ANALYSIS OF DIFFERENT SCENARIOS AND SUSTAINABILITY MEASUREMENT IN THE DISTRICT HEATING SECTOR IN SERBIA

Marina JOVANOVIĆ[1] *, Vukman BAKIĆ[1], Biljana VUČIĆEVIĆ[1], Valentina TURANJANIN[1]

[1]University of Belgrade-Institute of Nuclear Sciences 'Vinča', Laboratory for Thermal Engineering and Energy, P.O.BOX 522, 11001 Belgrade, Serbia

[*]Corresponding author; E-mail: marinaj@vinca.rs

The district heating system in Serbia, with an installed capacity of 6,600 MW, currently supplies 58 towns with thermal energy. As a candidate country for accession to the European Union, Serbia faces the obligation to reduce the level of its greenhouse gas emissions as part of environmental reforms. This paper presents a basic scenario and three alternatives for final energy consumption in the district heating sector for the years 2015, 2020 and 2025. It is suggested that demand for heating will increase 10% up to 2020 and by 15% up to2025, in relation to 2015 levels, while the share of each energy carrier will not change. Changing the structure of energy sources for heat supply assumes a decrease in the share of coal and liquid fuel, and increases in the use of biomass and natural gas. The results obtained were compared to the General Index of Sustainability which is a measure of the complexity of the proposed energy scenario. The paper considers the formation of related energy indicators as quantitative tools for the analysis of changes. It also proposes a methodology for multi-criteria analysis in the sustainability assessment of complex energy systems based on the stochastic evaluation of criteria (sets of indicators and sub-indicators). In this way, the results of the multi-criteria assessment can help in the decision-making process in cases where economic, social and ecological criteria are considered to be influential.

Keywords*: district heating system, energy scenarios, sustainability, multi-criteria decision*

1. Introduction

Public District Heating (PDH) systems provide services for about 30% of households in the Republic of Serbia (RS). In 2008, these systems consumed approximately 7,108 GWh with the share of natural gas equalling 67%, liquid fuels 19% and coal 14% [1]. The share of thermal energy in final energy consumption for energy purposes in 2015 amounted to around 8.77% [2]. The total emissions of greenhouse gases attributable to these systems amounted to about 2.0 million tonnes of CO_2eq per year.

The basic features of the PDH sector in RS are as follows: the mix of fuel used depends largely on the terms of payment and liquidity of the companies operating in the PDH sector; non-optimized distribution and delivery of heat is one of the problems that lead to inefficiencies in the distribution and delivery of heating energy; losses in the distribution of thermal energy also occur due to the poor state of the distribution network with large water leaks and insufficient insulation; 48% of the distribution network is more than 20 years old.

The Republic of Serbia signed the Convention on Climate Change (UNFCC) in 2001 and ratified the Kyoto Protocol as a non-Annex I country in 2008 [3]. As a candidate country for accession to the European Union (EU), Serbia assumed the obligation to apply European standards concerning the living environment and in the energy sector. As much as 30% of the legislation that needs to be adapted to EU standards is related to the energy sector and environmental protection. This provides the opportunity to contribute to the reduction of GHG emissions, increase energy efficiency, gradually implement the principles of sustainable development, and reduce the local pollution of the environment.

According to the strategy in the energy sector [1], these goals should be realized through implementation of the following measures:

a) Increasing the energy efficiency of heat distribution systems. The EU Directive on energy end-use efficiency and energy services, adopted in 2006, set a 9% energy efficiency improvement target for the period 2008 – 2016. In addition, the EU energy climate package “20-20-20” has defined an objective to achieve a 20% energy efficiency increase by 2020;

b) Introducing contemporary technical solutions characterized by highly efficient performance;

c) Decreasing specific energy consumption by introducing heat consumption metering and payment for the energy actually consumed, together with energy efficient building design solutions;

d) Further substitution of coal and heavy oil with natural gas and (RES), primarily biomass. Nowadays, energy scenarios plan to fully utilize renewable energy technologies in municipal facilities [4].

A techno-economic assessment of RES (biomass) and their use for combined heat and power generation in Serbia was presented in [5], defining characteristics of Serbian renewable energy potentials and their utilization in decentralized energy generation.

Planning for sustainable energy development is a serious and demanding job that requires, among other things, the application of various multi-criteria analysis and decision-making methods. Such analysis has been applied to cities, regions, and countries. The energy demand up to 2030 of Belgrade city, using multi-criteria decision-making tools is analyzed by [6].

Here three different scenarios for the district heating system are presented, offering different combinations of available energy technology and resources. The results of paper name of study by author [7] show how multi-criteria can be applied to evaluation of energy policy scenarios in an Irish city region. In this paper, three different scenarios are analyzed and the results show that absolute reduction and demand management should be prioritized over fuel substitution or renewable energy technologies. Renewable energy resources are an alternative to increasing the energy independence every country. In name of study by authors [8] AHP (Analytic Hierarchy Process) methodology is applied with five criteria for the possible use of renewable energy resources in Cyprus. A study by author [9] different energy scenarios for the district energy system in Vancouver were evaluated and ranked, based on multiple criteria. The evaluation criteria included GHG emissions, particulate matter emissions, traffic load, the maturity of the technology, cost and local source, while natural gas, biomass, sewer heat and geothermal as energy resources were included in the analysis. The results showed that using wood pellets is the best energy option for the Vancouver district heating system [10] considers the multi-criteria analysis which was applied to estimate the sustainability of various energy system options and scenarios taking into account technical, economic, environmental and social impacts.

2. The energy scenarios

Since 2000, the consumption of fossil fuels in district heating systems has grown from year to year [6]. In this same period, there was a significant increase in the use of natural gas to decrease the use of coal and oil derivatives Table (1-3). In 2000, the share of natural gas in the PDH system amounted to 56.7%, while in 2015 it amounted to 74.7%. The use of energy from RES in district heating systems in Serbia is negligible, amounting to only 0.3% in 2015 [2].

Table 1. Consumption of natural gas and liquid fuels used for heat production in PDH sector

Year	Natural gas [m^3]	Residual fuel oil [t]	Gas/diesel oil [t]
2000	307,854,400	105,923	922
2004	484,560,931	118,346	689
2005	509,341,004	141,083	636
2006	491,971,479	140,547	800
2007	456,990,787	149,892	530
2008	463,539,345	149,875	574
2015	563,451,000	87,154	532

Table 2. Consumption of solid fossil fuels in PDH sector

Year	Lignite from underground mines, [m^3]	Dried lignite, [t]	Bituminous coal, [t]	Sub-bituminous Coal, [t]
2000	40,207	14,975	18,149	177,634
2004	31,023	18,767	10,156	126,255
2005	30,967	23,269	15,434	141,763
2006	34,075	18,807	12,897	131,781
2007	27,179	10,508	14,146	127,259
2008	27,072	8,588	3,437	139,192
2015	28,257	5,544	3,543	145,361

Table 3. Energy consumption in PDH sector

Year	Liquid fuels [TJ]	Solid Fuels [TJ]	Natural Gas [TJ]	Biomass [TJ]	Total [TJ]
2000	4,297	4,143	11,095	-	19,535
2004	4,786	3,054	17,463	-	25,303
2005	5,698	3,521	18,357	-	27,576
2006	5,683	3,246	17,731	-	26,660
2007	6,047	2,973	16,470	-	25,490
2008	6,048	2,886	16,706	-	25,640
2015	3,544	3,250	20,338	83	27,215

The fuel used in the PHD sector in 1990 (liquid fuels 46.4%, solid fuels 26.2% and gaseous fuels 27.4%) has shifted gradually to the more environmentally friendly mix recorded in 2004 (liquid fuels 19.7%, solid fuels 12.5% and gaseous fuels 67.8%) [11] and 2015 (liquid fuels 13.1%, solid fuels 11.9%, gaseous fuels 74.7% and biomass 0.3%).

The strategic directions of the PDH sector are: continuous upgrading of existing heating systems, the expansion of the existing district heating system, increasing energy efficiency in the production, distribution and utilization of heat energy, the promotion of new energy systems which will reduce the use of liquid fuel and coal; greater use of biomass and (RES), the use of municipal waste in the production of thermal energy and the combined production of heat and electricity.

In 2015 the total heating surface area of buildings (residential, commercial and institutional) connected to the district heating system, amounted to about 12.5% of the total floor surface area of 315,000,000 m^2, i.e. 39,375,000 m^2 with an average specific heat energy consumption of 180 kWh/m^2. The surface of commercial and public buildings that are connected to the district heating system was approximately 19% of the total heated surface in the PDH sector, that is 7,481,250 m^2.

Based on the available data [1], almost 14% of the total heating area is heated using electricity, primarily due to low unit price compared to the price of final energy from liquid and gaseous fuels. Most electricity in Serbia is generated in lignite-fired power plants with a total efficiency of the energy transformation process of 0.33 and high levels of transmission and distribution loss. This high consumption of residential electricity for space heating is accompanied by correspondingly high GHG emissions in the energy generation sector.

Assessment of the projected growth of housing in Serbia up to 2050 is presented in [7]. Based on this assessment, the floor area of buildings will increase by 1.0-1.4% in the period from 2015 to 2030, and 1.4-1.7% between 2030 and 2050, so that the estimated total building floor area in Serbia will amount to 329,660,000 m^2 and 343,260,000 m^2 in 2020 and 2025, respectively. If we take into account the energy policy and commitments of RS to reduce emissions of greenhouse gases, it seems logical to assume that by 2030, the proportion of the housing stock connected to a district heating system will increase from 12.5% in 2015 to 14.5 % in 2020 and 16.5% in 2025, while the heating surface area in the public and commercial sector will remain at 19% of the total heated surface area which is connected to the district heating system.

PDH sector analysis was performed for the base and three alternative scenarios. The base scenario (BAU- 'business as usual') relates to the assumption that, compared to 2015, thermal energy demand will increase 10% by 2020 and 15% by 2025, while the fuel mix will remain unchanged. In all the alternative scenarios, the thermal energy demand from the PDH sector remains the same as in the BAU scenario, while the fuel share is changed from one scenario to the other. Table 4 presents a projection of using fossil fuels and RES in the PDH sector for different scenarios.

Table 4. Projection of energy consumption in PDH sector according to different scenarios

Year/ Scenario	Total energy [TJ]	Liquid fuel [%]	Solid fuel [%]	Natural gas [%]	RES [%]	Heat from TPP [%]
2015	27,215	13	12	74.7	0.3	0
2020-BAU	29,934	13	12	74.7	0.3	0
2025-BAU	31,297	13	12	74.7	0.3	0
2020- I	29,934	13	12	53	2.5	19.5

2025-I	31,297	13	12	50	5.0	20.0
2020-II	29,934	87.7	11.9	0	0.4	0
2025-II	31,297	87.7	11.9	0	0.4	0
2020-III	29,934	13	0	65	2.0	0
2025-III	31,297	13	0	53	4.0	0

• *The first alternative scenario (I).* The largest heating plant in Serbia, and supplies water for heating in winter and hot water in the summer period is located in the city of Belgrade annually consumes about of 300,200,000 m^3 of natural gas, 45,836 tons of residential oil and about 9,600 t of pellets. Approximately 40 km from Belgrade is the power stationTPP Obrenovac with an installed capacity of 1,522 MW boilers. To reduce the energy dependency rate and net imports, the construction of a hot water pipeline from TPP Obrenovac to Belgrade that would supply Belgrade with thermal energy by the year 2020 is considered. It is estimated that this would result in a saving of 150,000,000 m^3 of natural gas per year.

• *The second scenario (II).* The second scenario represents a hypothetical case in which the entire suplly of natural gas is substituted by liquid fuel. This situation almost became a reality when natural gas supplies were cut off in the winter 2008/2009 due to the Russia-Ukraine crisis. From 2019 Russia will stop delivering natural gas via Ukraine, which is the main direction of supply of natural gas for Serbia. At this moment there is no alternative connection (direction) for supplying Serbia with natural gas.

• *The third scenario (III).* In 2015, the consumption of renewable energy (biomass) accounted for 0.3% of total energy consumption. In this scenario are considered increasing the use of renewable energy with a share of up to 34% (biomass, solid recovery fuels, solar and geothermal energy) in 2025, reducing natural gas use and completely eliminating the use of coal.

2.1 Climate change and calculation of total (equivalent) CO_2 emissions in the district heating sector

One of the imperatives of social development and the preservation of quality of life, the environment and its potential, is the need to protect the air from pollution. According to new estimates of the International Energy Agency (IEA), global emissions from the energy sector in 2016 amounted to 32.1 Gt, as in the previous two years, while the world economy grew by 3.1%. This positive trend is the result of the growth of energy production from renewable sources, the transition from coal to gas, the improvement of energy efficiency and structural changes in the global economy. In order to keep atmospheric warming within the range of 2°C, the increase of greenhouse gas emissions should be halted and then reduced by 40 to 70% in the period up to 2050 compared to 2010.

In Serbia, material damage caused by climate change since 2000 is estimated at more than 5 billion euros, of which about 70% is due to drought (2012) and high temperatures. From the floods of 2014 alone, the damage amounted to more than 1.7 billion euros. Ratification of the two conventions (Convention on Long-Range Trans boundary Air Pollution-CLRTAP with EMEP Protocol (1987) [12] and the United Nations Framework Convention on Climate Change (UNFCCC) (1997) with the Kyoto Protocol (2007) [3], RS as a developing country did not have precise commitments to reduce CO_2 emissions, but had an obligation to report on emissions and the measures which it adopts. In 2017 RS ratified the Paris Agreement and committed to contributing in the future to reduce emissions of greenhouse gases at the global level [13].

A crucial challenge now faces Serbia: how to fight against climate change by reducing greenhouse gas emissions while at the same time developing the energy sector and the economy. The adoption of high environmental standards in the energy sector as the largest emitter of greenhouse gases, as well as in other sectors, is an obligation arising from the EU accession process and the situation facing the whole world.

In RS, the quality of air and the fight against climate change are regulated and defined by the Law on Air Protection ("Official Gazette of RS" No. 36/09 and 10/2013), where the environmental aspects of the operation of heat production plants are regulated in a comprehensive manner, [14]. This law also provides the basis for regulating the area of greenhouse gas emission control and the gradual decrease in the use of ozone-depleting substances. Furthermore, in 2009, a system for air monitoring was installed in the RS with 28 automatic metering stations and a reference laboratory.

In solving problems related to climate change, one of the basic tasks is the calculation of the greenhouse gas emissions. In this paper, the prescribed IPCC methodology (Intergovernmental Panel of Climate Change) is used to calculate the emissions of: carbon- dioxide (CO_2), methane (CH_4), nitrogen-suboxide (N_2O), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOC), carbon-monoxide (CO), sulfur-dioxide (SiO_2) and the total equivalent of carbon-dioxide (CO_2eq) [15,16]. Based on these data, national reports are produced that are comparable with the data of other such national reports. Table 5 shows the calculated greenhouse gas emission values in the district heating sector in Serbia, for the BAU scenario and the three different scenarios by 2025, using the IPCC methodology. Different scenarios result in different levels in the projection of future greenhouse gas emissions.

Table 5. Projection of GHG emissions according to different scenarios

Year/Scenario	GHG emission [t]							
	CO_2	CH_4	N_2O	NO_x	NMVOC	CO	SO_2	CO_{2eq}
2015	2,079,000	34.22	8.71	4,735	136	525	7,620	2,082,451
2020 - BAU	2,286,650	37.63	9.58	5,206	149	577	8,380	2,290,446
2025 - BAU	2,391,330	39.35	10.02	5,445	156	603	8,760	2,395,300
2020 - I	1,811,220	31.15	8.93	4,234	117	447	8,380	1,814,660
2025 - I	1,831,780	31.72	9.25	4,300	118	451	8,760	1,835,330
2020 - II	3,660,550	132.13	30.72	9,643	232	714	30,730	3,673,008
2025 - II	3,827,600	138.16	32.12	10,083	243	747	32,120	3,840,626
2020 - III	1,747,011	31.18	4.29	3,710	117	447	3,900	1,748,092
2025 - III	1,556,965	28.81	4.10	3,302	103	393	4,080	1,558,907

Figure 1 shows calculated CO_{2eq} emissions in the PDH sector, for different scenarios relative to 2015 CO_{2eq} emission levels. In the case of BAU scenario, characterized by an unchanged fuel mix, an increase of the GHG emissions is proportional to the increase in energy demand. The scenarios I and III obviously indicate the positive impact of reducing fossil fuels on CO_{2eq} emissions. The renewable energy resources and domestic fossil fuel resources will be the main energy resources in the future.

Scenario II shows a sharp increase in CO_{2eq} emissions as a result of fuel switching to liquid fuels, as examined for the case of natural gas supply cut-off.

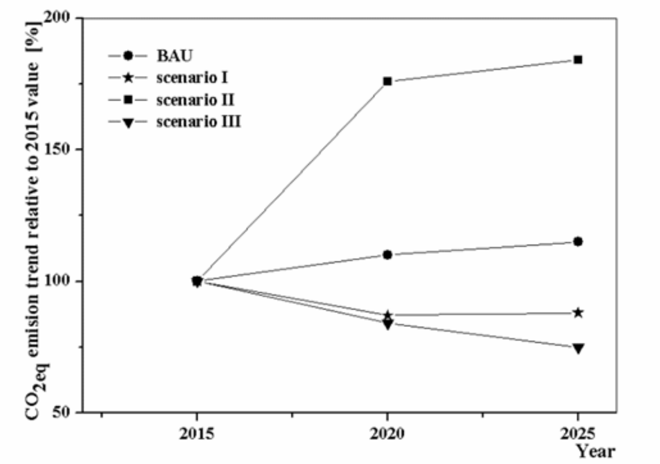


Figure 1. GHG emission projections until 2025 according to the scenarios

3. Selecting criteria and indicators for assessing sustainability

This paper describes business as usual (BAU) and three alternative scenarios which are presented as nine different options up to 2025 for thermal energy generated from coal, liquid fuel, gas and renewable energy sources in DHS in Serbia. All the scenarios imply different directions of fuel use and consumption in the future. Furthermore, they represent a tool for comparative assessment of different policies and strategies when considering a reduction of CO_2 emissions as well as in achieving sustainable development. Comparing and analyzing different scenarios provides insight and facilitates informed choice of a future path towards sustainable development of the observed energy system.

In the long term settings decision, sustainability of district heating system was estimated with a methodology which used for support in the decision-making process. Since the sustainable development of the complex energy system consideration and defines from the many aspects such as: economic, social and environmental, in this paper the energy indicators for sustainable development (EISD) for the energy district heating system are selected and defined.

This research analyzes a set of indicators for nine options which were defined in BAU scenario as well as the in three alternative scenarios for 2020 and 2025 (Table 6-8).

Table 6. Economy sub-indicators

Scenario	Year	Options	I_{EC1}	I_{EC2}	I_{EC3}	I_{EC4}	I_{EC5}	I_{EC6}
			kWh/m^2	EUR/hhmb	kWh/m^2	EUR	EUR	GWh/ GDP
BAU	2015	1	192.15	256.20	143.59	339,237,840	453,946,200	1.489
	2020	2	174.09	221.42	130.11	379,384,376	507,620,772	1.423
	2025	3	153.62	201.79	114.80	409,634,946	548,135,658	1.280
Scenario I	2020	4	174.09	119.98	37.76	110,108,294	391,117,644	1.423
	2025	5	153.62	108.02	37.46	133,649,334	435,028,300	1.280
Scenario II	2020	6	174.09	373.47	152.64	445,062,710	915,381,720	1.423
	2025	7	153.62	389.43	134.68	480,549,132	1,131,073,580	1.280
Scenario III	2020	8	174.09	271.61	16.98	49,500,402	915,381,720	1.423
	2025	9	153.62	284.58	33.43	119,270,340	1,131,073,580	1.280

Table 7. Social sub-indicators

Scenario	Year	Option	I_{SO1}	I_{SO2}	I_{SO3}	I_{SO4}
			kWh/hh	kWh/hh	%	%
BAU	2015	1	12.30	0.045	9.2	67
	2020	2	11.14	0.041	6.5	63
	2025	3	9.83	0.037	4.9	58
Scenario I	2020	4	11.14	0.482	3.5	63
	2025	5	9.83	0.850	2.6	58
Scenario II	2020	6	11.14	0.041	11.1	58
	2025	7	9.83	0.037	9.4	52
Scenario III	2020	8	11.14	3.025	8.1	71
	2025	9	9.83	4.128	6.9	72

Table 8. Environmental sub-indicators

Scenario	Year	Option	I_{EN1}	I_{EN2}	I_{EN3}	I_{EN4}
			kg/kWh	kg/kWh	kg/kWh	kg/kWh
BAU	2015	1	0.275	6.259E-04	1.007E-03	1.79306E-05
	2020	2	0.275	6.256E-04	1.007E-03	1.79266E-05
	2025	3	0.275	6.258E-04	1.007E-03	1.79308E-05
Scenario I	2020	4	0.407	9.52E-04	1.88E-03	2.62517E-05
	2025	5	0.411	9.64E-04	1.96E-03	2.64245E-05
Scenario II	2020	6	0.615	1.62E-03	5.16E-03	3.89758E-05
	2025	7	0.619	1.63E-03	5.19E-03	3.92499E-05
Scenario III	2020	8	0.293	6.23E-04	6.55E-04	1.96031E-05
	2025	9	0.252	5.34E-04	6.60E-04	1.67009E-05

This paper also introduces economic, social and environmental criteria in order to overcome randomness in the sustainability assessment of energy options for different scenarios. This paper shows that formed indicators numerical expressing the essential character of options and the sets of forming sub-indicators represent the aspects or consequences of energy production and consumption.

This means that the indicators for certain criteria show quantitative values (input date) in a mathematical model for computing the sustainability index. In order to analyze the sustainability of the chosen options, six economic and four social and environmental sub-indicators were selected, defined and computed. In Tables 6-8 the calculated values of the sub-indicator sets within each of the analyzed indicators are presented [17-25]. On the basis of statistical data, data from the literature and the estimated values, the following sub-indicators values were calculated: a) *Economic*: specific thermal energy consumption per unit heating surface area I_{EC1}(kWh/m^2); specific costs for home heating per household member, I_{EC2}(EUR/hhmb); the maximum expected potential to reduce the consumption of heating energy from gas production per unit heating surface area, I_{EC3}(kWh/m^2); the maximum expected potential to reduce the cost for heating by reducing the amount of gas and introducing renewable energy sources, I_{EC4}(EUR); total costs required for the production of thermal energy, I_{EC5}(EUR); thermal energy generation by GDP, I_{EC6}(GWh/GDP); b) *Social:* specific thermal energy consumption per household, I_{SO1}(kWh/hh); usage of renewable energies per household, I_{SO2}(kWh/hh); share of space heating cost in household revenue, I_{SO3}(%); energy supply security, I_{SO4}(%); c) *Environmental*: carbon-dioxide emissions per unit of energy production, I_{EN1}(kgCO_2/kWh); sulphur-dioxide emissions per unit of energy production, I_{EN2} (kgSO_2/kWh); nitrogen-oxide emissions per unit of energy production, I_{EN3}(kgNOx/kWh); emission of non-methane volatile organic compounds per unit of energy production, I_{EN4}(kg/kWh).

4. Assessment of sustainability of selected options by general index using MCDM

The result of this research illustrates an established methodology of multi-criteria sustainability assessment for the previously mentioned scenarios. The aim of the present paper is to assess the quality of the options with a view to sustainability and establish a ranking of options for thermal energy production in PDH with a General Index of Sustainability (IS). The ASPID (Analysis and Synthesis Parameters under Information Deficiency) multi-criteria method is used in this paper. This procedure is based on 'the fuzzy set synthesis technique', which is a mathematical system to support decision-making processes and is useful when dealing with vague information and uncertainty [26,27].

In this study we put forward and analyzed three cases when economic, social and environmental indicators are important [28]. Depending on the priority, which is given to specific criteria over weight coefficients, different priority lists of examined options can be obtained. In all the analyzed cases, the importance given to one of the sub-indicators varies. Rating scale of the options for different values of IS are shown in Table 9.

Table 9. Rating scale of options for different values of IS

IS	Descriptors
0 - 0.2	Very poorly ranked option
0.2 - 0.4	Low level of sustainability
0.4 - 0.6	Averagely ranked option
0.6 - 0.8	Well ranked option
0.8 - 1	Highly ranked option

Table 10. Option sustainability ranking for analysing cases

Option	CASE 1			CASE 2			CASE 3		
	Rating scale	IS	P	Rating scale	IS	P	Rating scale	IS	P
1	5	0.625	1	7	0.284	0.833	5	0.701	0.583
2	3	0.763	1	5	0.564	0.875	4	0.733	0.833
3	1	0.945	0.5	1	0.942	1	2	0.821	1
4	4	0.761	1	4	0.653	0.625	7	0.286	1
5	2	0.882	0.833	3	0.784	0.792	6	0.379	1
6	9	0	0.958	9	0.104	0.750	9	0.144	0.875
7	8	0.070	0.958	8	0.188	0.833	8	0.215	0.625
8	7	0.256	1	6	0.451	1	3	0.764	0.958
9	6	0.329	-	2	0.827	-	1	0.841	-

Figure 1 shows a ranking list of options for Case 1 where the economic indicator has priority (w=0.671; Sd=0.198) in relation to the social and environmental indicators which are equal in importance (w=0.164; Sd=0.099).When the economic indicator and economic sub-indicators of specific costs for home heating per household member have priority, Options 3 and 5 are place top of the priority list as the most sustainable. Options 1, 2 and 4, with values of IS= 0.625; 0.763 and 0.761, respectively are well-ranked options (Table 10), but option 7 is very poorly ranked (IS= 0.070).

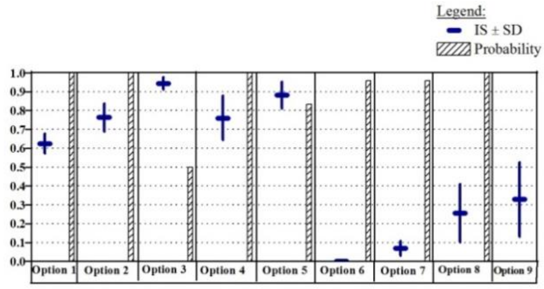
CASE 1

$I_{EC} > I_{SO} = I_{EN}$

Constraint:

$I_{EC}(I_{EC2}>I_{EC5}> I_{EC4}= I_{EC3}>I_{EC6}=I_{EC1}) > I_{SO} (I_{SO1}=I_{SO2}>I_{SO3}>I_{SO4}) = I_{EN} (I_{EN1}>I_{EN2}=I_{EN3}>I_{EN4})$

a)



b)

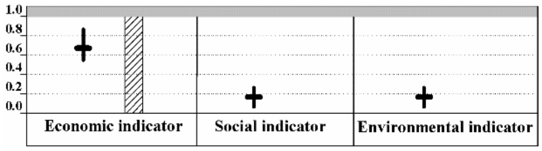


Figure 2. Priority list of options for Case 1 a) Index of sustainability b) weight coefficients

For Case 2, when priority is given to the social indicator (w= 0.671; Sd= 0.198) and the sub-indicator of the share of space heating costs in household revenue, Option 3 and Option 9 have the highest index of sustainability, Figure 3 and Table 10. Options 4 and 5 are in the well ranked group of options (IS=0.6-0.8). At the bottom of the priority list, are Option 6 and Option 7.

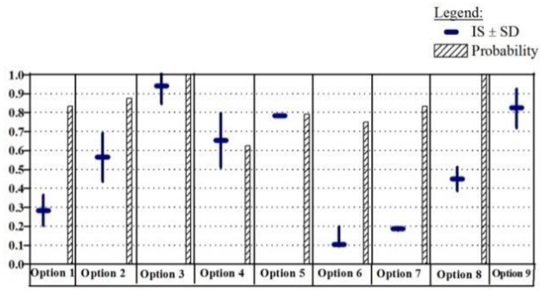
CASE 2

$I_{SO} > I_{EC} = I_{EN}$

Constraint:

$I_{SO}\ (I_{SO3}>I_{SO2}=I_{SO1}>I_{SO4}) > I_{EC}\ (I_{EC3}>I_{EC2}> I_{EC1} = I_{EC6}>I_{EC4}=I_{EC5}) = I_{EN}\ (I_{EN1}= I_{EN4}>I_{EN3}>I_{EN2})$

a)



b)

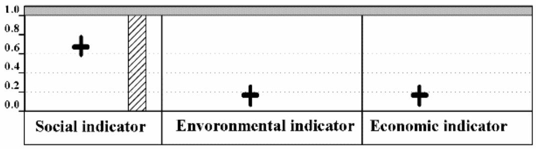


Figure 3. Priority list for Case 2 a) Index of sustainability (IS) b) weight coefficients (w)

For Case 3 in Figure 4, when the economic and social criteria are equally weighted and priority is given to the environmental dimension (sub-indicators of sulfur-dioxide emissions and nitrogen-oxide emissions per energy production), the best level of sustainability are provided by Option 3 and Option 9 as in the previous case (IO is 0.821 and 0.841, respectively). Options 1, 2 and 8 with value IO of 0.701; 0.733 and 0.764, respectively are very well-ranked on the priority list. Figure 3 shows that Options 6 and 7 are very poorly ranked.

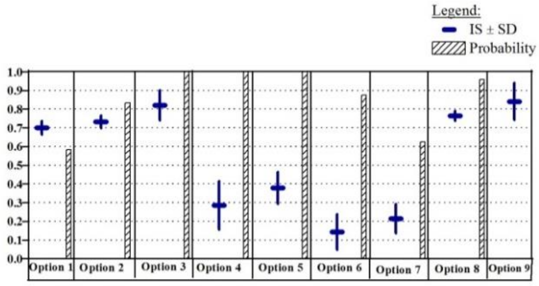
CASE 3

$I_{EN} > I_{SO} = I_{EC}$

Constraint:

I_{EN} (I_{EN2}=I_{EN3}>I_{EN1}>I_{EN4}) > I_{SO} (I_{SO2}>I_{SO1}>I_{SO3}=I_{SO4}) = I_{EC} (I_{EC4}=I_{EC3} >I_{EC1}>I_{EC2}=I_{EC5}= I_{EC6})

a)



b)

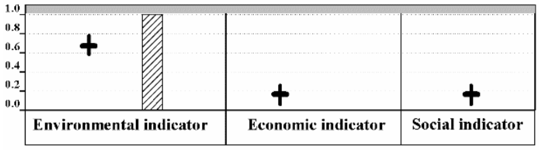


Figure 4. Priority list for Case 3 a) Index of sustainability (IS) b) weight coefficients (w)

The calculated values of probability (p>50%) for each pair of options, in all cases, shows that all combinations are realistic for the predefined constraint.

In this paper, the relative weight coefficients of the specific criteria (indicators) are determined using the mathematical procedure of the ASPID method and are numerically expressed and have a major impact on the IS as well as on the ranking of options.

5. Conclusion

Gas is the main source for the production of thermal energy in RS but because of the ever-present possibility of a gas crisis, the lack of domestic coal due to possible floods and environmental pollution and the unsustainable price of fuel oil, the alternative scenarios that were analyzed in this paper provide renewable sources (SRF, biomass, solar and geothermal) of thermal energy production.

To assess the sustainable development of district heating systems up to 2025 in the Republic of Serbia, the paper considers nine options for several scenarios. The first option is to use the BAU scenario that examines the consequence of continuing current trends in heat energy production technology. The data show that the heat energy produced in district heating systems in the RS in 2015 obtained from the gas of 75% and residual fuel oil of 13%. It is noted that in relation to the BAU scenario, the share of gas decreases to 22% or 10% in Scenario I and Scenario III. Scenario II does not predict gas consumption and the largest part of thermal energy production comes from the residual fuel oil. Also, reduction of gas consumption is made up for by the thermal energy from the thermal power plant (Scenario I) or introduction of RES in Scenario III.

The results of this research illustrate the use of the multi-criteria method and improve the quality of the evaluation of the most sustainable energy options according to different aspects of sustainability. For all of the cases option 3 is a perfect ranking option (BAU scenario for 2025), and for Case 3 and Case 2 Option 9 (scenario III for 2025) has the highest sustainability. Moreover, in every case, Options 6 and 7 (scenario II for 2020 and 2025) have a very low level of sustainability and are located at the bottom of the priority list.

The sector of thermal energy production and supply can develop in order to sustainable development, increased by the efficiency of final energy use and the production and delivery of safety and environmentally-friendly energy sources. Sustainable development requires the consideration of economic, environmental and social aspects to measure the sustainability index of energy systems. The main objective of this paper is to show that energy indicators represent a measure of criteria in order to estimate sustainability of energy scenarios and tool in establishing links between energy goals and sustainable development for those involved in the formation of a sustainable development policy. This paper considers ASPID method in multi-criteria decision approach in order to inform stakeholders, policymakers, investors, and analysts about the sustainability status of energy system options. The established methodology in this paper can help policy makers in finding future decisions in the selection of district heating system options.

Acknowledgment

This work was carried out within the framework of research projects: (1) "Improving the energy performance and the indoor air quality of educational institution buildings in Serbia with the impact on health", Project number: III42008 and (2) "Development of new meteorological mast for turbulence parameters characterization", Project number:TR33036; financed by the Ministry of Education, Science and Technological Development of Serbia.

References

[1] The strategy of energy sector development in the Republic of Serbia until 2015, Termotehnika, 31(2005), 1-2, pp.13-70 (in serbian).

[2] The energy balance of the Republic of Serbia for 2015, No.622, Federal Statistical Office, Belgrade, Serbia, 2017

[3] ***, Kyoto Protocol to the United Nations Framework Convention on Climate Change, UN 1998, http://unfccc.int/resource/docs/convkp/kpeng.pdf

[4] Tomic, T., Cosic, B., Schneider, D. R., Influence of legislative conditioned changes in waste management on economic viability of MSW-fuelled district heating system–case study, *Thermal Science*, 20(2016), 4, pp.1105-1120

[5] Glavonjic, B., Oblak L., Consumption of woody biomass in industry, commercial and public facilities in Serbia. Present State and Possible Contribution to the Share of Renewable Sources in Final Energy Consumption, *Thermal Science*, 16(2012), 1, pp.7-19

[6] Grujic, M., Ivezic, D., Zivkovic M., Application of multi-criteria decision-making model for choice of the optimal solution for meeting heat demand in the centralized supply system in Belgrade, *Energy*, 67(2014); pp.341-350.

[7] Browne, D., O'Regan, B., Moles, R., Use of multi-criteria decision analysis to explore alternative domestic energy and electricity policy scenarios in an Irish city-region, *Energy*, 35(2010), pp. 518-528.

[8] Theodorou, S., Florides, G., Tassou, S., The use of multiple criteria decision-making methodologies for the promotion of RES through funding schemes in Cyprus-A review, *Energy policy*, 38(2010), pp.7783-7792

[9] Ghafghazi, S., Sowlati, T., Sokhansanj S., Melin S., A multicriteria approach to evaluate district heating system options, *Applied Energy*, 87(2010), pp.134-1140

[10] Wang J.J., Jing Y.Y., Zhang C.F., Zhao J.H., Review on multi-criteria decision analysis aid in sustainable energy decision making, *Renewable and Sustainable Energy Reviews*, 13(2009), pp.2263–2278

[11] Cvetinovic, D., Stefanovic, P., Markovic Z., Bakic V., Turanjanin V., Jovanovic M., Vucicevic B., GHG (Greenhouse Gases) emission inventory and mitigation measures for public district heating plants in the Republic of Serbia, *Energy*, 57(2013); pp.788-795

[12] ***, 1979 Convention on long-range transboundary air pollution, https://www.unece.org/fileadmin/DAM/env/lrtap/full%20text/1979.CLRTAP.e.pdf

[13] ***, Paris Agreement, CCC/CP/2015/L.9, https://unfccc.int/resource/docs/2015/cop21/eng/l09r01.pdf

[14] The Law on Air Protection, No. 36/09 and 10/13, Official Gazette of RS, Belgrade, Serbia http://www.paragraf.rs/propisi/zakon_o_zastiti_vazduha.html (in serbian)

[15] IPCC 2006 Guidelines for national Greenhouse gas Inventories, Methodology Reports https://www.ipcc-nggip.iges.or.jp/public/2006gl/

[16] EMEP/EEA air pollutant emission inventory guidebook 2016, EEA Report No 21/2016, European Environmental Agency, 2016 https://www.eea.europa.eu/themes/air/emep-eea-air-pollutant-emission-inventory-guidebook/emep

[17] Stefanović, P., Bakić, V., Marković, Z., Jovanović, M., Turanjanin, V., Cvetinović D. et all. Emission of greenhouse gases in PE 'Heating plants' in the cities of the Republic of Serbia in the period 1990 to 2008, Internal report NIV-ITE 2010, No. 445, Institute of Nuclear Science Vinca, Laboratory of Thermal Energy and Engeneering, Belgrade, Serbia, 2010 (in serbian).

[18] The typology of the residential building stock in Serbia and modeling its low-carbon transformation Serbia, Report of the project: Support for Low-Emission Development in South Eastern Europe (SLED), december 2015

[19] Fundamentals of balancing energy building, Serbian Chamber of Engineers, Belgrade, Serbia 2012 (in serbian)

[20] The Official Gazette of the City of Belgrade, No. 56, Belgrade, Serbia, 30 september 2015 (in serbian)

[21] ***, Eurostat-Half-yearly gas prices, http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Half-yearly_gas_prices_(EUR).png

[22] ***, The World Bank in Serbia, http://www.worldbank.org/en/country/serbia/overview

[23] ***, Trading Economics,

http://www.tradingeconomics.com/serbia/gdp

[24] ***, http://www.deagel.com/country/Serbia_c0178.aspx

[25] Republic Institute for Statistics, statistics of employment and earnings, No.15-year LXVII: 25/01/2017, Belgrade, Serbia, 2017 (in serbian).

[26] Afgan, N., Carvalho, M., Jovanović, M., Biomass-fired power plant: the sustainability option**,** *International Journal of Sustainable Energy*, 26(2007), 4, pp.179-193

[27] Afgan, N., *Quality, sustainability and indicators of energy systems*, Instituto Superior Tecnico, Lisbon, Portugal; 2003

[28] Škobalj, P., Kijevčanin, M., Jovanovic, M., Afgan, N., Erić, M., Energy indicators impact in multicriteria sustainability analyze of thermal power plant unit, *Thermal Science*, 21(2016),2, pp.1143-1151