidy.

In distant areas with limited electricity consumption requirements, where remote energy supply doesn't make sense, stand-alone PV power plants represent ideal source of energy. Medium scale power plants could be suitable for idle surfaces such as roofs and facades in industrial or commercial facilities generating supplemental electricity during peak period. PV power plants with installed power comparable to traditional energy sources have significant land requirements. Abandoned territories like deserts with high sunlight intensity or contaminated lands are preferred for these installations, instead of areas with other potential such as fields and meadows.

The next graph clearly demonstrates rapid growth of the installed PV power in the past years. Despite the fact that local natural conditions in the Czech Republic are not optimal for large PV installations as in southern regions of the Europe, subsidy policies that have been available in the past decade influenced profitability of these projects and motivated investors to spend their money.

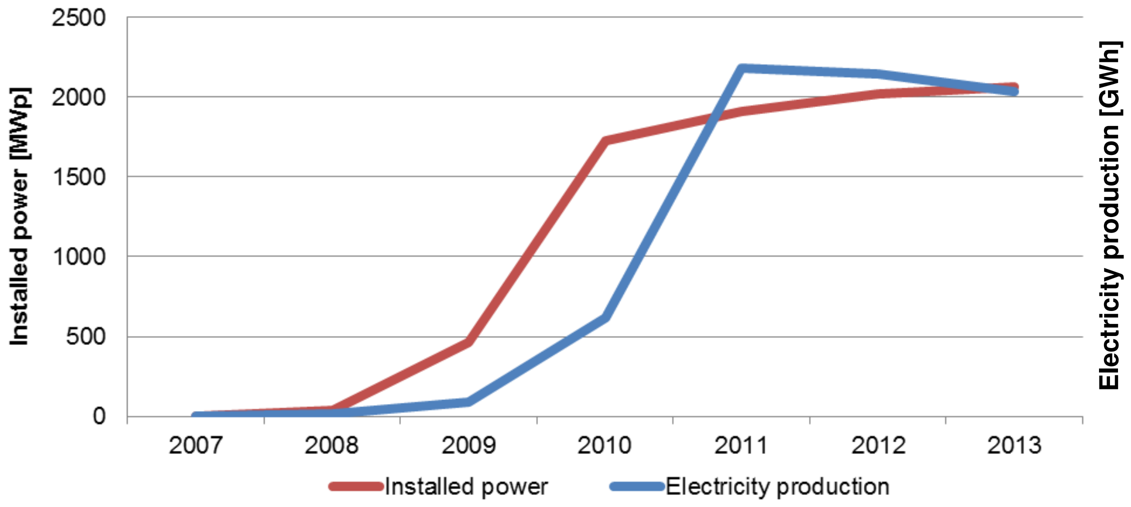


**Figure 25: PV power plant energy production in CZ[13]**

Since 2007, installed PV power in the Czech Republic has grown more than 500 times and total generated PV electricity almost 1000 times as shown in Figure 25. Considering that main motivating factor of guarantied redemption price significantly dropped in 2011, subsidy policy was reduced and so called "solar tax" introduced; it is expected that trend of PV boom experienced between 2008-2012 will not continue in future. Appreciable potential for further PV installations is in urban areas on facades and roofs of buildings. Construction of small PV power plants for own consumption or supply to distribution grid would improve amount of energy produced from RES without adverse impact on landscape like in case of field plants. The solar map of the Czech Republic shows intensity of solar radiation per year.

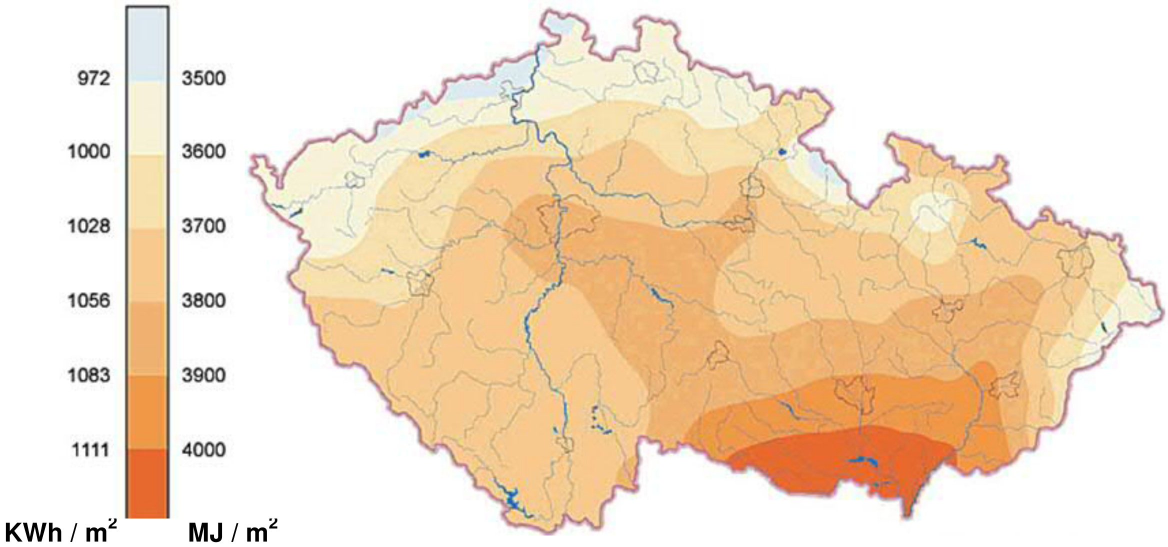


**Figure 26: Average annual solar radiation in CZ[20]**

The solar map in Figure 26 illustrates the highest solar intensity in southern and central regions, indicating about 90% of the area in the Czech Republic being relatively suitable for implementation of PV technology. Technical potential for PV plants in the urban areas was estimated at 22 $GW_e$ of installed power producing 22 $TWh_e$ per year dependent on technology used. Available potential is significantly lower at 5.3 GW installed power and 5.5 TWh electricity produced per year.[16]

### 2.4.7. Solar thermal systems

Solar thermal systems, operating on similar principle as heat exchangers, transform energy from solar radiation into sensible heat contained in liquid or air medium, stored and later distributed to the final consumer or transformed to another type of energy. The system usually consists of solar collectors, storage system required for regulation of energy utilization based on consumption requirements and distribution system. Ineffective storage of solar energy is currently the biggest disadvantage due to the fact, that most of the energy is produced during warm periods when demand for heating is actually low. This is why majority of the solar heating systems are only used for supplementary supply.

Due to the fact that in majority of the cases solar systems are operated by private owners, available statistics from MIT are based on survey conducted with producers/suppliers of those systems and not with final users.

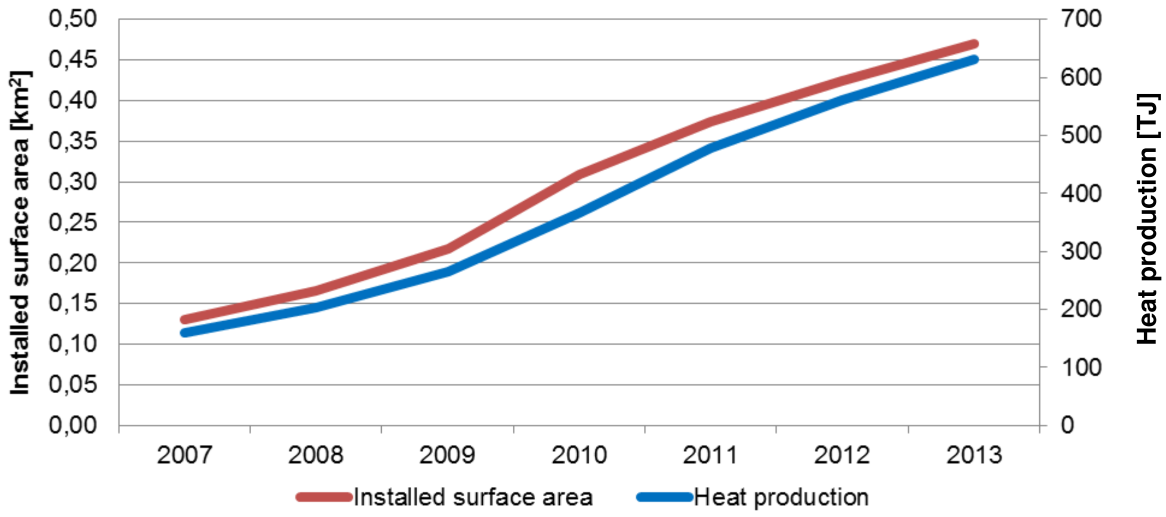


**Figure 27: Estimated Solar heating system energy production in CZ[13]**

According CZSO data shown in Figure 27, average growth of solar heating systems was about 25% per year in both monitored attributes of installed surface area and total heat production. The same graph also shows a trend of stable growth with little slow-down over the past years.

According to the statistics published by ESTIF[21] in 2013, installed solar thermal capacity in the Czech Republic was 31.4 kW per 1000 capita. In comparison with neighbor countries like Austria or Germany, where installed capacity per 1000 capita was much higher at 346 kW and 144 kW respectively, there is a high potential for improvement assumed. For further assessment, the same radiation map as in PV chapter can be used. In some cases, solar thermal plants could also produce electricity.

Technical potential for heat generation from solar panels was estimated at 25 TJ per year whilst available potential at 17 TJ, assuming efficiency about 550 kWh/m$^2$ in both cases. Small advantage is that the new solar systems can be easily connected to existing heat distribution systems.[16]

### 2.4.8. Heat pumps

Heat pumps considered in scope of the research transfer thermal heat with low potential from warmer environment (ground, water, air etc.) into colder environment for space or water heating in winter. During summer time, colder medium is suitable as heat sink for cooling. Only the delta between source and target environment temperature is considered as renewable energy for calculations. Water medium represents more than 96% of total heat pump installations.

Installation costs are comparatively high to other energy sources but in combination with lower operating and maintenance costs, heat pump becomes more attractive from overall lifecycle perspectives especially in areas with high temperature swings. Available statistics from MIT are based on survey conducted with producers/suppliers of the technology. Vast majority of the heat pump installations is in households and about 10% in commercial use.

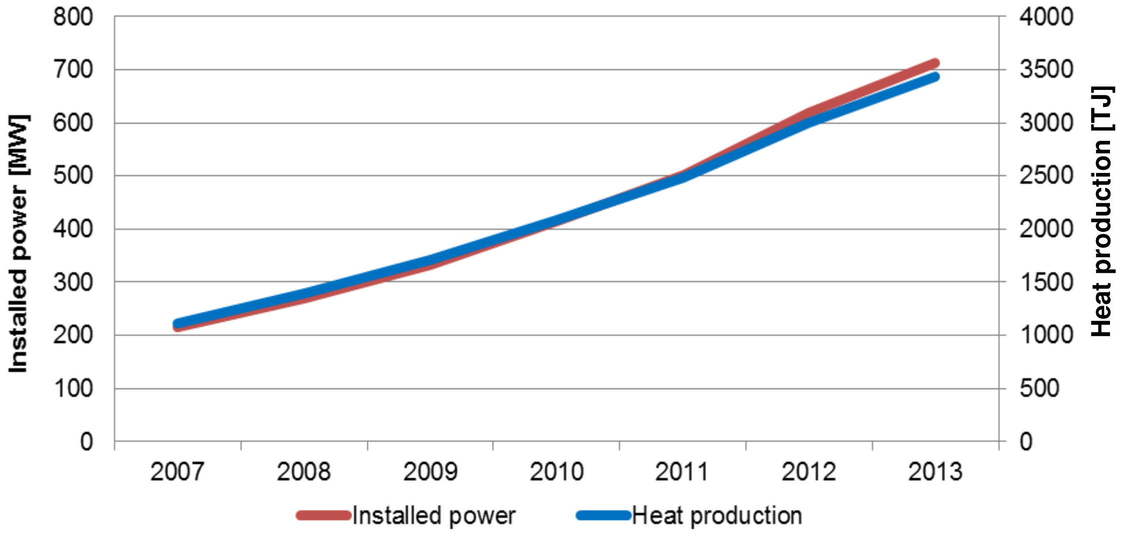


**Figure 28: Estimated Heat pumps energy production in CZ[13]**

Figure 28 shows rising trend of new installations as well as total heat production, growing more than three times during the measured period. Reversible heat pumps are able to supply both heating and cooling to the indoor space, but do not generate electricity. Due to the investment and capacity constraints mentioned earlier, heat pumps are more suitable for local installation with high energy costs. Although the available potential was estimated around 4 GW, technology growth in large scale is limited and therefore heat pumps are rather used as an alternative local energy source supplementing own consumption. On the other hand, geothermal plants are more suitable for large scale implementation.

### 2.4.9. Geothermal energy

Thermal energy stored in the Earth crust, available in specific geological locations, usually in depth of several kilometers, can be utilized for energy gains. In the Czech Republic, geothermal energy is utilized only in the north-west part of the region. Available potential for new plants, using hydrothermal technology, has been estimated for 125 MW installed power and calculated on the base of efficiency of existing facilities to 750 GWh energy produced annually. Potential of 3.4 GW installed capacity for heat plants running on principle of Hot Dry Rock (HDR) seems optimistic and requires further investigation as well as investments into technology improvement.[16]

## 2.5. Cogeneration

Cogeneration has exceptional position within energy production. It is derived from other energy sources described in previous chapters. Cogeneration also known as Combined Heat and Power (CHP) generation is a technology based on sequential production of electricity and steam from one fuel source. The plant recovers waste energy produced during primary electricity or heat generation, which would be normally in the form of steam released to the atmosphere. Additional use of waste energy from the same amount of primary fuel increases energy output thus improving transformation and production efficiency of the energy source. This is a significant improvement compared to separate heat and electricity generation, without any additional impact on the environment. The efficiency of the CHP plant is mainly dependent on the quantity of thermal energy released from primary process, used technology as well as consumers distance in case of secondary heat supply.

There are two basic principles of cogeneration, which are most commonly used in the Czech Republic. In the first case, primary fuels such as biomass, waste or fossil fuels are combusted in boiler to generate high-temperature pressurized steam for electricity generation in turbine, while waste heat is recovered for further use - also called as topping cycle. The other alternative called bottoming cycle is more used in heat demanding industry fields, where heat produced during fuel combustion is not entirely utilized in primarily intended transformation process, so it can be re-used in turbines to generate electricity.

Modernization of existing facilities and investment into CHP technology, utilizing same production capacities, usually requires less expenditure than construction of new plants generating same amount of energy. However, this might not be always feasible due to additional requirements for construction and space capacity. In general, instead of building new cogeneration facilities, most reasonable is to implement cogeneration technology in existing heat or power plants as a part of their standard lifecycle upgrade.

In sectors of Industry and Energetic, where consumption of heat in manufacturing and transformation processes is high, implementation of cogeneration would either reduce demand for the energy supplied from external sources or give opportunity to sell excess energy to the distribution network. Statistics published by Association for district heating[22] reported in Figure 29 indicate that about 13% of total electricity production in the Czech Republic over the past years was coming from heating plants with CHP technology. This also corresponds with the EU average and still offers potential for improvement.

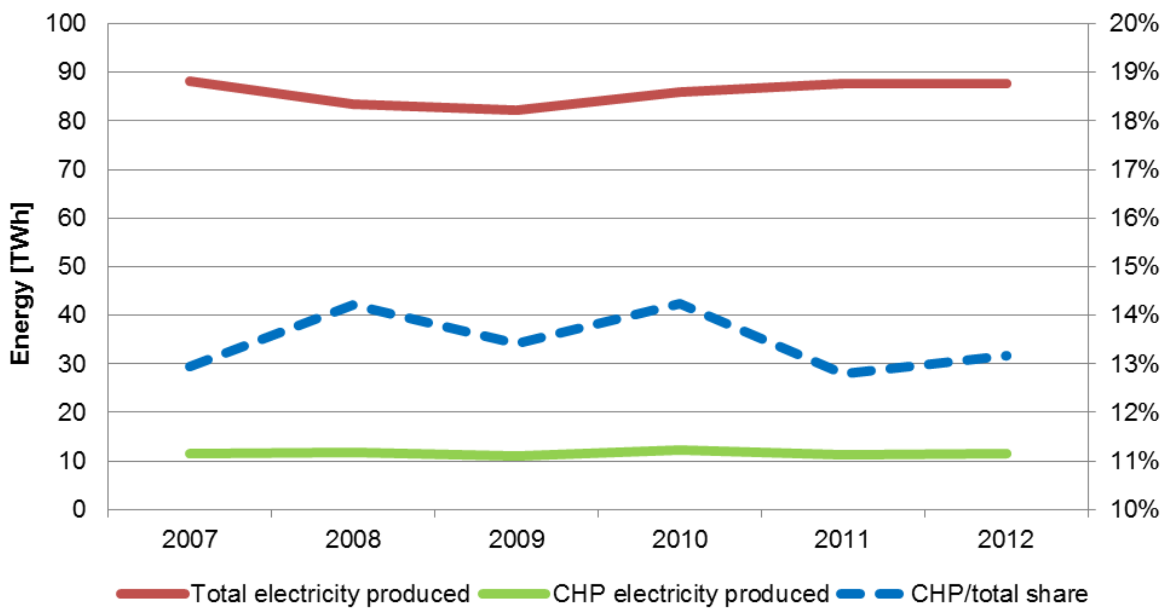


**Figure 29: CHP electricity production in CZ[22]**

Micro-cogeneration, represented by small CHP units with installed power up 100 kW, is an optimal solution for smaller plants or households and also fits into the concept of stand-alone Distributed Generation. Energy supply from micro-CHP is feasible on shorter distance ideally within the production site.

Trigeneration technology, where recovered energy from power generation is used for heating and cooling too, will not be covered in scope of the thesis because cooling loads in the Czech Republic could be solved in more cost effective manner. However, further research in this area is recommended.

According to the NAPEE[23], there is a comprehensive assessment of CHP and district heating potential planned to be conducted in 2015 in alignment with EU regulations. Investments into cogeneration are determined by act 165/2012 (CZ), identifying supported energy sources with installed power greater than 1 MW. Potential for installing new CHP production capacities was estimated at 5.6 TWh by 2020. Considering that amount of energy produced from CHP declined since 2005 from 13.6 TWh to 11.5 TWh in 2012, it is assumed that potential remained almost unchanged.

The biggest potential for implementing cogeneration in the Czech Republic is in large facilities burning coal or biomass as well as small and mid-size facilities burning gas as primary fuel. CHP technology is the most suitable in large facilities where electricity, heat and hot water supplies are required simultaneously through the whole year. Main disadvantage of CHP is that heat supplies are needed only in winter and running of CHP plant solely for electricity generation in summer period might not be profitable enough.

## 2.6. Distributed Generation

The concept of decentralized energy production from small stand-alone power generating plants with installed power less than 10 MW is called Distributed Generation (DG). Source of energy can be any of those mentioned in previous chapters, typically RES or fossil fuels. Single units can be connected to the grid and provide energy to distribution system. The other way around, need for energy supply from distribution grid to the consumer is reduced along with associated transmission costs.

Initial investment required for implementation of DG might be higher than expenses for building new centralized power plants using conventional fuels. However, associated benefits such as restore of energy supply during outage or levelling peak demand might be critical for operations and leverage the pros and cons of DG concept. Particularly facilities like data centers, hospitals, hotels or military complexes with high volume emergency power demand would benefit from DG. Other large scale premises such as manufacturing sites, universities and colleges can take advantage of supplementary energy source as well.

Feasibility of the DG depends on local conditions, for example availability of cheap/waste fuel close to the production plant. In combination with heat recovery or CHP technology becomes DG more efficient and competitive energy source for continuous operation. In large agglomerations and housing estates, centralized energy production remains more profitable than energy supply from multiple decentralized sources. Potential for growth in area of DG is considerable; especially when 25% of population in the Czech Republic lives in the countryside and can use local energy sources for power generation. Hypothetically, decentralized energy sources require connection to distribution infrastructure just in case when electricity is supplied to the grid. Implementation of DG concept in larger scale requires flexible distribution network able to react on intermittent energy supply and will be covered in the next chapters as a part of Energy Management.

Security associated with DG concept becomes essential in case of power outage. Creation of "power islands" with decentralized energy sources and solid distribution grid is the fastest way for recovery. DG concept also makes it difficult to purposely paralyze broader scope of energy supply, compared to large centralized facilities in combination with poor security measures and weak distribution grid.

## 2.7. Ecological aspects

Ecology was defined as one of the three imperatives for this research, to be considered in transformation of Energetic in the Czech Republic. Investment into new energy sources or modernization of those existing must reflect environmental factors associated with energy production and move towards those technologies that improve quality of living in given region. Amount and variability of contemplated factors is large and requires advanced model analysis covering multiple areas.

One of the methodologies used for evaluation is Lifecycle Energy Analysis (LCEA), providing complete view on required energy input, covering all phases of the product. In LCEA, amount of energy produced by specific energy source or technology is compared with total energy required for manufacturing, operation and disposal. This analysis reveals that some of the technologies would not produce enough energy during their entire life compared to actual energy input required. However, due to technology and efficiency improvements, RES have become more competitive and LCEA results have improved over the past decade.

Another view is to compare overall external costs, where RES demonstrate much better results than traditional fuels. This is mainly caused by monetization of environmental aspects during full lifecycle, where fossil fuels like oil and coal generate significant ecological loads during extraction, transformation and combustion. However, in both cases, ecological factors which are not necessarily linked to given region are considered. For example, manufacturing or fuel transformation can be performed elsewhere. Thus emissions of greenhouse gasses produced during energy generation remain the key aspect considered in the ecological analysis. The Global Warming Potential (GWP) of selected greenhouse gasses differs. For example, carbon dioxide has 56x lower GWP than methane and 280x lower than nitrous oxide in 20 years horizon.[24]

Important fact to highlight is that limitation of carbon dioxide ($CO_2$) released to atmosphere is rather politically than ecologically motivated initiative. Emissions of particulates dust ($PM_{10}$), carbon, sulphur or nitrogen x-oxides produced during perfect or imperfect combustion of solid fuels are much more critical for environment and human health. The map in Figure 30 shows amount of air pollution ($PM_{10}$) in the Czech Republic, identifying regions where ecological aspects must improve in order to secure sustainable development:

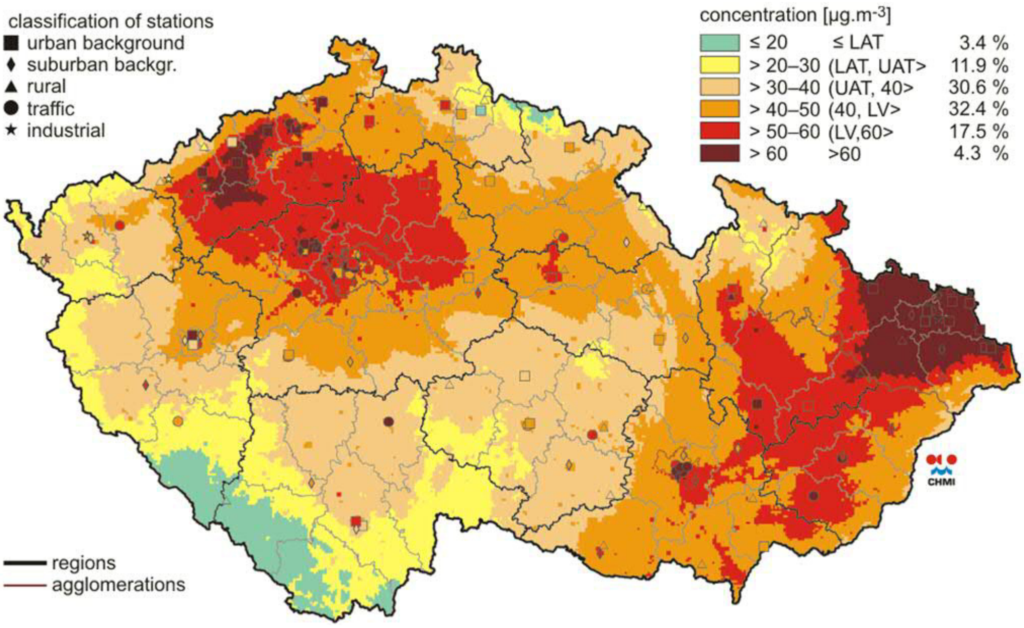


**Figure 30: Field of the highest 24-hour concentration of $PM_{10}$ in CZ for 2011[25]**

Similar to other countries in CEE area, most air polluting and health damaging energy sources in the Czech Republic are small units used in households for individual heating. These are mostly burning coal and release carcinogenic emissions to the atmosphere.[11]

The highest concentration of pollutants is in areas where coal is used as fuel for local and centralized energy production predominantly. These are traditionally north-west and north-east regions of the Czech Republic, followed by large cities and agglomerations. Situation in the north-east region, where concentration of $PM_{10}$ exceeds $60\mu g/m^3$, is adversely influenced by subcritical coal power plants in neighbor country. Table 6 illustrates amount of selected air pollutants released to atmosphere during energy production, normalized to 1 kWh per fuel or energy source:

| Emissions [mg/kWh] | $CO_2$ | $CH_4$ | $N_2O$ | $SO_2$ | $NO_X$ | $MP_X$ |
|---|---|---|---|---|---|---|
| Biomass CHP | 22 000 | 21 | 1 | 489 | 1 312 | 880 |
| Biogas CHP | 20 000 | 49 | 2 | 743 | 2 557 | 18 |
| ASF/MSW | 892 000 | -464 | 48 | 650 | 732 | -22 |
| Hydropower | 1 000 | 0.004 | 0.019 | 1 | 3 | 1 |
| Wind power | 44 000 | 69 | 1 | 33 | 84 | 10 |
| PV | 323 000 | 761 | 12 | 238 | 424 | 61 |
| Solar | 110 000 | 218 | 3 | 336 | 255 | 172 |
| Heat pump | 265 000 | 186 | 8 | 312 | 405 | 20 |
| Geothermal | 4 000 | 131 | 0.07 | 2 | 9 | 2 |

**Table 6: Emissions from 1 kWh produced per energy sources[26]**

Considering $MP_x$ as the most critical air pollutant, biomass has multiple times higher amount of emissions released to atmosphere per kWh in comparison with other RES technologies. On the other side, combustion of ASF/MSW in incineration plants produces less methane and $MP_x$ than in case of storing waste on landfills, resulting in negative figures shown in Table 6. In terms of $CO_2$ per kWh of produced energy, new biomass and biogas facilities are performing better than other RES. Higher $CO_2$ values reported for wind, photovoltaics, solar and heat pumps are caused by emissions during manufacturing, rather than operations.

Within fossil fuels, gas is considered as the most ecological source of energy. Amount of greenhouse emissions released to atmosphere during gas combustion is significantly lower than when coal or oil is used for electricity or heat production. Amount of emissions released to atmosphere from combusting biomass can be even higher than from burning gas or coal. This occurs mostly during imperfect combustion when legacy technology is used, for example, old boilers for individual heating in households.

Large biomass plants are usually equipped with new technologies for emissions filtering and prevent air pollution.[27] It is expected that modernization of obsolete facilities will always be aligned with reduction of air pollutants released to atmosphere. However, total elimination of fossil fuels especially coal in energy mix seems not realistic in the upcoming decades. On the other hand, gas combustion in all scale CHP plants offers opportunity for efficient and environment friendly energy generation.

This chapter concludes section focused on energy production, whilst the next one provides information about recent trends and energy mix from energy consumption perspectives.

## 3. ENERGY CONSUMPTION

Energy consumption in the Czech Republic had a growing tendency following global trends from a long-term perspective as described in Chapter 1. It has stabilized recently due to economic crisis associated with overall decline of the demand in the region as well as consequence of investment into energy efficiency measures in the past years. Similar to the rest of the EU, it is expected that total energy consumption in the Czech Republic will constantly grow whilst energy mix shifts from fossil fuels towards RES.[11]

Electricity and heat consumption in the Czech Republic is fully covered by inland production, but most of the PES must be imported. The graph below shows trends in total consumption of PES in the Czech Republic since 2007.

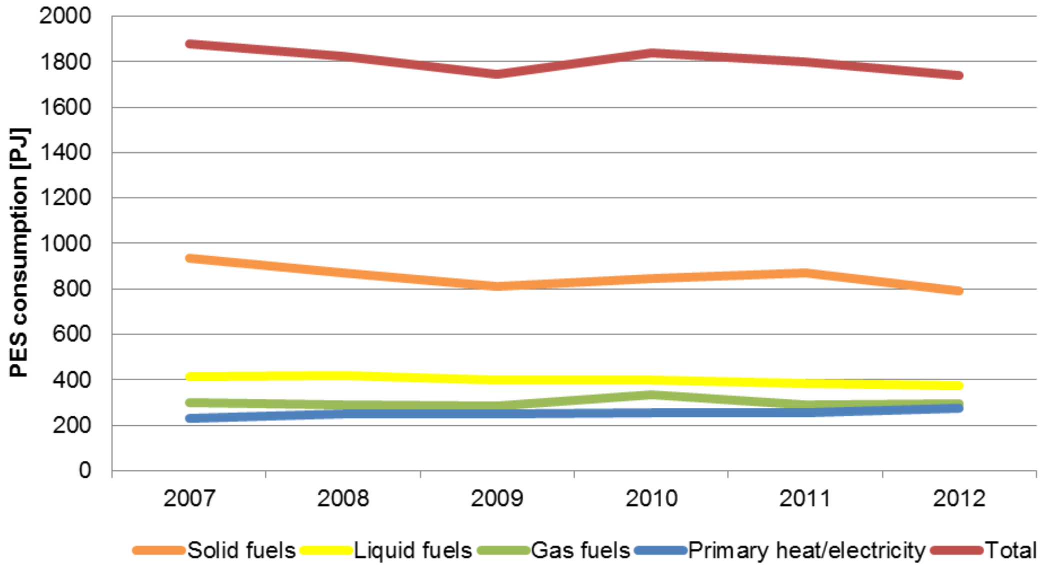


**Figure 31: Total PES consumption in CZ[6]**

There is a slow trend in reduction of solid and liquid fuels share. Gas fuels oscillated around 300 PJ and consumption of primary heat and electricity grew marginally in the past years. Overall annual consumption of PES oscillated around 1,800 PJ during measured period.

In 2012, solid fuels represented almost a half of the total inland fuel consumption, followed by liquid and gas fuels. The primary heat and electricity held only 14% share in 2012, but according to National Energy Policy[11], growing trend is expected to continue in future.

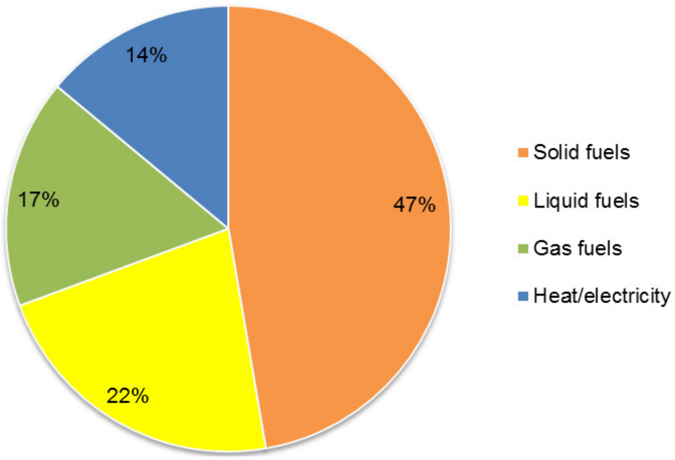


**Figure 32: Total PES consumption in CZ for 2012[6]**

Shift in the energy mix for the upcoming years will be driven by internal target set in National Action Plan for Energy Efficiency (NAPEE)[23] having 14% of total energy consumption covered by production from RES in 2020 (aligned with 13% committed to EU). In addition, high Energy intensity of the Czech economy, being double compared to EU average[4], and reduction of total energy consumption per capita mentioned Chapter 1, indicate potential to reduce overall consumption of PES in the Czech Republic by transforming selected sectors with highest energy demand as described in following chapters.

### 3.1. Energy consumption by sector

Several sectors with characteristic energy profiles/mix have been identified for further evaluation of Energy Management model. Based on the specific features of each sector and available statistical data, following areas were defined as a scope of the research:

- Industry
- Energetics
- Construction
- Households
- Transportation
- Agriculture and Forestry
- Others

Statistics published by CZSO report on total amount of energy delivered to final consumers. Figures exclude Energetics due to the fact that most of the energy consumed in this sector is used again for further energy production. Household sector represents energy consumption in all residential buildings. Commerce, public administration and services are covered in sector "Others". Final numbers represent sum of primary/secondary energy supplies summed with energy processes, but excluding energy inputs, operations and losses.

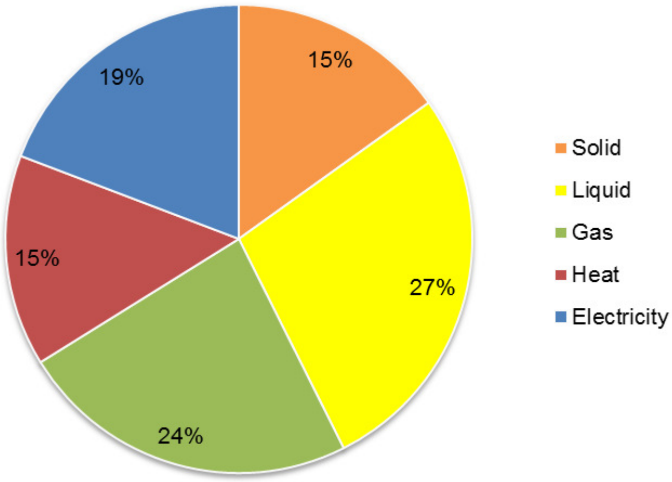


**Figure 33: Final net energy consumption share in CZ for 2012**[6]

The graph above illustrates shares in the final net energy consumption spanning all sectors. Primary fuels represent about two thirds and primary energy one third of the total energy consumption. Referring to Chapter 1, vast majority of liquid and gas fuels has to be imported, whilst all electricity and heat consumed in the Czech Republic is produced in the country.

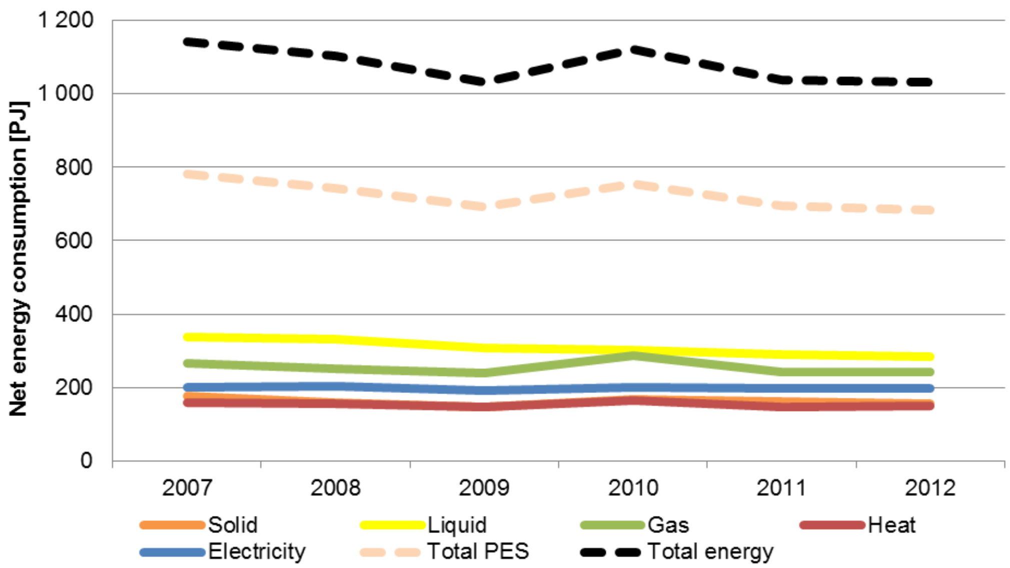


**Figure 34: Final net energy consumption in CZ**[6]

Figure 34 shows that total consumption of primary fuels in the Czech Republic has declined over the past years, primary energy rather stagnated. This positive trend corresponds with overall energy demandingness of national economy associated with recent crisis. Despite the decreasing course in final net consumption of primary fuels over the past years, it is expected that share of gas and biogas in energy mix will grow mainly due to Transportation sector, supported by growing utilization of electricity and CNG as future fuel for private vehicles.[11]

Both heat and electricity consumption will be our primary focus, representing vast majority of the energy consumed in defined scope. The graphs below illustrate average share of electricity and heat (without fuels) across all monitored sectors except Energetics.

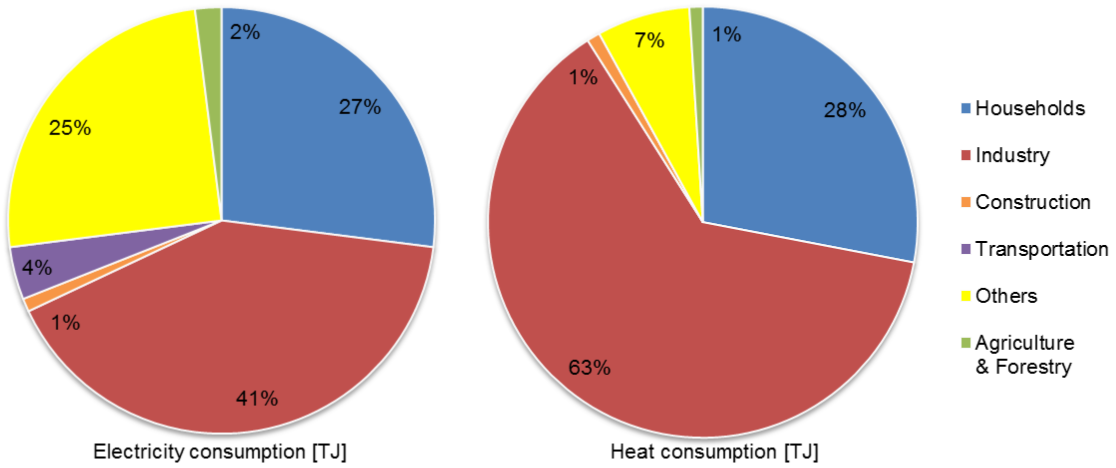


**Figure 35: Energy final net consumption per sector in CZ for 2012 (excl. Energetics)[6]**

Figures above indicate that most of the electricity and heat is consumed in Industry sector followed by Households. Industry represents 41% share on the total electricity consumption and 63% of the total heat consumption, followed by Households with 27% and 28% share respectively. Large energy consumption share of these two sectors defines focus area for our research, in order to improve efficiency by implementing Energy Management measures described in Chapter 5. Due to the fact that Transportation sector consumes majority of the energy directly from fuels instead of generated electricity or heat, it appears in selective rankings on the fourth place, otherwise would be just behind Industry on the second place in overall PES consumption chart and followed by Households. This view underlines selection of Households instead of Transportation for further assessment.

Industry has the biggest share in total consumption given by high energy demandingness of the traditional manufacturing sectors in the Czech Republic. Large heat and electricity supply is required for appliances in metallurgical and petrochemical industry as well as machinery. In sector of Households on the second place, more than 75% of the total energy is used for space and water heating. Thus, implementation of more efficient appliances and optimized processes for heat operations would reduce overall energy consumption in both sectors.

Number of devices consuming energy is rapidly growing together with increasing living standards in the region, but more efficient appliances and progressive insulation of building envelopes act in the opposite direction with tendency to reduce overall energy demand since 2001 and have accelerated with multiple subsidy programs since 2007.

In addition, according to PORSENNA 2013 analysis[28], annual energy consumption of buildings through all sectors was around 360 PJ in 2011, representing about 30% of the total annual energy consumption in the Czech Republic. In further breakdown, Households reported annual consumption of 221 PJ (with share of 137 PJ belonging to heating), leaving 139 PJ for remaining sectors (with 65% share of 90 PJ belonging to heating). This study has considered direct fuel consumption in calculations which differs from approach taken earlier in this chapter, minimizing impact of potential statistical error. Results obtained from both approaches are similar and indicate high potential for energy savings in space heating, although numbers has dropped since 2011 due to recently implemented saving measures.

In the next chapter, electricity and heat balance for Industry and Households is compared.

### 3.1.1. Electricity and Heat balance

Based on the CZSO[6] data from 2012, the balance of total energy consumed spanning all sectors except Energetics was 56% electricity vs. 44% heat. This almost equal split indicates that optimization of consumption for both types of energy (electricity and heat) is important with similar impact on the overall energy consumption. In the previous chapter, sectors of Industry and Households have been identified as critical scope, with 68% electricity and 91% heat shares contributing to total energy consumed across all sectors.

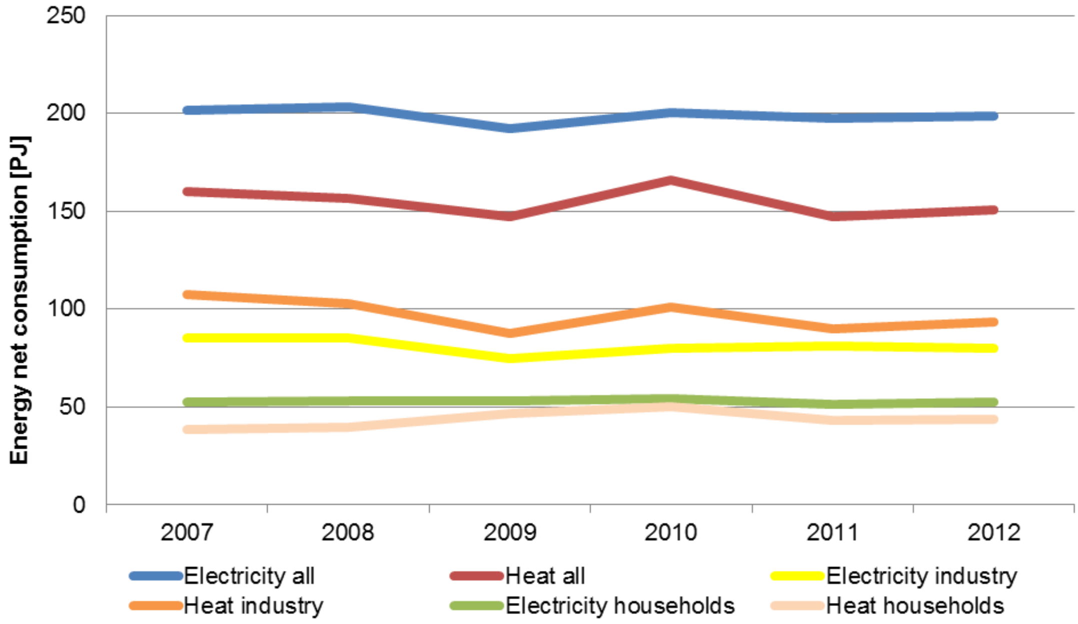


**Figure 36: Energy final net consumption in CZ[6]**

Comparison of final net consumption of electricity and heat in key areas has shown relatively stabilized trend over the past years. Most of the energy consumed across all sectors is in form of electricity followed by heat. This case applies for Households too, whilst Industry has reported opposite trend of consuming more heat than electricity.

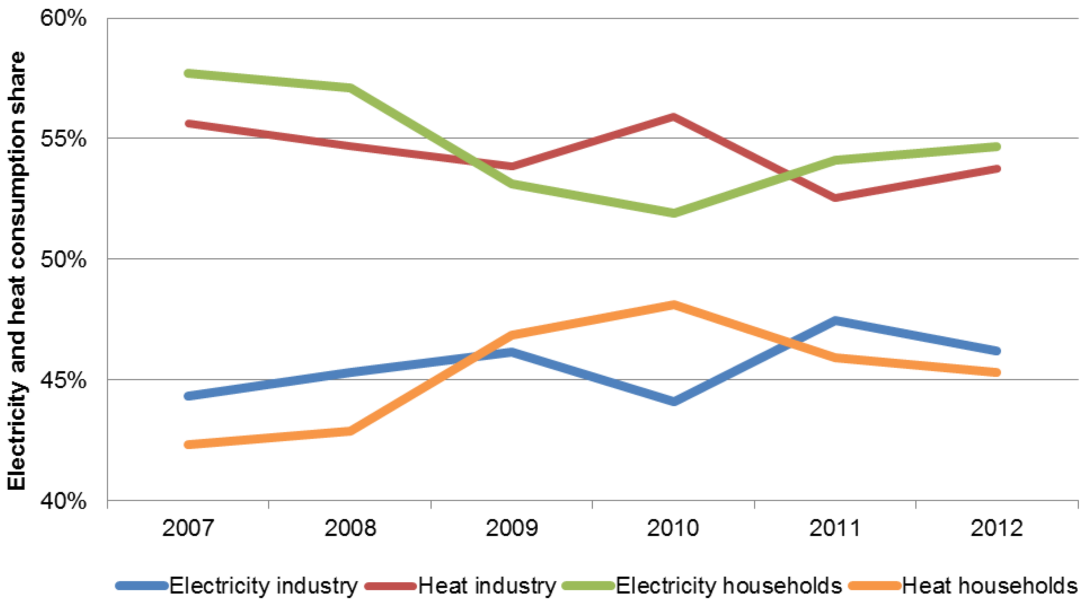


**Figure 37: Energy final net consumption share in CZ[6]**

From the statistics above it can be seen that both electricity and heat consumptions represent approximately half of the total energy consumption. Industry sector oscillates at 45% electricity vs 55% heat and Households at 55% electricity vs 45% heat on the average. Figures identify equal importance of these focus areas in further research. The following chapter brings us back to the level where all sectors are assessed.

### 3.2. Energy intensity by sector

As mentioned in Chapter 1, the total energy intensity of the GDP in the Czech Republic has been constantly decreasing over the past two decades. Breakdown of the energy intensity per sector based on CZSO[6] data in Figure 38 shows the highest potential for optimization in Industry and Agriculture/Forestry sectors representing 75% of the total GDP energy intensity. Despite the fact that Households represent 27% of the total energy consumption in the Czech Republic, contribution on the GDP is rather marginal and therefore has been removed from this particular calculation. Furthermore, due to exclusion of direct fuel consumption from the breakdown (e.g. Transportation), resulting total intensity ratio is different from the one presented in Chapter 1 but still relevant for this research. Sector of Energetics is excluded due to insufficient data with regard to consumption within the sector.

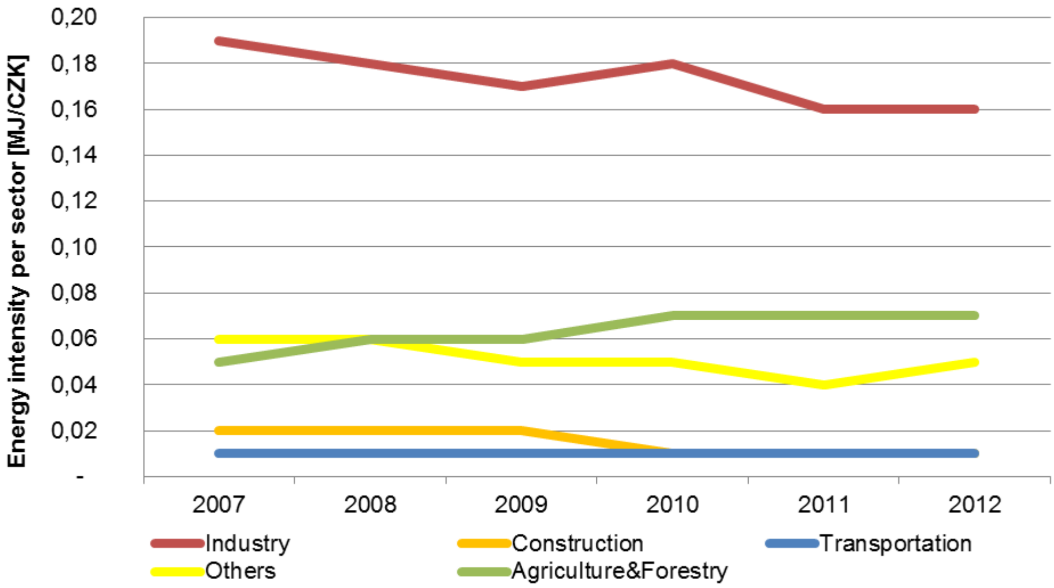


**Figure 38: Energy intensity per sector in CZ[6]**

The graph above shows positive trend of reducing energy intensity of Industry sector, representing more than a half of overall intensity. On the other hand, intensity has grown in Agriculture&Forestry, introducing opportunity for further research out of scope of this thesis.

In the next chapter, key indicator of RES share within total energy consumption is described.

### 3.3. Energy consumption produced from RES

RES in scope of this research have been identified and described in Chapter 2. Table 7 below shows a breakdown and share of consumed energy per renewable source for 2013:

| RES energy source | RES energy [TJ] | RES share |
|---|---|---|
| Biomass (excl. Households) | 40 330 | **26.2%** |
| Biomass (Households) | 50 664 | **33.0%** |
| Hydropower | 9 845 | 6.4% |
| Biogas | 23 910 | **15.6%** |
| Biodegradable waste | 4 470 | **2.9%** |
| Biofuels | 11 422 | **7.4%** |
| Heat pump | 3 431 | 2.2% |
| Solar thermal system | 630 | 0.4% |
| Wind power | 1 730 | 1.1% |
| Photovoltaics | 7 318 | 4.8% |
| **Total** | **153 750** | **100.0%** |

**Table 7: RES consumption share in CZ for 2013[13]**

Key indicator monitored by the government and the EU is an amount of total energy consumption being produced from RES. Considering targets set in National action plan for RES[29] that 14% of the total energy consumed will come from RES in 2020, together with planned reduction in overall energy demand to 1,245 PJ, it is logical that total energy consumption coming from RES must reach 174.1 PJ per year. This might not be so challenging to achieve compared to 153.8 PJ produced by RES in 2013. Further breakdown demonstrates that around 85% of consumed energy in 2013 coming from renewables is obtained by combustion, which is not entirely ecological solution due to associated air pollution.

According to ERO Annual report for 2013, the share of electricity produced from RES contributing to gross electricity consumption was 13.2% as shown in the graph below. Recent trends for sustainable energy supply have also demonstrated shift from non-renewable fuels towards RES as described earlier in Chapter 2.

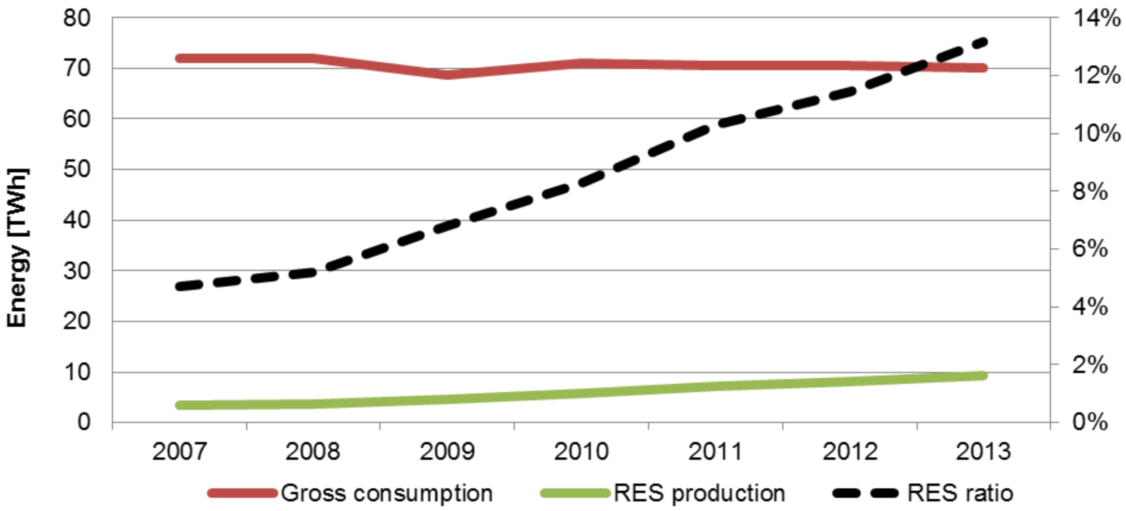


**Figure 39: RES contribution to overall energy consumption in CZ[5]**

The graph above illustrates that amount of energy produced from RES has increased by 272% since 2007 and keeps us on track to meet the 2020 targets. Due to stagnation of inland gross electricity consumption, the ratio of electricity produced from RES has increased by 290% in the same period. Main contributors to the growth were photovoltaic and biogas power plants. Since 2007, the installed power of PV and biogas facilities has grown more than thousand and hundred times respectively, but still being under the EU28 average in 2012. It is expected that photovoltaic boom in the Czech Republic will diminish due to significant limitation of generous governmental subsidy policy in the past years and investors will search for alternative RES in order to fulfil our targets for energy mix given by the EU.

The ratio of 13.17% of consumed energy coming from RES is an important indicator for monitoring and reporting provided by member countries within the "*Energy 2020*" roadmap.

# 4. ENERGY AND FUEL DISTRIBUTION

The fourth section of this thesis describes network and storage infrastructure for fuel and energy distribution, with attention to energy losses associated with electricity and heat transit.

Due to its geographic location, the Czech Republic is considered as a transit country for most of the energy and fuels transported on longer distance. The cross-border network connection brings strategic advantage with respect to dependency on imported fuels but also additional requirements on distribution capacities on top of local demand. Capacity, density and flexibility of distribution network are key elements determining secure energy supply in case of source outage, price fluctuation on global markets or electricity blackout.

Majority of the inland energy production comes from centralized energy sources. This energy has to be transported to end consumers via distribution network, because suitable storage technologies for energy accumulation and conservation in long-term period are not yet developed and also not cost efficient in comparison with centralized production. Technology for storage of primary fuels is commonly used, but accumulation of final energy has still considerable potential for improvement.[11]

For energy and fuel transmission on longer distance, distribution grids are used. In such case, total cost of energy must cover not only production costs but also distribution costs. Transportation of energy is also associated with losses dependent on distance and transmission medium as described further in this chapter.

Losses calculated for transportation of fossil fuels, such as gas, on longer distance are insignificant with respect to volumes and price of the fuel. Most of the RES utilize fuels available directly or nearby to the production facility so will be covered at high level only. District cooling is not covered in scope due to lack of statistical data being publicly available and can be addressed in further research. Thus, losses associated with electricity and heat distribution remain primary focus for this research.

## 4.1. Distribution network

Geographic position and current energy mix in Europe determines the Czech Republic to the strategic role of transit country. Inland and cross-border transport of fuels and energy requires stable, but also flexible distribution grid to fulfill local and regional requirements. Structure of the network and available storage capacities corresponds with current energy profile, having sufficient reserves for short-term stand-alone operations. However, strategy for long-term stand-alone operations is currently missing.[11] Instability of the distribution grid and increased risk of blackout is in fact caused by unpredictable intermittent energy supply from RES. For example, wind farms in the North Sea or solar parks in southern Europe increase the risk of blackouts in Europe and Czech Republic (as transit country) while feeding the distribution grid capacity with intermittent power supply.

Electricity network has sufficient capacity to fulfil requirements for inland distribution as well as cross-border transit. Challenges represented by intermittent energy flows from neighbor countries are solved by installation of new transformers preventing outages caused by overloaded network capacity. The Czech Republic had almost six million of registered electricity delivery points in 2013 operated by four companies. Distribution grid comprises 100,985 km power cables and 143,159 km power lines respectively, routed also to all neighbor countries for cross-border electricity supply. Implemented Demand Side Management (DSM) system allows effective balancing of energy supply in 46% households and 31% small enterprises based on principle of deferred consumption.[5;23] However, this solution might not comply with future requirements of distributed generation from RES, thus new concept should be introduced.

Distribution networks for district heating in densely populated areas are well developed and cover around 50% of the heat supply in the Czech Republic. Centralized heating systems are strongly competitive due to low operating costs and relatively cheap brown coal, transported on railways directly from mines to the production plant.[30]

Gas pipeline network in the Czech Republic is technically developed and functions well for transit between neighbor countries as well as local supply to individual consumers. International transit of gas in east-west stream Družba with capacity up to 51,000 mil.$m^3$/year combined with north-south stream Gazela having capacity 30,000 mil.$m^3$/year secure sufficient and continuous gas supply.[11]

Backbone for petroleum transit in the Czech Republic consists of two major oil pipelines, east-west axis represented by Družba with capacity 10 m.t/year and IKL from south with capacity 11 m.t/year. Supplementary role has MND in the south-Moravian region.[11]

Expansion of distribution grids must be flexible enough to follow transformation trends in future Energetics, such as change of the energy production mix, consumption profiles or growing number of distributed energy sources with uneven supply to the grid. Recent trends in global research and development indicate shift of energy mix in Transportation sector from fossil fuels towards electricity and gas associated with rapid growth of demand for distributed charging and storage capacities. Solution for flexible energy distribution and Demand Response Management (DRM) offer so called “Smart grids”.

Smart grids are equipped with information and communication technologies on top of their primary function to distribute energy. Concept of Smart grids covers full governance model including network devices for data gathering, capacity and system management for active measurement and control of energy flows. Price of monitoring and controlling devices decreases and becomes more attractive for investors and operators. Smart Governance allows energy producers, distributors and consumers to manage energy supply more effectively and in stable manner. Key areas of infrastructure modernization, grid digitalization and process transformation will be described in the next chapters.

## 4.2. Energy storage

Energy storage is essential for secure and reliable energy supply. Accumulation facilities and fuel reservoirs represent indispensable component of distribution network especially when all fuels, except for those solid, have to be imported. Inland fuel and energy reserves would be used in case of longer outage in supply from external suppliers.

Suitable technology for effective long-term electricity and heat storage in large scales is not yet advanced enough to compete with traditional fuel reservoirs or conversion to alternative energy in potential, chemical or kinetic form. Most common technique used for conservation of large electricity volumes is storing them directly in the distribution grid. Especially intermittent supply from RES during off-peak period takes advantage of reserve network capacity until demand increases again. The concept counts with connection of large amount of smaller storage devices directly to the grid, becoming even more efficient in combination with proper DRM.

First commercially available batteries with capacity up to 100 kWh represent promising potential for broader implementation of electricity storage technology in future. In such case, for example, batteries can supply energy to the distribution grid during peak period and recharge energy back during off-peak. Although heat can be stored in large tanks, accumulation towers or rock caverns, transformation of heat to electricity in CHP plants remains the most efficient approach.

Accumulation of potential energy in the Czech Republic is secured by four pumped-storage dams with the total installed power of 1.15 GW contributing 5.4% to the total installed power in 2013.[5] Technology for effective electricity or heat storage offers significant opportunity and topic for further research.

Gas reservoirs in the Czech Republic have capacity around 3,500 mil.$m^3$, which covers around 35% of annual consumption. From this amount of stored gas, approximately 95 PJ heat or 35 TWh electricity could be produced, where both figures are highly dependent on efficiency of technology used during energy transformation.

Petroleum reservoirs have capacity 1.55 mil.$m^3$, which represents around 30% of annual consumption in the Czech Republic, mainly in Transportation sector thus not considered in further analysis.[11]

## 4.3. Electricity transportation loss

Total loss of electric energy caused by transportation is decreasing due to technology improvement and decentralization of energy sources in the past years, but still amounts to around 8% of the net energy consumption similar to rest of the EU.

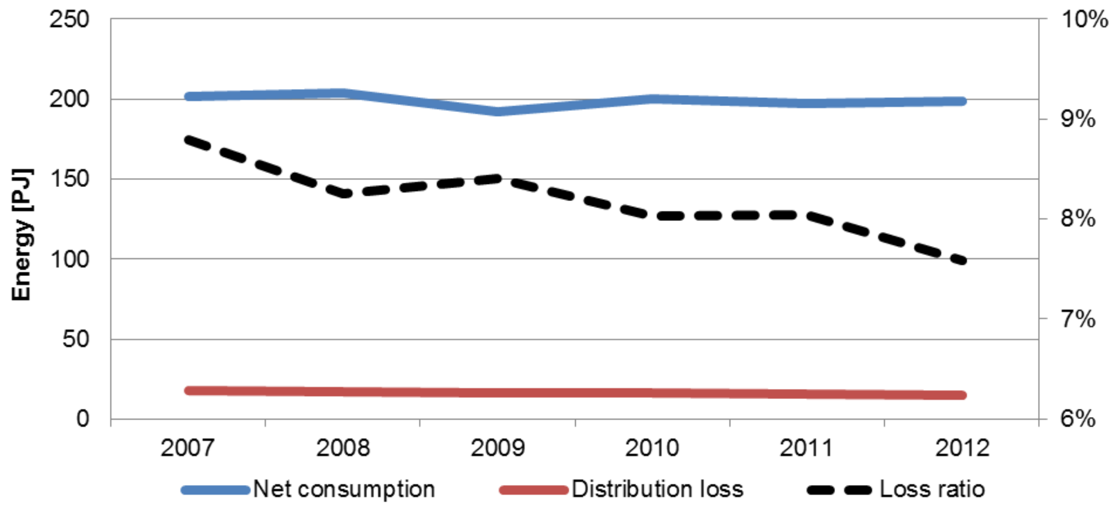


**Figure 40: Electricity distribution loss in CZ[6]**

Even though the electricity transfer loss is relatively low, distribution component accounts for about 40% of the total electricity price (paid to distributor). As a result, from the cost point of view, every MW of created electricity is more expensive due to transmission to the final consumer. These costs can be eliminated in case of local self-utilization of the produced electricity without using public distribution grid.

## 4.4. Heat transportation loss

Concept of district heating is based on transport of energy produced from PES in centralized location to final consumers via piping network. Decentralized “local” heating concept consists of multiple heat sources for each individual house, mostly natural gas. In case of small decentralized heating systems for households, statistics are based on estimates, for centralized heating systems, measured data are more precise.

There are two basic media for heat distribution irrespective of the original type of energy source - pressurized hot water and superheated steam. Both are transmitted through insulated pipes from production plant to final consumers where heat exchangers are usually installed to bring the heat to central heating systems.

As shown in Figure 41, the loss of heat energy caused by transportation has been around 12% on average over the past years. According to other studies[30], average losses are around 15% considering both primary and secondary loop, with potential for reduction by 2-4% after modernization of pipelines and better regulation. Heat transmission losses are dependent on the size of distribution grid, used pipe insulation and the enthalpy representing energy potential contained in the medium. Based on the information above, transport of heat energy on longer distance is not feasible. Instead, consumption of heat “in house” or conversion into electricity prior distribution is preferred.

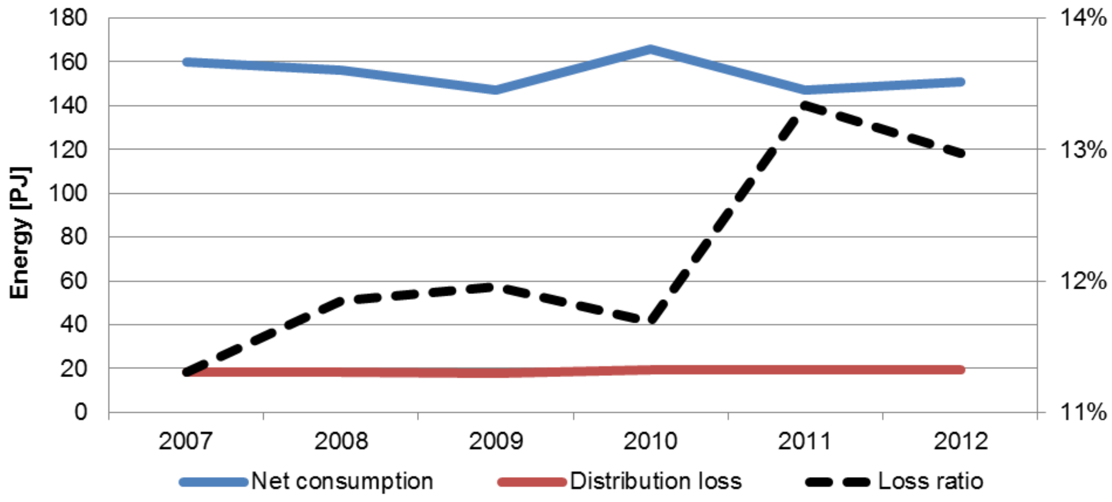


**Figure 41: Heat distribution loss in CZ[6]**

Uplift paid to distributors for heat transfer differs based on provider, in average around 35% of the total price. From this perspective, operation of individual energy sources and concept of distributed heat generation would be by one third less expensive than distribution from central heating systems with overheads included. Heat generating sector is less regulated than power production and final price is in most of the cases set by facility operators.

This chapter closes the topic of energy and fuel distribution, whilst the next describes various topics related to Energy Management, including energy efficiency and Smart Governance.

## 5. ENERGY MANAGEMENT

Energy Management was defined in one of the early chapters as key initiative to optimize energy production, consumption and overall operations, leading to cost reduction described further in the next chapters. Energy Management has been recognized and proven many times to be an essential part of the improvement endeavor for energy governance models, offering multiple opportunities for investments into overall cost reduction or profit increase in public and commercial institutions. General principles for implementation of cost-effective energy operations are scalable, starting with simple household energy systems up to the large-scale and complex energy frameworks at country or regional level.

From the domain perspectives, Energy Management can be defined as an intersection to multiple disciplines – primarily engineering, ecology, project management and economics. It is a set of interrelated areas merging together into one complex framework. Energy Management must be considered not only as a technical discipline, but it also takes into account various environmental, economic and social aspects. Project management plays an important role as well. It creates a backbone of the functional system and provides essential standardization for development and implementation of governance model.

Industrial progress supported by solid research and development introduces advanced technologies with better operational performance and materials with enhanced energy saving attributes. Implemented Energy Management measures improve overall energy efficiency, reduce final consumption through energy savings and are often considered as the most optimal energy source. Saved energy has no additional requirements for primary sources or losses associated with their transformation. In such case, positive impact on environment is even bigger in comparison with power generated in plants utilizing renewables. Energy saved during generation, distribution or consumption can be used elsewhere, without any additional production requirements. This confirms that savings are in fact the most economical and ecological source of energy. There are two options how to increase overall energy efficiency as defined below:

- Increase energy supply produced from the same/lower amount of primary sources
- Reduce energy demand whilst keeping same amount of produced output

Energy savings should not worsen quality of living but keep it at the same level or improve where possible. Thus investment into energy savings is considered as the most feasible approach among all cost reduction initiatives.

Proper Energy Management is always obtained by combination of multiple factors described in the following chapters. Some of them, for example modernization of energy source to improve energy efficiency or thermal insulation for demand reduction, require long-term investments. On the other hand, improvements such as optimization of facility utilization model can be achieved with minimal expenditures and in relatively short timeframe.

For example, PORSENNA study[28] declares technical potential for energy savings in households of around 50% compared to original consumption. However, due to missing Energy Management, poor discipline of occupants and non-optimized settings of the operating systems, it hardly reaches less than half from original plan resulting in only 25% savings compared to original consumption. This example demonstrates that investment into efficient equipment would not bring desired results without changing the habits of occupants as a part of an overall Energy Management strategy.

The NAPEE[23] updated in 2014 set as a target for saving additional 47.84 PJ (13.29 TWh) from total energy consumption in the Czech Republic by 2020. To identify and analyze opportunities for energy savings and efficiency, a set of steps called Energy audit needs to be carried out, following the same patterns independent of scope size, from single houses to regional level.

The following chapters describe various aspects of Energy management e.g. Energy audit with subsequent Energy Management Program, various energy saving measures related to reduction of energy demand or improving energy efficiency.

### 5.1. Energy audit

The first step towards effective Energy Management is to conduct an Energy audit. This initiative examines energy bills and processes in a facility or region and provides alternatives for improving energy efficiency. Various economic, environmental and technical assessments are made during the audit in order to provide comprehensive evaluation of the current state and identify opportunities for future energy-saving investments or potential for implementing Energy Management program.

According to the Energy Management Handbook, "*An energy audit consists of a detailed examination of how a facility uses energy, what the facility pays for that energy, and finally, a recommended program for changes in operating practices or energy-consuming equipment that will cost-effectively save dollars on energy bills*".[31]

The goal of an Energy audit is to analyze current energy flows in a facility from the volume and cost point of view, perform economic analysis and evaluate alternatives for cost reduction. Based on that, new solutions for improvements are proposed. Energy audit can be divided into three phases:

1. Data gathering - energy manager collects all relevant information about existing energy operating model. Gathering of data might require installation of additional monitoring systems. Detailed measurements are carried out in a given period of time, normally lasting for several months/years to cover four-seasons year cycle.
2. Data analysis - collected data, including list of facilities, production and consumption profiles with operating hours, are analyzed. This includes energy bills and geographical data such as weather conditions, heating/cooling degree days and facility layout. Variables impacting energy performance are identified and assessed.
3. Energy Performance Model (EPM) – development of EPM is based on the outcomes from data analysis, considering past trends and simulating expected energy use in future. Established baselines for future energy flows and impact analysis of the variables help to identify alternatives and recommendations for further improvements.

Based on previously developed EPM in the third phase of the Energy audit, implementation of recommendations in the form of Energy Management Program is the next step.

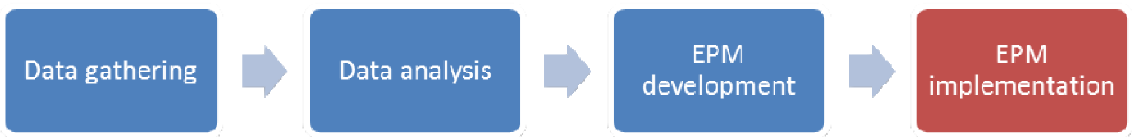


**Figure 42: Energy audit process flow**

## 5.2. Energy Management Program

Opportunities and recommendations identified during Energy audit are introduced into practice through Energy Management Program (EMP). The Program definition evokes intersection of multiple projects and processes coordinated in synchronized way in order to achieve strategic goals. Main EMP components are strategy statement with defined targets, plans and policies for monitoring, controlling and managing energy related process. Important parts of EMP are clear organizational structure, education framework and strong governance model. Optimization of energy operations via EMP has following focus areas corresponding with research goals:

- Reduce total energy demand
- Improve overall energy efficiency
- Develop and maintain energy operation strategy
- Ensure continuity and sustainability of energy supply
- Improve quality of the climate

While energy supply component is mainly dependent on local conditions such as type and availability of energy sources in given region, the other component of energy demand offers more options due to large variety of consumer profiles and their requirements. Ultimately, every EMP is unique due to many considered variables, but general rules and strategy do not change and stay independent of local conditions.

Implementation of EMP in bigger scale requires comprehensive knowledge of the environment and awareness of traditional habits of energy stakeholders in given region. Understanding the landscape or district layout with its economic and climate specifics, producer and consumer profiles, available energy sources and infrastructure for energy distribution is essential for design of an appropriate Energy Performance Model. EMP setup consists of standard project management steps typical for initiation phase. Those key steps are identification of stakeholders interacting with program, definition of requirements and scope in alignment with overall strategy, feasibility study and business case including economic analysis, because many investors are motivated by monetary incentives. EMP also contains mechanisms for evaluation and selection of new project, usually based on multi-criteria analysis in order to react to current needs and changes in policies or overall strategy.

Several examples of how an EMP can help to improve Energy Management in given region or facility are described in following chapters. Those associated with reduction of energy demand mainly refer to building envelope and optimized operations, whilst energy source efficiency and energy recovery improve overall efficiency of energy supply.

## 5.3. Reduction of energy demand

Main objective of EMP is to decrease overall energy consumption and associated expenses for energy supply. This can be achieved by reduction of energy losses as well as by process optimization. Financial stimulation and raising awareness through education help to motivate investors and operators, who are driven by incentives to improve energy performance of facilities among all sectors with positive impact on GDP intensity in the Czech Republic.

Leveling of demand during peak and off-peak periods, also called energy demand management, is another important aspect in relation with the cash flow. Energy utilization can significantly fluctuate during the day depending on consumer profile. Typical incentive for better demand management is a discounted price for energy tariffs during off-peak hours, encouraging final consumers to reduce energy consumption during peak hours.

In general, energy transferred through building envelope is intended to be kept at minimum level in order to reduce heating loads in winter period and cooling during summer. From the other perspectives, transmission of solar energy through glazed areas is desired during winter period in order to obtain passive solar heat gains. It is expected that consumption of heat energy per square meter will continue in declining trend. As a result, focus on heat demand reduction will remain important.

Overall potential for energy savings is described in the following chapters. Especially households offer significant opportunity by renovating building envelope. Agriculture and other sectors, with officially registered buildings in scope, represent potential for annual savings around 55 PJ. For Industry, consolidated figures dated back to 2009 estimated economic potential for savings around 14 PJ.[32]

Compared to the efficiency of energy sources described in other chapters, energy savings achieved through Energy Management are considered as 100% efficient, based on the fact that saved energy does not need to be supplied from source at all.

### 5.3.1. Building envelope

Definition of building envelope generally applies to those structural components surrounding indoor space of given facility, through which an energy is transferred. Reduction of heat losses or gains through building envelope is considered as one of the most cost-effective investment opportunities. Airtight building envelope with limited infiltration helps to stabilize indoor climate, being less exposed to changing outdoor conditions and providing natural ventilation critical for healthy living.

This can be achieved by thermal insulation of walls, roof and openings including removal of "thermal bridges". Selection of appropriate measures depends on multiple factors. Building construction, used material, age and maintenance are some of them. Size and types of openings are determined by need for thermal and light transmittance. Facility operations profile such as utilization model, level of comfort or fire hazard vary among sectors, for example residential and industrial buildings would have different requirements.

There is a target set by EU directives[33] for energy savings in government buildings and optionally in public buildings, where every year at least 3% of total heated/cooled floor space have to be renovated starting in 2014. Requirements for renewal of existing facilities and new construction projects are described in national regulations, setting maximal energy intensity targets supported by various subvention policies.

Several studies have been developed to analyze potential for energy savings in buildings. Potential results for the Czech Republic, achieved through renovation of building envelope, range from 48 to 87 PJ across all sectors. Those from households are relatively accurate, whereas industrial sector might deviate from reality. Assumption from 2012 is that about 80% of households have not had saving measures implemented yet but this number has decreased since then. According to NAPEE[23], residential buildings represent 77 PJ potential for savings achieved through renovated building envelope (45% of original cons.) in optimal standard and 140 PJ (81% of original cons.) in passive standard respectively.[23]

| **Emission [mg/kWh]** | **$CO_2$** | **$CH_4$** | **$N_2O$** | **$SO_2$** | **$NO_X$** | **$MP_X$** |
|---|---|---|---|---|---|---|
| Building envelope | 136 000 | 93 | 1 | 341 | 552 | 71 |

**Table 8: Building envelope manufacturing emissions[34]**

The table above shows amount of emissions released during manufacturing of thermal insulation for building envelope covering both thermal insulation and filling of the openings. Environmental aspects were calculated based on data from GEMIS study and producers of construction elements. Values listed in Table 8 correspond with information mentioned earlier in Table 6 and will be used later in detailed analysis.

### 5.3.2. Facility operations

After detailed analysis of facility operations carried out during Energy audit, appropriate EMP is developed and implemented in order to introduce energy savings in daily operations. Based on the assessment, some of the processes can be eliminated, combined together or improved. Change or upgrade of the equipment, process flow, operator or place might require additional expenditures but brings money back in overall savings from perspective of total lifecycle costs. Every facility has its unique operating cycle, but actions improving efficiency of energy processes are based on the same principle.

Typical example of investment into facility operations is replacement of old devices with new, energy efficient appliances. Education of occupants to maintain reasonable indoor temperature level and usage of automated heating/ventilation systems will also reduce energy wasting. Regulation of energy supply to prevent overheating of the space is essential. Hot water provisioning should not exceed the demand in terms of volume and temperature or get lost during transport due to higher distance of source from final consumer. Proper insulation of the distribution network helps to reduce losses during energy distribution within the facility. Modification of utilization profile with effective energy conservation reduces demand peaks and levels energy consumption during facility operating cycle.

Design of the operating model for given facility or district should meet desired level of comfort and not exceed given budget constraints. Selection of appropriate space zoning, equipment sizing and operating model respecting user's requirements is essential for efficient operations. Potential for savings achieved by implementation of energy efficient technologies in households was estimated in NAPEE[23] at 12 PJ (30% of original cons.) for water heating and 3.4 PJ (60% of original cons.) for lighting.

Total available potential summing all Energy Management measures together is 160 PJ.

### 5.3.3. Energy efficient design

Design of new facility or district layout provides opportunity for energy efficient solutions with minimum or no additional costs. Locations with low energy intensity, close to energy source and logistic hubs are optimal for efficient operations in future. Underground constructions, energy-conserving landscaping or layout and orientation are equally important.

Essential and the most cost effective concept to reduce energy demand is passive solar design. When applied, facility or district arrangements respect natural energy processes such as solar radiation or convection of thermal energy from sun. Application of several rules during construction phase can reduce heating and cooling loads or daytime lighting without any additional costs. Basic principles of passive solar design are the following:

- South/north orientation of the building to maximize/minimize exposure to sun radiation for heat/light gains
- Landscaping or shadings to increase/reduce heat gains in winter/summer
- Open space layout for passive energy distribution between absorber and air

The highest light and heat gains from passive solar design normally correspond with facility operation period. Despite the fact that direct or indirect gains can significantly reduce overall energy demand of the facility or district, passive solar design is not always the standard concept for new construction projects. Investment into training and education of designers might be appropriate.

### 5.4. Efficiency of energy supply

In the context of energy supply, an improved efficiency is achieved either by increased amount of energy produced from same/lower amount of primary sources or by minimizing losses required for transmission of the energy from production plant to final consumers.

Modernization of the existing centralized energy sources requires capital investment. Results of the Energy audit will help us to select the most cost effective solution based on identified opportunities. It might be recovery of the waste energy in form of heat or hot water, installation of new technology to streamline energy process or tuning energy sources based on operation profiles.

#### 5.4.1. Energy source efficiency

Efficiency of energy source depends on the type of primary fuel, technology used for energy transformation and target form of produced energy. Figure 43 consolidated from several studies[17;26;35;36] gives an overview of source efficiency based ratio between energy output/input per fuel type and used technology:

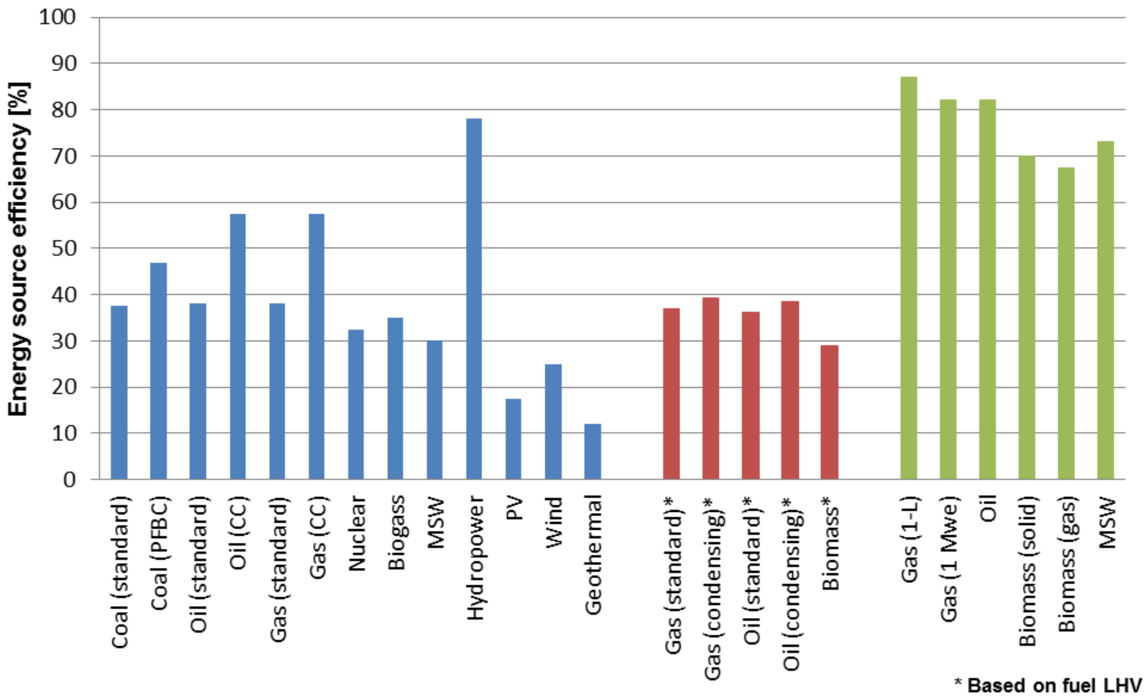


**Figure 43: Relative efficiency per energy source**

The graph is divided into three sections according to the color. The first group represents sources generating electricity, second generating heat and third using cogeneration for energy production.

Original values for heat generation are based on Low Heating Value (LHV) of given fuel and perform better in relative numbers than other two groups. However, due to lower "exergy" of heat described in Chapter 2, values for energy sources producing heat had to be adjusted. To compare CHP technologies, ratio between heat and electricity cogenerated from the same fuel must be known. In general, plants using CHP technology have an efficiency improved by 25-50% compared to plants solely generating electricity or heat. Mean value depends on benchmark fuel and technology used as well as point in lifecycle of the plant. Actual efficiency improvement achieved through CHP technology also depends on consumption requirements and period of the year.

Recently announced battery storage technologies from Tesla[37] have reported report efficiency of 92%, but performance in long-term usage has to be proven. Efficiency of solar thermal systems is comparable to photovoltaics in case of electricity generation. When heat is produced and storage capacity is available, solar thermal systems become more efficient in absolute terms. However, that is not case for this analysis. Heat pumps are measured by coefficient of performance, representing ratio between heating/cooling energy released against electricity consumed.

### 5.4.2. Energy recovery

Principle of energy recovery is based on utilization of output energy from one process as an input energy to the same or new power generating process, offering additional potential for further exploitation and provisioning benefit to user. Waste energy exists in different forms such as flue gases released to the atmosphere, boiler blowdown, solid waste or condensates. It is usually produced during primary fuel transformation process.

Waste heat could be utilized directly in exchange heaters or for power generation in steam turbines without need for additional fuel. The performance depends on many factors. Those key are temperature differences, transfer device efficiency or operation model. Energy recovery can be applied wherever it is economically feasible and technically possible. Based on energy potential and temperature of the waste heat, three types of use are defined:

- Low temperature heat up to 200°C for supplemental heating
- Medium temperature heat from 200 to 600°C for steam generation
- High temperature heat more than 600°C for cogeneration

Majority of heavy industry, incineration and heating plants in the Czech Republic use high-range temperature heat in primary processes. This represents an additional potential for implementing energy recovery as part of overall Energy Management.

Closing topic of energy efficiency for now, next two chapters focus on monitoring, reporting and controlling of energy flows in order to establish effective and "smart" governance.

## 5.5. Energy monitoring, reporting and controlling

Energy Management is highly dependent on reliable data. Effective control can be achieved only if we are able to measure, analyze and react properly. Analysis of historical data and real-time monitoring of energy processes is important for proper targeting and reporting of overall energy performance. Measurement of energy consumption including influencing factors over a time period helps to develop relationships and determine performance model for benchmarking. Reporting of actual performance allows us to manage and optimize energy flows towards meeting cost-effective targets. Typical influencing factors are weather conditions such as degree days, occupancy/operating hours and production level of the facility. During the measured time period, multiple baselines can be identified based on influencing factors.

Energy Management Control System (EMCS) for managing energy flows is applicable in different scales, from individual households to regional level, for centralized as well as distributed energy supply. It can be manual or automated, depending on complexity and potential for cost savings. General rule is that automated control devices eliminate human factor but usually require higher capital investment. Manual or basic automated controls like switches, timers, thermostats and various sensors are commonly used across all sectors and allow the facility operators to apply simple Energy Management patterns according to the consumption profile. Advanced computer based systems use modern technologies and programs to analyze information gathered from digital sensors in order to manage, predict and simulate future energy flows actively. Such systems automatically regulate fuel or energy flows and coordinate multiple sequential or simultaneous energy processes. In general, every automation initiative using predefined and repeatable operating model prevents inconsistent Energy Management performed by personnel and improves overall efficiency. Top EMCS with sophisticated cognitive computing system is able to "learn through experience" and becomes essential in complex environments, for example Smart Grid operations.

## 5.6. Smart Governance

Energy supplies from alternative sources as well as consumption loads are usually intermittent and in many cases hard to predict. The entire energy system including distribution grids has to be responsive and flexible enough to adjust energy flows according to the actual requirements. Ability to absorb additional energy produced from RES or immediately start-up reserve power sources during loss of energy intake are critical for stable operations. Implementation of smart metering and controlling devices together with advanced IT systems is necessary for automated Energy Management at regional level, preventing both producers and consumers from adverse impact caused by outage or volatile energy supply and demand.

Smart grids are able to recognize actual changes in the network or even perform near real-time forecasting. Automated synchronization and adaptive operations of all components within Smart grid ensure the overall stability of the distribution network, responding to variables associated with distributed generation as well as alternative energy sources. All mentioned above improves reliability, flexibility and efficiency in all the sectors. Implementing Smart Governance model could be divided into three domains:

1. System transformation – processes and operations transformation can be achieved by higher degree of automation and moving more responsibility from suppliers to final consumers. Optimized energy generation, distribution and consumption together with flexible regulation result in reduced operating costs.
2. Infrastructure modernization – infrastructure upgrade should start with areas offering highest potential for improved reliability and efficiency. Implementing advanced DSM capabilities or installation of sensors and control systems monitoring real-time energy flows would prevent system outage and secure fast recovery. Collected data from monitored facilities such as fuel consumption, output, performance or emissions help operators to optimize their energy processes.
3. Grid digitalization - digitalization of the whole system and integration of multiple operational components provide centralized governance and better coordination between production plants, energy distributors and final consumers.

Security and protection of the distribution grid is also critical aspect of Smart Governance. Preventing misused control over centralized energy production plants or cut-off supply to final consumers are key risks to be addressed in regulated sector of Energetics

Smart governance was the last topic in this section. The next one provides insight into the economy of investment with particular focus on Lifecycle assessment and available policies for subsidy funding.

## 6. ECONOMY OF INVESTMENT

Facility owners are forced by market to become more cost effective in order to survive in the competitive environment. As described in the previous chapters, Energy Management is an essential step towards cost reduction, but also improvement of cash flow and setting direction for sustainable development in future. Decreasing of overall energy demand or increasing of source efficiency usually requires capital investments, whereas operations optimization might be achieved with relatively low non-investment expenses. Investment costs associated with acquisition, utilization and disposal of equipment are relatively high compared to standard operating costs and require certain period of time for return.

There are various methods how to evaluate cost-effectiveness of identified opportunities and select the most appropriate. Basic method used for investment analysis is calculation of payback period where initial costs are compared to annual savings. However, this approach does not cover the period after payback horizon neither the time value of money. Thus other methods described later in this chapter should be used.

Discounted cash flow analysis or overall Life Cycle Analysis are more suitable when considering long-term investments into sustainable and decades lasting efficiency improvement programs. Amount of initial investment costs is not so critical either. Due to the fact that market is distorted by available subsidy programs stimulating attractiveness of specific energy sources, initial investment costs will not be compared in absolute numbers.

### 6.1. Economic aspects

Investment into technology improvement or Energy Management predominantly depends on energy price, respectively potential for cost savings resulting from it. Energy prices in the Czech Republic were growing in the past decades for both Households and Industry, but they have stagnated recently.[4] The price factor, differing for peak and non-peak periods, impacts not only consumption profile as mentioned earlier but also investment analysis. For example determination of payback period for Energy Management initiatives is influenced by fluctuating price of fuel and energy, mostly driven by political decisions rather than markets. Thus volatile price factor, which impacts investment decisions, is not considered in this analysis neither the amount of initial investment or payback period. It is considered that both factors, initial investment and payback period, are susceptible to available subsidy policies and easy to stimulate. From this perspective, it is more important to analyze other attributes such as costs of 1 kWh produced from energy source within the context of overall lifecycle costs instead of initial price.

Long investment cycle in Energetics and assumption of inflation trends in economy bring the requirement to consider time value of money during evaluation. Therefore discounted cash flow analysis is used as a part of the overall Life Cycle Analysis. Cumulative cost savings in future, achieved through applied Energy Management today, grow during the period of time. In contrast, cost of new technology decreases as well as efficiency improves for recent technologies, postponing the decision process. Common aspects usually considered in economic analysis are initial condition of the equipment used, lifecycle costs, investment period but also volatile energy prices. These are compared to the potential savings introduced by given initiative over the time.

Investments into technologies utilizing renewable energy sources are typically higher in comparison with investment into conventional fuels. However, initial costs have been decreasing over the past decades and became more attractive for investors in combination with additional subsidy incentives offered by government. According to the Energy Management Handbook[31], we can observe almost linear declining trend for technology initial costs, where 17% cost reduction correlates with doubled amount of global installed capacity. This means that in the past, when installed power of given technology increased by 100% globally, initial investment costs associated with this technology declined by 17%. Such trend indicates potential improvement of economic parameters for RES in the future, correlating with constantly increasing installed power of RES globally.

### 6.2. Energy source lifecycle assessment

Lifecycle costs represent all expenses associated with given technology or project covering acquisition, maintenance, operations including fuel costs and disposal. Despite higher initial costs, overall lifecycle expenses for RES technologies are more attractive due to low cost operations and fuel savings in a long-term perspective.[31] Although traditional power generating plants burning fossil fuels are dominant in the market due to massive growth and investments in the past centuries, considering their age within lifecycle period and costs associated with their modernization, RES will play more important role in the course of time. Hence, evaluation of overall lifecycle costs and regional benefits from long-term perspectives are appropriate, instead of short payback period usually desired by investors.

There were many studies and strategies developed defining profitability of investment into technologies generating energy based on type of PES. Energy returned on energy invested (EROEI) or Levelized cost of electricity/heat (LCOE/LCOH) are two main indicators considered in decision making process. Their calculation is very complex and dependent on many variables being sensitive to factors such as local conditions or level of process automation. Results of EROEI/LCOE studies vary in conclusions, which might be caused by different preferences of involved stakeholders and considered factors. Recommendations for utilization of coal for heat and electricity generation are substantially supported by representatives from mining industry, whereas renewable energy sources are promoted by ecological organizations.

Figure 44 shows values composed from multiple research studies published recently. Main source, World Energy Perspectives published by Bloomberg in 2013, is supplemented by inputs from other studies (Lazard, Institute for Solar Energy Systems) in order to present the most independent results. Available studies vary significantly and therefore interval model with minimum, maximum and mean values has been applied. Where applicable, conditions similar to those in the Czech Republic were considered as mean value for further analysis. In general, technologies utilizing fossil and nuclear fuels have lower LCOE than renewables but fluctuate more with fuel price.

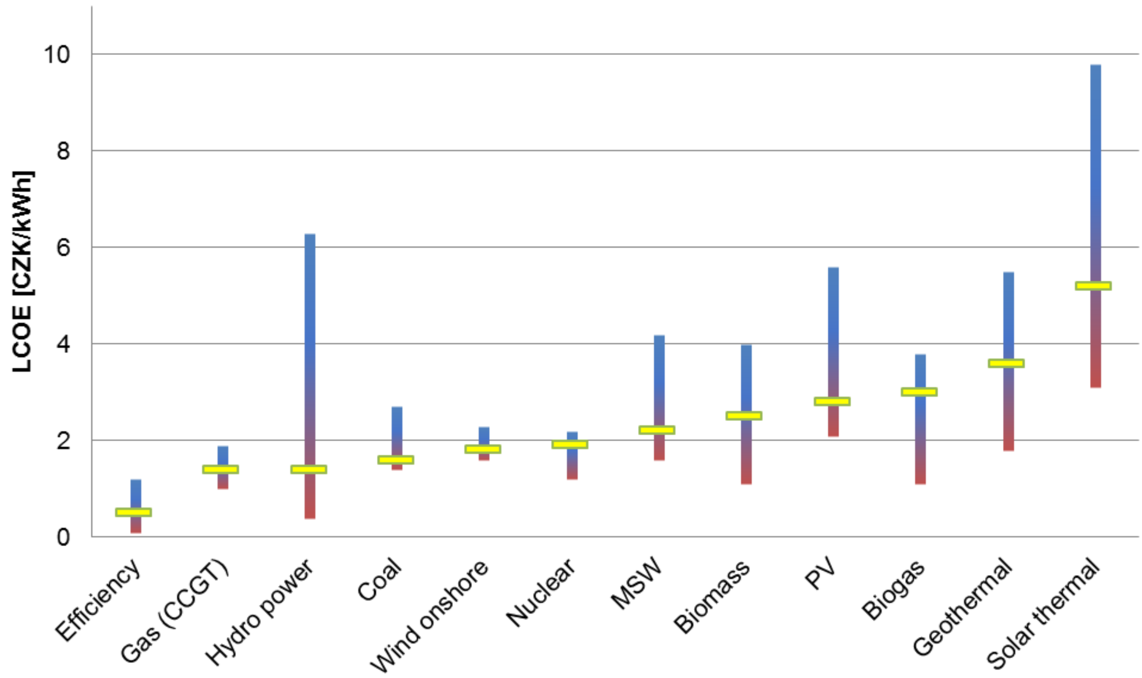


**Figure 44: LCOE per energy source[38;39;40]**

The graph above shows levelized costs of energy per kWh in 2013, sorted in ascending order by median LCOE value. As of today, only hydropower can compete with fossil fuels but following recent trends, it is expected that other RES will become more attractive in future. The incremental value of LCOE for CHP technology compared to Combined Cycle Gas Turbine (CCGT) power plant was calculated at 13 USD/MWh and 0.29 CZK/kWh respectively.[38] In 2014, average LCOE for battery storage was calculated at around 6.5 CZK/kWh.[40] However, this number changed in 2015 with recent Tesla announcements and it is expected to decline in future. When implemented in production, LCOE values for storage are added to LCOE values of RES, resulting in combined LCOE value.

Technological research and development reduce LCOE for RES. For example photovoltaics has experienced significant progress recently, where reduced investment costs and higher efficiency improved LCOE dramatically, decreasing by more than 65% between 2009 and 2013 in developed markets.[38]

In most cases, large scale utilities were used for calculations. They usually have lower LCOE than distributed energy sources with smaller installed capacity. On top of this, governments with targeted subsidy policy leverage profitability of RES and motivate investors to select projects that would not be feasible under normal conditions and purposely increase their attractiveness.

### 6.3. Subsidy policy and available funds

The EU has several instruments how to motivate member countries to follow the "*Europe 2020*" strategy and coordinate their future growth. Most effective measures with immediate impact are subsidy policies supporting expansion of RES. Besides others, the Czech Republic as an EU member country introduced Operational Program Environment (OPE)[41] with Priority Axis 3 focused on Sustainable Use of Energy Sources, offering EUR 673 mil. in 2007-2013 for projects in the following areas:

- Heat generation - construction/modernization of local/central heat sources using renewable energy sources for heating/cooling buildings and hot water heating
- Electricity generation - construction of photovoltaic, wind, small water, geothermal and biomass power plants
- Combined generation of electric energy and heat
- Realization of energy savings - thermal insulation of building envelopes
- Use of waste heat - applying waste heat recovery technologies

Improvement projects in supported areas can subsidize up to 85% of the total costs, which has significant impact on initial investment costs and calculation of payback period. Conditions for OPE in the next subsidy period 2014-2020 and selection of priorities will be specified during 2015. In addition, breakdown of the subsidy programs presented in NAPEE[23] gives us consolidated overview of priorities, targets and allocated funds:

| Energy savings [PJ] | Prgm | 2008-10 | 2011-13 | 2014-16 | 2017-20 | Funds [m. CZK] |
|---|---|---|---|---|---|---|
| Households | 8 | 4.1 | 3.1 | 7.5 | 20.9 | 62 100 |
| Industry & others | 6 | 1.3 | 4.6 | 14.1 | 13.0 | 34 500 |
| **Total** | **14** | **5.4** | **7.7** | **2.2** | **33.9** | **96 600** |

**Table 9: Subsidy programs 2008-2020[23]**

Total allocation of more than CZK 96 billion (dependent on exchange rate) over a decade is substantial support for investments into RES. Such intervention can distort the market and influence investment analysis, similar to volatile energy price. Moreover, emission allowances also stimulate investments into renewable technologies positively. These examples underline decision-based evaluation from previous chapters that LCOE will be used in further analysis instead of investment costs or payback period influenced by political decisions.

The section Economy of investment was the last topic in theoretical part of this thesis. Remaining sections provide overview of research goals and used methodology, leading into practical analysis of collected data and concrete results.

# GOALS AND METHODOLOGY

## 7. THESIS GOALS

The goal of this thesis is to develop an Energy Management concept at regional level, providing optimal renewable energy mix and set of recommendations with emphasis on streamlined operations in key areas of energy production, distribution, storage and consumption. The time horizon, constraints and targets of proposed solutions in this thesis are aligned with 2030 Energy Strategy[10] recently announced by the EU. Outcomes of the research can be used as an input for the new methodology determining sustainable Energy Management governance in given region. In context of the Czech Republic, used model, results of the analysis and recommendations in this thesis represent valid entry for planning and revision of national policies moving towards energy efficient and environmental friendly course with reliable energy supplies. As a result of its complexity, the main goal has been divided into several objectives as per below:

- Objective 1: Review recent trends in Energetics
- Objective 2: Analyze energy production, distribution and consumption in CZ
- Objective 3: Appraise economic considerations
- Objective 4: Develop framework for evaluation and perform multi-criteria decision analysis for selected alternatives
- Objective 5: Propose preferred mix of additional RES installations and Energy Management measures for the Czech Republic in 2030

Goals and objectives listed above have been selected with hypothesis that National Energy Policy in the Czech Republic improperly assumes replacement of fossil fuels in energy mix by nuclear power. I believe that renewable energy sources have sufficient potential to fill this gap by 2030 and share of nuclear fuel in energy mix can remain unchanged. Another hypothesis is that not all renewable energy sources are suitable for large-scale implementation in order to ensure sustainable regional development. I assume that fuel-less power plants such as photovoltaics, wind power or solar thermal power are not convenient solution compared to other RES burning fuels, thus cannot represent backbone of sustainable energy strategy. Therefore, in this thesis I try to prove that:

1. Potential of RES and Energy Management measures in the Czech Republic is sufficient to fill the gap caused by reduced share of fossil fuels in energy mix
2. Fuel-less power plants are not the most preferred solution for sustainable regional development and that other RES technologies and Energy Management measures represent better solution based on evaluation of multiple criteria

## 8. METHODOLOGY

In order to obtain defined objectives, the overall approach has been divided into three phases. The three-phase model shown in Figure 45 has been selected as the most suitable approach to discover optimal renewable energy mix and Energy Management measures.

In the first phase, focus is paid to review of current trends in Energetics, analysis of data collected about renewable energy sources, facility operations, economic and ecological aspects. Reliable and publicly available sources of information were identified for the research. Selected data are used as an input into the detailed analysis.

Second phase starts with development of the evaluation framework. Inputs to the analysis are represented by set of alternatives and criteria with defined importance and specific options. Priority (weight) intervals are assigned to the variables and processed in Multi-Criteria Decision Analysis (MCDA), which has been identified as the most suitable approach for the multidisciplinary evaluation.

In the last phase, concrete results and set of recommendations applicable for future implementation are presented. Conclusions and proposals for optimal energy mix and Energy Management measures are based on specific values resulting from MCDA, supported by general observations collected during overall data analysis.

The graphical expression of three-phase model is shown in Figure 45 below:


**Figure 45: Research methodology phasing**

Data collection and evaluation is covered in the next chapter, followed by review of available multi-criteria decision models. Various MCDAs are assessed in order to identify the most appropriate one for further analysis. Most suitable MCDA is aligned with proposed evaluation framework and described in details.

Implementation of the evaluation framework in other regions than Czech Republic would require redefinition of the scope including modified set of alternatives and criteria values relevant to specific region.

## 8.1. Data collection and evaluation

Multiple sources of information have been used to maximize objectiveness and relevancy of collected data. Key factors such as historical trends, current geopolitical situation and potential for future growth are evaluated based on available publications, studies and strategies covering end-to-end energy demand, supply and operations. Important figures and tables used for the analysis refer to publicly available statistics published by reliable sources, such as Czech Statistical Office, Eurostat, OECD, Energy Regulatory Office, Ministry of Industry and Trade etc. Additional information was gathered from various Policies and Action plans released by the European Union or government of the Czech Republic. Other important sources are research papers, studies and publications issued by academic, governmental, private or non-governmental institutions.

Various data sources use different units for energy measurements. Electricity is in most cases measured in Watts and related variations. Installed power for electricity sources is usually reported in Watts (xW) and production/consumption in Watt-hours (xWh). Figures representing general energy or heat operations are mostly available in Joules with conversion factor 1 kWh = 3.6 MJ. Primary energy sources can be in tonne of oil equivalent 1 toe = 41.87 GJ, representing amount of energy released during burning of one tonne of crude oil. These are mostly used for large volumes and in international context (e.g. OECD or Eurostat). Wherever possible, figures are converted to Watts, Watt-hours or Joules, representing standardized units for measurements and calculations.

Important fact to highlight is that information about energy production and consumption may vary based on source. During data analysis, it has been observed that institutions such as CZSO, ERO, MIT and Eurostat use different methodologies for data collections, analysis and conclusions. For example, CZSO follows methodologies applied in the Czech Republic before 1993 and may vary from those used by Eurostat or OECD today. Comparing mean values of measured data and assessment of key indicators have revealed discrepancies within acceptable range of two standard deviation. Majority of the collected data demonstrate identical percentage and trends in measured periods and so could be used in further analysis.

## 8.2. Multi-criteria decision analysis (MCDA)

The goal of multiple-criteria or multi-objective analysis is to choose the best or most preferred alternative out of a set of complex alternatives where full range of technical, environmental, economic and financial criteria has to be taken into account.[42] The complexity arises not only due to multiple parameters, but also due to their interactions, which, as a result, are subject to conflicts and trade-offs. Moreover, these alternatives are often of non-monetary nature (environmental or technical) where exact quantitative values cannot be easily assigned. Therefore, although there are various methods for carrying out multi-criteria analysis, only few are suitable for this research where these non-monetary values are of considerable importance. These methods also differ with respect to completeness and quality of information needed.

Evaluation of several MCDAs including sensitivity analysis and selection of the most appropriate MCDA is based on recommendations from comparative study.[42] Most simple and commonly used multi-criteria decision method is Weighted Sum Model analysis. This method evaluates multiple alternatives based on predefined decision criteria, where all options have to be compared using same units. This is not the case for our research, so Weighted Sum Model analysis is not suitable. The Weighted Product Model, also known as "dimensionless analysis", is similar to Weighted Sum Model analysis. The main difference is that Weighted Product Model can be also used to compare alternatives according to criteria with different dimensions, considering actual as well as relative values. However, it does not properly address non-quantitative aspects and therefore is not suitable for our analysis.

The other two methods, ELECTRE used for discarding alternatives and TOPSIS requiring normalization of criteria are not suitable for our research either. The first method removes alternatives entirely, the other creates ranking of alternatives without determining optimal solution.

On the other hand, the Analytical Hierarchy Process (AHP) and Revised AHP are used for evaluation of complex problems addressing non-quantitative aspects. The main advantage of AHP is revealed in situations when quantification of variables in the MCDA is not easy and options coming from multiple disciplines are considered during evaluation. This is the case of multi-disciplinary assessment performed in Energy Management, where several independent criteria such as efficiency, ecology or security have to be evaluated with assigned values in order to compare the alternatives. Therefore, the most suitable approach for this analysis, which also allows taking qualitative information into account, is the AHP introduced by Saaty.

## 8.3. Analytic Hierarchy Process

This method is based on pairwise comparison, assumes cardinal data scale - complete aggregation of data - and is based on linear additive model. This means that not only absolute information is available, but also the magnitude of preference with respect to each other. As a result, numerical values (weights or priorities), which are used to calculate a score for each alternative, are assigned by decision-maker according to relative importance of those parameters by pairwise comparison.[43] The decision-making process can be divided into five steps:

- Step 1: Define goal, alternatives, criteria and options
- Step 2: Set criteria priorities by pairwise comparisons
- Step 3: Set options priorities by pairwise comparisons
- Step 4: Calculate an overall performance of each alternative
- Step 5: Rank and select most preferred alternative

First, the overall goal has to be defined. Based on the nature of desired outcomes, alternatives and evaluation criteria are set for further analysis.

In the second step, priorities of different criteria are set by pairwise comparison between each other and decision matrix is created. The relative importance is assigned with range of numbers between 1 and 9. The question that has to be answered in every comparison is: "How important is criterion X relative to criterion Y?" Whereas "1" means that criteria are equally important and decision-maker is therefore indifferent or cannot assign importance, "9" means that first criterion is substantially more important than the second one.

Saaty proposed the following structure, where even numbers can be used for more precise determination of relation:

- Priority 1 - criteria are equally important, decision-maker is indifferent
- Priority 3 - first criterion is marginally more important than second one
- Priority 5 - first criterion is more important than second one
- Priority 7 - first criterion is substantially more important than second one
- Priority 9 - first criterion is absolutely more important than second one

Second criterion is then assigned a reciprocal value (1/9). Important fact to highlight is that consistency of the decision matrix must be considered prior assigning the priorities (weights) to specific criteria.

As a result, in a formal way, decision matrix comprises elements “*e*”, where:

$$e_{xy} = \frac{w_x}{w_y} \; ; \; x, y = 1, 2, \ldots n$$

and is of square nature, where:

$$e_{xy} = \frac{1}{e_{yx}}$$

Values on diagonal axis are 1, because each criterion is equally important with respect to itself. Next, the overall weight (importance) of each criterion is calculated as a geometric mean of particular row of the matrix in following way:

$$W_x = \frac{\left[\prod_{y=1}^{n} w_{xy}\right]^{\frac{1}{n}}}{\sum_{x=1}^{n}\left[\prod_{y=1}^{n} w_{xy}\right]^{\frac{1}{n}}}$$

In the third step, the same rationale is applied to different options within every criterion discussed above. In case where exact value and/or magnitude cannot be assigned (e.g. environmental impact), intervals are created, which then serve for the purpose of comparisons. Intervals/values are subsequently compared and weight of every option within each criterion is calculated in the same way as weight of criterion within alternative. The overall weight $w_{o1}$ (which serves as an input for final alternative evaluation in the fourth step) of an option 1 is then:

$$w_{o1} = w_c \times w_o$$

where $w_c$ is the weight of criterion and $w_o$ is the weight of an option value/interval.

In the fourth step, weights of different options are added up in linear additive model. In the last step, different alternatives are ranked according to this sum and most preferred alternative is selected.

## ANALYSIS AND FINDINGS

## 9. DATA ANALYSIS

The overall goal of Energy Management concept for the Czech Republic, selected as reference region for my research, can be defined by three imperatives leading towards sustainable regional governance. These imperatives are:

1. Maximize operational efficiency (Efficiency imperative)
2. Minimize environmental impact (Ecology imperative)
3. Secure energy supply (Security imperative)

In the area of energy production, scope of the research predominantly covers renewable and non-conventional energy sources, providing comprehensive and realistic assessment of suitable alternatives to conventional technologies. RES are considered as sustainable and environmental friendly solution, reducing regional dependency on imported fuels. However, with currently available technologies, some of the RES might not secure reliable energy supply due to intermittent production or insufficient fuel base.

Environmental aspects consider not only air pollution, mainly caused by local obsolete energy sources, but also aesthetical impact of large scale facilities on the landscape. On the other hand, concept of Distributed Generation using modern and efficient energy sources provides balance to predominant centralized production sites, reducing overheads required for facility operations as well as energy distribution. Selection of preferred technologies and measures from Chapters 2 and 5 has been supported by evaluation of distribution and consumption profiles in the region covered in Chapters 3 and 4 of this thesis. Industry and Households have been identified as sectors with the highest demand and significant potential for improving energy efficiency.

All three imperatives have been broken down into six evaluation criteria, where two sets of characteristics always represent one imperative as shown in Figure 46. Energy source efficiency and Levelized Cost of Energy (LCOE) belong to Efficiency imperative. Ecology imperative is represented by aesthetical impact of the energy source on the Landscape and environmental factors such as Emissions or pollutants released to the atmosphere during energy production. Scalability of the energy source desired in the concept of Distributed Generation as well as sufficient Potential for future expansion and fuel availability refer to the last Security imperative.

Assessment is developed in two scenarios with variable importance ratio for the supplementary seventh criterion. Scenario 1 assumes current state where suitable storage technology is not available to accumulate energy supplied from intermittent sources. Scenario 2 predicts availability of suitable storage technology and capacities in near future.

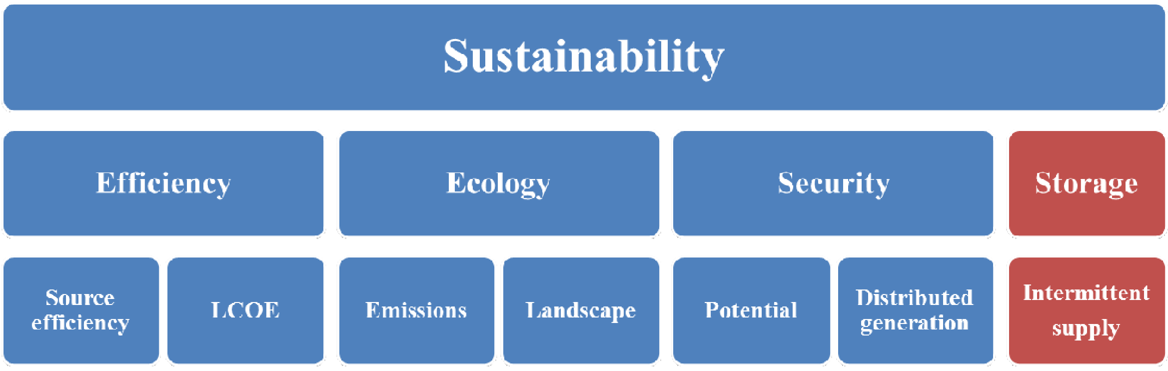


**Figure 46: Evaluation framework breakdown**

Graphical scheme above illustrates breakdown of key focus areas and selected criteria considered in the evaluation framework, corresponding with three imperatives defined at the beginning of this chapter. Seventh criterion of Intermittent supply differs based on selected scenario.

Next chapter defines alternatives and criteria used as an input for the MCDA, all based on information gathered and analyzed in Chapters 1 to 6.

## 9.1. MCDA Inputs – definition of alternatives and criteria

Inputs of the analysis consist of data selected during review of current state in the first section of this thesis. Alternatives and criteria have been evaluated according to multiple attributes, such as used technology, recent trends in installed capacity, fuel mix and potential for future growth.

There have been ten alternatives selected as a primary input of the MCDA (step 1a):

**Alternatives:**

- Biomass CHP – biomass plant producing energy by combustion of solid biomass with cogeneration technology for combined heat and electricity generation. The Biomass CHP alternative is referring to energy source described in Chapter 2.4.1.
- Biogas CHP – biogas plant producing energy by combustion of biogas using cogeneration technology for combined heat and electricity generation. The Biogas CHP alternative is referring to energy source described in Chapter 2.4.2.
- MSW CHP – incineration plant producing energy by combustion of municipal solid waste with cogeneration technology for combined heat and electricity generation. The MSW CHP alternative is referring to energy source described in Chapter 2.4.3.
- Hydropower – small hydro power plant generating electricity. The Hydropower alternative is referring to energy source described in Chapter 2.4.4.

- Wind power – wind power plant generating electricity. The Wind power alternative is referring to energy source described in Chapter 2.4.5.
- Photovoltaics – photovoltaic cells generating electricity, installed on facades and roofs of residential, commercial and industrial buildings. The Photovoltaics alternative is referring to energy source described in Chapter 2.4.6.
- Solar thermal – solar thermal system producing heat and alternatively electricity, installed on facades and roofs of residential, commercial and industrial buildings. The Solar thermal alternative is referring to energy source described in Chapter 2.4.7.
- Geothermal – geothermal power plant producing heat and electricity. The Geothermal alternative is referring to energy source described in Chapter 2.4.9.
- Energy Management – improvement measures for energy savings and efficient energy operations, including thermal insulation of building envelope and implementation of Energy Management governance. The Energy Management alternative is referring to energy saving measures described in Chapter 5.3.
- CHP technology – implementation of cogeneration technology in existing heat and power generating plants predominantly combusting fossil fuels. Only values representing difference in performance/attributes before and after implementing CHP technology in facility are considered as relevant criterion value. The CHP technology alternative is referring to energy efficiency measure described in Chapter 2.5.

Based on current state review conducted in the first section of this thesis, some energy sources have been removed from scope of the research and therefore do not appear on the list of alternatives as an input of the MCDA. Heat pumps are not considered as an alternative in scope of this analysis due their inability to produce electricity but only to consume energy during heat transmission. Heat pumps are not recommended in large scale installations at regional level, nor in passive or low-energy houses where benefit from energy and subsequent cost savings is not attractive enough to motivate investors. Instead, geothermal energy and solar thermal plants have been selected as an alternative to this technology. Other renewable technologies, for example offshore wind power plants or tidal power plants have been excluded from the scope due to zero potential for deployment in the Czech Republic. Power plants utilizing conventional fuels such as coal, gas, oil and nuclear cells are not included in the MCDA either.

Once the primary input of selected alternatives into MCDA is completed, secondary input of selected criteria is required.

There have been seven criteria selected for the MCDA (step 1b):

**Criteria:**

- Source efficiency – useful output of the electricity and/or heat produced from energy source compared to primary energy input required for conversion. Source efficiency has a data range from 0 to 100%. The higher Source efficiency is the better performance it represents in MCDA. This criterion is referring to Chapter 5.4.
- LCOE – total cost required to build, operate and dismount an energy source spanning its entire lifecycle, measured against common unit of energy output. LCOE has a data range from 0 to 6 CZK/kWh. The lower LCOE is the better performance it represents in MCDA. This criterion is referring to Chapter 6.2.
- Emissions – amount of selected air pollutants and gasses released to atmosphere measured against common unit of energy output during energy production. Emissions have a data range from 0 to 6 measured without units. Values are based on results from quantitative analysis and the lower Emissions are the better performance it represents in MCDA. This criterion is referring to Chapters 2.7 and 5.3.
- Potential – available potential for energy production/savings achieved through installation of new energy sources or implementation of new energy saving measures, based on accessibility and capacity of primary resources in given region. Potential has a data range from 0 to 15+ TWh of energy produced annually. The higher Potential is the better performance it represents in MCDA. This criterion is referring to Chapters 2.4, 2.5 and 5.3.
- Landscape – environmental aspect considering aesthetical impact of new energy source on landscape, including space demandingness and visual dimension of the facility. Landscape has a data range from 1 to 8 measured without units. The lower impact on Landscape is the better performance it represents in MCDA. This criterion is referring to Chapters 2.4, 2.5 and 5.3.
- DG concept – represents scalability of given energy source and applicability in the concept of Distributed Generation. DG concept has a data range from 1 to 8 measured without units. The higher DG concept (scalability) is the better performance it represents in MCDA. This criterion is referring to Chapters 2.4, 2.5 and 5.3.
- Intermittent supply – ability of the energy source to provide continuous and stable supply as well as agile adaptability to actual energy demand. Intermittent supply has a data range from 1 to 8 measured without units. The less Intermittent supply is the better performance it represents in MCDA. This criterion is referring to Chapters 2.4, 2.5 and 5.3.

Source efficiency, LCOE, Emissions and Potential are criteria with exact values or magnitudes collected during analysis of current state. Remaining criteria such as Landscape, DG concept and Intermittent supply have got qualitative intervals assigned according to recommendations from Saaty described in Chapter 8.3.

The MCDA inputs for all alternatives and criteria with assigned intervals are based on information gathered during current state review and described in Chapters 1 to 6 of this thesis. Tables 10 and 11 below show a consolidated overview:

| | Source eff. [%] | LCOE [CZK/kWh] | Emissions [-] | Potential [TWh] |
|---|---|---|---|---|
| **Biomass CHP** | 75 to 51 | 1.6 to 3.0 | 6.1 to 8.0 | 15+ |
| **Biogas CHP** | 75 to 51 | 3.1 to 4.5 | 4.1 to 6.0 | 5 to 0 |
| **MSW CHP** | 75 to 51 | 1.6 to 3.0 | 2.1 to 4.0 | 15 to 10 |
| **Hydro power** | 100 to 76 | 0.1 to 1.5 | 2.1 to 4.0 | 5 to 0 |
| **Wind power** | 25 to 0 | 1.6 to 3.0 | 2.1 to 4.0 | 5 to 0 |
| **Photovoltaics** | 25 to 0 | 1.6 to 3.0 | 4.1 to 6.0 | 10 to 5 |
| **Solar thermal** | 25 to 0 | 4.6 to 6.0 | 4.1 to 6.0 | 5 to 0 |
| **Geothermal** | 25 to 0 | 3.1 to 4.5 | 2.1 to 4.0 | 5 to 0 |
| **Energy Mgmt.** | 100 to 76 | 0.1 to 1.5 | 4.1 to 6.0 | 15+ |
| **CHP technology** | 50 to 26 | 0.1 to 1.5 | 4.1 to 6.0 | 10 to 5 |

**Table 10: MCDA quantitative criteria**

| | Landscape [-] | Distr. Gen. [-] | Intermittent [-] |
|---|---|---|---|
| **Biomass CHP** | 3 to 4 | 6 to 5 | 1 to 2 |
| **Biogas CHP** | 3 to 4 | 6 to 5 | 1 to 2 |
| **MSW CHP** | 5 to 6 | 4 to 3 | 1 to 2 |
| **Hydro power** | 5 to 6 | 6 to 5 | 3 to 4 |
| **Wind power** | 7 to 8 | 8 to 7 | 7 to 8 |
| **Photovoltaics** | 1 to 2 | 8 to 7 | 7 to 8 |
| **Solar thermal** | 1 to 2 | 8 to 7 | 7 to 8 |
| **Geothermal** | 5 to 6 | 4 to 3 | 1 to 2 |
| **Energy Mgmt.** | 1 to 2 | 8 to 7 | 1 to 2 |
| **CHP technology** | 1 to 2 | 6 to 5 | 1 to 2 |

**Table 11: MCDA qualitative criteria**

Having intervals for all alternatives and criteria defined, we can move now forward and process the data in MCDA as described in the following chapter.

## 9.2. MCDA processing – priorities assignment

During data processing, priorities (weights) for all selected criteria have been defined and assigned in alignment with recommendations from Saaty described in Chapter 8.4, considering that criteria priority matrix has to remain consistent. Even numbers have been selected to fulfill this condition.

Priority ratio 1:1 indicates that both criteria are equally important, 1:2 priority ratio indicates that first criterion is marginally more important than second one and 1:4 priority ratio indicates that first criterion is more important than second one. Based on the selected scenario, 1:8 priority ratio represents situation where first criterion is absolutely more important than second one or in reversed order 2:1 where second criterion is marginally more important than first one.

The overview of assigned priorities (weights) for selected criteria, independent of storage scenario, is represented by Criteria priority matrix in Table 12. The overview of assigned priorities (weights) for selected criteria, extended for storage scenario varying based importance of seventh criterion, is shown in Figure 47.

**Assigned criteria priority excluding storage scenario:**

Efficiency group is considered as the most important one, followed by ecology and security groups with identical average ratio against efficiency group. In further breakdown, Source efficiency and LCOE (both from efficiency group) are equally important having ratio 1:1. Emissions (ecology group) and Potential (security group) have been assigned with importance ratio 1:2 against efficiency group, at the same time Landscape (ecology group) and DG concept (security group) with ratio 1:4 against efficiency group. In such arrangement, efficiency group has in fact 1:3 priority ratio against ecology group and the same 1:3 priority ratio against security group, calculated as an average of corresponding 1:2 and 1:4 sub-ratios.

| | Source eff. | LCOE | Emissions | Potential | Landscape | Distr. Gen. |
|---|---|---|---|---|---|---|
| **Source eff.** | 1.00 | 1.00 | 2.00 | 2.00 | 4.00 | 4.00 |
| **LCOE** | 1.00 | 1.00 | 2.00 | 2.00 | 4.00 | 4.00 |
| **Emissions** | 0.50 | 0.50 | 1.00 | 1.00 | 2.00 | 2.00 |
| **Potential** | 0.50 | 0.50 | 1.00 | 1.00 | 2.00 | 2.00 |
| **Landscape** | 0.25 | 0.25 | 0.50 | 0.50 | 1.00 | 1.00 |
| **Distr. Gen.** | 0.25 | 0.25 | 0.50 | 0.50 | 1.00 | 1.00 |

**Table 12: Criteria priority matrix**

**Assigned criteria priority including storage scenario:**

Depending on storage scenario, importance ratio of Intermittent supply is 2:1 compared to efficiency group without storage (Scenario 1) and 1:8 with suitable storage being available (Scenario 2). In both scenarios, ratios between all criteria except Intermittent remain the same 1:2:4 to ensure consistent relationship within this group. Only the Intermittent criterion changes its priority from 1:8 to 2:1 (reversed 1:2 importance ratio) against efficiency group as required.

Figure 47 is a graphical overview of criteria priorities compared between two scenarios:

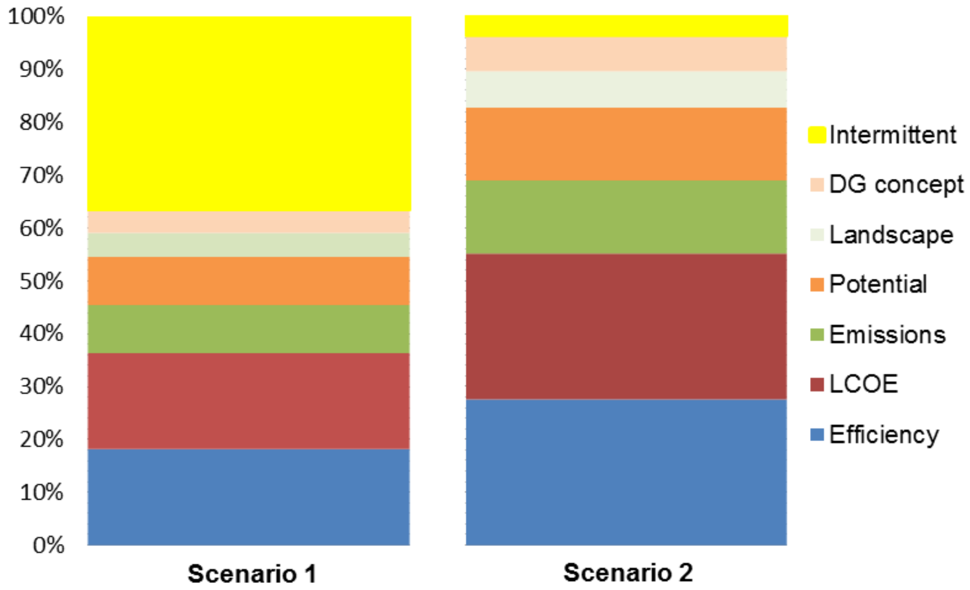


**Figure 47: Criteria priority per storage scenario**

Once all criteria have got their priorities (weights) assigned, same principle for intervals per each criterion has to be applied. Consolidated overview of all intervals with associated priorities and calculated weighted geometric mean per scenario is shown in Table 13 and described in the following chapter.

**Assigned intervals priority for both storage scenarios:**

There have been four intervals determined for each criterion and weighted geometric mean calculated according to defined importance and selected scenario. In this case, standard 1:2:4:8 priority ratios between all intervals have been applied across all criteria to ensure consistent data processing.

As a result, seven matrixes, consolidated in one Table 13, have been created with interval priorities defined for both scenarios (step 3).

| Efficiency [%] | 100 to 76 | 75 to 51 | 50 to 26 | 25 to 0 | Scenario 1 | Scenario 2 |
|---|---|---|---|---|---|---|
| 100 to 76 | 1.00 | 2.00 | 4.00 | 8.00 | 0.097 | 0.147 |
| 75 to 51 | 0.50 | 1.00 | 2.00 | 4.00 | 0.048 | 0.074 |
| 50 to 26 | 0.25 | 0.50 | 1.00 | 2.00 | 0.024 | 0.037 |
| 25 to 0 | 0.13 | 0.25 | 0.50 | 1.00 | 0.012 | 0.018 |
| LCOE [CZK/kWh] | 0.1 to 1.5 | 1.6 to 3.0 | 3.1 to 4.5 | 4.6 to 6.0 | Scenario 1 | Scenario 2 |
| 0.1 to 1.5 | 1.00 | 2.00 | 4.00 | 8.00 | 0.097 | 0.147 |
| 1.6 to 3.0 | 0.50 | 1.00 | 2.00 | 4.00 | 0.048 | 0.074 |
| 3.1 to 4.5 | 0.25 | 0.50 | 1.00 | 2.00 | 0.024 | 0.037 |
| 4.6 to 6.0 | 0.13 | 0.25 | 0.50 | 1.00 | 0.012 | 0.018 |
| Emissions [-] | 0.1 to 2.0 | 2.1 to 4.0 | 4.1 to 6.0 | 6.0 to 8.0 | Scenario 1 | Scenario 2 |
| 0.1 to 2.0 | 1.00 | 2.00 | 4.00 | 8.00 | 0.048 | 0.074 |
| 2.1 to 4.0 | 0.50 | 1.00 | 2.00 | 4.00 | 0.024 | 0.037 |
| 4.1 to 6.0 | 0.25 | 0.50 | 1.00 | 2.00 | 0.012 | 0.018 |
| 6.1 to 8.0 | 0.13 | 0.25 | 0.50 | 1.00 | 0.006 | 0.009 |
| Potential [TWh] | 15+ | 15 to 10 | 10 to 5 | 5 to 0 | Scenario 1 | Scenario 2 |
| 15+ | 1.00 | 2.00 | 4.00 | 8.00 | 0.048 | 0.074 |
| 15 to 10 | 0.50 | 1.00 | 2.00 | 4.00 | 0.024 | 0.037 |
| 10 to 5 | 0.25 | 0.50 | 1.00 | 2.00 | 0.012 | 0.018 |
| 5 to 0 | 0.13 | 0.25 | 0.50 | 1.00 | 0.006 | 0.009 |
| Landscape [-] | 1 to 2 | 3 to 4 | 5 to 6 | 7 to 8 | Scenario 1 | Scenario 2 |
| 1 to 2 | 1.00 | 2.00 | 4.00 | 8.00 | 0.024 | 0.037 |
| 3 to 4 | 0.50 | 1.00 | 2.00 | 4.00 | 0.012 | 0.018 |
| 5 to 6 | 0.25 | 0.50 | 1.00 | 2.00 | 0.006 | 0.009 |
| 7 to 8 | 0.13 | 0.25 | 0.50 | 1.00 | 0.003 | 0.005 |
| DG concept [-] | 8 to 7 | 6 to 5 | 4 to 3 | 2 to 1 | Scenario 1 | Scenario 2 |
| 8 to 7 | 1.00 | 2.00 | 4.00 | 8.00 | 0.024 | 0.037 |
| 6 to 5 | 0.50 | 1.00 | 2.00 | 4.00 | 0.012 | 0.018 |
| 4 to 3 | 0.25 | 0.50 | 1.00 | 2.00 | 0.006 | 0.009 |
| 2 to 1 | 0.13 | 0.25 | 0.50 | 1.00 | 0.003 | 0.005 |
| Intermittent [-] | 1 to 2 | 3 to 4 | 5 to 6 | 7 to 8 | Scenario 1 | Scenario 2 |
| 1 to 2 | 1.00 | 2.00 | 4.00 | 8.00 | 0.194 | 0.018 |
| 3 to 4 | 0.50 | 1.00 | 2.00 | 4.00 | 0.097 | 0.009 |
| 5 to 6 | 0.25 | 0.50 | 1.00 | 2.00 | 0.048 | 0.005 |
| 7 to 8 | 0.13 | 0.25 | 0.50 | 1.00 | 0.024 | 0.002 |

**Table 13: Interval priority matrixes**

Based on previously defined criteria priorities (step 2) and interval priorities (step 3), an overall performance for each alternative (step 4) can be calculated now. Thus outputs of the MCDA are described in the following chapter.

## 9.3. MCDA Outputs - interpretation of results

In this chapter, results of the analysis are described. Presented graphs show absolute and relative rankings of alternatives as well as comparison between both scenarios.

Resulting preferences of selected alternatives vary in absolute values between scenarios, summing into different total values due to various priorities assigned to Intermittent supply criterion. In such case, absolute values can be used to compare preferences within one scenario, but relative ranking with same denominator has to be introduced in order to compare values between scenarios. With respect to determined goals of the research, preferences in relative values will be presented in proportional (percentage) form with interval 0-100%, where 0% represents less preferred alternative and 100% most preferred alternative in ideal energy mix for given scenario.

The first output of the analysis is shown in Figure 48. It is a ranking of preferences in absolute values, representing total score achieved by selected alternatives during processing in MCDA for Scenario 1. Colors in bars account for specific criteria and their resulting preference breakdown in scenario without storage.

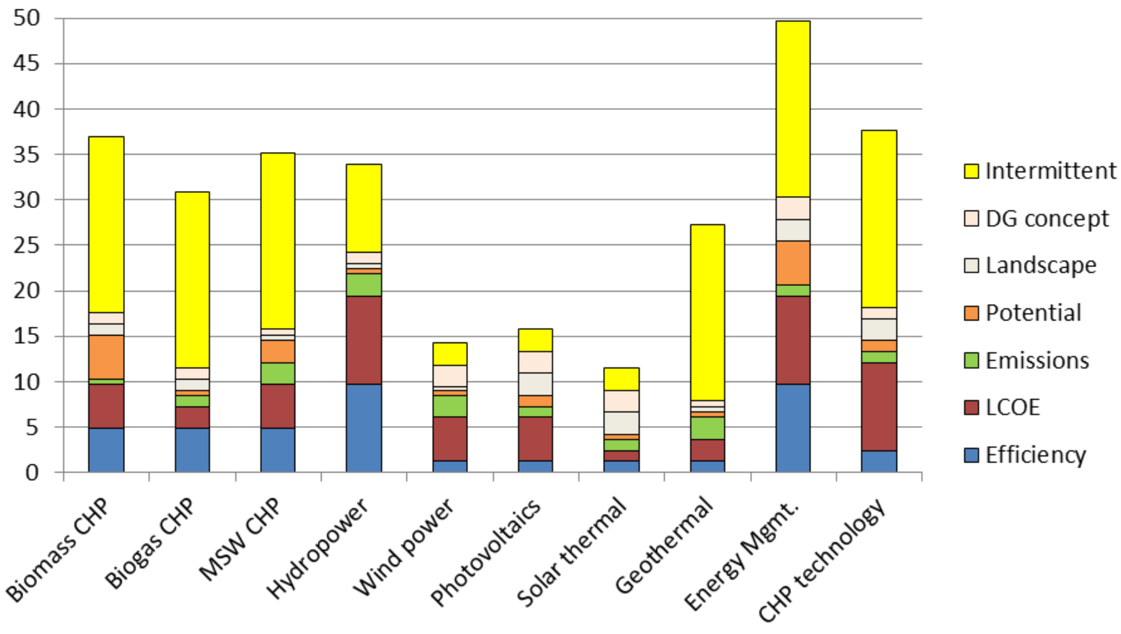


**Figure 48: Breakdown of absolute preferences in Scenario 1 without storage**

As expected for Scenario 1, the graph above indicates best performance of alternatives with continuous energy supply. The reason behind is that importance ratio for intermittent supply criterion in scenario, where suitable storage technology is not available, is very high compared to other criteria as described in Chapter 9.2.

Ranking of the alternatives in Figure 49 shows the same results as Figure 48, but converted from absolute to relative values and arranged in descending order from the most preferred alternative to the less preferred alternative in Scenario 1.

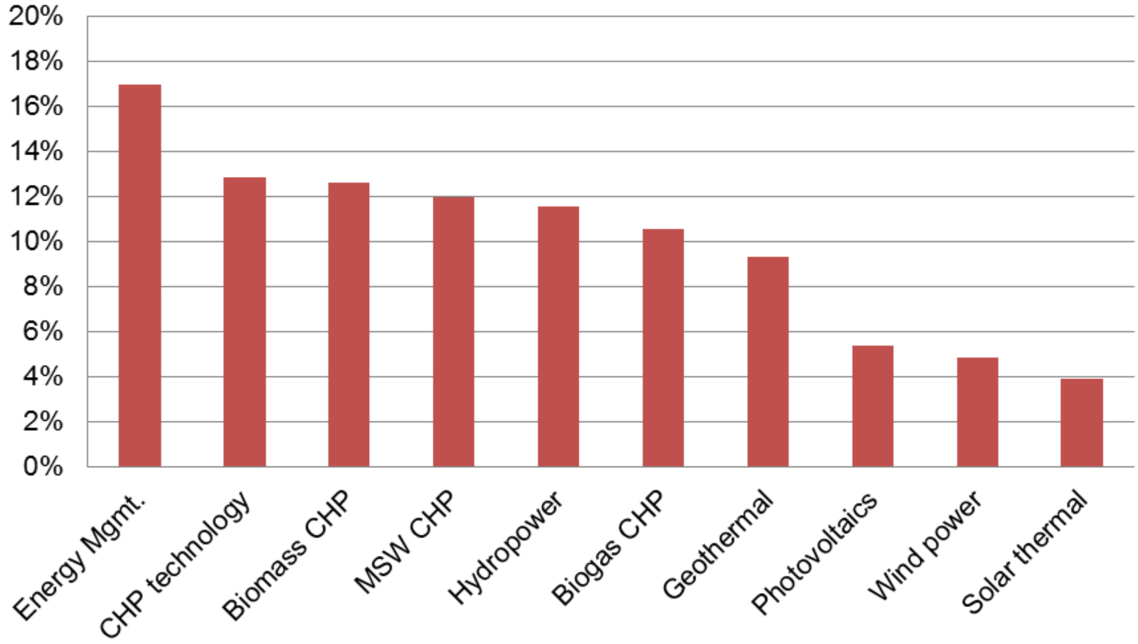


**Figure 49: Ranking of relative preferences in Scenario 1 without storage**

Results indicate the highest performance of about 17% allocated to Energy Management followed by a group of energy sources combusting fuels and using CHP technology with preference around 12%. In this Scenario 1, where no suitable storage technology is available, RES with intermittent supply such as wind, photovoltaics and solar power are rated below average among all energy sources, being less than 6% preferred solution. Despite low potential for future growth, other clean RES represented by hydro and geothermal power plants belong to the upper part of the diagram, having performance interval between 9% and 12%, supported by relatively continuous energy supply. Ranking of alternatives in Scenario 1 could be divided into three groups from the visual perspective too. Energy management with leading position on the top is followed by a group of RES with continuous energy supply, leaving RES with intermittent energy supply at the end.

In Scenario 1, the results of the analysis should be interpreted in the way that Energy Management alternative is from 17% most preferred solution. Compared to RES on the other side of the chart, where for example solar thermal alternative with only 4% performance is about 4 times less preferred than Energy Management solution. The same approach can be applied to compare all alternatives in pairwise manner.

Relative values in Figure 49 can be used for comparison of preferences between two scenarios, but also to derive preference allocation for new RES and EM alternatives per scenario in 2030 as shown later in Figure 58.

The second output of the analysis is shown in Figure 50. It is a ranking of preferences in absolute values, representing total score achieved by selected alternatives during processing in MCDA for Scenario 2. Again, colors in bars account for specific criteria and their resulting preference breakdown in given scenario, this time having suitable storage for energy accumulation available.

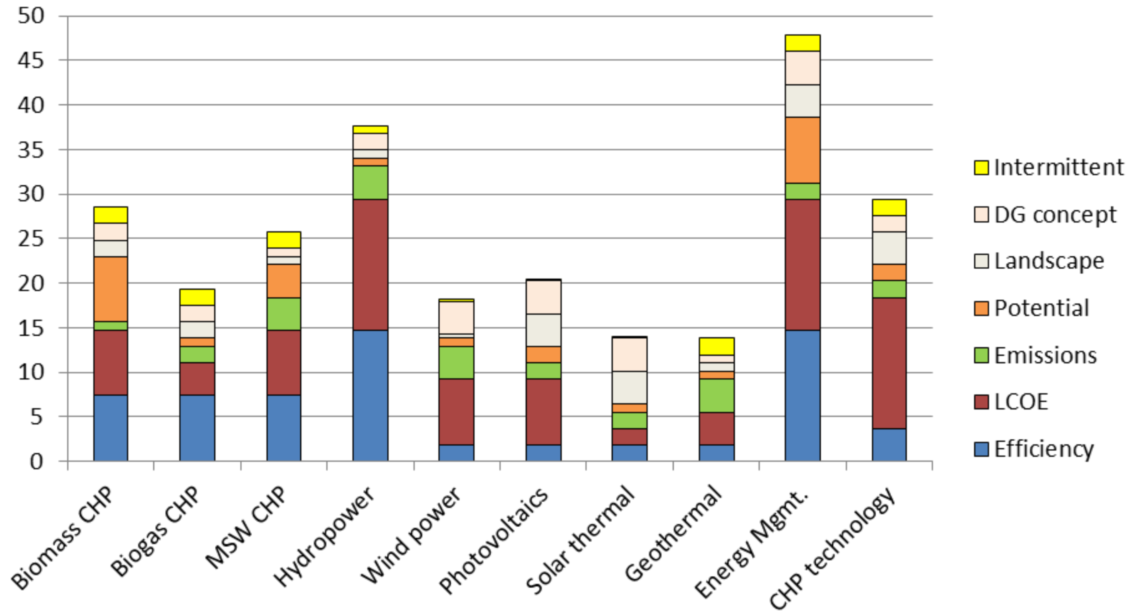


**Figure 50: Breakdown of absolute preferences in Scenario 2 with storage**

In Scenario 2, it was foreseen that alternatives with intermittent energy supply improve their performance. This would be caused by the fact that importance ratio for intermittent supply criterion in scenario, where suitable storage technology is available, is not so critical compared to other criteria as described in Chapter 9.2. On the other hand, remaining criteria become more important at the same time. In this situation are resulting preferences more influenced by criteria such as Source efficiency or LCOE, where some of the fuel-less alternatives do not perform well and their performance is rather driven by DG concept and Emission criteria.

Taking the same approach as in previous scenario, absolute values of each alternative in Figure 50 above will be converted into relative values and arranged in descending order to visualize the preferences as shown in Figure 51.

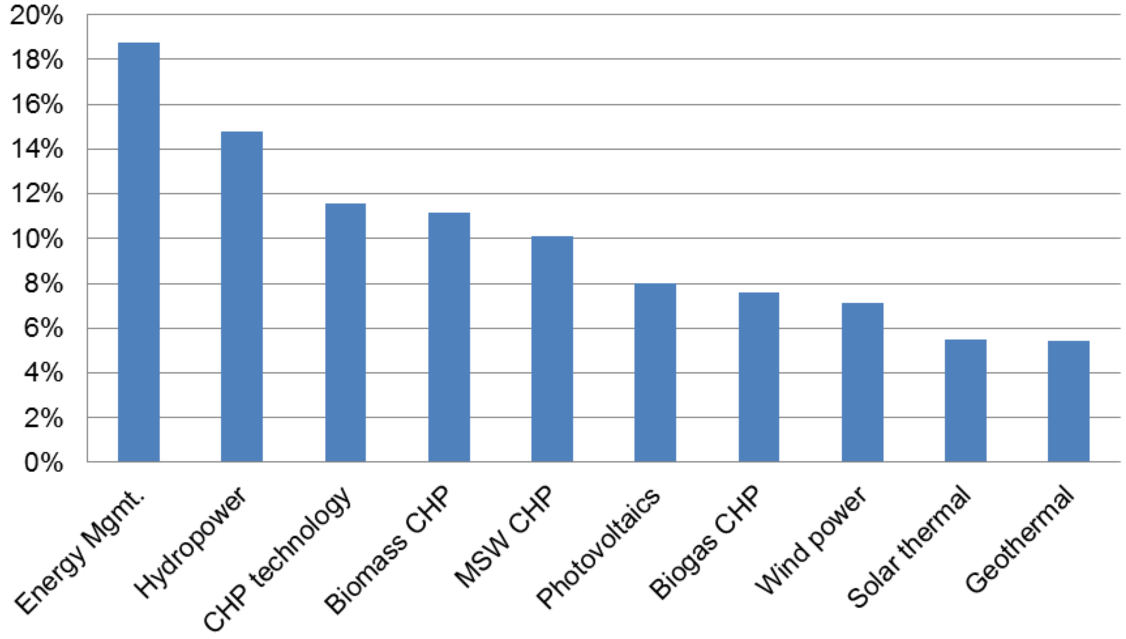


**Figure 51: Ranking of relative preferences in Scenario 2 with storage**

Ranking in Scenario 2 demonstrates change in performance for majority of the energy sources. This Scenario 2 assumes that technology for storing electricity produced by intermittent RES is available, reducing risks for discontinued energy supply. Energy Management remains the most preferred alternative with almost 19% preferences, followed by hydropower with 15% preferences. Wind power and photovoltaics become more competitive compared to other RES with improved preferences to 7% and 8% respectively. However, they still perform less than most of the CHP technologies ranking in interval between 7% and 12%.

Performance ranking of alternatives in Scenario 2 is more gradual from visual perspectives. Energy management keeps its leading position on the top, followed by a mix of energy sources with continuous as well as intermittent energy supply. At the end left solar thermal and geothermal power pulled down by performance in Efficiency and LCOE criteria.

In Scenario 2, results of the analysis should be interpreted in the way that Energy Management alternative is from 19% most preferred solution. Comparing other RES, for example hydropower with more than 14% is twice more preferred solution than wind power with 7% only. As in previous case, same approach can be applied to compare all alternatives in pairwise manner.

Figure 52 compares relative performance of all alternatives for both scenarios, with and without suitable storage, in one single chart. It compounds relative values from previous rankings and it is in fact combination of Figures 49 and 51 shown earlier in this chapter.

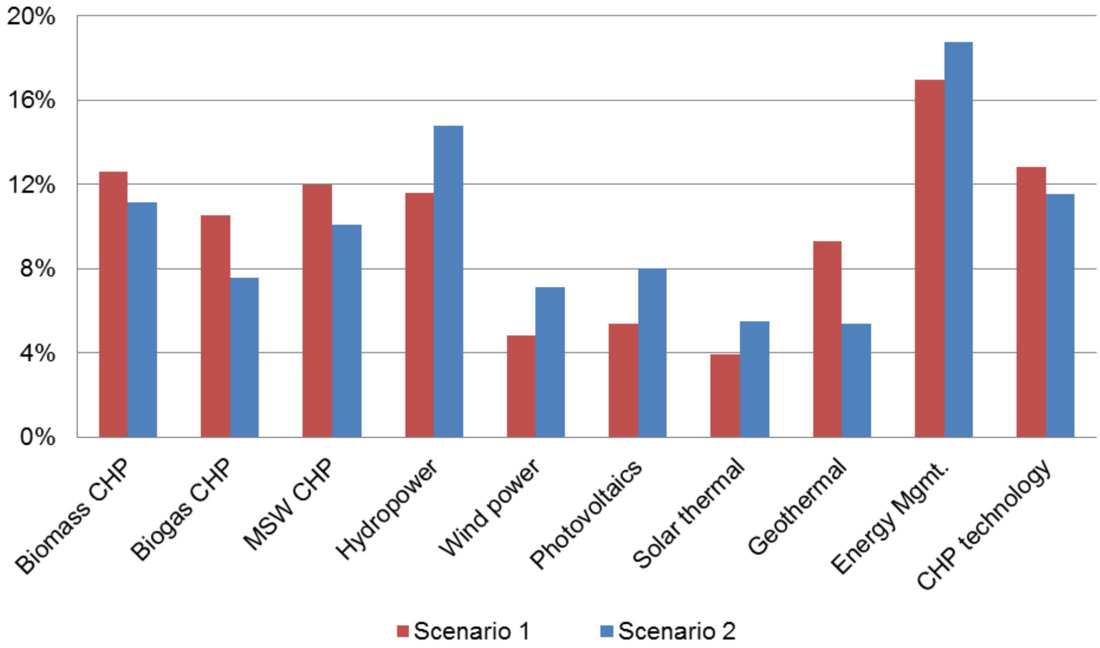


**Figure 52: Comparison of relative preferences between Scenarios 1 and 2**

With introduction of suitable storage capacities, all energy sources combusting fuel reduce their magnitude and lose dominant position, whilst importance of fuel-less RES grows, except for geothermal. Energy Management has even strengthened its leading position by almost 2% remaining the most preferred solution. In combination with new storage technology, significant improvement has been registered for most of the fuel-less intermittent energy sources as shown in graph below.

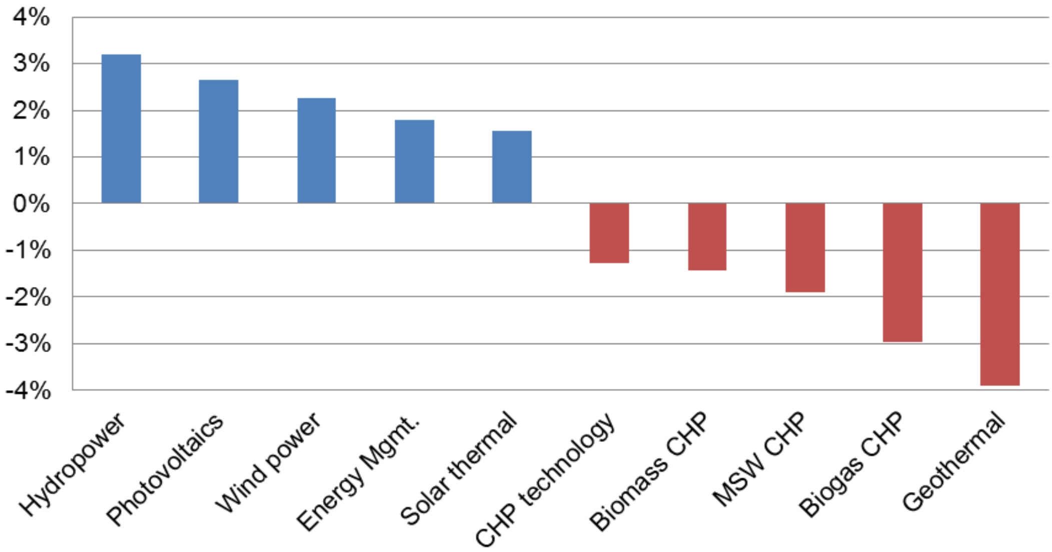


**Figure 53: Change in relative preferences between Scenarios 1 and 2**

According to Figure 53, performance of all CHP technologies combusting carbon fuels decreased by 1-3% and geothermal power reduced its performance even by 4%. On the other side, all remaining RES technologies improved their performance points in Scenario 2. Especially hydropower improved its position around 3%, followed by photovoltaics and wind power with more than 2% increase.

All of the following four graphs in Figures 54-57 illustrate ranking of alternatives per selected criteria group as identified earlier in the middle row of the Evaluation framework breakdown in Figure 46. These are Efficiency, Ecology, Security supplemented by Storage. The first one to start with is efficiency group.

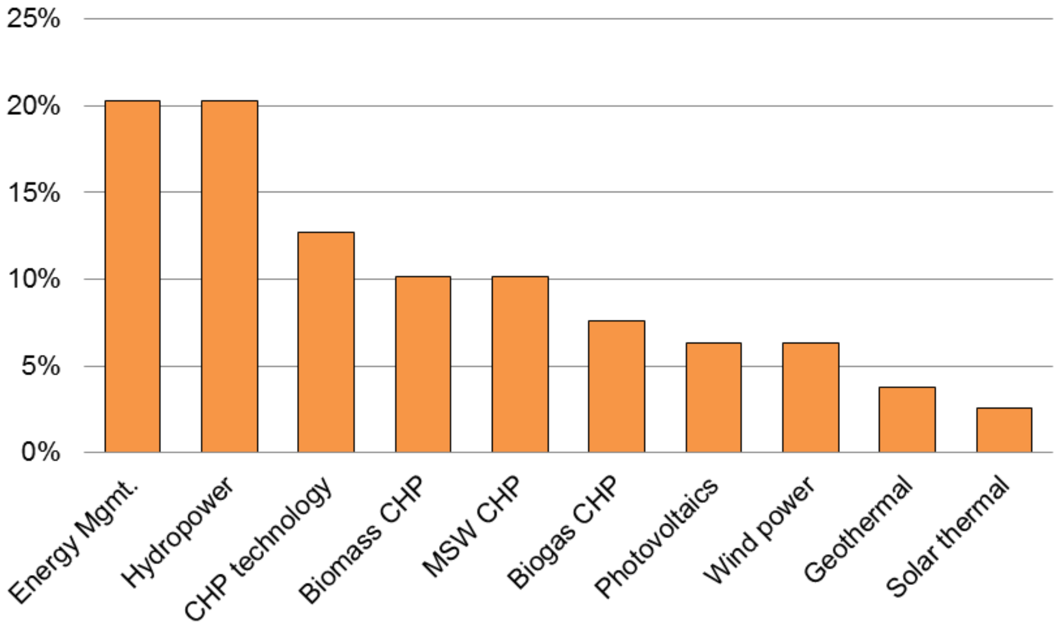


**Figure 54: Relative preferences ranking for Efficiency**

As expected, Energy Management and hydropower, with more than 20% preferences allocated, have the best performance in efficiency group as illustrated in Figure 54. This group is represented by two criteria, Source efficiency and LCOE, as described in Figure 46. All RES with CHP technology occupy middle part of the chart, followed by fuel-less power plants such as photovoltaics and wind power. Geothermal power and solar thermal have obtained the worst results, below 5% preferences, and rank at the end of the chart.

The next chart in Figure 55 considers ecology group as the reference, comprising Emissions and Landscape criteria. Due to the fact that technologies burning fossil fuels have been removed from the scope of this analysis and only renewables are considered, ranking of the alternatives in ecology group is relatively balanced within 8% to 12% interval of preferences. The biomass CHP with 6% preference only is the less preferred alternative from ecology perspectives, as shown in the next graph in Figure 55.

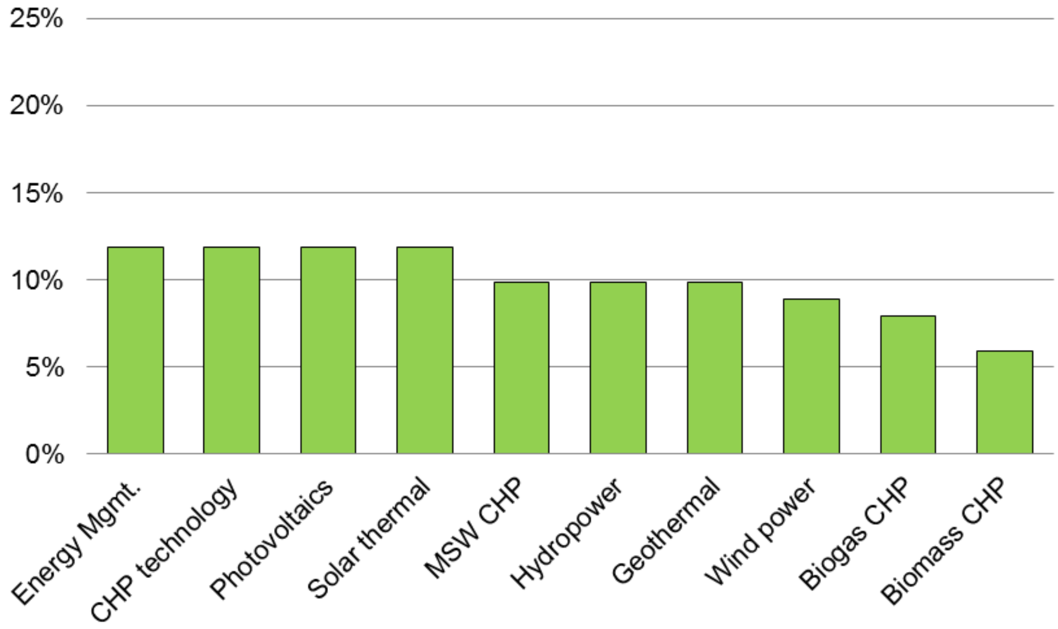


**Figure 55: Relative preferences ranking for Ecology**

Security group in Figure 56, covering criteria such as Potential and DG concept, demonstrates best performance for Energy Management and Biomass CHP around 20%. Interesting is that third most preferred from security perspectives are photovoltaics (more than 10%), followed by wind power and other two alternatives. Mainly due to low potential are hydro and geothermal power less preferred solution with only 5% and 4% respectively.

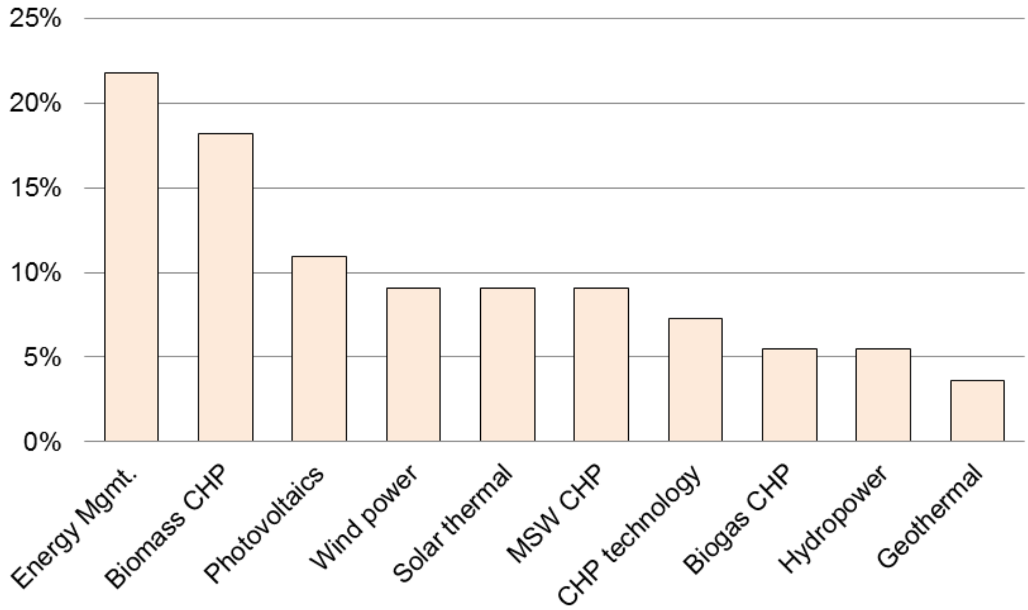


**Figure 56: Relative preferences ranking for Security**

The last graph considers storage group represented by the only scenario of Intermittent supply. Basically, all alternatives able to provide continuous energy supply and control energy output according to demand share the same preference rank of 15%. Hydropower, being partially dependent on sufficient water level, is less preferred. Alternatives that are typical intermittent RES such as photovoltaics, solar thermal and wind power performed worst with only 2% preferences allocated as shown in Figure 57 below.

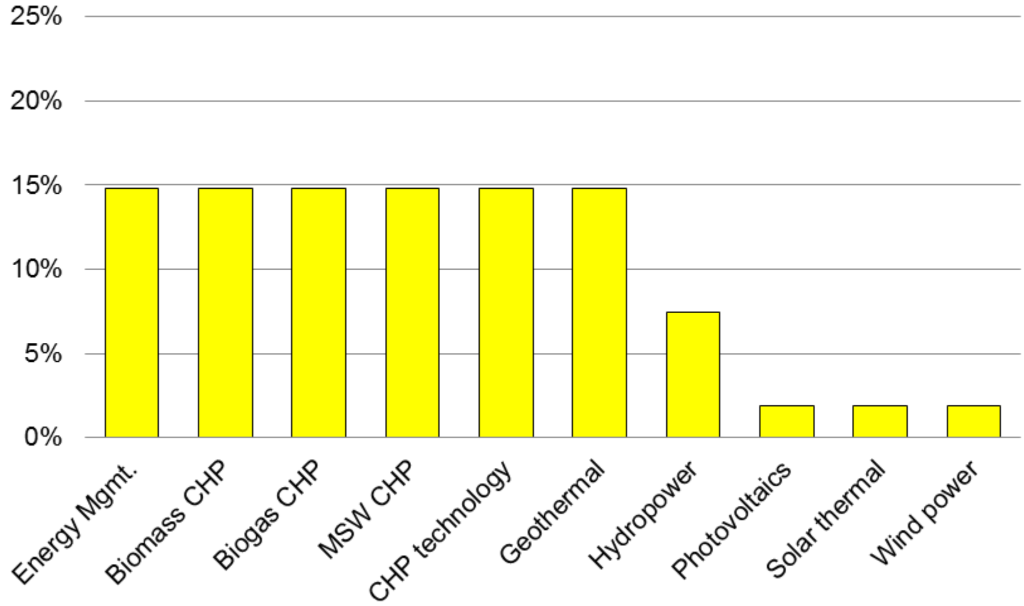


**Figure 57: Relative preferences ranking for intermittent supply**

With the charts in Figures 54 to 57 that are illustrating preferences in alternatives per selected criteria group, chapter with MCDA outcomes is closed. The next part focuses on general observations gathered during analysis of current state in Chapters 1 to 6 of this thesis.

## 9.4. General observations

In chapters 9.4.1 to 9.4.6, key observations collected during information analysis in previous sections are described, providing general overview of each topic in scope of the research. Overall summary together with concrete outcomes from the MCDA analysis result into set of implications and recommended solutions, summarized in Energy Management strategy for sustainable regional development. Each of the chapters bellow more or less corresponds with one specific chapter from early part of this thesis, for example 9.4.1 covers observations from Chapter 1, whilst 9.4.2 corresponds with Chapter 2 and so on.

### 9.4.1. General observations from trends in Energetics

From a long-term perspective, energy consumption at global, regional and local level is continuously growing (Figures 1 and 2). Sustainable Energy Management prevents individual's energy poverty and is critical for regional prosperity. Sustainable energy operations at regional level can be defined by three imperatives – efficiency, ecology and security. RES in general are considered as ecological energy source with "unlimited" fuel availability. However, they have not matured yet enough to replace all conventional energy sources. Especially efficiency and security aspects of RES have to improve, until suitable storage capacities become available, in order to eliminate risk of intermittent supply. Diversification of energy mix based on RES and construction of supplementary distribution grids would strengthen overall energy security.

The Czech Republic and the European Union have common strategy to reduce emissions of greenhouse gasses as well as energy dependency of the region. This can be achieved by decreasing of final energy consumption and improving efficiency while staying competitive.

### 9.4.2. General observations in energy production

The Czech Republic is self-sufficient in electricity and heat production from the installed capacity perspective, but fuels except for coal must be imported. Fossil fuels represent 70% of all PES required for energy production, where 58% of electricity comes from thermal and gas turbine power plants (Figures 6 and 9). Only 31% of attainable installed power for heat generation is represented by CHP plants (Figure 11). Many large energy production facilities combusting fossil fuels come to an end of their lifecycle. This situation gives an opportunity to modernize obsolete power plants and implement more efficient and "green" technologies.

Strategy to reduce share of fossil fuels in energy mix will increase dependency on imported fuels until sufficient RES capacity is installed. This gap is planned to be filled temporarily by nuclear power. Currently, biomass keeps the biggest share among RES, followed by hydropower and photovoltaics (Tables 2 and 3). There are three incineration plants operating in the Czech Republic and additional four are planned or under construction.

As of today, most of the electricity produced from RES is supplied into the distribution grid, whilst heat is predominantly consumed "in-house". Intermittent energy sources such as photovoltaics, wind power or solar thermal plants can produce energy without any fuel supply. However, only in combination with other technologies (e.g. combusting biomass), RES are able to react on actual energy demand flexibly and provide stable energy supply until suitable storage capacities and "Smart grids" are available. Most ecological RES technologies are hydropower and geothermal power.

### 9.4.3. General observations in energy consumption

As a reaction on recent economic stagnation, total energy consumption in the Czech Republic has stabilized or declined over the past years, accompanied by long-term reduction in PES consumption (Figures 31 and 34). Another positive trend shows continuous decline in overall energy demandingness of the national economy (Figure 5). Energy intensity of Industry and Construction sectors has decreased, whereas the other sectors have oscillated or increased (Figure 38).

More than two thirds of all energy is consumed by Households and Industry sectors in form of heat or electricity (Figure 36). Energy consumption profiles across all sectors are influenced by various factors such as economy structure and cycle, demographic development or technology availability.

One of the key indicators measured and reported by the EU is contribution of RES in total electricity consumption. The RES ratio has grown significantly up to 13% with biomass having approx. 60% fuel share (Figure 39).

### 9.4.4. General observations in energy distribution

The Czech Republic has solid network for primary energy/fuels distribution and acts as a transit country due to its strategic position in Central Europe. The cross-country electricity, gas and oil transmission network allows external supply from multiple sources and strengthens national energy security. The Czech Republic also has a reasonable volume of fuel storage capacities as well as reserves of coal.

Electricity distribution has lower percentage of distribution loss per distance compared to heat pipes, supplying energy to housing estates and factories. In the Czech Republic, more than 50% of heat is supplied by district heating systems. Small distribution grids are more efficient in operations and incur lower overheads as well as minimal loss associated with energy transfer from producer to the end consumer. Energy transmission costs are also reduced in concept of Distributed Generation. However, capacity and governance of these distribution grids must be adjusted in order to secure stable energy supply.

Main challenge is that suitable technology for effective energy storage is not available. As of today, only four pumped-storage hydro power plants, representing around 5% of total installed power in the Czech Republic, can accumulate energy in bigger volume for longer period. Suitable storage capacities are critical for distribution networks receiving intermittent energy supply from RES.

### 9.4.5. General observations from Energy Management

Improved living standards in the Czech Republic lead to higher energy requirements, but overall demandingness declined due to applied energy saving measures and utilization of more efficient technologies across many sectors. Opportunities for energy savings are identified during an Energy audit (Figure 42). Efficiency and savings in operations can be achieved through implementation of Energy Management Program. For example, renovation of buildings and optimization of facility operations reduce energy demand, whilst improvement of energy transformation processes by modernization of existing plants and investment into efficient technologies streamlines energy supply.

Combined heat and electricity generation from single energy source is more efficient than separate production (Figure 43). Typical examples are CHP plants but also combination of photovoltaics and solar thermal technology in one panel.

Automation and stronger governance minimize human factor and to certain extent prevent irrational behavior of personnel and occupants in both energy production and consumption. Implementation of Smart Governance enables flexible network capacity utilization, coordination of distributed energy sources and effective energy consumption. The concept of Smart Governance including flexible distribution grids and meters for reversed energy supply has potential in future, but practical implementation in larger scale has to be tested.

### 9.4.6. General observations from economy of investment

Investment into Energy Management measures can be at low cost starting with process optimization up to high capital expenditures. Volatile energy prices and initial investment costs are rather politically driven and strongly influenced by available subsidy policies as well as wide range of technologies available on the market.

An LCOE value based on discounted cash flow model should be considered as the main factor for evaluations. The LCOE reflects total costs of technology per unit of produced energy, excluding any financial support mechanisms. RES have typically higher LCOE than conventional technologies. However, improving efficiency and decreasing investment costs have made RES more attractive recently (Figure 44).

Investment into modernization of large facilities with poor operational efficiency is the most reasonable solution, offering better return on investment. These facilities are typically represented by obsolete centralized energy production plants as well as frequently occupied buildings with high operating costs.

# CONCLUSIONS AND RECOMMENDATIONS

# 10. IMPLICATIONS AND RECOMMENDATIONS

The following chapters provide further interpretation of results from previous analysis as well as concrete proposals in Energy Management strategy for sustainable regional development. Besides general recommendations for three imperatives defining sustainability (efficiency, ecology and security), proof of two hypotheses formulated in Chapter 7 will be provided in this part of the thesis.

## 10.1. Implications from MCDA

RES alternatives evaluated in MCDA change their overall performance based on selected scenario (Figures 52 and 53), but ranking of specific criteria remains the same independent of storage (Figures 54 to 57). MCDA results (Figures 49 and 51) show that Energy Management and Hydropower are the most preferred alternatives in both scenarios. This result is driven by solid performance in the most important criteria of Source efficiency and LCOE, combined with continuous energy supply. On the other side of the chart, low performance of Solar thermal solution in both scenarios is caused by poor results in Efficiency, LCOE, Potential as well as Intermittent supply.

Along with Hydropower and Energy Management, alternatives such as Biomass CHP, MSW CHP and general CHP technology perform well in Scenario 1, where energy storage technology is not available. However, they lose their dominant position in Scenario 2, where suitable technology for energy storage becomes available in near future. Average performance of Wind power and Photovoltaics slightly improves with suitable storage, whereas Biogas CHP and Geothermal lose for the same case. (Figures 52 and 53)

Four alternatives have reached top performance in Ecology. These are Energy Management, CHP technology, Photovoltaics and Solar thermal solution. From RES in scope of this analysis, Biomass CHP has the worst impact on environment. In terms of Security, Energy Management is again the best performing alternative; in contrast with Geothermal power that is less secure due to low potential and scalability for DG concept. (Figures 54 to 57).

My proposal of most preferred new RES/EM alternatives for the Czech Republic in 2030 follows results of the MCDA and takes all evaluated criteria with assigned priorities into consideration. The only limitation is available potential of specific alternatives, because some of the preferred energy sources (e.g. hydropower) might not have sufficient potential to fulfill their desired share in optimal energy mix. Referring to the 2030 objectives set in the National Energy Policy described in Chapter 3 of this thesis, amount of 316.8 PJ associated with reduction of coal share in energy mix is taken as the target for our proposal. This means that total potential of 378 PJ representing sum of all evaluated alternatives is sufficient to cover this gap as shown in Table 14.

| Alternative | Available potential [PJ] |
|---|---|
| Biomass CHP | 86 |
| Biogas CHP | 16 |
| MSW CHP | 41 |
| Hydro power | 2 |
| Wind power | 14 |
| Photovoltaics | 20 |
| Solar thermal | 17 |
| Geothermal | 3 |
| Energy Mgmt. | 160 |
| CHP technology | 20 |
| **Total** | **378** |

**Table 14: Total available potential of RES/EM in the Czech Republic**

Due to the fact that total available potential is higher than gap caused by reduction of coal share in energy mic, allocation of preferences for new RES installations and EM measures for 2030 is shown in Figure 58. Graphs have been developed for two scenarios, with and without storage, representing results from the MCDA and considering limitations with regards to available potential of 378 PJ described earlier in Chapters 2 and 5.

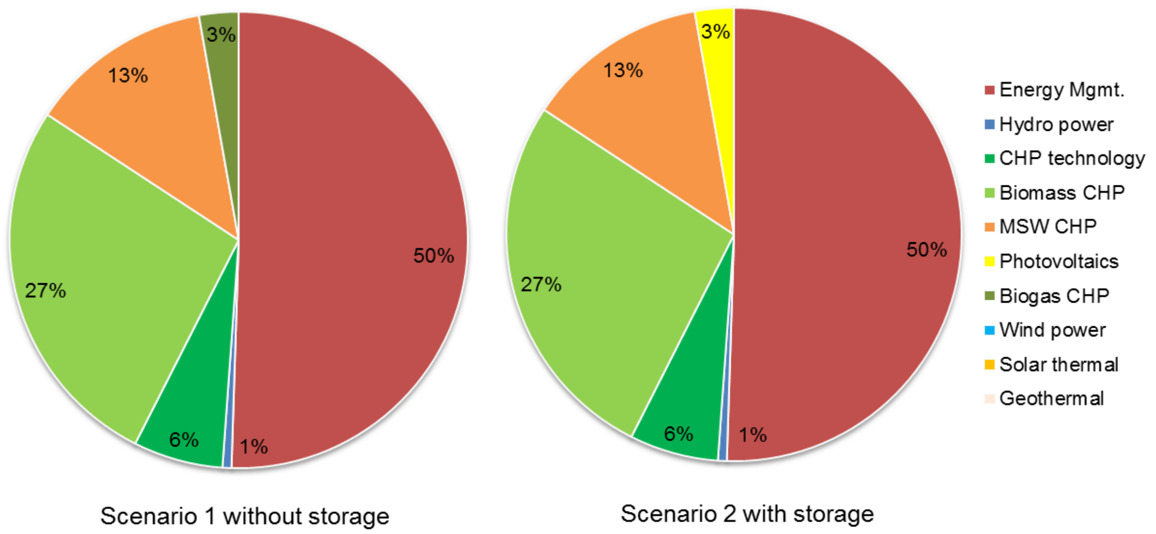


**Figure 58: Preference allocation for new RES and EM alternatives per scenario in 2030**

Final proposals for both scenarios in 2030 do not differ much. Maximal utilization of available potential achieved through Energy Management would cover half of the total energy potential. Second biggest share of 27% has biomass CHP, followed by MSW CHP with 13% and general CHP technology with 6%. Although hydro power is one of the most preferred alternatives, its available potential is very low and represents only 1%. All of the five alternatives above would utilize all their available potential as listed in Table 14.

The sixth alternative biogas CHP in Scenario 1 is preferred until suitable storage technology becomes available, whilst photovoltaics would be more preferred in Scenario 2 with suitable energy storage. However, none of these two alternatives utilizes its full potential unless the total gap caused by reduced coal share increases. Remaining alternatives such as wind or geothermal power will be selected only in case when available potential of other more preferred alternatives is fully utilized and at the same time the gap from reduced coal share exceeds currently expected 316.8 PJ.

### 10.2. Proof of hypotheses statement

Conclusions from previous Chapter 10.1 together with results of the MCDA calculated in Chapter 9.3 confirm that both hypotheses defined earlier in Chapter 7 are valid:

1. Potential of RES and Energy Management measures in the Czech Republic is sufficient to fill the gap of 316.8 PJ energy caused by reduced share of fossil fuels in energy mix. Available potential for new RES installations and EM measures is 378 PJ, being realistic for fulfillment by 2030. Thus, increase of installed capacity in nuclear power plants is not necessary and maintaining of current share would be sufficient.
2. Power plants generating energy without utilizing fuels are not the most preferred solution for sustainable regional development. Other RES technologies and Energy Management measures represent better solution based on evaluation of multiple criteria. Independent of the scenario whether a suitable energy storage technology is or is not available, most of the preferred energy sources with respect to available potential are Energy Management measures and most of the RES alternatives utilizing CHP technology including biomass, biogas and MSW. Based on information available today, photovoltaics would replace biogas CHP in preferred energy mix with introduction of suitable energy storage technology. However, this might also change in future in alignment with improved performance of selected criteria.

### 10.3. Implications from general observations

This chapter summarizes logical implications resulting from general observations described in Chapter 9.4 and provides supplementary information to concrete results discussed in previous Chapters 10.1 and 10.2.

In the regional context, the Czech Republic should follow political targets set by European Commission to reduce emissions of greenhouse gasses, increase share of RES and improve energy efficiency in order to become more independent on external supply of PES.

The lifecycle of many centralized production plants comes to an end, offering an opportunity to modernize existing or build new facilities with possibility to utilize multiple fuels and implement technology for combined heat and electricity generation. This means for example installation of boilers, combusting biomass and fossil fuels (alone or combined), giving flexibility for future operations and diversifying energy mix in case of fuel supply outage. Conversion of centralized heat and power plants reaching end of their life into highly efficient energy sources, cogenerating electricity and heat, is one of the most preferred solutions. Where applicable, new technologies combusting renewable fuels can replace fossil fuels and subsequently preserve coal-mining limitations.

National Energy Policy counts on ongoing reduction of coal share compensated by increased nuclear fuel share in energy mix. I see this more as an opportunity to build new RES in DG concept rather than new blocks of nuclear power plants. Until suitable storage is available, expansion of low efficient and intermittent RES (e.g. photovoltaics or wind power) can be driven by LCOE comparable to other RES, rather than subsidies as described in Chapter 6.

Based on results from Chapter 10.1, construction of new RES, especially electricity generating power plants, would provide sufficient energy supply to cover inland consumption and surplus of produced electricity could be exported to neighbor countries. From this perspective, plants generating only heat are less interesting due to inefficient energy transport on longer distances. In combination with low consumption profile, even local electric heaters might become more attractive.

Strategy to decrease consumption of energy and fossil fuels has positive impact on environment associated with lower emissions and limited air pollution as per Chapter 2.7. Reduced demand for energy and fuels achieved through efficiency and implementation of RES improves overall energy security as well as dependency on external supply.

It is not clear whether inland demand for energy would increase in future alongside economic growth or would remain stable as experienced in the past years. However, listed recommendations for sustainable Energy Management are applicable in any case. Insulated envelope on existing buildings and construction of new buildings in passive or low-energy standard will not only reduce overall operating costs, but also improve comfort of living. Together with subsequently optimized operation processes and adjustment of energy distribution systems, energy saving measures will lead to real energy savings.

Initial expenses for complex Energy Management solutions are typically high due to capital expenditures. Energy Performance Contracting (EPC) offers opportunity for consumers to implement energy saving measures and return high investment costs from energy savings guaranteed by facility operator. Ongoing subsidy programs should focus on individual households and support investment into small/mid-size Energy Management projects in alignment with DG concept. At the second stage, such initiatives would also support economic growth. Subsidies at regional level should focus on investments into distribution grids and overall governance.

Infrastructure reinforcement is critical for sufficient capacity provisioning, allowing connection of new distributed energy sources. On top of that, Smart Governance ensures flexibility of the grid in case of intermittent energy supply and volatile consumption. Modernization of existing distribution networks and improving insulation parameters especially for heat supply would decrease losses by several percent. Application of Distributed Generation concept to both heat and electricity would also reduce operating costs compared to centralized facilities.

Absence of suitable technology for energy storage doesn't play critical role in strategic decision making yet but remains the biggest challenge in future. In this context, the Czech Republic should increase storage and extraction capacities of fuel reservoirs to secure strategic reserves for energy supply in case of outage.

Distributed Generation from multiple energy sources is one of the solutions towards independency on PES import and in alignment with the EU directives. To remain cost-effective, small energy units have to be able to supply energy into the distribution gird in case when it cannot be consumed "in-house" or effectively stored. Possibility of reversed energy supply ensures supplementary role of distributed sources to existing centralized sources.

Stability of the energy network and secured supply will be covered by modernized large facilities supported by smaller units flexible to adjust according to current and local conditions. In Smart grids, overall governance of energy demand management can be coordinated automatically, while transferring more responsibility from utilities to final consumers. However, full implementation of deferred consumption can be a challenge until suitable power storage technology is available.

Keeping stand-by production capacities unutilized is too expensive, but concept of distributed energy sources with controllable energy output reduces the risk of power outage. The ability to adjust energy output during power shortage or grid overload reduces the risk probability, while localized "power islands" with energy supplied from decentralized flexible sources minimize risk impact. Any plant combusting fuels or pumped-storage hydro power plant able to start-up or switch-off immediately are convenient solutions, accompanied by available storage capacity in future. Energy distributor plays a key role in coordination of recovery. It is desired that local government keeps a control share in strategic companies operating critical infrastructure for energy production and distribution.

In current conditions, energy production in the Czech Republic should always exceed inland energy consumption. Excess energy can be exported or in future stored. Along with higher energy security, profit from exported energy is another benefit to be considered as long as local facilities stay competitive to those in neighbor countries.

## 10.4. Proposed solutions

In the context of the Czech Republic, specific proposals for Energy Management strategy have been selected based on results from analysis described in Chapter 9. The following list reflects current situation in 2015 and its revision is recommended every five years in order to ensure that technology development and actual trends are reflected. The proposals are:

- Diversify energy mix and utilize locally available resources such as hydro power, biomass or municipal solid waste in combination with energy saving measures, instead of increasing our dependency on external PES supply as of today
- Implement energy saving measures across all sectors and in full scale in order to utilize available potential of 160 PJ savings. These are mainly thermal insulation of building envelope and heat distribution grids, semi-automated control systems and efficient appliances
- Replace existing inefficient or build new small/mid-size distributed energy sources with efficiency at least 60%, levelized cost of energy under 2.5 CZK/kWh and operational flexibility, such as small hydropower plants or micro-CHP combusting renewable and alternative fuels
- Build new pumped-storage hydro power plants for balancing energy flows in distribution grid as well as surplus energy accumulation in order to strengthen energy security of the Czech Republic
- Finalize construction of four incineration plants with CHP technology and capacity to absorb additional 500 kt of waste per year bringing about 3.5 PJ of additional energy
- Modernize existing centralized energy sources by implementing highly efficient and relatively ecologic CHP technology flexible to switch and combust multiple fuels instead of single one
- Implement waste heat recovery in existing nuclear power plants and supply energy to nearby agglomerations, representing unused potential of about 43.2 TJ attainable installed power
- Reinforce and digitalize distribution infrastructure including implementation of Smart Governance for automated energy production, distribution, consumption and accumulation including reverse energy supply from distributed energy sources
- Introduce lifecycle management dimension into decision making process for public tenders, to consider overall lifecycle costs instead of the lowest price during bidding processes
- Gradually reduce 316.8 PJ share of fossil fuels in energy mix by 2030 and replace it by RES in concept of distributed generation rather than building new nuclear blocks

- Redefine preferences in subsidy funding to support investments into small/mid-size distributed energy sources as well as reinforcement and automation of distribution infrastructure
- Invest into technology research & development to improve efficiency in energy production, consumption, distribution and accumulation
- Introduce concept of Energy Management at regional level into the system of higher education in order to provide basic awareness as well as expertise in Energy Management to broader population

### 10.5. Areas for future research

Topics that have been only partially covered in this thesis as well as action plans for implementing proposals are an opportunity for further research:

- Develop Energy Management Program for specific region based on principles described in Energy Management strategy for sustainable regional development
- Assess obsolete centralized energy sources, operating with low efficiency and adversely impacting environment. Based on energy demand in given region, assess whether these facilities should be closed or modernized and propose actions
- Evaluate potential for construction of new strategic energy sources, such as pumped-storage and SHP or CHP plants combusting renewable fuels
- Analyze options for utilization of spare energy from cogeneration facilities, especially during summer period when heat consumption decreases. Energy for cooling can be an alternative
- Review growing trend of energy demandingness of Agriculture & Forestry sector and propose measures for improvement
- Explore suitable technologies for energy storage

## 11. CONCLUSION

Defining right Energy Management strategy for sustainable regional development is essential for setting the right course for future growth.

The majority of published studies about Energy Management focuses on one specific technology or compares one specific parameter for multiple technologies. In order to define comprehensive strategy, my research provides complex evaluation of multiple technologies and parameters, including proposals and concrete solutions for sustainable development. Sustainability has been previously defined by three imperatives - efficiency, ecology and security.

Analysis of the current state and trends in Energetics is covered in the first part of this thesis. All the stages in the process are assessed, including energy production, distribution, consumption and accumulation. Multiple Energy Management measures are reviewed and relevant economical aspects described. Main part of the research examines selected alternatives according to defined criteria, resulting in absolute and relative comparison between them. Presented implications and recommendations are combination of outcomes from decision analysis and general observations.

Results of this research and methodology used can be applied by individual investors and policy makers as an input for conceptual planning and Energy Management governance at local and regional level. There is a plan to update National Energy Policy paper for the Czech Republic in 2015. Presented conclusions can be an input to broader discussion about future strategy in Energetics and related sectors of national economy, including prioritization and allocation of subsidy funds. Methodology used in this research can also be applied for other regions, by modification of input values for selected criteria.

Implications of the results described in this thesis indicate upcoming transformation in all stages of the process, impacting all key stakeholders including energy producers, distributers and consumers. A new role is being assigned to traditional players in Energetics and they will need to transform their business models in order to stay competitive. Thus, legitimate question has to be raised:

*Are we just entering the new era of Energetics?*

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**ABBREVIATIONS**

| | |
|---|---|
| AHP | Analytic Hierarchy Process |
| ASF | Alternative Solid Fuels |
| CHP | Combined Heat and Power |
| CNG | Compressed Natural Gas |
| CZSO | Czech Statistical Office |
| DG | Distributed Generation |
| DRM | Demand Response Management |
| DSM | Demand Side Management |
| EM | Energy Management |
| EMCS | Energy Management Control System |
| EMP | Energy Management Program |
| EPC | Energy Performance Contracting |
| EPM | Energy Performance Model |
| ERO | Energy Regulatory Office |
| EROEI | Energy Returned on Energy Invested |
| ESTIF | European Solar Thermal Industry Federation |
| GDP | Gross Domestic Product |
| GWP | Global-warming potential |
| HDR | Hot Dry Rock |
| IEA | International Energy Agency |
| LCEA | Lifecycle Energy Analysis |
| LCOE/LCOH | Levelized Cost of Electricity/Heat |
| LHP | Large Hydropower Plant |
| LHV | Low Heating Value |
| MCDA | Multi-Criteria Decision Analysis |
| MIT | Ministry of Industry and Trade |
| MSW | Municipal Solid Waste |
| NAPEE | National Action Plan for Energy Efficiency |
| OECD | Organisation for Economic Co-operation and Development |
| OPE | Operational Program Environment |
| PES | Primary Energy Source |
| PV | Photovoltaics |
| RES | Renewable Energy Source |
| SAO | Supreme Audit Office |
| SHP | Small Hydropower Plant |
| UNFPA | United Nations Population Fund |

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