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DOCTORAL THESIS STATEMENT

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Faculty of Electrical Engineering

Department of Electroenergetics

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LONG-TERM ENERGY SYSTEMS PLANNING IN RESTRUCTURED POWER SYSTEM

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1. CURRENT SITUATION OF THE STUDIED PROBLEM

The planning is a term which brings us the vision of future at present. It is not only a term since it describes a procedure with a huge complexity. With the procedure of planning start all processes with the goals of spending the investment expenditures. The aim of the planning process is to choose the best option which satisfies all involved parties in accepted level. When considering the planning of the energy systems several conflicting criteria must be considered in analysis of long-term scenarios. The process of planning and decision-making is described in this statement. However the aim is to focus only on planning of energy systems and test the methods which help the decision-maker to sort out their preferences.

1.1. Long-term energy systems planning

The energy systems can be characterized as the physical connected energy production (generation), transmission and distribution assets operated as an integrated unit which consist several energy carriers [9]. In the case of energy systems which are in scope of this statement these are electricity, heat and natural gas, waste etc. Energy system planning can be defined as a choosing process of sources and technologies needed for energy generation, transmission and distribution to satisfy community needs [9]. There are several time horizons of planning processes, e.g. Very short term (next 24 h), Short term operation (1 – 2 weeks), Medium term operation (1 – 3 year) and Long-term investment planning (10 – 20 years). This statement is dealing only with long-term planning.

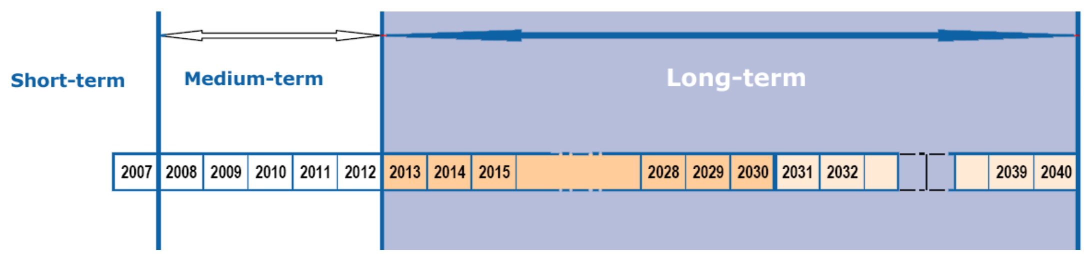

Figure 1 Time horizons of planning processes

Deregulation of the electricity market has made the planning of an energy system more important than before. The purpose of planning is to set up an energy system that is able to meet the current and of course future increase of energy demand and peak power demand for electricity and heating in an area, in order to ensure of sustainable development of society. This issue has to consider the new features and challenges of energy sector which have been mentioned above. However, it is important to point out that the energy planning is not a one-time event, but a continuous process. Therefore, there must be a space to change a common plan, if the assumption of the planning will be changed.

Basically the process of planning is seen as a process of decision-making. In general, the output of decision-making is a choice, while the output of planning is a plan. A decision can be distinguished in time and space and identified as a choice of a particular alternative, planning is an ongoing issue. The terms a planer and a specific planning problem represent the main scope of initial process of planning procedure. Once the planner deals with the planning task it always means that he has a set of alternatives how the system can be designed in future. Now the most important task of planning procedure must be managed – decision-making process.

Three different parties can be identified in decision-making process [8]:

1. A decision-maker (DM) is a person, organization or any other decision-making entity, who is empowered to make decisions concerning the decision-making problem at hand. In most cases the DM is also responsible for the decision and possible consequences.
2. A decision analyst provides insight and advice to the DM in difficult decisions. His / her task is to help the DM to find the most appropriate decision alternative(s) with possible reasoning and facilitate the decision-making process.
3. A stakeholder is a person or a body with an interest in the decision under consideration.

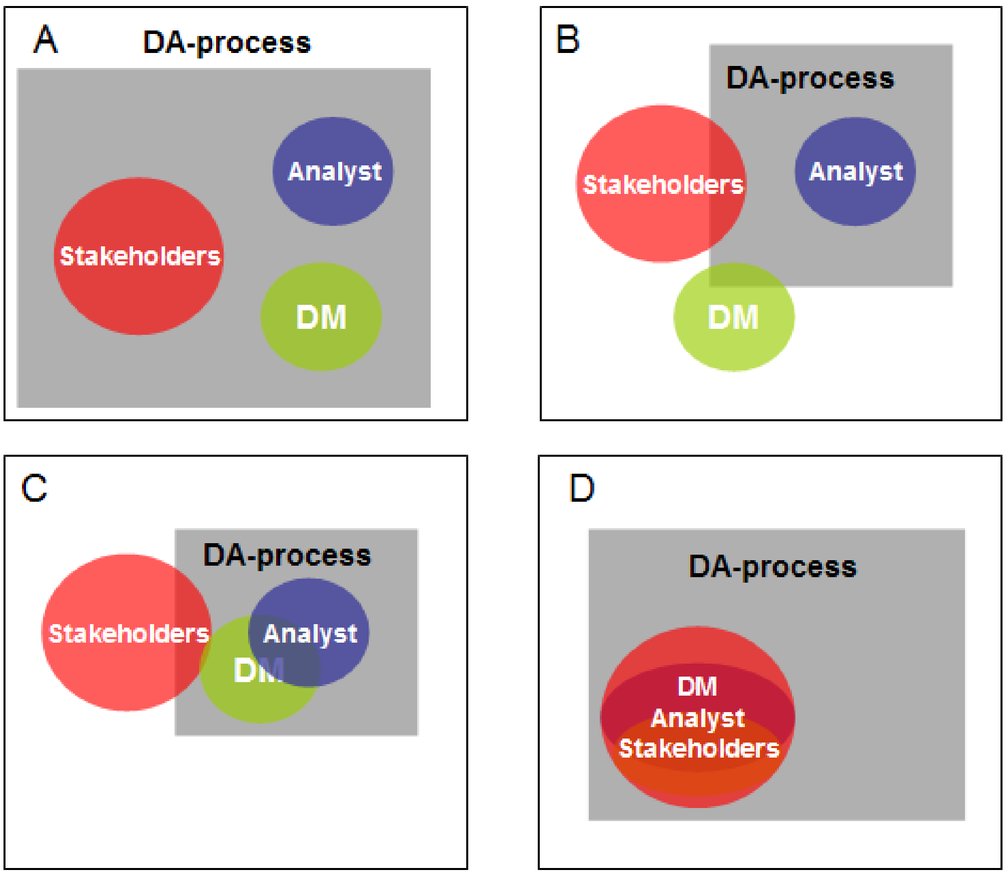

Figure 2 Relations between different parties in decision analyses (DA) process [33]

Some key players are not necessarily included in the analyses. For example, it might take a considerable effort to identify all the stakeholder groups that may have only a little relevance to the decision analysis process – figure B. The roles of the decision maker, analyst and stakeholder may overlap. That is, they can partly represent the same body – figure C, or may even be a single person – figure D. As figure 2 shows, the analyst can be a separate person, or body, or the decision maker can act as an analyst herself / himself.

2. AIMS OF THE DOCTORAL THESIS

The traditional attitude to the energy system planning is to look for the minimum cost solution that meets present and future power demands. Other criterions, such as environmental impacts (e.g. emissions, waste...) and the reliability, quality and security of supply are often included in the cost criterion. This task represents an optimization problem of power system, where a common goal is status of energy supply with minimum production cost or eventually emissions. In mathematical view, it is considered like a problem of search for an extreme of function in case of equality and inequality constraints. Following equation defines this task.

$$\min\left\{ f(\bar{x}) \middle| \; g_i(\bar{x}) > 0, i = 1,2,...q, h_j(\bar{x}) = 0, j = 1,2,...p \; \right\} \quad (1)$$

This traditional optimization issue provides a solution. The use of constraints is not particularly helpful in evaluating alternatives. For instance, if an alternative is not able to meet the performance target for one of the more existing criterion, the alternative will be eliminated, even thought the alternative might be among the best for all other criterion.

The change of the energy markets, liberalization and growing attention on environmental impacts from production of energy have led to focus more in systematic methods for decision aid. An advanced planning approach has to enable balancing the various criterions and it could provide an acceptable compromised solution. Without the help of tools, decision-makers may appear to focus only a small subset of the criterions, formulate their opinions based on insufficient information, or miscalculate with regard to uncertainties.

These limitations of the competition between different kinds of technical and economic criteria are the main topics of this statement. Traditionally, in integrated planning, this competition did not play a big role, especially environmental criterions, since the same state authority made all decisions. However, in the deregulation period it is no longer obvious who the planner is. In many cases, planning decision involve at least three main interest groups: energy companies, the state authorities and stakeholders.

This statement of the thesis is focusing on adaptation of changes in concept to the energy-system planning with respect different kind of criterion. Planners have to take into account all restructuring aspects and new energy-system planning issues. The Figure below shows the main priorities of the thesis. The main objective is to propose of an improved framework for problem structuring, modeling and decision-making in the long-term energy-system planning.

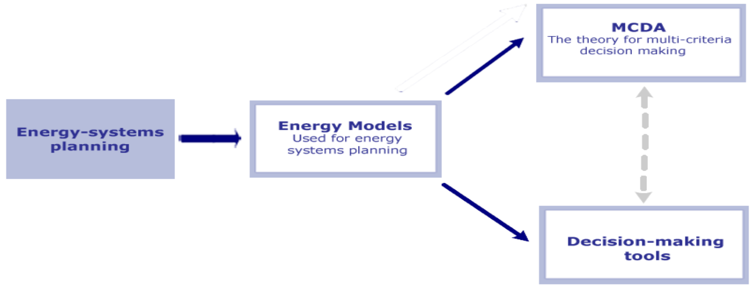

Figure 3 The main directions described in this thesis

Three different focused directions will be introduced related to the energy-system planning. The aim of the thesis is to describe and investigate the whole process of long-term energy-system planning. The goals and scientific contribution of the thesis is that this study will go through the energy-system planning process and will focus on the weak points which have not been previously sufficiently studied. The strategic process and problem definition of energy-system planning will be discussed at the beginning. Following works will focus on modeling of energy systems. The part will introduce and compare two models suitable for energy-system planning. One chosen model will be used for further analyses and testing. This analysis will introduce the phase of impact assessment which will start the next phase decision-making process. Decision-making process is a key phase of this thesis. The long-term energy system planning is a so-called multi-criteria task and the solution of this task is an aim of the thesis. In order to handle the multi-criteria problems the tools and the methods of multi-criteria decision analysis (MCDA) will be investigated and their usage in decision-making process of long-term energy system planning will be tested. The existing mathematical models convenient for MCDA analyses will be tested in order to study their usage in long-term energy system planning. The models should include several MCDA methods and the results of the different models and methods will be compared. In order to test the overall steps of MCDA process a so-called case study will be described. The subject of the case study will be supplying the energy into the fictive area. The generation of the energy will be managed by different energy sources in different investments scenarios. The alternatives of expansion of energy systems will be compared through process of MCDA.

This thesis is will go through to the following points:

A. Describing and initializing of the problem

B. Modeling of the integrated energy systems

C. Decision – making tools

3. WORKING METHODS

The goal of this part of the statement is to concentrate on the role of DM and present one of the new approaches suitable for energy system planning which could help the DMs to perform and judge their decision. One of these new planning tools is so-called – Multi criteria decision-making (MCDM) or another term is used Multi-criteria decision analyses (MCDA).

Multiple-criteria planning present an issue to make plans in cases characterized by multiple conflicting criteria that must be taken into consideration [8]. The use of MCDA will help decision makers clarify the decision-making process, i.e. to organize and integrate the information they have collected, so that they can better understand and identify the fundamental criteria in the decision problem. At present, MCDA is not often used for energy planning. There are several older methods which had been more used in the past. However, MCDA it seems to be more useful technique in providing energy system planning issue in liberalized environment. Considering the application of the decision analyses process into the energy-planning problem there are six main steps of energy-planning MCDA process, illustrated on the following picture.

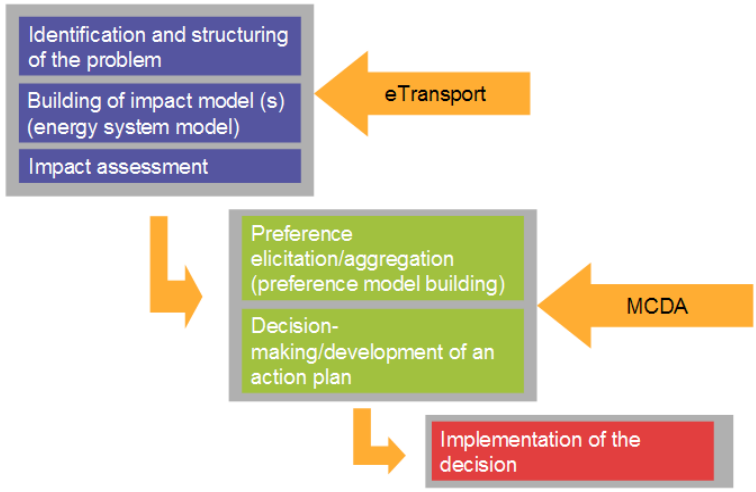

Figure 4 The main phases of the energy systems planning MCDA processes

3.1. The basic formulation of a multi-criteria problem

A decision-maker needs to select from a set of feasible alternatives ***A*,** an alternative *a*, that complies best with his set of criteria ***C***. The levels of achievement in all criteria considered, over the set of alternatives can be measured, and these are $\boldsymbol{C_k}$, where ***k*** is the number of criteria considered, $k \in [1,..n]$.

Then, the basic decision problem can be formulated as:

$$\underset{s.t. a \in A}{Max} F[C_1(a), C_2(a), \ldots C_n(a)] \quad (1)$$

where **F** is decision-maker's unknown preference function [31].

The assumption that a preference function can be estimated is central to a multi-attribute analysis. What this function actually does is to bring all criteria to a common measurement scale ('sum up') through the perception of a decision maker. Then, what remains is to analyze the different alternatives according to where they are situated on this scale. It is important to remember that such a function does not (necessary) exist in the mind of a decision-maker. Moreover it is not necessary to explicitly define the function in order for a decision-maker to make decisions which are consistent with his underlying values [31].

Such a function can represent part of the subconscious preferences a decision-maker has regarding different criteria in the problem analyzed. It is, in a way, a measure of the awareness and understanding gained by the decision-maker during the decision making process. This preference function is what conceptually distinguishes multi-criteria methods from other methods because it explicitly introduces the decision-maker's contribution into the analysis [8].

Several MCDA methods can be found in the literature. Some of these methods will be are presented in my PhD thesis. In this statement I will focus on multi-attribute value theory (MAVT)/multi-attribute utility theory (MAUT) and analytical hierarchy process (AHP).

3.2. Multi-attribute value theory - value-measurement methods (MAVT)

Multi-attribute value theory (MAVT) can be used in problems where the decision maker has a set of alternatives to choose from and a set of attributes on which the decision is based. The problem is often structured into a hierarchical form called a value tree. The objective is to obtain values for each alternative. These values are compared of the ratings of the alternatives with respect to each attribute, and of the weights of the attributes [40].

MAUT is suitable for incorporating risk preferences and uncertainty into multi-criteria decisions problem in a consistent manner. In MAUT, a multi-attribute utility function U describes the preferences of the decision maker. The multi-attribute utility function measures preferences along several dimensions. First, both the strength-of-preference (valuation of outcomes) and the attitude towards risk are represented for each individual criterion. Second, trade-offs between different criteria are also included in the function. An 'ideal' alternative (all attributes at their best level) will by definition achieve a total utility value of 1.0, while an alternative where all attributes are at their worst will have a zero total utility [9].

A common approach is to use the additive form of the multi-attribute utility function. Additive models are easier to understand and construct than alternative models. However, the use of additive utility functions requires that the attributes are additive independent, which is a strong assumption, explained in detail by Keeney and Raiffa [42]. In the additive form, the total utility of an alternative equals the weighted sum of the single attribute utilities [9]:

$$U(a) = \sum_{i=1}^{m} k_i \cdot u_i(x_i(a)) \quad (2)$$

where $U(a)$ is the total utility value of alternative a

$x_i(a)$ is alternative a's performance value for attribute i, $i=1, 2 \dots m$

$u_i(\cdot)$ is the partial utility value reflecting the performance for attribute i

k_i is the weight of attribute i

The ranking of the alternatives is based on the calculation of the total utilities. The best alternative, according to MAVT, is the one with the highest total utility [9].

In value-measurement methods, a numerical value (or score) U is assigned to each alternative. This produce a preference order for the alternatives such as a is preferred to b ($a \succ b$) if and only if $U(a) > U(b)$. When using this approach, the decision maker defines a set of relevant criteria for planning problem. For each criterion i, a partial value function u_i must be established that reflects the performance on the considered criterion i. The partial value function must be normalized to some convenient scale. The various criteria are given weights that represent their partial contribution to the overall score, based on how important each criterion is for the decision maker. The criteria weights should indicate how much the decision maker is willing to accept in the trade-off between criteria. Because poor performance values on some criteria can be compensated by high performance value on other criteria, the value-measurement methods are also known as compensatory methods [9].

3.3. The analytical Hierarchy Process (AHP)

The analytical Hierarchy Process is another method which can be used to elicit the decision-makers preference. In this method the problem is structured into a hierarchical form in the same way as in MAVT. The fundamental difference between these two methods is that on the lowest level, MAVT uses the values of the alternatives but in AHP, the lowest level weights are normalized similarly as on the other levels. The terminologies of MAVT and AHP differ slightly from each other. For example, the structure of the model is called a value tree in MAVT and a hierarchy in AHP. [40]. The Analytical Hierarchy Process (AHP) developed by L. Saaty [36] has many similarities to the multi-attribute function approach. The main characteristic of the AHP method is the use of pairwise comparisons, both of the alternatives with respect to the criteria (scoring), and of the criteria to estimate the criteria weights (weighting) [9, 29]. For each criterion, the decision makers are asked which of the two alternatives they prefer, and to what extent this alternative is preferred. The same approach is taken in the comparison of criteria; the decision-makers are asked which of the two criteria they find most important, and how much more important they find this criterion than the other [9].

The results from the comparisons are put into matrixes. From these matrixes, the alternatives' partial values (scores) v_i for each criterion i, and the criteria weights w_i are calculated, and total values $V(a)$ for each alternative a are derived. The alternative with the highest total value is preferred. The mathematical procedure, which is based on calculations of eigenvectors of the matrixes are the used and performed with special software tools [9, 36].

The model that underlies the AHP method is an additive weighted preference function, which is similar to (2) [9, 36]:

$$V(a) = \sum_{i=1}^{m} w_i \cdot v_i(x_i(a)) \qquad (3)$$

where $V(a)$ is the total value of alternative a

$x_i(a)$ is alternative a's performance value for attribute i, $i=1, 2 \dots m$

$v_i(\cdot)$ is the partial value function reflecting the performance for attribute i

w_i is the weight of attribute i

In AHP, the decision-makers can express their preferences either verbally (e.g. moderately more important), numerically (e.g. 5 times as important), or graphically (by adjusting bars) [7]. However, numbers are necessary for computations. Thus, if verbal judgments are used, it is necessary to convert them into numbers.

These chapters above have offered an overview of the main concepts, methods and techniques in the MCDA discipline. The theory has helped to describe how MCDA can be useful in decision-making process. MCDA can provide a theoretical background for conduction detailed analyses of complex multi-criteria decision problems and also it helps decision-makers to justify their decision, through a better understanding of decision problems and of their own contribution to the solution. Finally it must be stated that MCDA methods can help in modeling decision-makers' contribution to the decision.

This part of the thesis has helped to determine which methods will be used in further analyses of the case study and which techniques will be in scope of these analyses. The several applications which contain some of these MCDA techniques will be tested during the case study analyses. The MODM (Multi-objective decision making) methods have not been discussed in further details. The reason is that only the MAVT, MAUT and AHP methods of MCDA will be tested during a case study in the chapters of the thesis below.

3.4. Modeling of energy systems

In the previous chapter we defined the process of MCDA. One of the important steps of this process is an impact model building. The following chapter will introduce and will discuss this part of MCDA. The two kinds of the energy systems models were presented in original PhD thesis as tools of energy system modeling. The focus of this part will be on energy models and their use for long-term energy-planning purposes. The main goal of energy modeling is to create tools for decision support in the long-term energy-system planning and policy orienteering. Energy models are generalized descriptions of the physical energy systems. In planning process is necessary to estimate the consequences of each alternative. For complex systems, it is important to establish an impact model for this purpose. The reason of the impact model is to calculate the operational attributes, which are required for the multi-criteria analyses (discussed below). It is necessary to determine the various alternatives' or scenarios' performance values on criterions being considered [9]. In the origin PhD thesis I introduced two types of models suitable for energy systems. In this statement I will present only one of these models, which are intended for energy system modeling.

3.5. eTransport model

The eTransport model [25, 26] is a linear optimization model for energy-system planning currently under development at SINTEF Energy Research in Norway. I got in touch with this model during my stay at the Norwegian University of Science and Technology in Trondheim (NTNU) where I spend several months during my PhD study. SINTEF closely cooperates with NTNU in Trondheim, where I was pleased to spend several months in year 2007. The eTransport model has been specially designed for planning of energy systems where different energy carriers and technologies are considered simultaneously. The model gives the user an overview of a given energy system consequences and use of local energy resources. The main task of the model is to optimize investments in infrastructure over a planning horizon between 10-30 years to bring available energy to the end user in such form that the end users demands are covered in the economically and environmentally best way possible. Accordingly, the eTransport model is well suited as the impact model for energy-planning problems, which is the topic of this thesis. As part of the investment analyses, however, the model also optimizes diurnal operation for different periods of the year for each alternative system design. This operational module can be run independently from the investment module. Mathematically, the model uses a combination of linear programming (LP), mixed integer programming (MIP) and dynamic programming (DP) [8, 9, 44]. I am not going to present further details of eTransport model in this statement of the thesis. The reader can find out more information in my PhD thesis about the modules, structure and techniques of model building in eTransport.

4. RESULTS

The MCDA methods presented above seems to be a suitable decision-making tool used in long-term energy systems planning. In long-term energy system planning a decision-maker is always force to decide which investment alternative he prefer and will finally promote. MCDA could help decision-makers to manage and justify this decision. In this part of the statement the investigation of application of MCDA in long-term energy system planning will be tested. Obviously in long-term energy planning a decision-maker has several investment alternatives to be considered. In order to compare the alternatives and decision-maker preferences in MCDA the so-called impact model of the investment alternatives must be created. The impact model can be build up in the modelling software which is suitable for energy systems modelling. In this statement the issue of energy systems models will not be presented and evaluated. Only the impact of such case study analyzed in the impact model eTransport will be used as a base for testing of MCDA procedure. eTransport is linear optimization model for energy-system planning currently under development at SINTEF Energy Research in Norway. The case study consists with four investment alternatives and the results of impact model are presented in the following table (Figure 5) for several criteria.

For a case study I will consider a fictive area with specific electricity load and heat load. I have decided to consider a medium-size city as a fictive area including all infrastructures which is common for these areas. The energy demand of this area must be covered all over time. The load of electricity is 55 GWh. The load of heat is 200 000 GJ (55 GWh). The electricity load must be met by electricity. The heat load must be met by various energy carriers. This load is much more flexible and can be provided by several technologies. The goal of the case study will be testing of the several possible manners of energy supply into this area and especially testing of planning of several scenario investments into the energy generation for this area. Since the electricity load will be covered by electricity for all scenarios I will only consider four scenarios which will focus on alternatives of supplying of heat:

1. CHP_1 – district heating system with gas fired CHP
2. CHP_2 – district heating system with domestic waste fired CHP
3. CHP_3 – district heating system with prefabricated waste fired CHP
4. EL_spot - electricity heating system with the electricity boiler

ALT	ANNUAL OP COSTS [EUR]	TOTAL INV.COST [EUR]	CO2 emissions [t]	NOx emssions [t]	CO emissions [t]
1	14 272 780.3	22 169 588.6	108 799 200.0	48 355.2	19 447.2
2	62 895 817.2	22 169 588.6	123 893 548.8	55 063.8	22 145.2
3	145 446 667.1	11 090 333.9	57 926 359.0	25 745.0	10 354.0
4	162 188 645.1	11 079.3	0.0	0.0	0.0

Figure 5 The results of the impact model for the case study

The MCDA process will be tested in one of the decision-making tool. For the purpose of testing the application of MCDA in long-term energy system planning the SuperDecisions software will be tested. The Super Decisions is software which can be used for decision-making with dependence and feedback. It implements a multi-criteria decision method the Analytic Hierarchy Process (AHP), and the Analytic Network Process (ANP). Both use the same fundamental prioritization process based on deriving priorities by making judgments on pairs of elements, or obtaining priorities by normalizing direct measurements.

In the SuperDecisions the process always starts with the creation of a hierarchical decision model which contains a goal, criteria that are evaluated for their importance to the goal, and alternatives that are evaluated for how preferred they are with respect to each criterion.

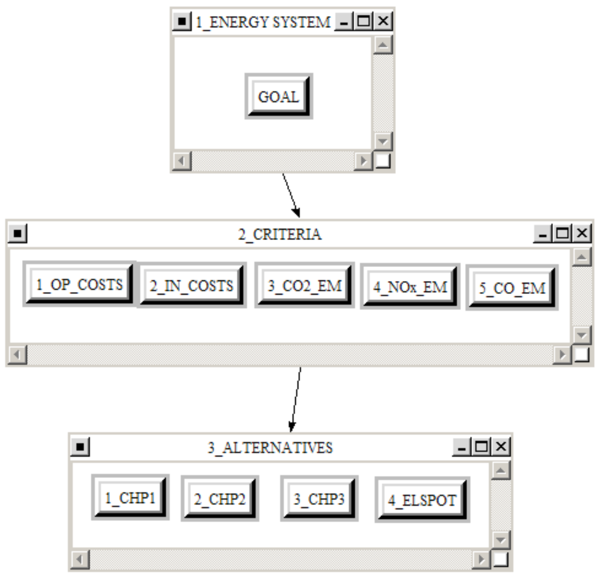

Figure 6 Hierarchical mode of the case study in SuperDecisions

In the SuperDecision the most developed method of MCDA is AHP. Therefore the testing of AHP on energy systems planning will be managed. The AHP decision-making process starts with the pairwise comparisons for the criteria with respect to the goal. In the model SuperDecisions the pairwise comparison has been already implemented and the process of decision-making in SuperDecisions will start with this task. There are different ways of pairwise comparison in SuperDecisions, questionnaire, matrix pairwise comparison, verbal and graphical comparison. I will present only one of these methods which is according to my opinion the most useful and appropriate for a pariwise comparison.

The questionnaire comparison is guided trough Questionnaire Comparison Screen where all criteria must be compared in pairwise way among each other. A decision-maker has to evaluate the preference of the criteria according to his view. The comparison is made by using the fundamental scale for making judgments – for more information please see the relevant part of my PhD thesis.

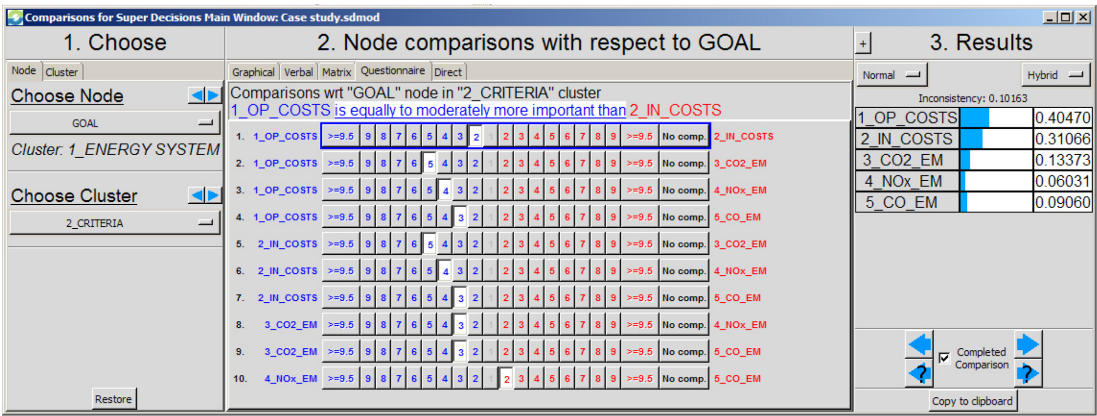

Figure 7 Results from the synthesis command in SuperDecisions

Once the pairwise comparisons have been finished for all criteria and all alternatives the results of the analysis can be calculated. The results are obtained with the synthesis command. The results of the analysis of the AHP decision-making process are summarized in the following picture.

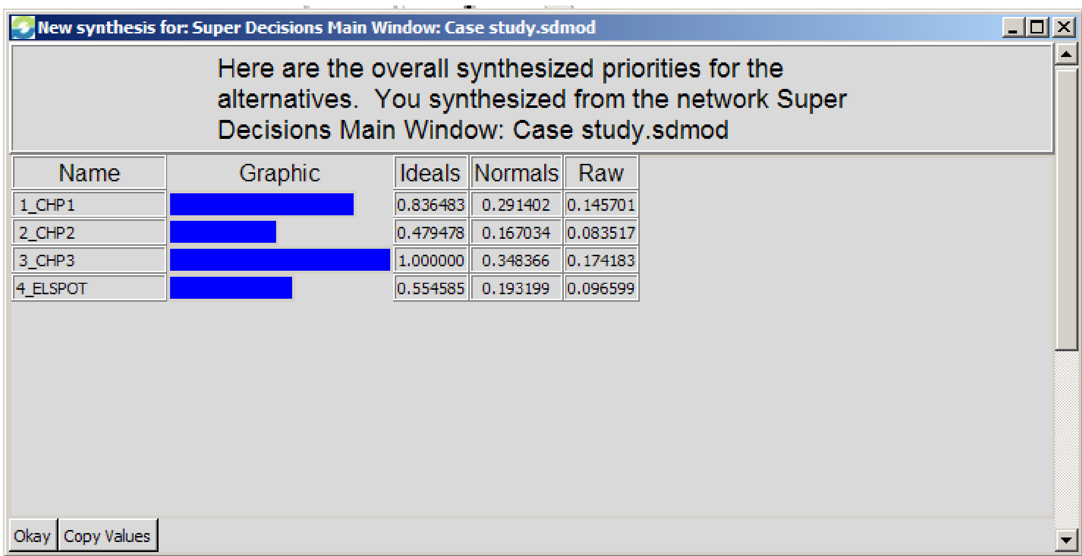

Figure 8 Results from the synthesis command in SuperDecisions

The Normals column presents the results in the form of priorities. This is the usual way to report on results. The Ideals column is obtained from the Normals column by dividing each of its entries by the largest value in the column. The Raw column is read directly from the Limit Supermatrix.

The results of the analyses of the case study show that the alternative 3 would be the best choice for the relevant decision maker. The “Ideal” column shows the results divided by the largest value so that the best choice has a priority of 1.0. The others are in the same proportion as in “Normals”. The interpretation of these results is following: Alternative 1 – is 83,6 % as good as Alternative 3. Alternative 4 – is 55,4 % as good as Alternative 3 and Alternative 2 – is 47,9 % as good as Alternative 3. The AHP process in SuperDecisions has given us the best choice and judge an investment into Alternative 3 for this relevant decision maker.

The SuperDecisions tool also allows expressing sensitivity analyses of the results. The sensitivity analyses help us to indicate how sensitive the priorities of the alternatives are to the change of the local weights of the attributes. In practice, it shows how rapidly and to which direction the score of the alternatives are changing when the weights of an attribute is changing. The sensitivity functions for each alternative are presented in the graphical are in and Sensitivity Analyses Windows in SuperDecisions – see the following figure.

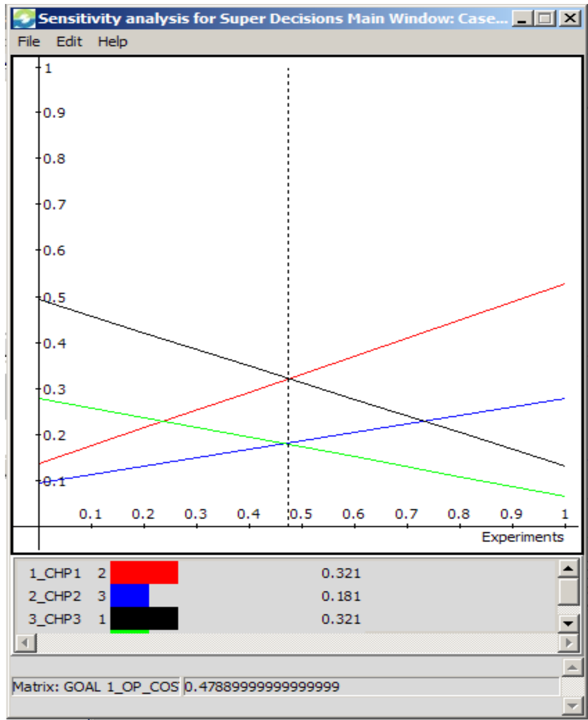

Figure 9 Sensitivity Analyses of the case study for operating cost

The priority of one chosen criterion is plotted on the x axis and the priorities of the alternatives are plotted on the y axis. In our case I have chosen to analyses the sensitivity of the criteria of operating costs (OP_COSTS). The graph is telling us that if the priority of operating costs is greater than about 0.47, Alternative 1 – becomes the preferred choice. Before that the Alternative 3 – is the best alternative. Of course the sensitivity for other criteria can be expressed in SuperDecisions as well.

In the statement of the thesis I have only briefly presented the outcomes of the analyzed case study. It was out of scope of this statement to present the whole process of modeling of the case study in eTransport model as it was done in PhD thesis. Also testing of MCDA has been limited only on presenting one of the models of MCDA desion-making tool – SuperDecisions. In PhD study another models which are suitable for multi-criteria decision analyses are tested and presented. For further details readers should please study the original thesis.

5. CONCLUSION

The long-term energy system planning is a task which influences many environments. It is a task which also involves a number of authorities from different field of business and also public. The goal of the person/authority who is going to decide which alternative will be realized is to be able to compare alternatives that have different performance levels for various criteria and to create more formalized and better-informed decision-making process. This is important for all parties involved in energy-system planning - energy policy or strategy making (Ministries, Regulatory Authorities, Companies, Stakeholders, etc.) in restructured power system. However it is essential also for public. The decision-makers need to be able to provide documents for various stakeholders (including public opinion) that their decisions actually have been thoroughly considered and is the best alternative considering all factors, all criterion and all opinions.

The outcomes of the decision-making analyses have shown that MCDA approach is a suitable for energy-planning process which led to investigation of the decision-makers priorities and defining of the one best choice alternative to be developed by involved stakeholders. The tested MCDA tools can be used for decision-making phase of energy-system planning process. However in the real case this process I have tested is quite comprehensive and for relevant analysts and decision-makers could be too complex and complicated. They must be able to handle the impact model tools and also the decision-making tools which take a significant effort and time in a more user friendly way. The more developed energy-system planning should ensure that the decision-makers are able to handle their process in one supporting tool. It is essential to include the decision-making part (currently available only in different software tools) into the one modeling tool which will enable to build up the energy-models and also to facilitate the decision-making process. The development of such models should use MCDA optimization tools also for energy planning and decision-making in alternatives assessment. For this purpose it necessary to carry out certain amount of theoretical studies. I believe that my original PhD study is one of the useful works concerning this task. This should help to orientate the further studies of energy-system planning and decision-making process on a building a comprehensive tool to be used in real energy-system planning studies.

Generally the MCDA process can activate and increase discussion among stakeholders, help them to investigate the problem eventually find out the new alternative of the system during the analyses or pre-discussions. The process also should activate the people who are not normally participants. Furthermore the MCDA process will help to increase the acceptance of trade-offs made during the analyses and also solve the conflicts and focus more on the target oriented discussions in order to find the results – the best alternative. MCDA process gives documentation of the decisions which gives the decision-makers right and possibility to study why this alternative was chosen in future. A proper judgment and documentation of the decision will increase increasing the confidence to decision maker at the end.

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List of candidate's works relating to the doctoral thesis

A. Related to PhD thesis:

1. Impact papers:

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2. Reviewed papers:

Fialka, M.	Development of Power System with Renewable Energy Sources, Electric Power Engineering 2006, EPE 2006, Brno, ISBN 80-214-3180-6.
Fialka, M., Tůma, J.	Renewable energy sources – Perspectives of Electricity and Heat Production and their mathematical modeling, 4th International Scientific Symposium ELEKTROENERGETIKA 2007, 19.-21. 9. 2007, s 187-190, Stará Lesná, Slovak Republic, ISBN 978-80-8073-844-0.
Fialka, M. - Foltýn, D. - Tůma, J. - Chemišinec, I.	Renewable Power Sources Operation in the Czech Power System. In Present-day problems of power engineering. Gdansk: Gdansk University of Technology, Faculty of Electrical and Control Engineering , 2007, s. 123-131.
Fialka, M., Tůma, J., Žák, P.	Prognosis of development of power system and security of supply, ELEN 2006, Prague, 2006.
Fialka, M. - Andrlík, Z. - Tůma, J.	Optimization of power energy supply in the Czech Republic with respect on environmental impacts, In 7th International Conference "Control of Power & Heating Systems 2006, Zlín , 2006, s. 1-4. ISBN 80-7318-409-5.
Fialka, M. – Tůma, J. – Chemišinec, I.	The way of integration of the European Electricity Markets, to be presented and published at IEEE PES Trondheim PowerTech 2011, 19 - 23 June 2011.

3. Patents:

-

4. WOS:

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5. Other:

Fialka, M.	Minimization of negative environmental impact of the power generation, NTNU in Trondheim, 2007

The shares of co-authors on publications are the same.

B. Non-related to PhD thesis:

1. Impact papers:

-

2. Reviewed papers:

Fialka, M., Tůma, J.,	Terms of increased use of renewable energy sources in production of electricity, Electric power engineering 2007, Dlouhé Stráně, s 1-10, 2007, ISBN 978-80-248-1391-2.

3. Patents:

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4. WOS:

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5. Other:

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Fialka, M., Chemišinec, I., Tůma, J.	The role of renewable energy sources in the Czech power energy system, WEC Regional Energy Forum – FOREN 2008, Neptun, Romania.

Unpublished presentations

Fialka, M.	Support of Power Generation from Renewable Energy Sources, Regulatory Workshop 2006, ConPro, s.r.o., Prague, 2006.
Fialka, M.	Support of production of electricity from renewable energy sources in 2007, Czech Energy Agency, Prague, 2006.

The shares of co-authors on publications are the same.

SUMMARY

The energy demand is going to continue increase despite of assumption in all of the World. On the other hand, the capacity for energy production as well as the primary energy sources will be insufficient to meet increasing energy demand in following years. Moreover, the several attributes must be considered once the new energy generation is considered to be planned which involve several concerned parties. In such conditions it is needed to take into account a particular action plan of the development of energy production which ensures that the energy demand will be covered in a requested range and quality – it is necessary to make a decision. This thesis is focused on the integration of aspects related to the planning of the energy systems on long-run time schedule. The main issues of energy-systems planning are discussed and the most important part deals with the decision-making process related to the long-term energy systems planning. At the end the aims and the suggestion of further studies of this topic are discussed.

In long-term energy systems planning the several existing and conflicting criterions influence the decision of the decision-makers. The decision-maker in such a task is then responsible for final-decision making. The input of his analyses is always a set of alternatives which must be compared considering all criterions which the analysts would like to consider. This problem represents so-called multi-attribute decision problem. The mathematic methods of solving such multi-attribute task have been defined. The goal of the thesis was to investigate the application of these methods in long-term energy system planning. For that reason also the modeling part of multi-criteria decision analyses was tested in order to get the inputs for further decision-making process. The outcomes of the analyses confirmed the sufficient applicability of multi-criteria analyses in long-term energy systems planning.

RÉSUMÉ

Navzdory předpokladům spotřeba energií v celosvětovém měřítku neustále roste. Naproti tomu kapacita výrobní části energetické soustavy stejně jako zásoby primárních energetických zdrojů nebudou schopni pokrýt potřeby rostoucí poptávky po energiích v následujících letech. V případě plánování rozvoje výrobní části soustavy je nezbytné rozhodnout včas o jednoznačném akčním plánu, který zajistí, že energetické potřeby společnosti budou uspokojeny v odpovídajícím rozsahu a kvalitě – je nezbytné udělat rozhodnutí. Tato práce se zabývá aspekty, které ovlivňují plánování rozvoje energetických systémů v dlouhodobém horizontu. Hlavní otázky plánování energetických systémů jsou prezentovány a velká část práce se zabývá rozhodovacím procesem související s dlouhodobým plánováním energetických systémů. V závěru práce je sumarizován návrh témat pokračování studia tohoto tématu.

V případe dlouhodobého plánování energetických systémů existuje několik neslučitelných kriterií, které mohou ovlivnit rozhodnutí účastníků rozhodovacího procesu, kteří mají pravomoc provést finální rozhodnutí. Vstupem pro rozhodovací analýzy je obvykle soubor alternativ, které jsou porovnávány v rámci několika kriterií. Tato úloha reprezentuje tzv. multi-kriteriální rozhodovací úlohu. Matematické metody umožňující řešit takové úlohy jsou definovány. Cílem této práce bylo

najít a ověřit tyto metody, které by mohly být aplikovatelné v úloze dlouhodobého plánování energetických systémů. Z tohoto důvodu úloha modelování energetických systémů byla prezentována a testována, jelikož výstup modelování slouží jako vstup multi-kriteriálního procesu rozhodování. Výsledek analýz potvrdil vhodnost a aplikovatelnost testovaných metod multi-kriteriálního rozhodování v úloze dlouhodobého plánování energetických systémů.