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Application of multi-criteria decision-making model for choice of the optimal solution for meeting heat demand in the centralized supply system in Belgrade

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ABSTRACT

The expected growth of living standard, number of inhabitants and development of technology, industry and agriculture will cause a significant increase of energy consumption in cities. Three scenarios of energy sector development until 2030 and corresponding energy consumption for the city of Belgrade are analyzed in this paper. These scenarios consider different level of economic development, investments in energy sector, substitution of fossil fuels, introduction of renewable energy sources and implementation of energy efficiency measures. The proposed model for selection of optimal district heating system compares different options for fulfilling expected new heat demand through eight criteria for each scenario. Proposed options are combination of different energy sources and technologies for their use. The criteria weights are set according to Serbian economy and energy position. The criteria include financial aspects, environmental impact and availability of energy. Multi-criteria method ELECTRE (ELimination Et Choix Traduisant la REalite) is used as a tool for obtaining the optimal option. It is concluded that combination of CHP (combined heat and power) plant and centralized use of geothermal energy is optimal choice in the optimistic scenario. In the pessimistic and business as usual scenario the optimal option is combination of new gas boilers and centralized use of geothermal energy.

1. Introduction

Planning of sustainable energy development is a complex and very responsible process. Since many decision makers are involved in the process, only adequate multi-criteria analysis can create a good basis for a quality decision. Many papers propose assessments and suitable tools, with different criteria and associated weights, for the selection of the optimal option [1,2]. Researches based on multi-criteria analysis are applied to cities, regions and islands [3–7]. The most frequently used multi-criteria decision analysis (MCDA) methods are ELECTRE (ELimination Et Choix Traduisant la REalite) [6,8–11], PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) [2,4,6,7,9,11] and AHP (Analytic Hierarchy Process) [6,10].

As a tool for multi-criteria analysis, this research use ELECTRE (ELimination Et Choix Traduisant la REalite) method. It was applied in many cases, studies or researches for decision making in energy sector. This method of multi-criteria analysis was created in the 1960s in order to select the best action from a proposed set of actions, but it was applied to choosing, ranking and sorting. This outranking method of decision making appears in many forms. It is used to discard some unacceptable alternatives. ELECTRE is used successfully for planning and evaluating regional energy development: – the action plan of using renewable energy sources (RES) at the island of Sardinia [10] and for the Energy Strategy of the island of Crete [7]. In both cases, numerous technical, economic, political and environmental criteria are set, in order to assist in decision making. This method was also used for ranking of alternatives for the selection of heating systems [10] and for planning of community heating systems [12].

Planning of sustainable energy development is also characterized by sometimes very far time horizon. There are some significant researches, strategies and papers which deal with long-term energy planning (20–40 years). Some of them were done in developing countries [13,14], but there are good examples related to the most developed countries in the world [15–18].

Since presented research is suitable to be applied to cities, the model proposed in this paper is applied to Belgrade. Different

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Table 1
Structure of energy consumption by sector and by fuel in 2010 in Belgrade (GWh).

Energy source	Households		Public and commercial activities		Industry		Agriculture		Transport		Total – by fuels	Share of fuels (%)
	GWh	%	GWh	%	GWh	%	GWh	%	GWh	%	GWh	
Electricity	3910.24	47.36	2299.25	38.01	760	17.16	98.41	18.18	201.9	3.50	7269.8	29.03
Natural gas	313.28	3.79	64.73	1.07	711	16.05	32.15	5.94	0	0	1121.16	4.48
Coal	639.75	7.75	93.16	1.54	1022	23.08	23.11	4.27	0	0	1778.02	7.10
Liquid fuels	68.43	0.83	2744.46	45.37	1936	43.71	363.44	67.14	5566.8	96.50	10,679.13	42.64
Heat from district heating	2446.89	29.64	756.13	12.50	0	0	0	0	0	0	3203.02	12.79
Geothermal energy	16.50	0.20	1.21	0.02	0	0	0	0	0	0	17.71	0.07
Solar energy	0.82	0.01	0	0	0	0	0	0	0	0	0.82	0
Biomass	860.70	10.42	90.13	1.49	0	0	24.20	4.47	0	0	975.03	3.89
Total – by sectors	**8256.61**	100	**6049.07**	100	**4429.0**	100	**541.31**	100	**5768.7**	100	**25,044.7**	100
Share of sectors (%)	32.97		24.15		17.68		2.16		23.04			100
TOTAL	**25,044.7**											

aspects of Belgrade energy sector development has been previously analyzed [13,19–21]. The simulation model MAED (Model for Analysis of Energy Demand) was used to estimate energy demand in the city for a long time period (from 2002 to 2020), and the evaluation of scenarios' sustainability was obtained by method of multi-criteria analysis [13,21]. The attention was also dedicated to a multi-criteria evaluation of the sustainability of different energy options for obtaining heat energy [19]. Similar multi-criteria analysis was used in Ref. [20] to evaluate sustainability of residential buildings in Belgrade. Basic characteristics of these analyses are that the energy development in Belgrade was considered globally and without concrete solutions for the case of significant development of the economy and society.

In 2008 the City government adopted The Strategy of energy development in Belgrade until 2030 [22] which had proposed different and ambitious measures aimed to increase the level of energy efficiency, and reduce environmental impact of energy production and consumption. However, the Strategy was completed before the economic crises, and includes too optimistic assumptions related to the economic development.

In this paper current energy situation in Belgrade is presented in brief. Energy balance for 2010 is given, as it was used as the base year. The main characteristics of municipal energy systems and current energy policy are pointed out. One of the main characteristics of Belgrade energy system is that almost 50% of all households are connected to district heating network. This fact makes the optimal development of district heating system one of the highest priorities in all scenarios concerning energy development.

Three possible scenarios of further energy development in Belgrade until 2030 (realistic, business as usual (BAU) and optimistic) were discussed [23]. These scenarios are characterized by different energy consumption, but also by different availability of funds for investment in new facilities, different energy prices, different level of substitution of fossil fuels with RES, different level of implementation of energy efficiency measures, reduction of energy losses, etc. However, all considered scenarios have identified the need for further significant development of heat production facilities. Therefore, various options of possible heat producers are analyzed. Multi-criteria decision-making model, based to ELECTRE method, for selection of an optimal solution for meeting heat demand in the centralized supply system is proposed. This model considers characteristics of every proposed system for heat production, but their evaluation is given in accordance to specific development. Model includes several criteria for ranking and comparison of options, but ranking order is in accordance with selected scenario of energy and economy development. In this way, proposed model by complex and comprehensive analysis of options for district heating system development and by the selection of the optimal one provides adequate basis for decision-making.

2. Energy consumption and energy efficiency in Belgrade

Belgrade is the capital and dominant center of Serbia, due to number of inhabitants, economic and political significance, as well as the energy consumption. Belgrade participates in Serbian population with approximately 21%, but much more in energy activities – approximately 30% in energy consumption and 50% in electricity production of the Republic of Serbia.

For further analyses 2010 is taken as the base year. Structure of energy consumption, by fuel and sector is presented in Table 1. Data concerning electricity consumption, heat from district heating plants and natural gas consumption were obtained from the distribution companies [24–27]. Other data are estimated from different sources [22,28–30]. Household sector has the greatest share in energy consumption. Public and commercial activities and transport sector (23.04%) have similar share, but in transport sector liquid fuels are dominant. The sector of industry characterizes lower energy consumption, compared to other sectors, due to deindustrialization process that lasts for more than 20 years.

Due to consumption in transport sector, liquid fuels are dominant in Belgrade's energy mix. Share of electricity and district heating are relatively high, while other fuels (coal, natural gas and RES) have relatively smaller shares.

Some specific issues related to final energy consumption in Belgrade should be pointed out:

a) *Poor insulation of older buildings*; majority of buildings in Belgrade were built before more than 30 years and have an average or poor insulation; almost 37% of housing facilities have no insulation [28]; this fact certainly indicates that the energy retrofit of building can significantly increase the potential for energy savings in this sector; one third of almost 300,000 dwellings connected to district heating system have average energy consumption higher than 140 kWh/m^2/annum [24–26]; number of dwellings with consumption higher than 200 kWh/m^2/annum is also significant; these facts are the main reason for the great share of households and public and commercial sectors in final energy consumption; adopted Energy Efficiency Law [31] requires energy certificate for all buildings.
b) *High share of electricity used for heating purposes*; the price policy that treat electricity as a social category has led to the paradox, that consumption of electricity for heating is more cost-effective than consumption of natural gas or heat from