Resiliency Analysis of Energy Demand System in Finland.

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RESILIENCY ANALYSIS OF ENERGY DEMAND SYSTEM IN FINLAND

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Abstract. Investigating the performance and productivity level of different energy consuming sectors in all countries is an inevitable action. This procedure will be conducted by comparing the energy input and the output of the system which is vital to ensure that the system is used properly. The proper utilization of systems will lead to more efficiency in the energy consumption section. One of the most important tasks in this type of study is the analysis of uncertainty indicators. The analysis and evaluation of uncertainty indices in energy consumption system is a tool that prioritizes the indicators in terms of importance and impact on each of the consumption targets. These consumption goals include energy, environmental, technical, economical, and social objectives. Ultimately, the output data of the uncertainty analysis will be very helpful for making the system more reliable and usable. In this study, we first introduced different sectors of the energy consumption system in Finland and examined each of these sectors in terms of physical and environmental goals. Then the uncertainty indexes in different sectors are extracted, evaluated qualitatively and quantified using the fuzzy logic method. Finally, indicators are prioritized based on the level of effectiveness and uncertainty. According to the results of this research, among 44 considered indices, the security of energy supply, carbon emission, equivalent annual cost, reliability, and political acceptability are respectively the most important indices for energy, environmental, economic, technical and social goals.

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Introduction

Energy is one of the crucial elements in most economic, environmental, social,

technological and other activities. The national security of many countries around the world also depends on secure energy access. Therefore, the future of the production and consumption of energy carriers and its optimal use is of particular importance [25]. As a result, considering the issues mentioned, the importance of system analysis in the energy sector is doubled. It should be kept in mind that the simple chain of energy includes exploration, extraction, transformation, transportation, storage, distribution, conversion, and consumption [26]. In order to have a dynamic system of energy with the least risk, all system components of the energy chain must be analyzed. This study investigates the energy consumption in Finland [27]. This sector, as the ultimate ring of energy chain, is of particular importance in energy system analysis.

First, we discuss about overall background of Finland. Afterwards, the country's energy consumption system will be analyzed. After that, with the introduction of uncertainty indices of uncertainty will be discussed. Finally, using the fuzzy calculations, the most important indicators in each field will be presented.

1. Background

1.1. Overview of Finland

Between 1995 and 2005, the GDP of Finland grew by 49.77%. On the other hand, according to energy consumption tables and charts during the same period, it can be seen that energy consumption has increased by 32%. So, given that the GDP growth rate is higher than the increase in energy consumption, it can be concluded that the energy consumption structure in Finland was efficient between 1995 and 2005. Similarly, from 2005 to 2015, Finland's GDP faced a growth of 40.39%. Comparing this escalation with the increase in energy consumption between these years, it can be deduced that the energy consumption structure has been beneficial for Finland over the period 2005 to 2015. In general, a profitable energy efficiency structure could be seen from 1995 to 2015 for Finland. The interesting point is that the GDP growth rate in the second decade between 1995 and 2015 is 10% less than the increase in the first decade. Finland was a developing country between 1995 and 2005, while between 2005 and 2015, Finland has become a developed country. This fact could be attributed to a 10% reduction in GDP[1]. In Fig 1, the share of each energy sector from total budget invested in energy efficiency in Finland between 2008 and 2014 could be found.

The rate of unemployment in 2005 was 45.71% lower compared with 1995. But the unemployment rate in the second decade between 2005 and 2015 increased by 12.45%. The main factor behind this increase is the stagnation in Europe [3]. Inflation has also followed a trend similar to that of the unemployment rate. Inflation fell by 33% between 1995 and 2005 and escalated by 105.9% from 2005 to 2015.

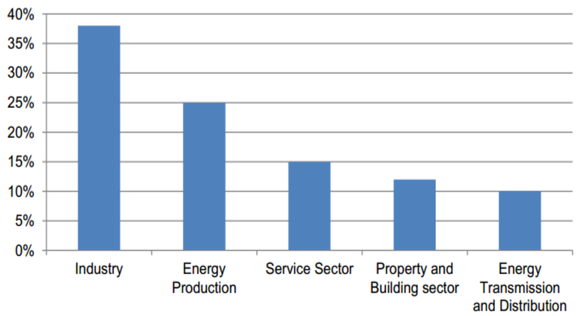

Fig 1. Percentage of all investments in energy efficiency of Finland's different sectors from 2008 to 2014 [2].

1.2. Energy consumption in Finland

The overall energy consumption increased between 1995 and 2015, indicating an increase in both production and wealth creation. But a very important point about the amount of energy used in different sectors is the significant reduction of energy use from 1995 to 2015 in the industry sector. To be more specific, the industrial sector energy consumption share from total energy consumption was 41.36%, 37.04% and 34.29% in 1995, 2005 and 2015 respectively [5]. These changes are due to increased efficiency in the industrial sector through savings and energy audit activities. Also, the rise of welfare level led to the growth of other energy consuming sectors share, which in turn has reduced the industry's share [6].

- According to Coal's share of total energy consumption in 1995, 2005 and 2014, coal's share has declined over the years. This fact suggests that CO2 emissions from Coal consumption have decreased over the years.
- The share of oil products in 2005 was slightly higher than 1995, and then declined slightly in 2015. Generally speaking, it can be said that the share of oil products in total consumption remained steady.
- Considering the share of natural gas from total energy consumption in the industrial sector, this energy carrier has a similar decreasing trend like coal.

- In the case of biofuels and waste, the share of total consumption in the industry initially fell by about 4% in 2005 compared to 1995. Also, it fell by about 7% in 2015 compared to 2005.
- Consumption in the electricity sector has generally remained steady relative to the total consumption in the industry, and this share was about 32%.

2. Energy consumption analyze

In this research, the systemic analysis of energy consumption in Finland is analyzed from two perspectives of physical and environmental [8].

2.1 Physical analyze

On one hand, according to Table 1, the share of renewable energy is approximately one third of Finland's energy consumption [9]. On the other hand, almost 100% of fossil fuels used in this country are imported [10]. Considering these facts, it can be concluded that Finland has relatively low energy security.

Table 1. The share of renewable energy in 1995, 2005 and 2015 [9]

year	1995	2005	2015
Renewable energy share	25.9%	29.5%	33%

To analyze the physical purpose, we consider four main sectors of industry, transportation, household, and agriculture.

2.1.1 Industry

Between different sectors of energy consumption in Finland, the industrial sector uses almost all of the available energy resources, so that all energy

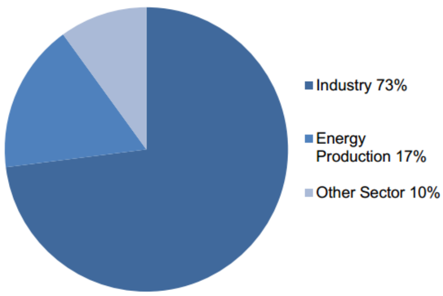

Fig 2. Annual energy savings in 2014 in different sectors [2]

sources can be said to be decisive for the industrial sector. Considering that after the services sector, the industrial sector is the second most important economic sector in Finland, energy consumption in this sector is significant compared with other sectors [5]. The reason for success in this sector is 85% improving efficiency in energy consumption. As shown in Fig 2, the efficiency improving for the 2014 industry sector is 74%. This section includes approximately 200 companies and more than 350 business locations by signing an official agreement [11].

2.1.2 Transportation

The main sources of energy in the transportation sector are oil products, biofuels and waste, electricity, and heat. The transportation system in Finland has developed well, which can be attributed to the dispersed population, the long distance between cities and cold weather. Finland is strong in this sector because of its strong transport infrastructure. Railways, ports, and airfield infrastructure have made Finland the second largest country in the European Union in terms of transportation infrastructure. Although this ranking has fallen for the Finland road section. The high quality of transport infrastructure in Finland can be illustrated through the index of the global economic market [12].

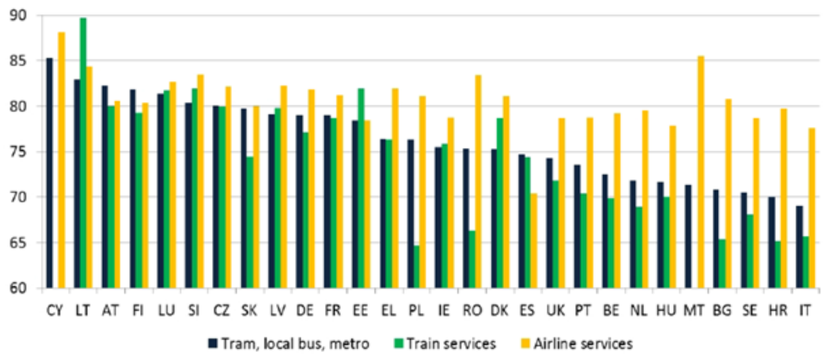

Fig 3. Transport performance index for three types of transport markets in 28 EU countries [13]

In Fig 3, the transportation performance index for three types of transport markets in 28 EU countries is provided.

As it is illustrated in Fig 4, in terms of transport infrastructure between the 28 EU member states in 2014, Finland is ranked the first based on overall ranking [13].

Due to the high growth of Finland in transportation and the increase of technology in this sector, employment is increasing in this area, which is currently the highest average in the European Union [13].

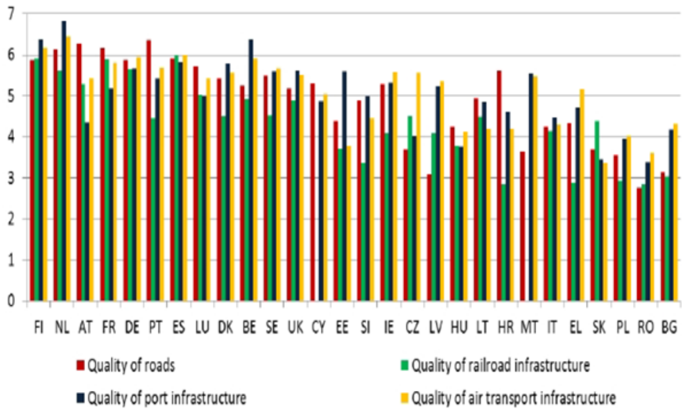

Fig 4. The satisfaction level of the transport sector's infrastructure, in order of better performance for the 28 EU member states [13].

2.1.3 Household

Concerning the main energy sources in the household sector, it has the same energy sources as transportation sector which are oil products, biofuels and waste, electricity, and heat. It is noteworthy that the role of coal and natural gas is relatively low. According to the Finland Meteorological Institute, the average temperature in a cold year is between 5 degrees in the south and -3 degrees in the north of the country, and in the longest winter season is the temperature below zero [7]. As a result, there is a need for continuous heating in a few months, which is more energy demand than the other sectors. That's why many energy sources in Finland are used to generate heat. In the household sector, the majority of energy consumption is used for heat generation purposes as it is noticeable in Fig 5 [2].

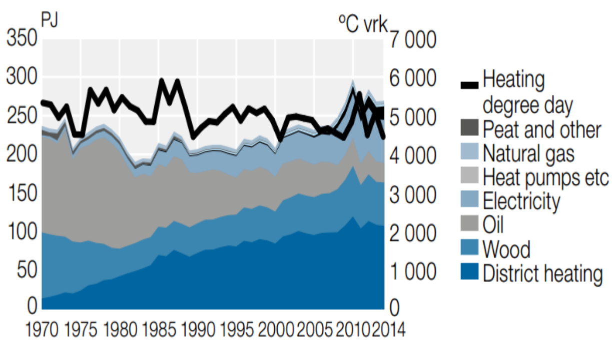

Fig 5. Consumption of energy for heating residential, commercial and public buildings 1970–2014 [7]

According to Fig 5, in Finland, the supply of heating for different sectors is mostly provided by electricity heating, which is an increasing trend.

2.1.4 Agriculture

The main sources of energy consumption in this sector are three sources of oil products, biofuels and waste, and electricity, which, however, contribute much less to this sector than to other sectors.

Finland has been a member of the European Union since 1995. Since then, the common agricultural policy of the European Union has also been implemented in Finland. The economic role of agriculture alone is decreasing in its gross domestic product and employment in primary production. However, when it comes to the food and forestry industry, agriculture forms a significant part of the economy of Finland. The number of farms has steadily declined for the past decades, declining from 80,000 to 60,000 between 2000 and 2012. The agricultural sector of Finland employed 125,000 people in 2010, which is 30% lower than 2000. The focus of the fields has increased on the production of livestock products in the north and east of the country. Agriculture in Finland has progressed with the advancement of technology and modern methods of production have been introduced to farmers along with this development. In addition, the use of a wide range of modern chemical fertilizers, insecticides, agricultural machinery and seed remedies has greatly improved the products. The energy consumption in the agricultural sector in Finland has faced insignificant changes and in general, it can be said that it remained almost constant [14].

The fluctuations of energy intensity in the agricultural sector of Finland could be found in Fig 6 [14]. The share of energy consumption in agriculture sector is much lower than other sectors, including industry and transportation, and is almost the same as the household sector.

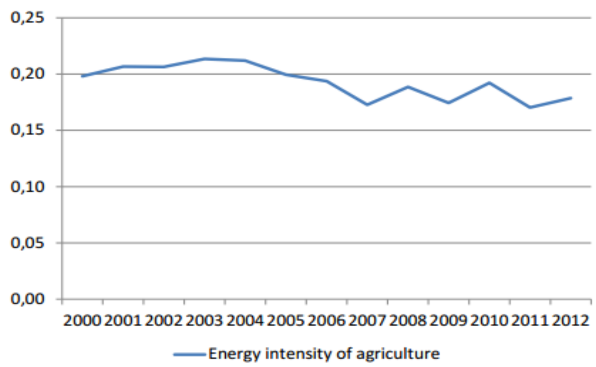

Fig 6. Energy intensity in agriculture in Finland in 2000-2012 [14]

2.2. Environmental analyze

As it is noticeable in Fig 7, fossil fuel sources form about two thirds of Finland energy consumption, it can be said that the energy consumption sector is considered as a polluting sector [14]. Nevertheless, it should be taken into account that consumption of coal and oil products over the past two decades has decreased by 64% and 52% respectively, which has reduced emissions [5]. The percentage of emission reduction due to the lower energy consumption of different energy sources in Finland could be found in Table 2 [5].

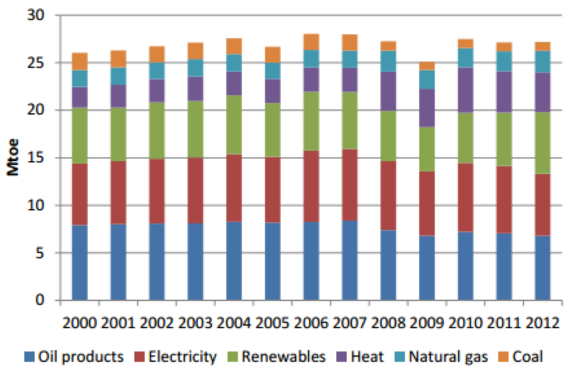

Fig 7. Final energy consumption by fuel in Finland in 2000–2012 [14]

Table 2. Reducing emissions (%) due to reduced consumption of three main types of fossil fuels and other types of fuels [5]

year	coal	Oil products	Natural gas	Biofuels & waste
1995	8.3	59	6.8	25.9
2005	6	48	6.5	39.5
2015	3	28	36	33

It is revealed in Fig 8 that in the last few years, Finland has also experienced a significant decline in its CO2 emissions from fuel consumption in spite of increased energy consumption [1].

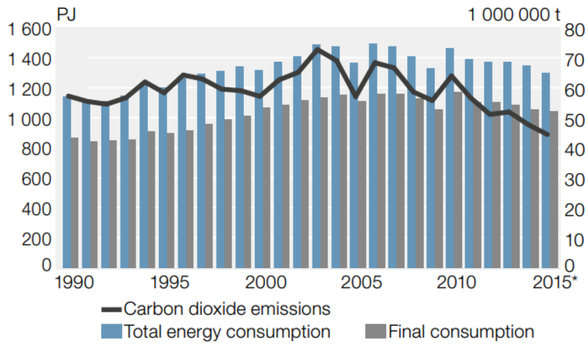

Fig 8. Energy consumption and carbon dioxide emissions [7]

3. Methodology

In recent decades, significant progress has been made in describing and defining the uncertainty of a model, which has been based on planning, decision making, and evaluations. However, the existing uncertainty typology is shared only in partially. Also, in the field of energy planning, less attention has been paid to the uncertainty aspect. In this research, the target is defining the uncertainties of integrated energy planning as well as energy modeling uncertainties. Nowadays, uncertainty analysis in the planning and modeling of energy by planners and energy sector scientists has been neglected. On the other hand, competitive energy markets increasingly have required the analysis of uncertainty [15]. Also, the scarcity of fossil fuels, climate change, increased environmental constraints, and the high share of intermittent energy sources such as wind or solar energy in the energy system will further clarify the need for uncertainty analysis. The effects of uncertainty on competition in the energy sector are not easily predictable and uncertainty in this section should be explicitly examined. Ideally, the energy system should be modeled in such a way that the uncertainty of the various scenarios is examined and the cost of each energy policy can be compared with other policies. In other words, uncertainty is a vital element in the planning of integrated resources. In Fig 9, an overview of the category of uncertainty parameters is shown in the study of the energy system. The most important issue in examining the uncertainty of a model is how to quantify this survey in numbers and figures, which can be easily perceived [16]. There are different methods of quantifying this analysis and conducting the qualitative review. The main difference between these methods is the use of different uncertainty describing methods. For example, membership functions are used in the fuzzy method. While in a random method, we use the probability density function and their similarity is used to determine the quantity of the effect of the input parameter on the output of the model [17].

In this study, we will examine the importance of each uncertainty indicators on the Finland energy consumption system by using the collected data and previous works. The method used in this study is the fuzzy logic. Table 3 provides different indicators which influence the uncertainty of energy consumption.

The basic ability of the theory of fuzzy sets is its ability to represent obscure data and the real world phenomena in which uncertainty exists. Also, this theory allows math and planning operators to use fuzzy domination. A fuzzy set of classes of objects with a continuum membership degrees. Such sets are defined by a membership function, which assigns a membership degree to each object varying between 0 and 1. In fuzzy theory, linguistic variables are used, whose values are fuzzy words instead of numbers, which are rooted in natural language. Fuzzy words, while being inaccurate, are very understandable to human kind and in our languages are used extensively. In Table 4, triangular fuzzy numbers are assigned to each of the language variables specified [24].

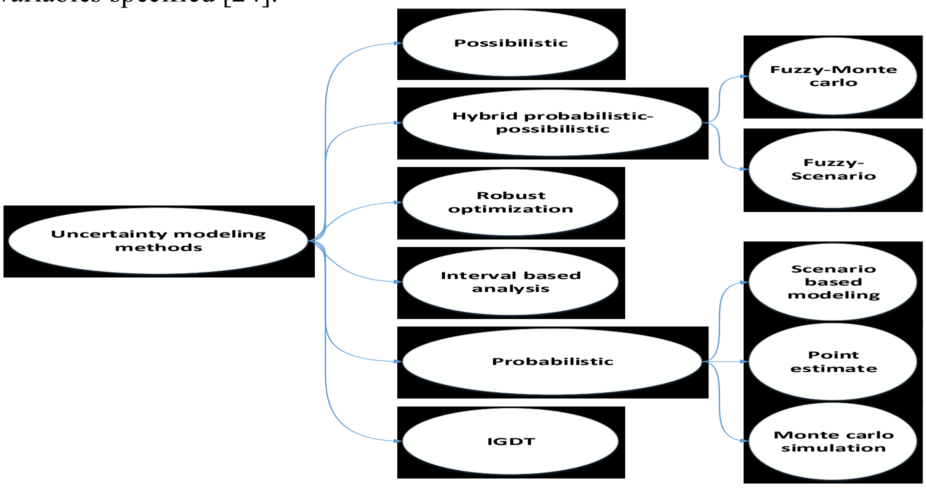

Fig 9**.** An overview of uncertainty quantification tools [16]

At this stage, a questionnaire of uncertainty indicators was developed, and this questionnaire was weighed by more than ten experts in this field, including the professors of the energy sector of the Finland universities. The effectiveness of each uncertainty indicator in the questionnaire could be specified by five options differing from very little effect to very impressive level options. Then, the fuzzy matrix of each index was obtained.

To convert fuzzy numbers to definite numbers, it is sometimes necessary to compare two fuzzy numbers to determine which one is larger than the other.

Sometimes, due to the large variables and the large-scale calculation of fuzzy numbers, fuzzy numbers must be converted to definite numbers. This is called defuzzification or the transformation of numbers from fuzzy to definite. The most important methods for defuzzification are averaging method, the center of sum method, and alpha cutting method.

Table 3. Identification of effective indicators on energy consumption uncertainty

Indicators	Indicators	Indicators
Energy price stability [18]	Market size [18]	Safety [19]
Security for energy supply [18]	Reasonableness for investment cost [18]	Reliability [22]
Low energy prices [18]	Operation and maintenance cost [19]	Maturity [23]
Stability for energy generation [18]	Service life [19]	Feasibility [22]
Carbon emissions [19]	Equivalent annual cost [19]	Risk [22]
SO2 and NO2 emissions [19]	Implementation cost [22]	The duration of preparation phase [22]
Environmental sustainability [18]	Availability of funds [22]	Continuity and predictability of performance [22]
Land use [19]	Development cost [20]	Difficulty of development [20]
Noise [19]	Duration of construction [20]	Difficulty of capacity expansion [20]
Water pollutant [20]	Annual production [20]	Social acceptability [19]
Soil pollutant [20]	Evaluation of domestic resources [21]	Social benefits [19]
Acid rain [21]	Resource potential [23]	Compatibility with the national energy policy objectives [22]
Local economic development [18]	Efficiency [19]	Political acceptability [22]
Increasing employment [18]	Exergy efficiency [19]	Labor impact [22]
Potential for commercialization [18]	Primary energy ratio [19]	

Table 4. Triangular fuzzy numbers associated with each of the linguistic variables

Language variables	**Fuzzy numbers**
Very little effect	0 0 0.3
low effect	0.1 0.3 0.5
Average	0.3 0.5 0.7
Full effect	0.5 0.7 0.9
Very impressive	0.7 1 1

In this research, the center of sum method is used. For each of these indicators, eight to ten answers were received from different faculty members. First, we have converted the fuzzy matrix to the matrix required by this method.

This process is done by using triangular numbers. Then, the center of sum method was applied to the resulted triangular fuzzy matrix in order to conduct the defuzzification procedure.

Then we obtained the average of all fuzzy matrices. The average fuzzy matrix is $(s-l \quad s \quad s+l)$. We extract the triangular fuzzy matrix $(s \quad l \quad r)$ from the previous matrix and the three-dimensional average of the triangular fuzzy matrix gives us the definite number.

Definite number = $\dfrac{s+l+r}{3}$

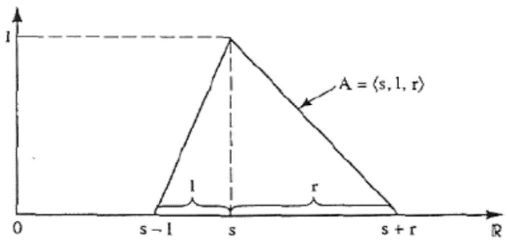

Fig 9. Triangular fuzzy numbers are used

The defuzzification results are given and the definite numbers of each index, which represents the indeterminacy of the index in its domain, are depicted in the spider diagrams. The sequence of steps taken for this quantification is shown in Fig 10.

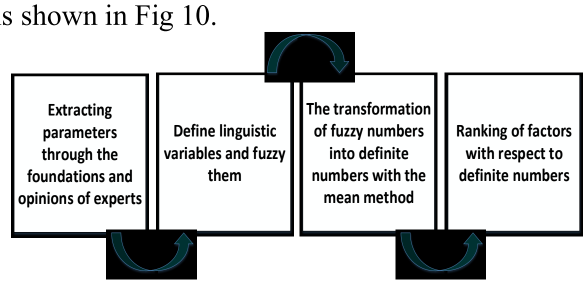

Fig 10. Arrange the quantum steps of uncertainty

4. Results and discussion

As it is mentioned previously, after gathering and analyzing the data of Finaland’s energy consumption system, important uncertainty indicators were extracted from different international references. Then, for each section of Finland’s energy consumption system, an online questionnaire was designed. Some energy experts in Finland participated in these surveys which provided required raw data. Afterwards, these data were weighted and by utilizing the center of sum method, the important indicators in each section were determined. In Figures 11 to 15, which are related to the general goals of energy, environmental, economic, technical, and social, the value of each index can be seen.

Regarding the energy goal indices, among the four noted indices, the security of energy supply index has the highest definite number. This fact suggests that the importance of energy supply security is higher than supply sustainability and energy price in Finland. Moving to environmental goal, the carbon emission index has the highest importance. Albeit, by implementing carbon taxes as a first country, Finland had illustrated its concerns regarding the carbon emission. Therefore, the high value of carbon emission among these indices was not unexpected.

With regards to economic indices, it should be kept mind that despite the magnitude of equivalent annual cost index, other indices such as the potential for commercialization, reasonableness for investement cost and implementation cost are still an important factor in economic aspect. Considering the technical goal, despite the presence of indices like efficiency, maturity, feasibility, and risk, the reliability index will be the most importand factor. This reveals the crucial role of reliability in the technical aspect.

In the social goal diagram(Fig 15), among five suggested indices, the political acceptability has been chosen as the most important index.

To sum up, among 44 considered indices, the security of energy supply, the carbon emissions, equivalent annual cost, reliability, and political acceptability are respectively the most important indices for energy, environmental, economic, technical and social goals.

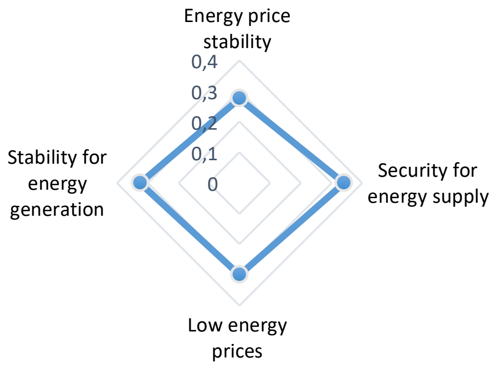

Fig 11. Graph of energy goal index

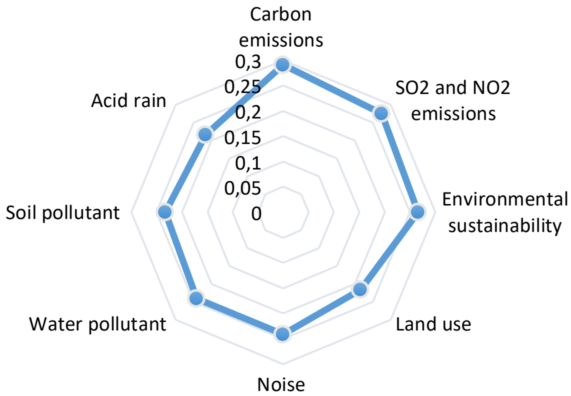

Fig 12. Graph of environmental goal index

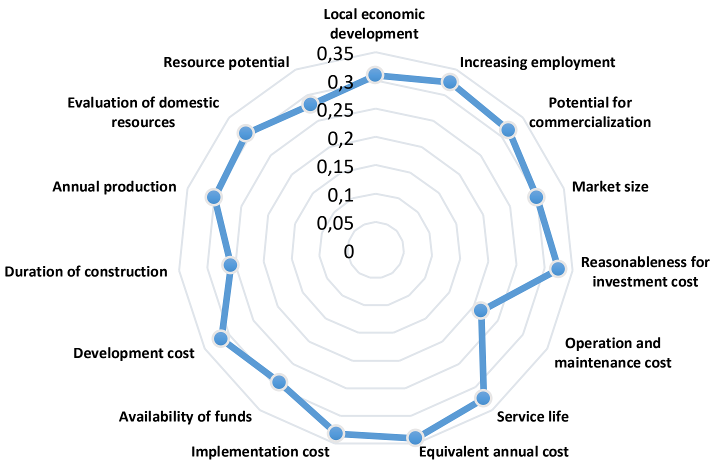

Fig 13. Graph of economic goal index

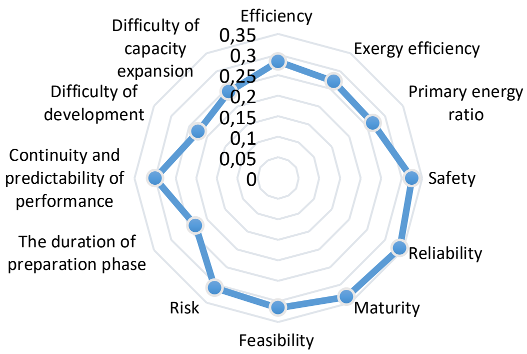

Fig 14. Graph of technical goal index

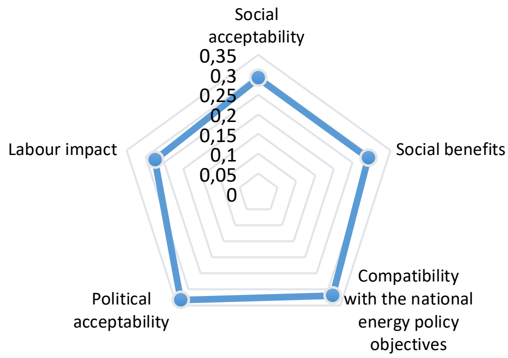

Fig 15. Graph of social goal index

Conclusion

Since energy is one of the most important factors in human activities, analysis of this factor is vital. The analysis of current energy system of Finland is discussed in this article. It should be noted that Finland is dependent on energy imports, and because of the high energy consuming industry, the importance of energy system analysis is doubled. Due to the two factors of complexity and rate of change, the uncertainty assessment in this energy system is unavoidable. In this research, first, the background of Finland's energy consumption in different sectors was studied. Then, a systematic analysis of the energy consumption structure in Finland from both the physical and environmental perspectives was provided. In the next step, various energy indices in most sectors were studied. Here is a brief summary of the findings of this research.

According to the results of the analysis and studies on the energy consumption in Finland, energy consumption and GDP increased between 1995 and 2015. Considering that the increase in GDP has been higher than the increase in energy consumption, it can be concluded that the Finland energy consumption system has been efficient during these years. Another significant point in the Finland energy consumption system between 1995 and 2015 is the increased share of renewable energy in total energy consumption, which may be one of the main reasons for the reduction of CO2 emission. By analyzing the physical and environmental goals of Finland's energy consumption system between 1995 and 2015, it can be concluded that Finland has moved towards these goals year by year. With regard to the above, the result is that the policies taken to improve the system of consumption and exploitation have been successful. According to the output data from the quantification of uncertainty using fuzzy logic (Table 5) and the provided spider diagrams, energy security, carbon emissions, equivalent annual cost, reliability, and political acceptability are the most important indices. These five indices are related to general goals of energy, environmental, economic, technical, and social, have the highest number respectively. The upcoming proposal for this study is to find the uncertainty score of final energy system for Finland. It should also be considered that the study was carried out with the following limitations: due to the lack of direct and complete access to the energy professors of the Finnish universities, the questionnaire was not transmitted comprehensively and few of these were completed by our questionnaire. It is suggested to use the interview method in future.

Table 5. Effective indicators on energy consumption uncertainty along with Triangular matrix numbers, and their final definite numbers after defuzzification..

Ser.	Main goals	Sub-indicators	Fuzzy matrix	Definitive number
1	Energy goal	Energy price stability	0.462,0.1625,0.2	0/275
2		Security for energy supply	0.675,0.212,0.137	0/341
3		Low energy prices	0.537,0.2,0.162	0/3
4		Stability for energy generation	0.612,0.2,0.162	0/325
5	Environ-mental goal	Carbon emissions	0.512,0.162,0.2	0/291
6		SO2 and NO2 emissions	0.45,0.15,0.225	0/275
7		Environmental sustainability	0.45,0.175,0.175	0/266
8		Land use	0.287,0.125,0.237	0/216
9		Noise	0.375,0.137,0.212	0/241
10		Water pollutant	0.35,0.15,0.225	0/241
11		Soil pollutant	0.35,0.137,0.212	0/233
12		Acid rain	0.3,0.1,0.25	0/216
13	Economic goal	Local economic development	0.557,0.185,0.185	0/309
14		Increasing employment	0.587,0.212,0.175	0/325
15		Potential for commercialization	0.587,0.2,0.162	0/316
16		Market size	0.525,0.187,0.187	0/3
17		Reasonableness for investment cost	0.587,0.175,0.212	0/325
18		Operation and maintenance cost	0.562,0.175,0.212	0/216
19		Service life	0.625,0.212,0.137	0/325
20		Equivalent annual cost	0.675,0.212,0.137	0/341
21		Implementation cost	0.65,0.212,0.137	0/333
22		Availability of funds	0.5,0.185,0.185	0/290
23		Development cost	0.562,0.175,0.212	0/316
24		Duration of construction	0.387,0.175,0.212	0/258
25		Annual production	0.525,0.187,0.187	0/3
26		Evaluation of domestic resources	0.562,0.2,0.162	0/308
27		Resource potential	0.471,0.186,0.185	0/281
28		Efficiency	0.487,0.162,0.2	0/283
29		Exergy efficiency	0.457,0.162,0.2	0/271
30		Primary energy ratio	0.437,0.162,0.2	0/266
31		Safety	0.65,0.2,0.125	0/325

32	Technical goal	Reliability	0.662,0.2,0.162	0/341
33		Maturity	0.625,0.187,0.187	0/333
34		Feasibility	0.587,0.2,0.162	0/316
35		Risk	0.55,0.187,0.187	0/308
36		The duration of preparation phase	0.328,0.142,0.228	0/233
37		Continuity and predictability of performance	0.537,0.2,0.162	0/3
38		Difficulty of development	0.337,0.1,0.237	0/225
39		Difficulty of capacity expansion	0.375,0.137,0.212	0/241
40	Social goal	Social acceptability	0.5,0.187,0.187	0/291
41		Social benefits	0.5,0.187,0.187	0/291
42		Compatibility with the national energy policy objectives	0.6,0.2,0.157	0/319
43		Political acceptability	0.65,0.212,0.137	0/333
44		Labour impact	0.462,0.162,0.2	0/275

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