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ENERGY MANAGEMENT STRATEGY FOR SUSTAINABLE REGIONAL DEVELOPMENT

DISERTATION THESIS - RÉSUMÉ

DISERTAČNÍ PRÁCE - RÉSUMÉ

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CONTENT

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 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.

The first part defines the goal and methodology 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 second part of the research, I focus on current status review and analysis. 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. Thus, national strategy should be aligned with strategy of the EU, but it primarily should address national interests and respect local conditions. Particular renewable energy sources and Energy Management measures are selected for further evaluation based on their relevance with regard to sustainability.

In the third 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. 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.

1 THESIS GOALS AND METHODOLOGY

The goal of this thesis is to develop an Energy Management (EM) 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 proposed solutions in this thesis are aligned with 2030 Energy Strategy 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 the 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

1.1 Methodology

In order to obtain defined objectives, the overall approach has been divided into three phase as shown in Figure 1.

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. 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). In the last phase, concrete results and set of recommendations applicable for future implementation are presented. Conclusions and proposals for optimal energy mix are based on specific values resulting from MCDA.

The graphical expression of three-phase model is shown in Figure 1 below:

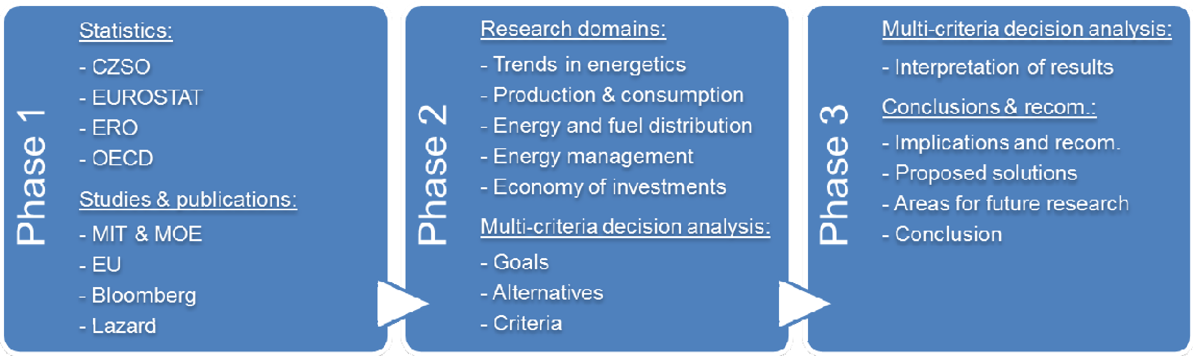

Figure 1: Research methodology phasing

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.

1.2 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 and financial criteria has to be taken into account. The main advantage of Analytical Hierarchy Process (AHP) is revealed in situations when quantification of variables is not easy and options coming from multiple disciplines are considered. 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.

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.

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

2 ANALYSIS OF CURRENT STATE

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

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.

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

Nuclear power, with 338 PJ energy produced in 2013 and approximately 20% share of total electricity consumed in the Czech Republic, has specific position in the energy mix. The National Energy Policy counts with growing share of nuclear fuel in energy mix until 2040 and beyond, to the gradual exclusion of coal.

2.2 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 the following Tables 1 and 2:

RES type	Gross prod. [GJ]	Share in RES	Share all sources
Biomass total	52 101 988	82.8%	7.5%
Biogas total	3 571 077	5.7%	0.5%
MSW + 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 1: Heat production from RES in CZ for 2013

RES type	Gross prod. [MWh]	Share in RES	Share all sources
Hydropower	2 734 740	29.4%	3.1%
Biomass total	1 683 272	18.1%	1.9%
Biogas total	2 293 593	24.6%	2.6%
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 elect.	9 308 724	100.0%	**10.7%**

Table 2: Electricity production from RES in CZ for 2013

According to statistics provided by the Ministry of Industry and Trade, 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% in the same statistics. 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, rather than larger agglomerations.

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. 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.

2.3 Energy management

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. Energy saved during generation, distribution or consumption can be used elsewhere, without any additional production requirements. There are two options how to increase overall energy efficiency:

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

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.

2.4 Energy source potential

Potential for future growth of selected alternatives is summarized in Table 3. It represents available potential for additional energy production/savings achieved through installation of new energy sources or implementation of new energy saving measures, based on accessibility and capacity of primary energy resources in given region.

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

Table 3: Total available potential of RES/EM in the Czech Republic

2.5 Ecological aspects

Emissions of greenhouse gasses produced during energy generation remain the key aspect considered in the ecological analysis. 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 combustion of solid fuels are much more critical for environment and human health. Table 4 illustrates amount of selected air pollutants released to atmosphere during energy production, normalized to 1 kWh per fuel/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
Building envelope	136 000	93	1	341	552	71

Table 4: Emissions from 1 kWh produced per energy sources

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. 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. Higher CO_2 values reported for wind, photovoltaics, solar and heat pumps are caused by emissions released during technology manufacturing.

Emissions released during manufacturing of thermal insulation for building envelope, covering both thermal insulation and filling of the openings, are calculated based on data from GEMIS study and producers of construction elements.

2.6 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 2 consolidated from several studies gives an overview of source efficiency based ratio between energy output/input per fuel type and used technology:

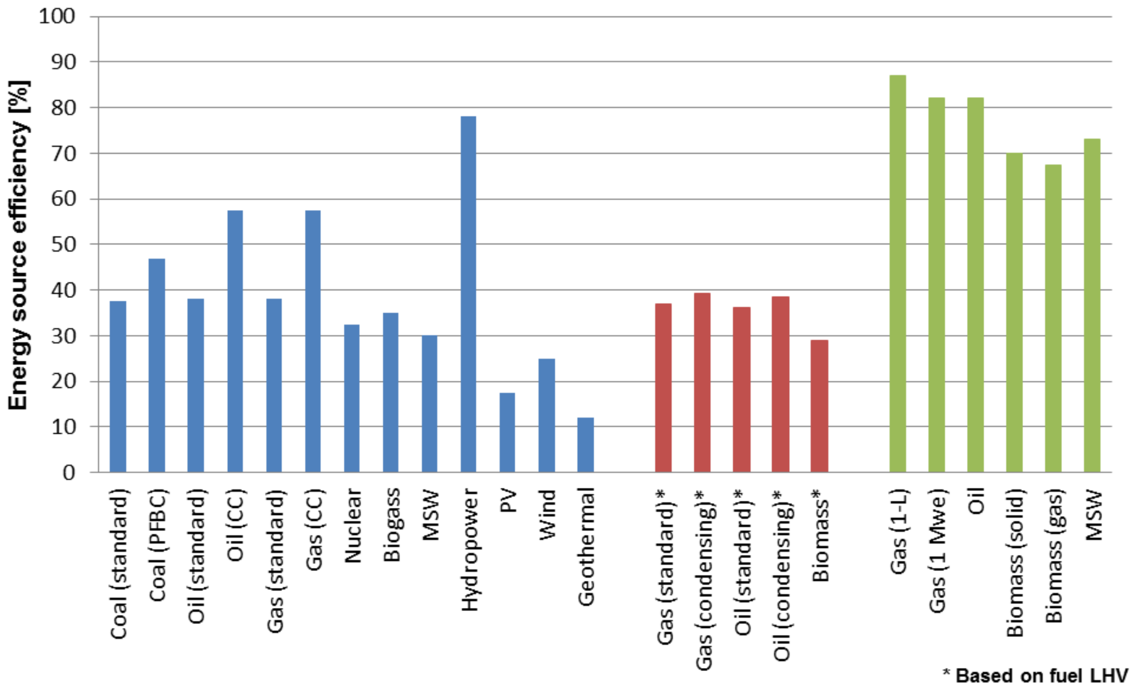

Figure 2: Relative efficiency per energy source

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, 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.

2.7 Energy source lifecycle assessment

Figure 3 shows values composed from multiple research studies published recently. 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 Levelized Cost of Energy (LCOE) than renewables but fluctuate more with fuel price.

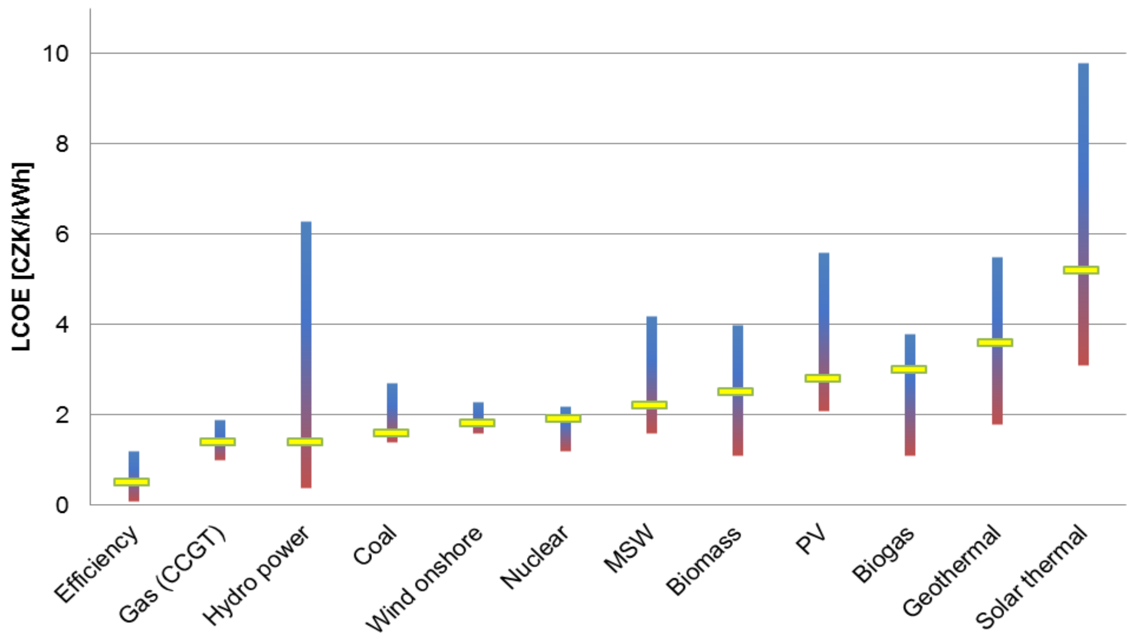

Figure 3: LCOE per energy source

The Figure 3 shows LCOE per kWh in 2013, sorted in ascending order by median 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.

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.

3 DATA PROCESSING

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 assessment of suitable alternatives to conventional technologies.

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 DG using modern and efficient energy sources provides balance to predominant centralized production sites, reducing overheads required for facility operations as well as energy distribution.

All three imperatives have been broken down into six evaluation criteria, where two sets of characteristics always represent one imperative as shown in Figure 4.

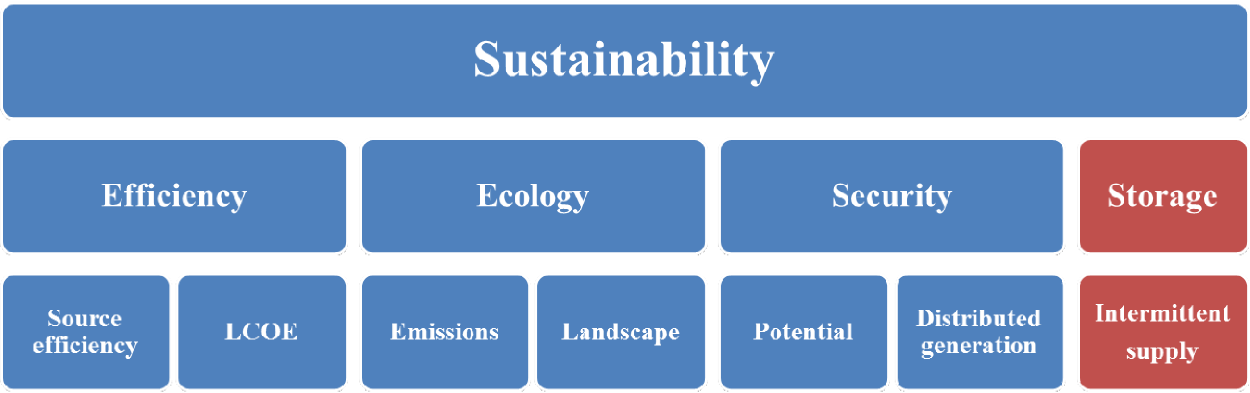

Figure 4: Evaluation framework breakdown

Energy source efficiency and LCOE belong to Efficiency imperative. Ecology imperative is represented by aesthetical impact on the Landscape and environmental factors such as Emissions released to the atmosphere during energy production. Scalability of the energy source in the concept of Distributed Generation (DG) as well as sufficient Potential for future expansion and fuel availability refer to the 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 from intermittent sources. Scenario 2 predicts availability of suitable storage technology in near future.

Graphical scheme in Figure 4 illustrates breakdown of key focus areas and selected criteria considered in the evaluation framework, corresponding with three blue imperatives defined at the beginning of this chapter. Seventh red criterion of Intermittent supply differs based on selected scenario.

3.1 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. 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.
- Biogas CHP – biogas plant producing energy by combustion of biogas using cogeneration technology for combined heat and electricity generation.
- MSW CHP – incineration plant producing energy by combustion of municipal solid waste with cogeneration technology for combined heat and electricity generation.
- Hydropower – small hydro power plant generating electricity.
- Wind power – wind power plant generating electricity.
- Photovoltaics – photovoltaic cells generating electricity, installed on facades and roofs of residential, commercial and industrial buildings.
- Solar thermal – solar thermal system producing heat and alternatively electricity, installed on facades and roofs of residential, commercial and industrial buildings.
- Geothermal – geothermal power plant producing heat and electricity.

- Energy Management – improvement measures for energy savings and efficient energy operations, including thermal insulation of building envelope and implementation of Energy Management governance.
- 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 value.

Based on current state review conducted earlier in the 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. For example power plants utilizing conventional fuels or heat pumps are not included in the MCDA.

Once the primary input of selected alternatives is completed, 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.
- 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.
- 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.
- Potential – available potential for energy production/savings achieved through installation of new energy sources or implementation of new energy savings, 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.
- 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.

- 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.
- 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.

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. The MCDA inputs for all alternatives and criteria with assigned intervals are shown in Tables 5 and 6.

	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 5: 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 6: 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.

3.2 MCDA processing – priorities assignment

During data processing, priorities (weights) for all selected criteria have been defined and assigned in alignment with recommendations from Saaty, 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 7. The overview of assigned priorities (weights) for selected criteria, extended for storage scenario varying based importance of seventh criterion, is shown later in Figure 5.

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 7: 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 5 is a graphical overview of criteria priorities compared between scenarios:

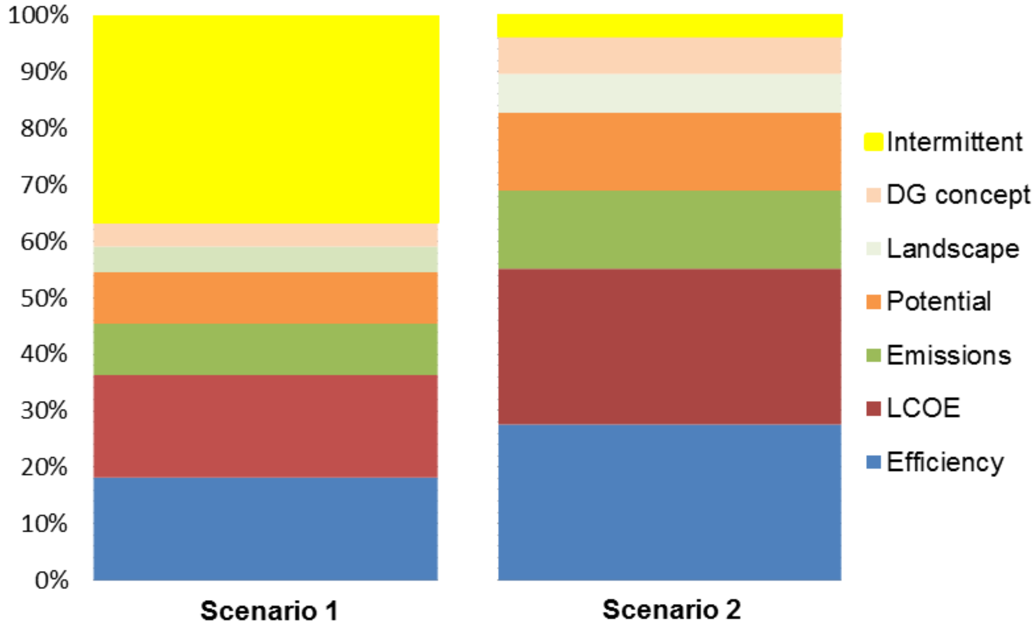

Figure 5: Criteria priority per storage scenario

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 8 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 8, 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 8: Interval priority matrixes

Based on defined criteria priorities (step 2) and interval priorities (step 3), an overall performance for each alternative (step 4) can be calculated now.

3.3 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. 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 6. 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.

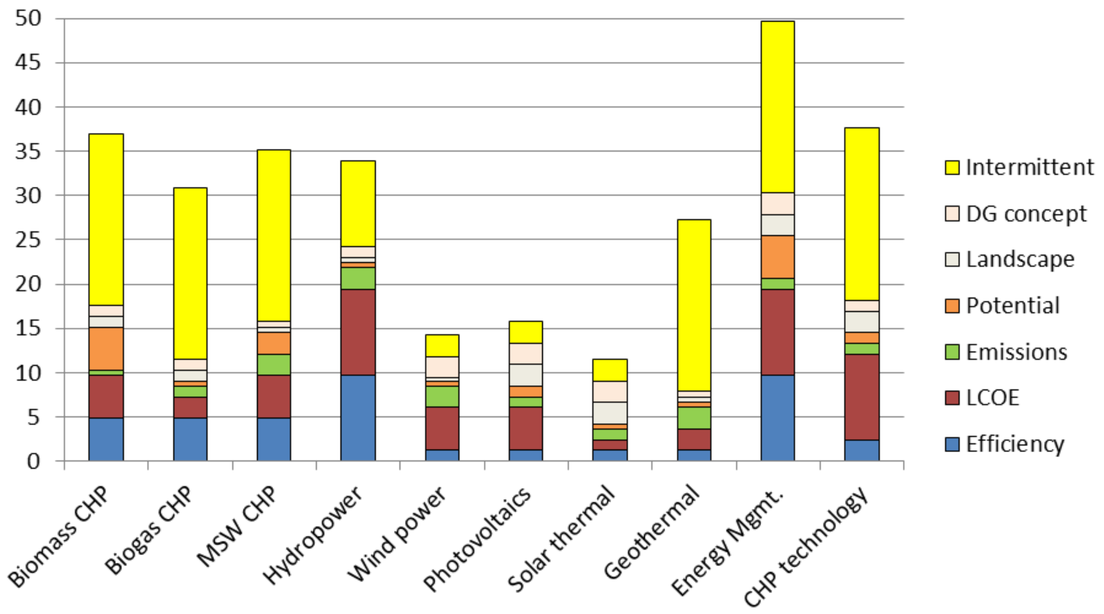

Figure 6: Breakdown of absolute preferences in Scenario 1 without storage

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 earlier.

Ranking of the alternatives in Figure 7 shows the same results as Figure 6, 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.

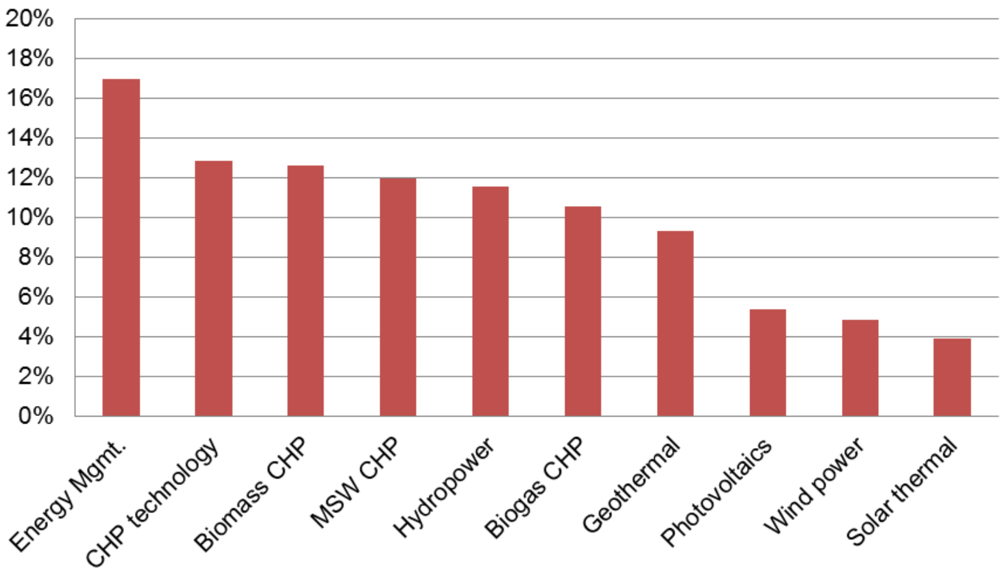

Figure 7: Ranking of relative preferences in Scenario 1 without storage

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 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.

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 7 can be used for comparison of preferences between two scenarios, but also to derive preference allocation as shown later in Figure 12.

The second output of the analysis is shown in Figure 8. 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.

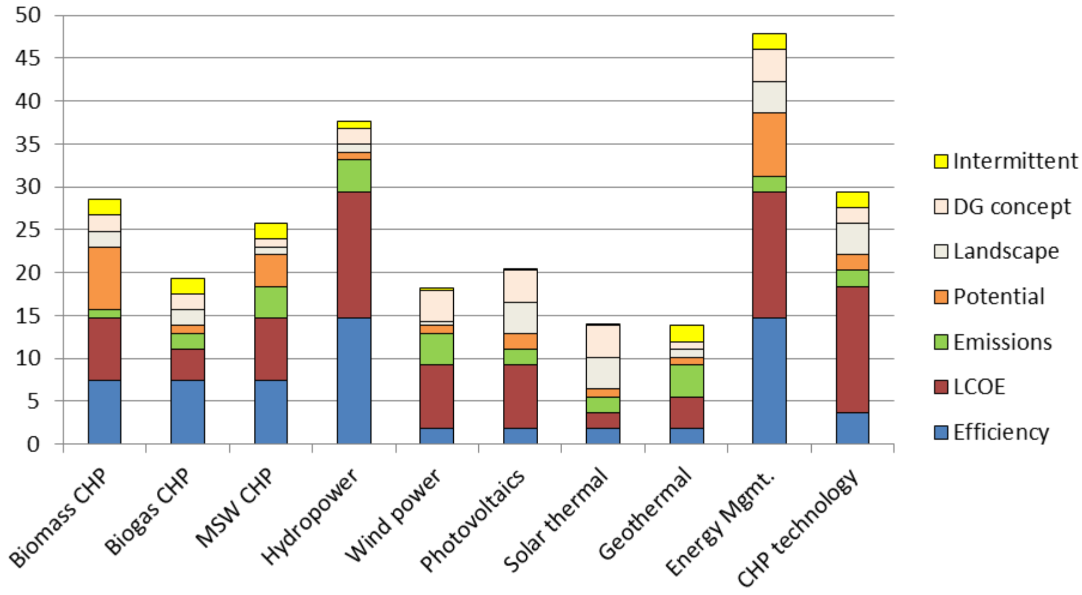

Figure 8: Breakdown of absolute preferences in Scenario 2 with storage

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. 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.

Absolute values of each alternative in Figure 8 above are converted into relative values and arranged in descending order as shown in Figure 9.

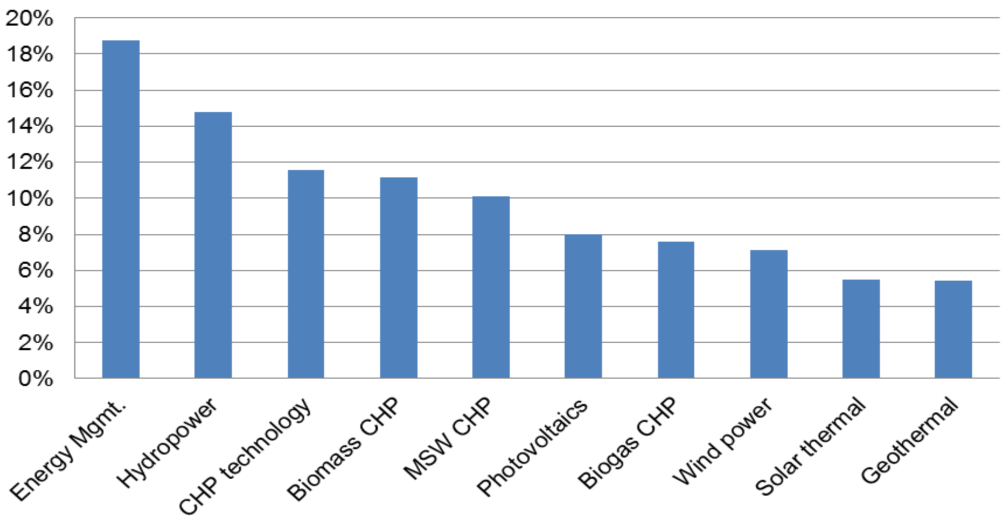

Figure 9: Ranking of relative preferences in Scenario 2 with storage

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%.

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 10 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 7 and 9 shown earlier.

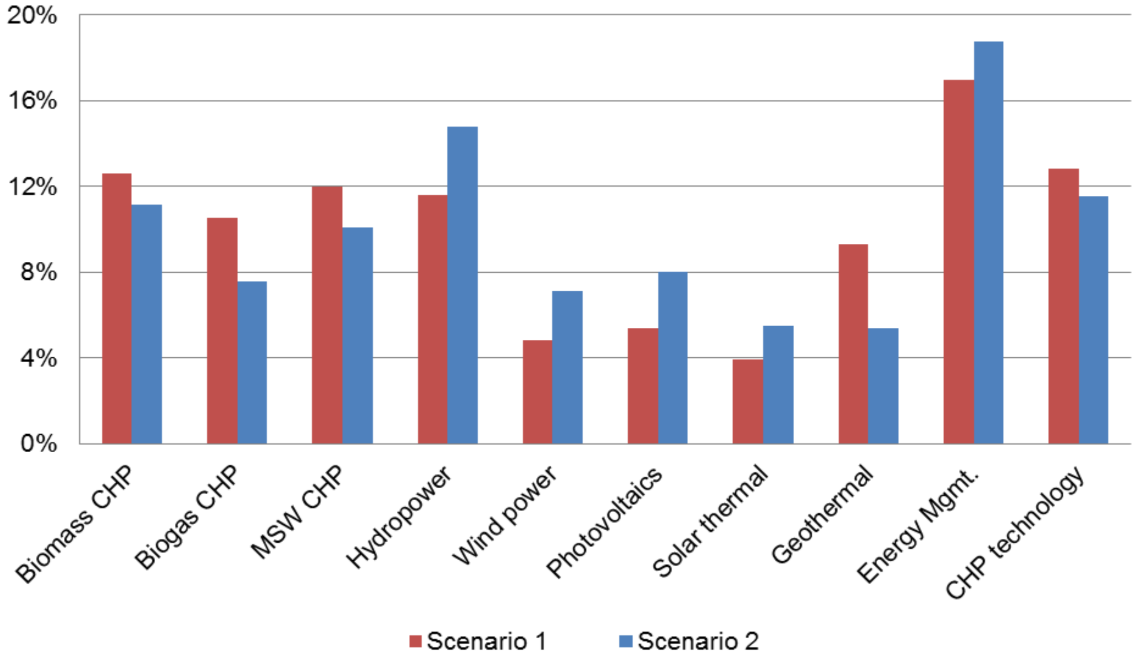

Figure 10: Comparison of relative preferences between Scenarios 1 and 2

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 storage technology, significant improvement has been registered for most of the fuel-less intermittent energy sources as shown in the next graph.

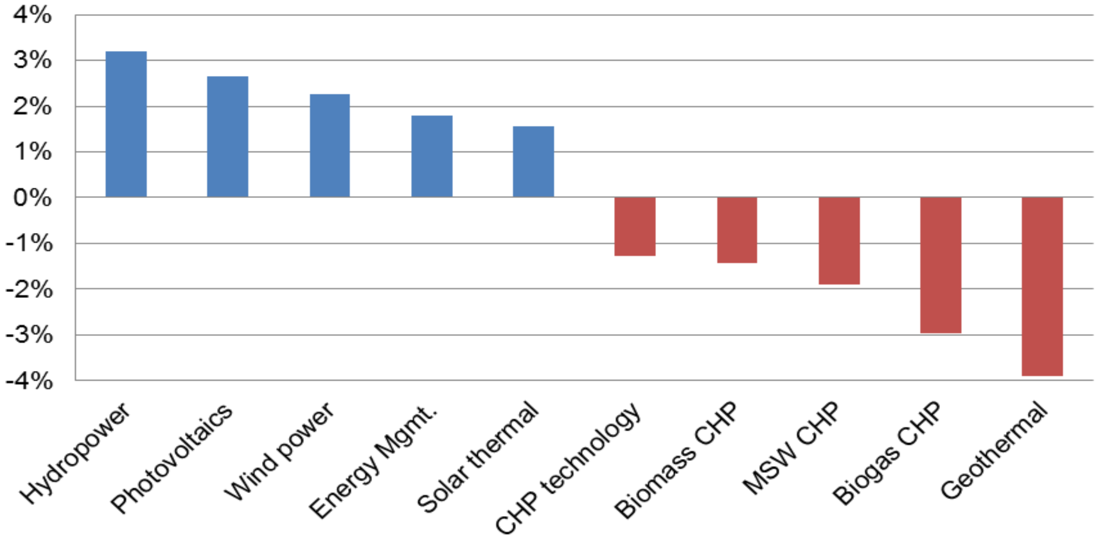

Figure 11: Change in relative preferences between Scenarios 1 and 2

According to Figure 11, 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.

4 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 1 will be provided in this part of the thesis.

4.1 Implications from MCDA

RES alternatives change their overall performance based on selected scenario (Figure 10). Results 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 and continuous energy supply. On the other side, low performance of Solar thermal solution 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 with suitable technology for energy storage. Average performance of Wind power and Photovoltaics slightly improves with suitable storage, whereas Biogas CHP and Geothermal lose for the same case.

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, 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 earlier in Table 3.

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 12. Graphs have been developed for two scenarios, with and without storage, representing results from the MCDA and considering limitations of available potential at 378 PJ described earlier.

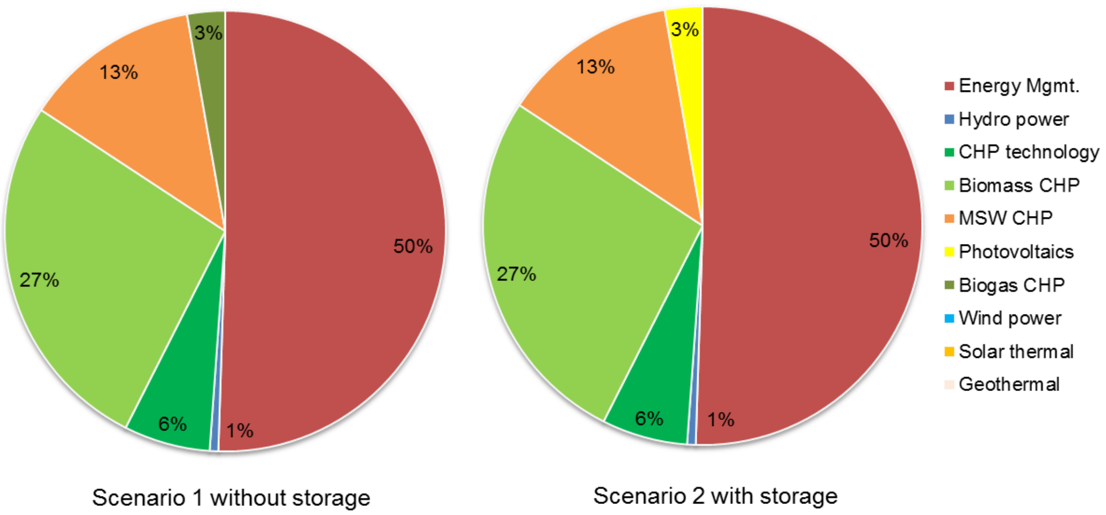

Figure 12: Preference allocation for new RES and EM alternatives per scenario in 2030

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 low and represents only 1%. Five alternatives listed would utilize their available potential as listed in Table 3. The sixth alternative biogas CHP in Scenario 1 is preferred until suitable storage technology becomes available, replaced by Photovoltaics in Scenario 2 with suitable energy storage. Remaining alternatives such as wind or geothermal power will be selected only in case when the gap from reduced coal share exceeds currently expected 316.8 PJ.

4.2 Proof of hypotheses statement

Conclusions from previous chapters together with results of the MCDA confirm that both hypotheses defined 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, most of the preferred energy sources with respect to available potential are Energy Management 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.

4.3 Proposed solutions

In the context of the Czech Republic, specific proposals for Energy Management strategy have been selected based on results from analysis. The following list reflects current situation in 2015 and its revision is recommended in future 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
- 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
- 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

4.4 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 EM 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
- 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

5 CONCLUSION

Defining right Energy Management strategy for sustainable regional development is essential for setting the right course for future growth. The majority of related studies 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 EM 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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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.