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Energy Supply Preferences as Multicriteria Decision Problems: Developing a System of Criteria from Survey Data

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Abstract: Decision support techniques have a key role in investment and strategic decisions in the energy sector. As complex decision-making problems involve the simultaneous consideration of an extensive set of different factors, it is an essential part of the methodology to define, structure, and integrate the criteria. The main purpose of the study was to develop a system of criteria and weights that are suitable for general application in the energy sector and can best describe the decision-making mechanisms present in society and various social groups. When developing the system of criteria, we moved away from the hierarchical approach related to the three pillars of sustainability; therefore, a wide range of notions were assessed based on a population representative survey data collected in Hungary. We used algebraic methods to explore the internal structure of the set of criteria that had been previously defined by means of social sciences, while the importance weights were specified by applying the method of analytic network process. Furthermore, the ranking of heating and electricity generation alternatives were determined.

Keywords: energy preferences; survey; multi-criteria decision model; analytic network process

1. Introduction

Ongoing expansion of energy demand presents a major political challenge all over the world. To meet the European targets on emission reduction and renewable energy source expansion, both generation and infrastructure investments are needed. Energy attracts general attention in the whole of society.

Challenges in energy utilization are interrelated with the goals of modern societies: A wide range of applications (from household to production systems) and aspects (human need, mobility, diversity, etc.) come to demand. Meeting these needs was only a question of money and technological availability until 1970s energy crisis. Then the upcoming environmental degradation due to ongoing energy production caused the reconsideration of a technological solution became unavoidable. Energy planners had to take into consideration a much wider range of evaluation criteria, and it also became necessary to take into account all kinds of unclearly formed preferences of all involved groups of interest. As the stakeholders' interest or the available abilities and preoccupations differ in each problem, the set of criteria varies. As it is recognized by the research community and introduced by Wüstenhagen et al. [1] that social acceptance may be a constraining factor in achieving government energy targets, beside technical and economic indicators, environmental and social aspects are also needed to be treated which makes energy planning much more complex in the current era. As there exists no historical patterns or globally accepted treatment of any involvement of environment indicators, it could be stated that the analysis taking these criteria into consideration bears a great uncertainty [2]. As the phrasing, the content, and the meaning of an expression and individual preferences change from time to time, it has to be updated regularly. Energy sustainability, one of the most complex criteria, is widely studied in the literature; however, the conceptualization of sustainable development shows great difficulty [3]. In the report of Kumar et al. [2], it was summarized how the scientific results deal with changing criteria during the last decade, finding the optimal results in complex scenarios including various indicators. It has also been stated that the ignorance or less importance of social factors led to failure of energy projects even with sophisticated and affordable technologies. From this, we can conclude that an energy system design must take account of social factors at least to the extent of equal importance as other factors. To take into consideration these needs, multicriteria decision analysis (MCDA) was found to be an excellent supporting technique in decision making where economic, environmental, societal, institutional, technical, and aesthetic objectives may be analyzed [4]. Most of the studies available are performed in national, regional, or a particular geographical location level; however, local organizational level still seems missing [2]. As it is clear that the socio-political acceptance of the energy innovation process is a determining factor, the framing phenomenon becomes important to analyze. A glossary of phrasing in energy planning published by Wolsink [5] showed that several frames tend to be part of similar narratives. It is common that different actors in policymaking use various phrasing; however, their content seems to be in line. At the same time, the overlapping and related expressions are not always used in a consistent way. As framing is essential to all political processes, it is fundamental to analyze the framing phenomenon related to socio-political acceptance of energy innovation processes.

It can be summarized that major energy investments or emerging new technologies are topics of general state-of-art social interest on which the adult population tends to make opinions. To be able to effectively communicate with residents and communities, and to take their opinion into consideration, it is essential to understand what is important and preferable for those people who are affected by regional investments, or for those who need supporting. As messages reaching different social groups are transmitted by different media, there could be extreme differences in the language and terminology used by people. It is essential for social consensus-based decision-making to understand the everyday life meaning of various trendy (like sustainable) and other simple (like safety) terms. To guarantee a safe heating supply, or to form a sustainable national energy system, it is recommended to know what decision aspects these notions infer and by what relevance it should be taken it into consideration during the decision process. The aim of our study was to provide a social survey-based background for MCDA models applied in the energy sector regarding criteria and their importance. Among MCDA models, the analytic hierarchy process (MCDA-AHP) model is the most commonly used decision-supporting technique in the energy. The main point of the MCDA-AHP method is that well measurable indicators are linked to each element of a previously fixed hierarchical system of criteria, which enables the comparison of decision alternatives. To succeed the summing of indicators the only task is to determine the importance weights of the studied criteria during the full ranking of the decision alternatives. The two most important questions of the MCDA-AHP method such as the completeness of the system of criteria and the fulfilment of the disjoint sub-criteria could be answered by the precise definition of criteria. This need of exactness brings in the problem of phrasing: Are the expressions interpreted in the same way among the questioner and the responder? In one of our previous study [6], it was found that responders often did not understand or misunderstood the abstract notions used related to energy strategy. Thus, our aim was to devise a method where the responder defines the utilized notions. It is clear that it follows that we had a loose hold of predetermined indicators, as well as the guarantee of disjoint terms. However, it is a great advantage that instead of indicators, the responder compares the alternatives known by himself, with the criteria also known by himself. The mathematical evaluation of this joint system of criteria was chosen to be the MCDA analytic network process (MCDA-ANP). The technique introduced in this paper creates the opportunity to integrate wide social classes in the decision process. This is substantial to ensure that not only a privileged group of decision makers dominates but also the opinions of wider social classes could be modeled [7]. Preparation of such models are also important because there is no mandatory requirement for such an energy investment-related poll in the EU; thus, there is rarely any survey done prior to long-term and remarkable investments due to financial deficit or traditional reasons. Thus, to help at least decision-makers, it is fundamental to explore the progress and variability in phrasing from socio-demographic aspects. Simple and more complex criteria that are suitable to make judgments on energy alternatives and scenarios constitute an integral part of energy-related terminology. The method introduced in our study is not capable to substitute surveys for each unique situation; however, it is suitable to help decision preparation in cases of large industrial investments, and forming energy strategies and supporting schemes. Because of the availability of supporting framework, our work was based on a survey analysis performed in Hungary, but it is our long-term goal to extend this study to other countries as well.

The primary objective of the research was to describe the complex criteria of evaluation by simple criteria, and to develop a hierarchical system of criteria this way. Furthermore, it was a further goal of the study to rank the decision aspects according to their importance. The mathematical realization of this is to assign weights to the whole hierarchical system of criteria that can form a basis for a multicriteria decision-making model. The set of criteria considered in this work was selected based on previous studies [8–11] and on focus group discussions. These conversations were moderated small group discussions performed in several places nationwide. The central topic of the talk was the energy alternatives and aspects related to them. It was the moderator's task to supervise the free conversation towards the set of criteria which were selected based on the above-mentioned studies. Criteria occurred during the discussions were edited later to avoid synonyms and negated notions to specify the final set of criteria. As a result, a detailed survey could be designed. To be able to form the system of criteria and to evaluate the weights of each criterion, we combined two methods in the survey: For specifying the importance weights of the complex criteria, we used pairwise comparison, while for exploring the internal structure of the whole system of criteria, we used direct ranking of energy supply alternatives. In the course of the pairwise comparison complex, criteria were compared in pairs on a five-degree scale (importance of first criterion is much higher; higher; equal; less; much less than that of the second one). Direct ranking of the energy supply alternatives which the respondent was familiar with was directly evaluated on a five-point score (1 to 5) from each aspect of the complex and simple criteria. For the selected alternatives, only the application and the energy sources were highlighted without further specifying the technology and the capacity range. The primary reason for involving alternatives in the evaluation of criteria was that it is often very difficult to perform a pairwise comparison for abstract categories with a distant meaning; in these cases, the problem can be eliminated by evaluating the criteria for more concrete alternatives.

The use of alternatives in the survey had a twofold goal: First, to explore the hierarchy of criteria, where selected complex criteria are prepared by the combination of simple sub-criteria; secondly, to rank the sub-criteria where they were the set of alternatives that transmitted the ranking of the complex criteria towards the sub-criteria. The intermediate set of alternatives transmitting the ranking can be considered as the set of network clusters in the analytic network process (ANP) model, so we reversed the conventional roles of alternatives and sub-criteria in our study.

The most important questions in our survey are in line with the topics of international surveys that often include the ranking of energy supply alternatives [12–18] or the rating of certain evaluation criteria [19–23]; however, our survey stands out with higher complexity. The enhanced complexity of the survey is due to separation of heat and electricity supply that implied separate evaluations:

One related to single users and one related to large-scale production. These two levels affect different areas of energy supply: Energy generation of single users where heating alternatives and related aspects are predominant, and national energy supply where electricity generation alternatives and their evaluation aspects are present. Besides these, the number of criteria studied is far higher than it is benefited in the studies available in the literature [2]. A further complication for the contents of the survey was introduced by the feasibility of the mathematical evaluation as it required both the direct evaluation of alternatives for all criteria and the pairwise comparison of complex criteria.

As it is rather exhausting to complete the direct evaluation and the pairwise comparison for both electricity and heat supply, only a very limited number of important additional questions were included in the survey addressing the social status, energy poverty, and climate impact. The socio-demographic section of the survey is essential not only for the confirmation of the representativeness, but also for the definition of the social identifiers of groups having the same preferences. As the evaluations provided by the respondents were based on their experience or theoretical knowledge, the number of evaluated alternatives differ from respondent to respondent. It would help the mathematical evaluation if more comparison is performed. Additionally, a more detailed set of alternatives would be desirable from energetic aspect; however, the increasing complexity of the survey would cause a bigger lack of data which could damage the mathematical analysis. On the whole, the criteria included in the evaluation was found to be easily manageable, and a systematic lack of data was not encountered at either the rating of the alternatives based on the criteria, or at the pairwise comparison.

In this paper, first we present a brief summary of focus group discussions, and also the criteria and alternatives selected on the basis of these. Then we introduce the structure of the survey and the mathematical methods applied for the analysis. In the third part we present the multiple results determined. Beside the definition of the set of criteria and alternatives based on a socially widespread investigation, the importance weights of complex and simple criteria as well as the ranking of alternatives for both heat and electricity supply are demonstrated. Also, the significant socio clusters of criteria and alternatives are introduced. Final remarks are summarized in the conclusion section.

2. Methodology

The focus of the research was to specify a structured system of criteria and importance weights that allow for a detailed description of the decision mechanisms of society and different social groups in Hungary concerning investments and strategic decisions in the energy sector. The research was based on social survey, which was evolved in two steps. The target group consisted of adult Hungarian residents.

In the first step, focus group discussion/s were performed which enabled qualitative analysis of the opinion of different groups of residents in more detail. This investigation enabled to identify the general interpretation of the most important scientific terms or to detect the lack of any interpretation.

In the second step, based on the outcome of the investigation relying on focus group discussions, we specified the system of evaluation criteria of the survey and selected the heating and electricity generation alternatives. In the quantitative section of the survey, the importance of some highlighted criteria was determined by pairwise comparison. A 1–5 rating scale was used for the direct rating of each criterion and alternative. In addition to the statistical evaluation of raw data, a mathematical assessment was also performed using two main approaches: Hierarchical structuring of criteria and general network modelling. Despite using a compact set of criteria, it was rather challenging to meet the expectations of the scientific approach applied by social sciences and to guarantee the mathematical evaluation and to insist to the correct use energy-related terms at the same time.

2.1. Research Methodology

2.1.1. Qualitative Assessment

At the focus group discussions, we studied the general interpretation of the most important energy-related scientific terms or detected the lack of any interpretation. Based on the group discussions of people of different age, gender, education, place of living, no common views were encountered that could be generalized, but rather deeper knowledge or beliefs regarding the problems that were subject of the study. The focus group participants discussed the notions, energy supply alternatives, technologies and the related evaluation criteria that were freely introduced by the group leader. Starting from the more general warm-up questions, the groups restricted a more concrete notion system; finally, at the end of the discussions, a short section of possible survey questions was filled by the participants. As a result of the documented discussions and evaluated outcomes, the survey questions were written in a clear language that is understandable by a population sample with no specific background. The method of the focus groups discussions also enabled to test the applicability of the more complex type survey questions.

The discussions took place in November and December 2017. Based on the statistics presented by the Hungarian Central Statistical Office the aim was to define groups which are representative for socio-demographic indicators (gender, age, education, income, and living conditions), types of opinion, and knowledge. The composition of the groups was decided after analyzing the available databases [24]; people were selected using the self-developed network for social surveys established by the Centre for Social Sciences. After arranging the participants into groups, we conducted 8 focus group discussions during the study. In cases of the discussions taking place in both cities and in the country, it was an important objective that the users of the most important building types (urban tenement house; residential building; single house; multi-flat row houses; multi-flat row house in greenbelt area; other) and heating types (district heating; gas network; LPG tank; natural gas tank; electricity; wood; coal; oil fuel; renewable; other energy source) should have been represented in the groups; furthermore, people facing energy poverty should have been addressed. The guideline of the focus group discussions was established so that during the first general energetics-related questions the moderator recorded the upcoming heating and electricity generation alternatives and notions so that our database from previous works [11] could be broadened. During the second part of the discussion, the expanded system of phrases was examined from the aspect of collected alternatives. We wanted to know if these aspects are capable for the comparison of all occurring alternatives which essentially determined the preparation of the survey. Thus, based on the outcome of the focus group discussions, we developed the system of the evaluation criteria to be used in the survey where the occurring 55 terms were reduced to 41 criteria (specified in Table 1) by eliminating the overlapping terms. For comparability we used positive formulation for the criteria in every case (e.g., *landscape-compatibility* instead of *landscape damage*), but in this paper, we used the common, more compact terms. Terms were divided into two groups (complex and simple criteria) depending on the complexity of their interpretation, and were set to be simple criteria, the description of which was considered to be obvious. Some of the complex criteria were given a prominent role; these are set as the main criteria and marked in bold in Table 1. In addition, every complex criterion was determined as the aggregate value of simple criteria, which are called the sub-criteria of a certain complex criterion.

Table 1. List of complex and simple criteria used in the survey.

Classificationtitle	Criteria
Complex criteria	***Economy, Safety, Environment, Reliable, Comfortable, Landscape****damage, Sustainable, Renewable, Efficiency, State-of-the-art*
Simple criteria	*Investment cost, Fuel cost, Consumption, Lifetime, Maintenance, Flammable, Health effect, Inexhaustible energy source, Waste quantity, Climate change effect, Air pollution, Biodiversity, Domestic source, Storable energy source, Adjustable operation, Independent operation, Manual work, Employment, Noise pollution, Odor impacts, Life quality, Supported, Job creation, Increasing the value of property, Soil and water contamination, Hazardous waste, Long-term fuel supply, Geo-political factors, Accidental risk, Risk aversion, Natural disaster-proof*

The selection of alternatives (specified in Table 2) was also determined from the evaluation of the recorded focus group conversations taking into consideration the up-to-date publications [25–28].

Table 2. Selected electricity production and heating alternatives. SH = Stand-alone Heating, DH = District Heating.

Utility-scale electricity production alternatives	Solar PV, Wind, Hydro, Lignite, Geothermal, Natural gas, Biomass, Nuclear
Residential heating alternatives	Electric SH, Natural gas DH, Biomass DH, Coal & Lignite DH, Solar thermal SH, Heat pump SH, Natural gas SH, Firewood SH

As we separated the questions related to residential heating and utility-scale electricity generation, the list of criteria followed that distinction; thus, every simple criterion was categorized into the related two energy generation groups. Due to the personal experience and the household size in the case of heating alternatives, there were extra notions (comfort, manual work, etc.) related to this group which did not apply in the case of industrial scale electricity generation. As the energy sources are the same, but the scale of heating and electricity generation techniques differ, the formed sets of criteria were not completely the same; there was an 80% of overlapping. The components of the sets of criteria were categorized as simple or complex criteria. Regarding the complex criteria, we selected four main criteria, where we analyzed the structure of the simple criteria that can be assigned to them, while for the other complex criteria, we explored that which simple criteria can be used to describe their meaning. In the quantitative part of the study, not only the system of sub-criteria consisting of simple criteria was provided for the main criteria, but also their importance rankings were evaluated.

2.1.2. Quantitative Assessment

As a basis for the study, a survey was conducted in October 2018 with a sample of 1000 people, representative of the population with respect to age, gender, education, and type of residence. The list of the settlements taking part in the sampling and the quota to be applied were selected based on the population census data of the Hungarian Central Statistical Office [24]. The survey interviews were conducted in the periphery, in the inner and intermediate zones, and in the center of the settlements, considering the differences in the housing conditions and heating systems.

The survey questionnaires consisted of five sections, three of which contained socio-demographic questions. The introductory questions were related to age, gender, education, and the energy sources used in the household. The second socio-demographic section (separating the two sections asking for the direct evaluation of electricity and heat supply alternatives) was made up of questions related to energy poverty. The closing questions gathered information on the heat supply technologies used by the households and their willingness to pay.

The two quantitative sections addressing heat supply and electricity supply used a different approach in comparison with conventional survey structure. There was a rating table for the 1–5 scale rating of the heat and electricity supply alternatives with a line-by-line rating by each criterion (Figure 1).

This rating method enabled us to compare the alternatives from the aspect of criteria, and also provided the opportunity to study the importance of the criteria for each alternative. By this approach, a back and forth evaluation of alternatives and criteria was performed. Respondents were asked to fill the table only in cases of alternatives where they had personal experience or firm knowledge, to ensure that evaluations had a sound basis. We should note that the changing number of alternatives posed difficulties for the mathematical evaluation; however, the information about which alternative was chosen to assess is important information. The applied mathematical model required that each questionnaire should evaluate at least three alternatives. In addition to the rating table, questions asking for pairwise comparison of main criteria were also included for both heat and electricity supply.

In order to simplify the rather complex and time-consuming survey, the pairwise comparison was formulated in a multiple interdependent format containing gaps.

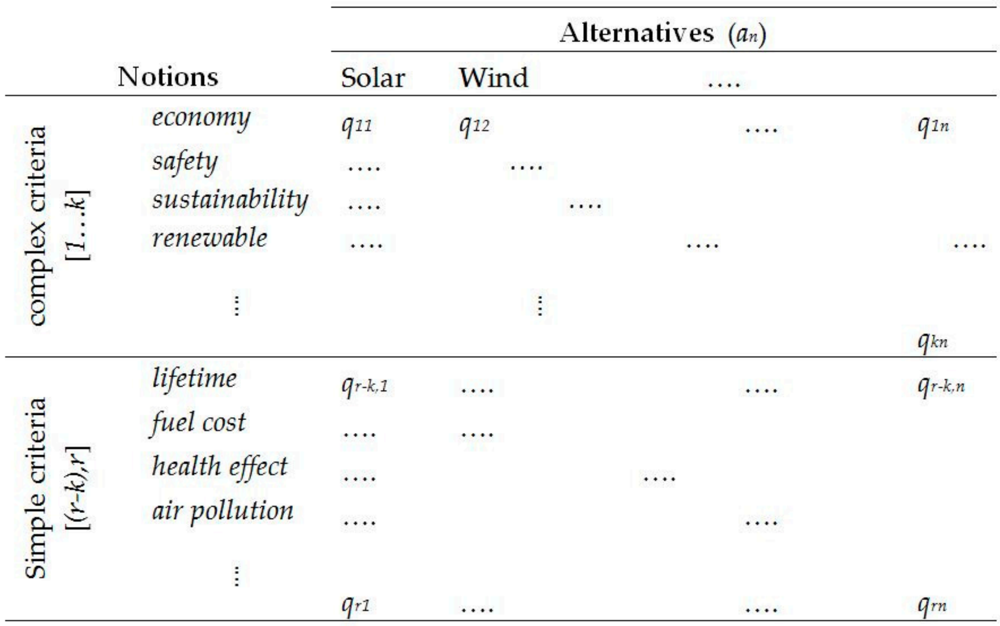


Figure 1. A section of the survey with the mathematical notations of variables.

2.2. *Assessment Methodology*

2.2.1. Hierarchical Analysis of the System of Criteria

The analytic hierarchy process-based multicriteria decision analysis (MCDA-AHP) [29] is often applied for the comparison of energy scenarios or alternatives, as reported by several international studies [21,30–36]. In our previous work, we have also used MCDA-AHP for similar problems [11,37,38]. Although the formulation of the hierarchical system of criteria is a simple tool for the mathematical evaluation, it is an important disadvantage that the independence of the main criteria is not ensured. We had a twofold objective at the hierarchical analysis of the system of survey criteria that were closely interrelated. In the cases of the main criteria, we focused on the exploration of the sub-criteria system connected to each main criterion, and their hierarchical formulation. The overlapping of sub-criteria between main criteria was also studied. In cases of other complex criteria, we tried to investigate how they can be defined by the specified sub-criteria, i.e., how such terms can be defined as *sustainable* or *reliable*. Of course, the interpretation of complex criteria and, within them, the main criteria can be different for each person; these data as such provide valuable information. Moreover, the parallel evaluation of these data with further socio-demographic data was also very promising.

In addition to these objectives, our aim was to specify the criteria weights of the whole hierarchical system which was intended to describe the importance of each criterion. In order to achieve that, we selected the set of alternatives (Table 2), which are in general public use based on the focus group discussions. This set of alternatives consisted of n elements $\{a_1, a_2, \dots . a_n\}$; the elements of which could be well-rated according to each of the criteria (Table 1). The ratings of the alternatives by each of the $\{1, \dots k\}$ complex criteria and $\{k + 1, \dots r\}$ sub-criteria were defined as components of a rating vector s:

$$\underline{s}_1(q_{11}, \dots q_{1n}) \dots \underline{s}_k(q_{k1}, \dots q_{kn}); \text{ and } \underline{s}_{k+1}(q_{k+1\,1}, \dots q_{k+1\,n}) \dots \underline{s}_r(q_{r1}, \dots q_{rn}),$$

where q_{kn} is a normalized rating of the nth alternative of the kth criterion (Figure 1), and equals to the 1–5 rating given by the respondent. This should be interpreted so that a sequence of numbers is calculated for each criterion where each element of the sequence specifies the importance of the criterion for each alternative.

Each of the rating vectors belonging to the $i \in [1; k]$ main criteria was provided as an optimal linear combination of the rating vectors of the sub-criteria belonging to the main criteria with an $0 \leq \lambda_{il}$ coefficient and δ_i error. $\underline{s}_i = \lambda_{i\,k+1}\underline{s}_{i\,k+1} + \ldots + \lambda_{i\,r}\underline{s}_r + \delta_i$ where $\sqrt{\sum_{j=1}^{n}\left(q_{ij} - \sum_{l=k+1}^{r}\lambda_{il}\cdot q_{lj}\right)^2} = min.$

Based on that, a $\lambda_{i\,r}$ coefficient is specified for each of the i complex criterion characterizing the correspondence between sub-criterion r and complex criterion i. This could be considered as a weight, which helps to choose those sub-criteria that on the basis of which the assessment of alternatives is possible. In addition to the trivial hierarchy, this similarity served as the primary basis to explore the system of sub-criteria. To define the set of sub-criteria belonging to each of the complex criteria, we specified a pre-defined initial set (e.g., for the main criteria of *economical*, we considered all cost-related criteria) with an index set H and complement set $\overline{H}$. After that, the initial set belonging to complex criterion i was extended by the sub-criteria, for which the geometric means of the evaluated weights provided by the respondents were above the threshold K_i. When defining the thresholds K_i, it was not possible to use a predefined, uniform value for each of the complex criteria, since the coefficients of the linear combination, and, as a consequence, the criteria weights, depend on the cardinality of the defining set of the complex criteria. Based on that, the threshold K_i had the value of $K_i = max_{k\in\overline{H}}\{\lambda_{i\,k}\}$, i.e., the defining set was extended until reaching the first sub-criterion that clearly could not have been attributed to the complex criteria. For a threshold defined this way, the sets of sub-criteria in the established hierarchical set of criteria are not disjoint, and they result in clear interdependencies between the complex criteria. As an important consequence of the fact that the sets were not disjoint, the hierarchical approach (MCDA-AHP) was not suitable to specify the general criteria weights. As a result of the process described above, some less dominant aspects were eliminated from the system of criteria. For example, the sub-criteria *job creation*, *increasing the value of property* fell out from the list of the system of criteria because they were closely linked to all main criteria and lost their unique characteristics. As a result, we could define the notional composition (by sub-criteria) of each complex criterion. However, the hierarchical model was not suitable to establish the ranking of the alternatives or sub-criteria based on the criteria weights of the not completely independent complex criteria.

2.2.2. Analytic Network Process Analysis of the Results

For a coherent evaluation of sub-criteria and alternatives, the ANP method [39] was chosen, using the rating table, and the pairwise comparison data available only for the selected complex criteria which are the main criteria. The model that has been developed can be summarized as follows: The known ranking of the main criteria was projected towards the sub-criteria by a single intermediary system of sets. This intermediary system of sets consisted of disjoint sets in which elements could be mutually evaluated based on both the main criteria and the sub-criteria. In our study, we considered the group of the evaluated alternatives as the intermediary system of sets. By this, we deviated from the conventional approach, as in most cases the intermediary system of sets was made up by the sets of sub-criteria. However, the observations in the focus group discussions confirmed the expectations that it was often difficult to perform pairwise comparisons for categories and aspects with a distant meaning, and in these cases, it could be easier to compare more concrete alternatives and aspects. Of course, the reverse use of the set of sub-criteria and alternatives did not require any modification in the mathematical implementation of the ANP method, therefore we relied on the commonly used SuperDecisions (SDS) software during the evaluation [40]. During the mathematical implementation, the super decision matrix (SDM) was constructed so that it consisted of ratios of importance of main criteria, sub-criteria and alternatives. Each generated SDM was linked to a certain questionnaire. In the matrix, there were non-zero parts only in cases of the mutual pairwise comparisons of main criteria $i \in [1; k]$, $j \in [1; k]$ (where $a_{ii} = 1$ and $a_{ij} = \frac{1}{a_{j\,i}}$), the direct evaluation of alternatives based on the main criteria $t \in [k+1;k+n]$ and the reverse values (where $a_{i\,t} > 0$, $a_{t\,I} > 0$, but $a_{i\,t} \neq \frac{1}{a_{t\,i}}$ because of the difference arising from normalization), the direct evaluation of alternatives based on the sub-criteria $h \in [k + n + 1; r + n]$ and the reverse values (where $a_{h\,t} > 0$, $a_{t\,h} > 0$ and $a_{h\,t} \neq \frac{1}{a_{t\,h}}$). Due to the reasons described above, the pairwise comparison matrix of the main criteria was a sparse matrix; therefore, additional preliminary computations were necessary to complete the SDM. The sparse pairwise comparison data series were computed based on the least square method, the logarithmic least square method, and based on the method of eigenvalues. As the weights established by using the first two methods differed less significantly from each other, the most characteristic weights provided by the method of eigenvalues were used for further calculations. For the construction of the unweighted supermatrix, the ratios of the main criteria were used. The computed limit matrix that was calculated from the weighted supermatrix by the SDS software specified the unified weights of the alternative, sub-, and main criteria. After establishing the importance weights, further analysis was done using statistical and quantitative social scientific methods. The most important part of the quantitative assessment by social scientific methods was the application of an ANOVA model (analysis of variance; IBM SPSS Statistics Version 21), searching for explanatory factors by variance analysis on the whole set of data obtained by the survey. The most obvious explanatory factors enabling the grouping of the respondents based on their identical opinions were socio-demographic data. In our analysis, we considered five age groups (18–29; 30–39; 40–49; 50–59; 60 and above) and similarly, five groups based on the education level (primary education; vocational education; A level or equivalent; A level or equivalent + vocational education; Bachelor/Master's degree or higher).

For the evaluation, we used five income categories where the average range was defined between 85% and 115%, based on the net national income per capita (1025 EUR). Below that, the range between 60% and 85% was considered as a lower income, while the range below 60% as a low income. The range of a higher income was set between 115% and 145%, while the range of a high income was above 145%. It was an important part of our study to make a comparison based on the living conditions, types of settlement, and building typology. We focused on defining groups of identical perspectives based on the above-described socio-demographic data or living conditions; or, for the contrary, to conclude that the views are represented in each group of the society by similar variances.

3. Results

3.1. Determining the System of Criteria

When looking for an answer for simple questions, such as "Is wind energy better than solar energy?" or "Is wood firing preferred to gas firing?", the question naturally arises for a well-reasoned counter-question: From which aspect? In our study, we considered common energy-related aspects, the evaluation based on them, and their aggregates. When constructing the system of criteria, the starting point was the outcome of the focus group discussions. There were numerous synonyms, expressions of similar meaning, or negated formulations among the aspects that were mentioned during the discussions. Their classification by themes was a difficult task itself; however, the standardization of the formulations posed more challenges. We applied two different approaches for the classification of notions and aspects. At first, we analyzed the number of positive and negative associations that were attached to the different energy supply alternatives (Table 3), which was first studied universally, without size scaling and precise technology definition.

The critical attitude of the public towards the use of fossil fuels and, not surprisingly, the resistance against nuclear energy are well reflected by the groups. The aspects are more balanced for the more conventional renewable energy sources, while the utilization of electricity was clearly characterized by positive expressions. However, it is worth pointing out the outstanding number of negative formulations attached to the use of biomass. At the second classification, we divided the evaluation criteria collected in the focus groups into groups by a thematic distinction both at a household level and at a national level (Table 4).

Table 3. Notions and criteria mentioned during the focus group discussions based on the report, attributed to the energy supply alternatives.

Alternatives	Solar	Firewood	Natural Gas	Nuclear	Heating Oil	Coal	Geothermal	Electric Heating	Wind	Hydro	District Heating
Positive associations	17	7	5	5	1	3	5	9	4	4	4
Negative associations	15	19	15	12	16	3	11	4	4	4	3

Table 4. Thematic classification of the notions and aspects mentioned during the focus group discussions.

Classification	Impact on Human Health and Environment	Security of Supply	Costs	Support and Raising Awareness	Operation	Insecure	Logistics and Storage
Households	29	22	21	1	19	11	3
National	37	25	24	36	12	14	9

Based on the cardinality of sets, the groups of aspects of the evaluation related to human health, environment, security of supply, and economics are of nearly equal importance. Using the aspects and notions attached to the tables, the main focus was to construct a standardized system of criteria; however, it can be assumed that the number of notions assigned to the groups are in line with the main themes of public opinion and discourse, as well. This might be underlined by the fact that support being an integral part of political rhetoric appearing in media was frequently mentioned.

3.2. Interpretation of Notions Using Analytic Hierarchy Process

In the survey, a third form of classification was chosen to construct the standardized system of criteria. The standardized system of criteria where synonyms and antonyms were eliminated was divided into complex and simple criteria. Complex criteria were defined as the aggregate values of the linear combination of sub-criteria. Our calculations allowed for a ranking of the importance of sub-criteria in the definitions of complex criteria (Table 5). Since criteria related to heating and electricity generation sectors were partly different, the composition of complex criteria was analyzed separately for each sector. It is comprehensible that notions like *safety* has different meaning in the case of household heating than related to a national electricity network.

Table 5. Ranking of sub-criteria assigned to the main criteria on a scale of 0–100, until threshold K_i.

The Notion of *Sustainability* in the Heating Sector	*Inexhaustible Energy Source*	100
	Biodiversity	92
	Air Pollution	78
	Health Effect	62
	Domestic Source	59
	Climate Change Effect	55
	Noise Pollution	52
	Waste Quantity	43
The Notion of *Sustainability* in the Electricity Sector	*Soil and Water Contamination*	100
	Hazardous Waste	51
	Long Term Fuel Supply	46
	Geo-Political Factors	46
	Health Effect	42
	Air Pollution	39
	Climate Change Effect	36

Table 5. *Cont.*

The Notion of *State-of-the-Art* in the Heating Sector	*Health Effect*	100
	Consumption	92
	Manual Work	88
	Odor Impact	85
	Flammable	80
	Waste Quantity	73
	Maintenance	70
	Air Pollution	70
	Inexhaustible Energy Source	65
	Climate Change Effect	63
The Notion of *State-of-the-Art* in the Electricity Sector	*Accidental Risk*	100
	Climate Change Effect	95
	Air Pollution	89
	Lifetime	86
	Adjustable Operation	76
	Biodiversity	71
The Notion of *Reliable* in the Heating Sector	*Independent Operation*	100
	Lifetime	78
	Maintenance	76
	Adjustable Operation	68
	Storable Energy Source	67
The Notion of *Efficiency* in the Electricity Sector	*Lifetime*	100
	Long term fuel supply	52
	Adjustable operation	49
The Notion of *Renewable energy* in the Electricity Sector	*Climate Change Effect*	100
	Hazardous Waste	84
	Air Pollution	82
	Long Term Fuel Supply	80
	Soil and Water Contamination	71
	Health Effect	61
	Biodiversity	60

Despite the major smoothing effects of the 1000-respondent sample, the sets of sub-criteria resulting from the calculations cover the notions of *sustainable* or *state-of-the-art* well, for which it is difficult to find a simple definition. The selected set of sub-criteria shows high similarity for the two sectors; only the centers in the ranking orders have different positions. As mentioned above, some compact and clearly understandable complex criteria were selected as the main criteria (*economy*, *safety*, *environment*, *landscape damage*, *comfortable,* and, in case of electricity production, *reliable*) in order to explore their relationships by pairwise comparisons. It was an important part of the investigation to assess the internal relations to compare the systems of sub-criteria and to evaluate if they could be modeled as a hierarchical structure. Focusing on the three commonly used main criteria (*economy*, *safety*, *environment*), it could be clearly seen that the resulting sets of sub-criteria defining the main criteria were by far not disjoint (Figure 2); therefore, hierarchical models could not be applied in this case.

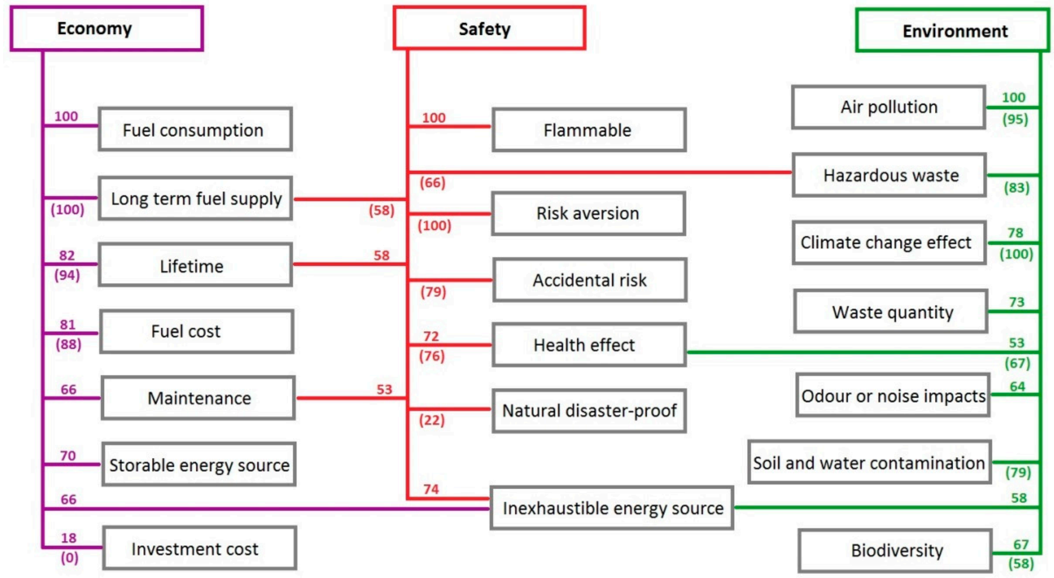


Figure 2. The system of sub-criteria under three main criteria with assigned importance weights, in a 0–100 scale until the limit of K_i, for the heating and electricity sector (values for the electricity sector are provided in brackets).

It might be interesting to highlight two sub-criteria that were not weighted as we previously expected in the ranking of sub-criteria. One of them is the *investment cost*, which belongs without doubt to the main criterion *economy*; however, this criterion is completely ignored by the public opinion. Similarly, the *natural disaster-proof* criterion is certainly a component of the main criterion *safe*, but received negligible weight. Both criteria appear in Figure 2, as it is important to see where and how they are considered by the public opinion. The ranking of criteria for the two sectors are quite similar; however, it is an interesting result that in case of heating sector the *air pollution* overtakes the *climate change*, which highlights that in case of rural, individual poor efficient equipment, air pollution is a recognized serious problem. As the two main criteria were different for the two sectors, their values are given separately (Table 6). For the heating sector, where subjective direct experience comes to play, the main criterion *comfortable* is two times interlinked to the category of *environment*; while for the utility-scale electricity generation, the *reliability* criterion is closely interrelated to *safety*. This relationship can be clearly explained by the fact that the main criterion *safety* covers security of supply, as well.

Table 6. Ranking of the sub-criteria assigned to different main criteria on a scale of 0–100, until threshold $K_{i.}$

The Notion of *Comfortable* in the Heating Sector			**The Notion of *Reliability* in the Electricity Sector**			
Manual Work	*Waste Quantity*	*Odor Impact*	*Adjustable Operation*	*Hazardous Waste*	*Lifetime*	*Natural Disaster-Proof*
100	70	62	100	57	45	43

However, some methodological limitations related to our approach were found. Among the main criteria, the results for the criterion *landscape damage* were very uncertain and did not allow a clear interpretation. This suggests that in the system of criteria, the *landscape damage* is isolated and cannot be interpreted by the other sub-criteria. Based on that, we used four main criteria in the further assessment.

3.3. Determining the Importance Weights of the Criteria Using Analytic Network Process

As the sets of sub-criteria in the system of criteria were not disjoint, the hierarchical model could not be applied for a standardized evaluation of the sub-criteria. Considering interdependences in the system of criteria, the ANP method was chosen to establish the importance weights of the criteria (Figure 3). At the same time, the ranking order of the alternatives was also obtained (Section 3.6).

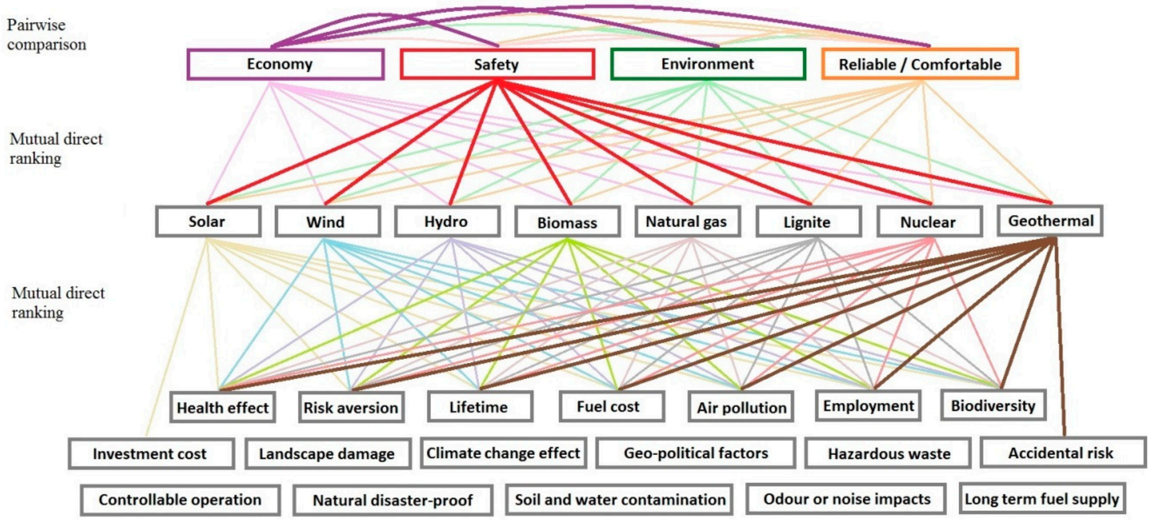


Figure 3. The structure and comparisons of the analytic network process (ANP) method applied for the evaluation.

The evaluation tables contained in the survey allowed for a bi-directional assignment of weights to the edges, linking the main criteria and sub-criteria to the alternatives. As a five-point scale was used in the evaluation tables, the normalized scores were suitable to be directly included in the unweighted supermatrix, unlike for the main criteria. The importance weights of the main criteria, as a starting point of the application of the ANP approach, was established based on the pairwise comparison part of the survey. It is worth having a closer look at the normalized importance weights of the sparse matrix of pairwise comparisons that were obtained by the eigenvalues method, since they are the most important part of the supermatrix. Of course, the aggregate values of the weights assigned to main criteria in the electricity and heating sector resulted in a different ranking order (Figure 4).

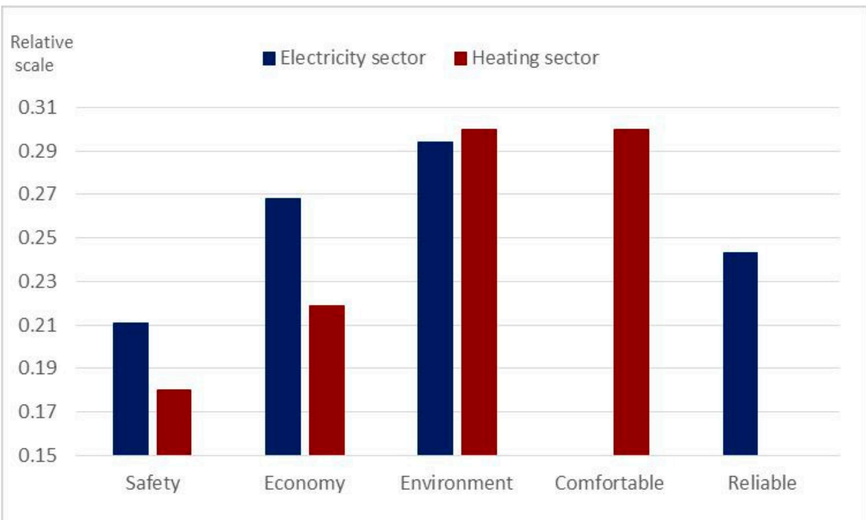


Figure 4. Aggregate normalized values of main criteria weights (four for each).

For heating, the most important main criterion was found to be *comfortable*, which is not surprising considering the single-user level. The next criterion, *environment,* reached almost the same importance. However, the importance weight of the main criteria *economy* lagged far behind the key factors at the single-user level, which was unexpected. On the contrary, the criterion *economy* took the second-best position behind *environment* in the case of utility-scale energy production. *Safety* was in both cases the least highlighted main criteria. Of course, the use of average values had a smoothing effect on the variation in the individual responses or the opposite opinions of different groups. The aggregate importance weights of the main criteria showed important conclusions and tendencies; however, it is worth having a closer look at the level of individual responses. When analyzing the individual weights assigned to the main criteria, it can be clearly seen that the results show an almost homogenous distribution between the four main criteria, and only a few particular directions can be detected (Figure 5).

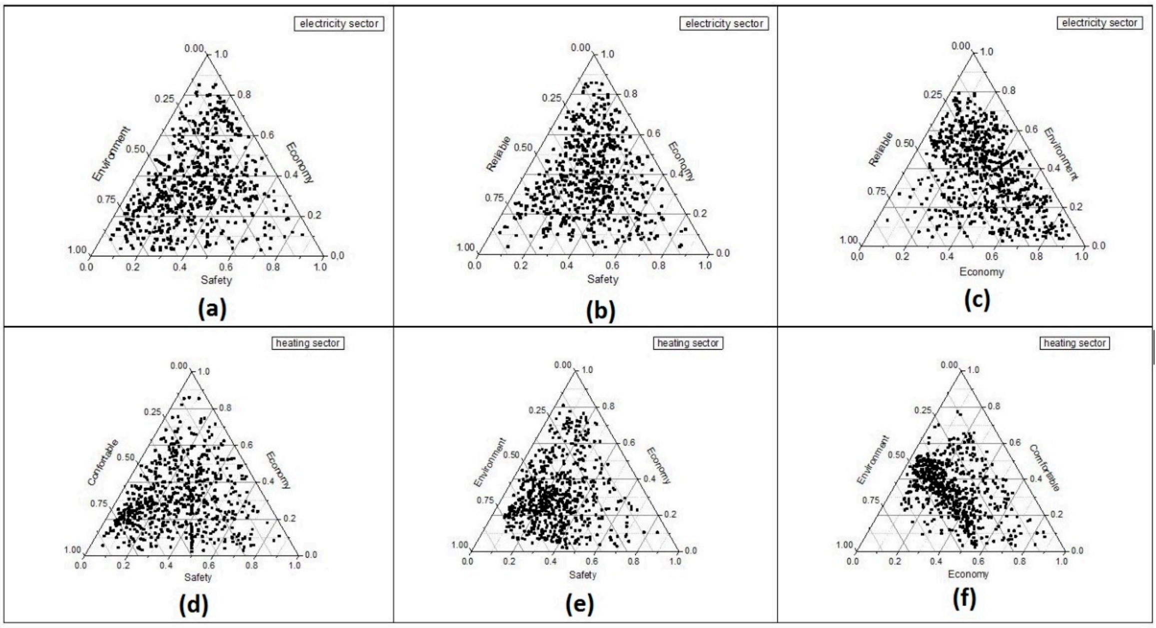


Figure 5. The distribution of the individual importance weights assigned to the main criteria on ternary plots.

The particular directions were identical to the highlighted importance weights of the aggregate results. Consequently, *environment* and *comfortable* were overrepresented in the heating sector, while *reliable* and *safe* were underrepresented in the electricity sector.

3.4. Determining Social Clusters of Criteria

It was an important part of our study to search for social groups, which attach higher importance to one of the main criteria, since additional opinions were formulated certainly. For the underlying variance analysis to establish the social clusters, an ANOVA model was used with a general significance level ($p < 0.05$). When evaluating the main criteria by individuals, our results did not show statistically acceptable relationships to the basic socio-demographic factors (education level, income, age) at all, contrary to previous expectations. From one side, these results are favorable, as they tend to suggest a homogenous society; however, some consequences are quite surprising. Perhaps the most interesting among them is that the income was not an influencing factor when evaluating the main criterion, *economy*. When considering the living conditions of the respondents, the expressed views were less similar. Based on the type of settlements, people living in towns (population below 5000) tended to assign high importance weights to the main criteria of *safe* and *environment*, while *economy*, *fuel cost*, and *comfortable* were clearly relevant for people living in the capital city. As for building typological groups, the criterion *comfortable* was of higher importance than the average for the survey participants living in medium-scale buildings (located both in the green-belt areas and in the city center) and large-scale multi-flat buildings. The aspect *economy* was more relevant for people living in multi-flat buildings, while the criterion *environment* was essential for the respondents living in multi-flat buildings located in the city center. *Safety* was a crucial aspect for those who use electric heating. As for electricity, the main criterion of *safety* was of extraordinary importance for the participants living in towns and flats without modern conveniences. Respondents from the capital city emphasized the importance of *economy*, while people living in towns and large-scale multi-flat buildings accentuated the relevance of the *environment* aspects. *Reliable* was more relevant for the residents of larger towns and for people using renewable energy sources.

3.5. Ranking of Sub-Criteria Using Analytic Network Process

In addition to the evaluation of the selected main criteria and the analysis of social clusters, it was an objective of the study to rank the sub-criteria, as well. As the evaluation of the sub-criteria was performed by the SuperDecision software applying the ANP method where the starting point was the ranking order of the main criteria, the average weights assigned to the sub-criteria were in line with the most important characteristics (Figure 6).

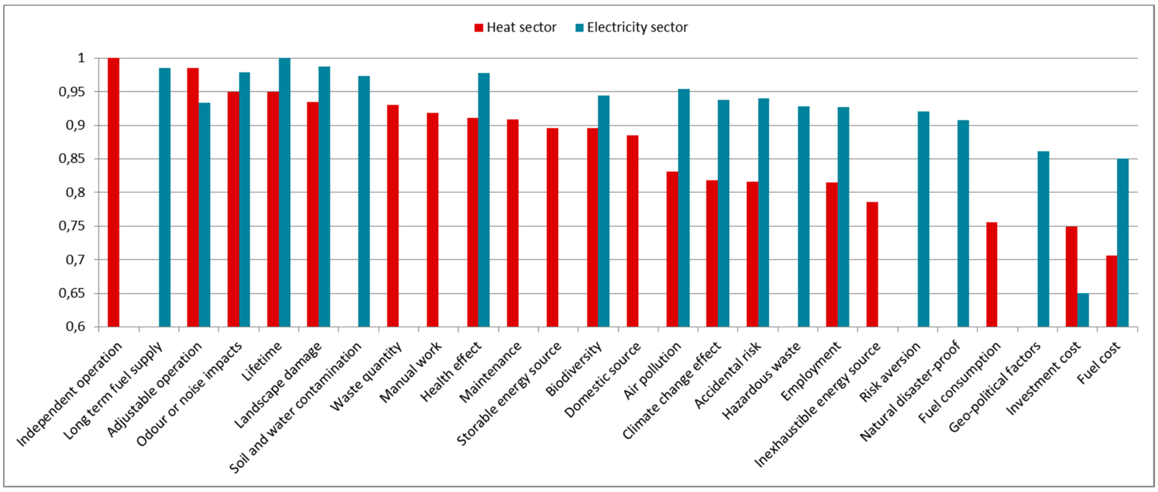


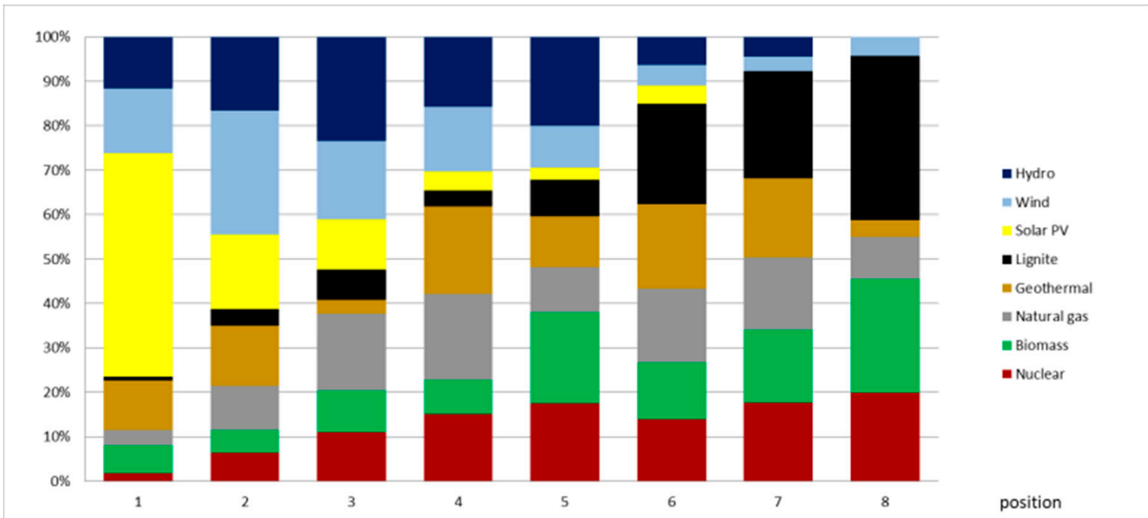
Figure 6. Ranking of the average sub-criteria weights in the heating and electricity sectors.

In the case of heating, clearly the aspects related to flexible operation were at the top of the ranking, while the medium range of the ranking order was dominated by the factors related to the *environment* and *comfort*. *Economic* aspects were at the end of the ranking order, almost without exception. If we are looking for the main criterion that can best aggregate the sub-criteria at the top of the ranking, i.e., for the most important decision factor in the heating sector, *reliable* was the most adequate answer; it contained three out of the first four sub-criteria; therefore, it is more suitable than the main criterion of *comfortable*. For the electricity production, the ranking of the sub-criteria was more leveled. In addition to *efficient*, *state-of-the-art* was also elevated as an important evaluation criterion along with the well-performing main criterion of *renewable*. At the same time, all three main criteria preceded in rank, the main criterion *environment*. As for the heating sector, the economic factors were at the end of the ranking order of sub-criteria, while the aspects related to safe operation attained a hardly better position.

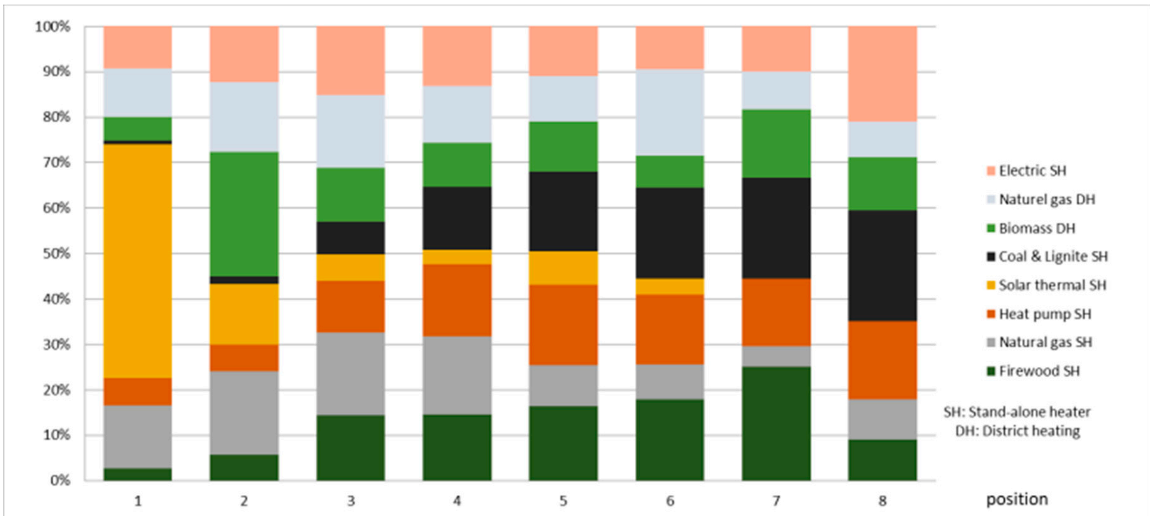
3.6. Ranking of the Alternatives Using Analytic Network Process

After evaluating the main and the sub-criteria, the last step was the ranking of the alternatives, the cluster set of the ANP method. As the evaluations provided by the respondents were based on their experience or theoretical knowledge, the number of evaluated alternatives differ from respondent to respondent. On average, three out of the eight alternatives appear in the answers. The flexibility in the set of alternatives made the mathematical evaluation more difficult; however, it provided important information by making it obvious that the knowledge in the society on renewable energy sources (solar energy 42%; wind energy 26%) is limited in comparison to the more conventional energy sources, natural gas and nuclear energy (natural gas 68%; nuclear energy 49%).

In the completed survey questionnaires, the alternatives were evaluated based on all criteria, but it was a difficult challenge to aggregate them, as the main criteria were not disjoint. The ranking order was established by the SuperDecision software applying the ANP method once again, and the medal table (Figure 7) created from the outcome corresponded with the results of the collection of positive and negative ideas during the focus group discussions.



(**a**)



(**b**)

Figure 7. Medal table of (**a**) electricity production and (**b**) heating alternatives.

It can be clearly seen that the utilization of solar power was prominent in both sectors; most of the responders rated it to the first place. The second and third place in the case of electricity generation was the ordinary wind and hydro energy utilization; however, surprisingly, in case of heating alternatives, the district heating by biomass and natural gas stood at these positions. It is also obvious that coal and lignite were at the end of hierarchy; nevertheless, the judgement of natural gas, which is also a fossil fuel, was expressly positive in the heating sector. Biomass using in electricity production was found to be rather negative. This is a sensible question between experts, since it was not clear if the incineration of biomass for electricity generation was the correct, most effective way for the utilization of such a widely used industrial material. One of the most wondrous results was the high turn-down of firewood stoves, which is still the most popular heating alternative at countryside settlements. Based on these, it can be concluded that the use of firewood was more owing to indigence rather than a free choice. Electric heating and heat pumps are in the second half of the midfield on the medal table, as well as nuclear energy in case of electricity production, of which it is hard to define the exact position.

3.7. Determining Socio Cluster of Alternatives

The results are well in line with the key role of renewable energy sources, highlighting the importance of solar energy, and the high level of opposition to coal and lignite firing. Opinions on other energy sources were less uniform; therefore, we found it important to search for social clusters, similarly to the main criteria. We obtained some simple results after defining social groups based on the supported alternatives and fundamental socio-demographic background variables (education level, income, age). These results can be explained by the fact that the knowledge and experience related to the alternatives drew sharper borders in the society than the main criteria of a more subjective meaning, for which the categorization was not successful. Considering the five income categories, we can conclude that the evaluation of the use of biomass for electricity production was more favorable in the categories of the highest and lowest income, i.e., in the more extreme categories, while it was considered as disadvantageous by the respondents with an income close to the average. The common use of biomass by the people living in poverty was not surprising as wood is easily available, simple to use, and both the equipment and fuel is cheap. The attitude towards nuclear energy was very similar; respondents from a higher income category had a more favorable opinion, while people with an average income had shown lower acceptance. Contrary to this, the opinions on hydro energy had a reverse structure, as the participants from the highest income category downgraded this alternative, while people with an average or lower income gave a better rating. However, it should be noted that in addition to the use of hydro energy, people of average income had a more favorable opinion on lignite-based energy supply, as well, in comparison to people belonging to the other income categories. As for heating, central heating systems using natural gas achieved a higher importance among people of average income; at the same time, lower importance was attributed to it by the participants with less income. Supplementary heating by solar energy had a higher importance weight in the assessment of people with the highest income, while respondents with an average income found it less important. Preferences highlighted by different income categories suggested interesting results, which requires further studies to explain. However, from the aspect of our study, it was essential to specify results which were previously expected (such us high popularity of biomass burning among poor classes), which confirmed the goodness of the method developed.

Similarly to the income, the search for preferred alternatives based on a categorization by settlement types and living conditions was an integral part of the interpretation of the results. Based on that, people living in villages were overrepresented among the respondents showing a preference for wood- and coal-firing, while for the residents of the capital city, district heating with natural gas, and electric heating were of outstanding importance. Considering the housing conditions, it was found that wood-firing had an above-average support from people living in single houses and multi-flat row houses located in the green-belt areas. Coal-firing received a better rating only from respondents who live in single houses. For people living in medium-scale multi-flat buildings, the importance of the use of supplementary heating by solar energy had a higher importance than the average. From participants living in medium-scale and large-scale multi-flat buildings, district heating received an outstanding rating, while the acceptance of electric heating, mostly as supplementary heating, was high among people living in medium-scale multi-flat buildings. There is perhaps no need to emphasize that most of the consequences drawn above were trivial; this stood out especially for the types of buildings and preferred alternatives to heating.

We can also state only one observation with respect to education level. Based on that, the importance weight of the wood-firing was much higher among the respondents who had completed primary or vocational education only, while people having at least an A level or equivalent gave a much lower rating.

The trivialities that are summarized above were also important and affirmative; being in line with the expected results, they clearly demonstrate the explanatory power of the constructed model. We need to highlight that the ranking order of the alternatives is not a result of a direct evaluation by respondents, but they are established as an outcome of the ANP method relying on the mutual pairwise comparisons of criteria and the evaluation of the alternatives based on the criteria. Based on that, the obvious conclusions described above confirm the results with respect to the criteria, as well. At the same time, they underline the need for further research to clarify the somewhat ambiguous individual importance weights or income-related preferences.

4. Conclusions

The aim of our study was to develop an energy sector-related system of criteria, to determine their importance weights and to examine the energy supply preferences based on focus group discussions and a representative questionnaire survey. As a result of the processed survey the developed energy criteria and preferences gives scope for the application of multicriteria decision models for decision preparation in cases forming energy strategies and supporting schemes prior to large industrial investments. The realization of uniformed modeling of such a wide area is rather difficult. The aim of studies investigating different scales like regional energy strategy or a design of a household heating system could be similar, as with the determination of climate effect or reduction of air pollution; however, due to the differences in the scaling the analysis, this requires the consideration of completely different aspects. The survey was separated into two parts, first focusing on household-sized energy utilization which principally referred to household heating alternatives, and secondly, the national-sized energy utilization which processed the alternatives of electricity development. The resulting differences in the ranking of alternatives and weights of criteria clearly demonstrates that differing problems are highlighted in the case of personal experience-related household alternatives compared to the evaluation of a far power plant system. Differences are certainly due to the variant system of criteria; however, it is undeniable that the amount of questions due to the separated two levels became too high, which increased the lack of data and the risk of mistakes. These gaps in the data caused the mathematical evaluation to be more difficult.

As a first step, the set of evaluation criterion was determined based on the notions connected to energy alternatives. The elements of the system of criteria were structured in a hierarchic construction based on the results of the survey. It has to be emphasized that besides the smoothing effect of the big sample, misinterpretations, and data gaps, the definition of complex criteria as the aggregate values of sub-criteria was found to be consistent with results in the literature, which shows the efficiency of the applied mathematical method. The evaluated importance weights met the expectations, except for the *economic* criterion, which for whichever conventional costs (*investment cost* and *fuel cost*) were under rated. To assess the unified whole set of notions and alternatives, the well-known ANP method was used. To simplify the response in the survey, the set of sub-criteria and alternatives were reversed in the model. The most important criteria were found to be *reliable* and *comfortable* in the heating sector, whilst these were *efficient* and *state-of-the-art* in the case of the electricity sector. *Investment* and *fuel cost* were found to be the least important, which is consistent with our previous results. The ranking of alternatives resulted such that conventional renewable energy sources (solar, wind, hydro) are in the forefront. Nuclear, biomass, and natural gas energy were found to be commensurate in the midfield, and, not surprisingly, lignite was the last in the ranking.

Evaluation of energy criteria from the socio-demographic aspect resulted such that the public opinion was uniform. This result is most interesting from the perspective of education, as it highlights that the current didacticism in this region is not capable to raise environmental awareness. It would be favorable to conclude that due to educational activity, the environmental criterion overtook the sub-criteria of comfort.

Supporting techniques for strategic decisions in energy sector are in global focus; thus, it is favorable to expand the study region of our research. As the size of the collected database is representative for Hungary, it is strongly desirable to assimilate results into international studies which could highlight comprehensive regional differences in personal energy supply preferences.

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