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Sustainable development of the Belgrade energy system

Marina Jovanović [a,*], Naim Afgan [b], Predrag Radovanović [a], Vladimir Stevanović [c]

[a] Laboratory for Thermal Engineering and Energy, VINCA Institute of Nuclear Sciences, 11001 Belgrade, Serbia
[b] Mechanical Engineering Department, Insituto Superior Tecnico, 35121 Lisbon, Portugal
[c] Faculty of Mechanical Engineering, Belgrade University, 11000 Belgrade, Serbia

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ABSTRACT

Cities are the most important energy consumers of any country in all energy vector components. Nowadays, Belgrade as a cultural, educational, scientific, administrative, political, and business center of the region with its own structure of production, transportation, services, and urban system, represents significant consumer of different energy forms. Only useful and final energy is delivered to energy consuming sectors of a city. Simulation model MAED was used in this paper to estimate energy demand in city for a long time period. On the basis of energy demand forecast for three major 'energy consumers' (sectors of household/service, industry, and transportation) until 2020, the sustainable development 'scenarios' of Belgrade energy system are developed (2005–2010, 2010–2015, 2015–2020). For each 'scenario', the energy systems of primary resources are determined so to satisfy the predicted differences in energy consumption for the mentioned time intervals until 2020. In this case different 'scenarios' are evaluated. The evaluation of 'scenarios' sustainability is obtained by method of multi-criteria analysis. Using energy indices for sustainable development, the following indices are taken into consideration for the assessment of scenario sustainability: economical, social, and environmental. The obtained results can be used by experts in decision-making process.

1. Introduction

Energy system of modern society shows elements of unsustainable development due to growing use of fossil fuel, increasing energy consumption and emission of environmental pollutants. In order to maintain balance of ecosystem and stimulate economic development, it is necessary to change and moderate these elements of unsustainable energy system development. So far, the activities related to the sustainable development of energy system have included reducing of emission of greenhouse gases and pollutant gases, increasing the safety of energy supply and use of renewable energy sources, improving of energy efficiency and quality of life.

In evaluation of energy conditions in the world or certain country, it is necessary to analyze energy system in cities. Concentration of social and economical forces in cities is in increase, making them the most important and the largest energy consumers.

According to recent statistical data, there are 1,700,000 people living in Belgrade today, in 16 city municipalities with a total of 670,000 households. Belgrade (670,000 consumers) is supplied with the electricity generated mostly in domestic coal-fired power plant. The most numerous category of consumers is the 'household' sector. The electricity consumption in the household sector was 4.051 TWh during 2005, as follows: 2.432 TWh for space heating, 0.81 TWh for heating of sanitary water and for cooking, and 0.810 TWh for air-conditioning and household electrical appliances [1].

Consumer area of Belgrade is supplied with thermal energy by district heating system consisting of 15 heating plants which use gas and crude oil as basic fuel. Statistical data show that 38% of buildings are connected to the district heating system, that is, 240,000 flats and 7500 business offices are heated in that way [2,3]. In the scope of the Belgrade environmental protection programme, construction of thermal network and gas distribution network in downtown area takes an important place, so approximately 800 individual solid fuel boilers have been shut down so far. Table 1 shows structure of total final energy consumption in the 'household' and 'service' sector in 2005.

Structure of used final energy in the 'transportation' sector in 2005 is shown in Table 2. Electricity consumption in 'transportation' sector refers to the electricity consumption used for operation of trams and trolleys. Also, energy consumption of all motor fuel types used in the city of Belgrade for freight and passenger transportations is shown.

* Corresponding author. Tel.: +381 11 2458 222; fax: +381 11 2453 670.
E-mail address: marinaj@vin.bg.ac.yu (M. Jovanović).

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Nomenclature

EcIec	economy sub-indicator of energy cost ($/kWh)
EcIinv	economy sub-indicator of investment ($/kWh)
EcIef	economy sub-indicator of plant efficiency (%)
EcIei	economy sub-indicator of energy intensities (kWh/$)
SoIeh	social sub-indicator of energy use per household (kWh/hh)
SoIsi	social sub-indicator of share of household income spent on fuel and electricity (%)
SoIni	social sub-indicator of number of injured per energy produced (kWh^{-1})
SoIwh	social sub-indicator of working hours per energy produced (h/kWh)
($EkI^{(1)}_{CO_2}$)	ecology sub-indicator CO_2 emission per energy produced ($kgCO_2$/kWh)
$EkI^{(1)}_{NO_x}$	ecology sub-indicator NO_x emission per energy produced ($kgNO_x$/kWh)
($EkI^{(2)}_{CO_2}$)	ecology sub-indicator CO_2 emission per capita ($kgCO_2$/cap.)
$EkI^{(2)}_{NO_x}$	ecology sub-indicator NO_x emission per capita ($kgNO_x$/cap.)
P_{ins}	installed power of gas fired PP (MW_e)

Abbreviations

MAED	model for analysis of the energy demand
ESPR	energy system of primary resources
ESRR	energy system of renewable resources
GIS	general index sustainability
EISD	energy indices of sustainable development

Table 3 presents structure of energy consumption in the 'industry' sector in 2005. Consumptions of motor fuel (crude oil and other liquid fuels used in industry), electricity consumed in industry at the voltage of 10 and 35 kV, and useful thermal energy (steam production, heating of furnace, space, and water) are shown in this table.

2. Sustainability in urban area

Cities are the biggest consumers of the country's energy production. The increase in annual consumption of total primary energy is 3% and its largest part is used for lighting, cooking, heating, cooling, and transport of freights and passengers. Large quantity of energy is lost due to inefficient energy consumption in the sectors of household, transportation and industry [4].

It should be noted how important it is to reduce the energy consumption level, by changing the forms of consumption and making improvements in technology and lifestyle. Sustainable forms of energy production, distribution and use represent the goals of sustainable development. A city is considered to be sustainable if it establishes the balance between economic and sociocultural development on one side and progress in environmental protection with active participation of citizens on the other side [5].

Nowadays, every city faces the challenge of meeting these goals. Experts can provide important assistance in attaining sustainability, but the key role belongs to the community which has to achieve the sustainable quality of life both for its present and future members.

Table 1
Consumption of final energy in the sectors of 'household' and 'service', 2005

'Household' and 'service' sectors			
Non-commercial fuel (wood, etc.) (TWh)	Electricity (TWh)	District heating (TWh)	Fossil fuels (TWh)
1.015	4.460	4.335	2.965

Table 2
Consumption of final energy in 'transportation' sector, 2005

'Transportation' sector	
Electricity (TWh)	Motor fuels (TWh)
0.017	2.046

Table 3
Consumption of useful and final energy in the 'industry' sector, 2005

'Industry' sector		
Electricity (TWh)	Motor fuels (TWh)	Useful thermal energy (TWh)
1.176	0.176	2.173

3. Assessment of Belgrade long-term energy needs

Belgrade today, as a cultural, educational, scientific, administrative, political, and business center of the region with its own structure of production, transportation, servicing, and urban system presents the important consumer of various energy carriers. Energy system of Belgrade has a complex structure and consists of numerous suppliers of different energy forms on one side and many energy consumers on the other side. Since only carriers of useful and final energy deliver to the consumer sectors in town, 'energy consumer' condition refers to the structure of both energy consumption sector and carrier of various energy forms.

In this paper, according to the type of consumer, energy consumption includes the following sectors: (a) household and service (residential and public consumption), (b) industry, and (c) transportation. Residential energy consumption refers to consumption in a household, while public energy consumption refers to total energy consumption in various buildings intended for public use. 'Industry' sector includes all industry consumers. 'Transportation' sector consists of energy consumption in public transport, and also by cars, trucks, buses, and other vehicles supplied with fuels in the Belgrade area. Air-transport is taken into consideration as well, because this is also supplied through the city commercial network.

When analyzing energy needs of some city or a region, in order to predict production development and energy consumption, various models are applied for analysis of energy needs. In this paper, the simulation programme model for analysis of the energy demand (MAED) has been used for estimation and analysis of long-term energy demand in Belgrade [6]. This model links together specific energy needs for production of different goods and services with sets of social, economical, and technological factors which have influence on these needs. On the basis of the foreseen 'scenario of development', expert planners can predict long-term trends and goals of the city policy from the aspect of current developments. Fig. 1 presents the predicted consumptions of electricity, motor fuels and thermal energy in the main energy consumption sectors.

Set of input data in the programme consists of independently determined parameters which define the expected future trends and make up the 'scenario of development'. These are initial parameters and constant values related to the basic year, as well as time dependant parameters which define all other values in the scenario, for each and every year. When these parameters are known, the systematic estimation of various categories of energy needs for each considered sector and sub-sector of economy is done. On the basis of the obtained results, total energy needs for Belgrade can be calculated.

When selecting the year which would be the most appropriate as a basic year, one must have in mind that it should belong to the past period when there were no sudden increases in energy consumption, no natural or national catastrophes, as well as that it should be close to the year when actual analysis is carried out. The selected year is crucial not only for the study but also for prediction of future energy needs. On the basis of information about energy structure in the basic year and changes of parameters for each defined year in scenario, the MAED programme calculates energy needs up to 2020.

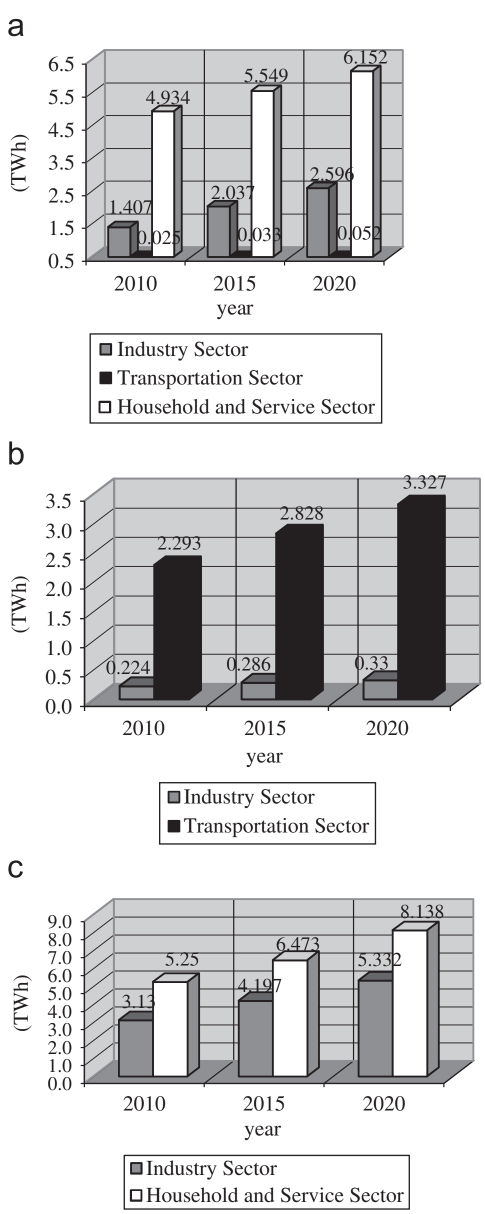

Fig. 1. Predicted electricity, motor fuels, and thermal energy consumption for the main energy consumption sectors. (a) Electricity (b) motor fuels and (c) thermal energy.

In this paper, for the selected 'basic year' (2002), the first step in programme execution is reconstruction of energy consumption in Belgrade with respect to energy carriers, consumption sectors and final energy users [7–10]. In the next step, the future scenario of development of Belgrade up to 2020 is defined and divided into two sub-scenarios. One of them refers to the social and economic development of Belgrade and includes parameters such as demography data (population, population growth rate, active labor force), GDP (gross domestic product), GDP per capita, annual GDP growth rate, numbers of public transport users in urban and suburban traffic, average total distance travelled by person using public transport, average dwelling size, heated area of dwelling, etc. The other part of development scenario is related to the technology factors used in calculation of energy needs, such as efficiency of energy carriers, market penetration of energy carriers, insulation in buildings, vehicles efficiency, etc.

The calculation of energy needs for three main energy consumers is achieved for one or few social and economic and technology parameters, with values given as a part of scenario. The output values in the programme are information which define annual energy needs of certain energy sectors.

Different energy carriers (electricity, fossil fuels, etc.) which satisfied energy needs of final consumer categories are calculated in the forms of useful and final energy.

4. Assessment of Belgrade energy system sustainability

In the assessment of scenario sustainability, sustainability measurement is essential. Criteria for assessment of scenario sustainability have to be defined on the basis of several aspects: economical, social, and environmental [11]. In accordance with the energy needs calculation of three main energy 'consumers', scenarios of energy system development for Belgrade until 2020 are formed, Table 4.

For each scenario, the energy system of primary resources (ESPR) that should satisfy the predicted differences in consumption of electricity and thermal energy, and motor fuels for the time intervals of 2005–2010; 2010–2015; 2015–2020 are determined, Table 5.

The quality of selected scenarios is defined by energy indices of sustainable development (EISD), which represent certain parameters and measure of criterion in sustainability evaluation. In order to quantify criteria for sustainability evaluation of certain scenario, the basic sub-indices set of energy indices is defined. Fig. 2 shows scheme of selected energy indices and sub-indices related to the sustainable development.

In this paper, values of ESPR, energy system of renewable resources (ESRR), and motor fuel sub-indices for each scenario are

Table 4
Scheme of defined scenarios until 2020

	2010	2015	2020
Scenario	I/10	I/15	I/20
Scenario	II/10	II/15	II/20
Scenario	III/10	III/15	III/20
Scenario	IV/10	IV/15	IV/20
Scenario	V/10	V/15	V/20

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Table 5
Scheme of ESPR for each scenario in 2015

Scenario I 'business-as-usual'	*Scenario* II	*Scenario* III	*Scenario* IV	*Scenario* V
ESPR (coal)	ESPR (water)	ESPR (gas)	ESPR (gas)	Import
ESPR (gas)	ESPR (gas)	ESPR (crude oil)	ESPR (gas)	ESPR (gas)
ESPR (crude oil)	ESRR (biomas)[a]	Motor fuels	ESRR (solar)[a]	ESPR (gas)
Motor fuels	Motor fuels	Fuell cells	ESPR (gas)	Motor fuels
–	–	–	ESRR (biomas)[a]	Fuell cells
–	–	–	Motor fuels	–

[a] ESRR—energy system of renewable resources.

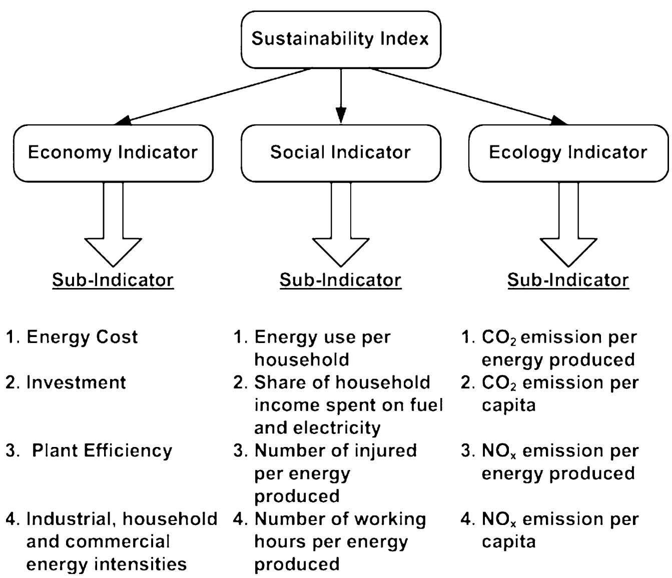

Fig. 2. Scheme of energy indices and sub-indices of sustainable development.

calculated first; then, sub-indices for scenarios (I–V) are determined when the share amount of produced energy, for each ESPR, ESRR, and motor fuels, in total energy demand is multiplied by certain sub-indices of ESPR, ESRR, and motor fuels. In calculation of energy sub-indices, it is assumed that energy consumption in Belgrade amounts to 33% of total energy consumption in the country [7–9].

4.1. Scenarios of energy system development for 2015

In this paper, as an example, the results obtained for 2015 are shown, together with sustainability analysis of scenarios I–V for this year. According to the development strategy until 2015, liquid fossil fuel would remain predominant in use, but with tendency to decline. Also, increasing use of natural gas and gradual decrease of electricity use are predicted.

The selected ESPR and ESRR for each scenario in Table 6 present various technologies for generation of electricity, thermal energy in 'household' and 'service' sectors and useful thermal energy in 'industry' sector. Also, in this table option of motor fuels presents consumed total amount petrol, diesel, and heating oil fuels.

4.1.1. Scenario I 'business-as-usual'

ESPR in *scenario* I ('business-as-usual'), from the aspect of energy generating technology, are the same as the ESPR in *scenario* I for 2010 and 2020. For additional production of electricity and thermal energy in *scenario* I for 2015, the following is planned: completion of construction of thermal power plant 'Kolubara B' construction, which has the key role in electricity production; construction of new city gas heating plant and industrial crude oil power station [12,13]. Total installed capacity of CPP 'Kolubara B' (coal-fired power plant) is $2\times350\,MW_e$ and it accounts for 31% of total electricity production that should satisfy demand. The planned busbar cost of electricity is 0.0234 $/kWh and it includes costs of coal, plant operation, and maintenance. CO_2 emission factor for lignite of 112 kg/GJ is adopted, while CO_2 emission of 0.58 $kgCO_2$/kWh is calculated for the plant [14]. The installed thermal capacity of new Belgrade gas-fired heating plant (City HP) is 160 MW_t and it accounts for 30% of the total energy need that should satisfy. Predicted busbar cost of thermal energy is 0.0835 $/kWh, while the specific investment cost is 500 $/kW. This gas heating plant emits 0.181 kg/kWh of CO_2 [14]. The *scenario* I for 2015 provides for additional technological thermal energy from the industrial power stations which would deliver 25% of the total energy demand. The installed capacity of heating sources that use crude oil as a basic fuel is 33 MW_t. Specific investment cost of its construction is 600 $/kW [15]. Thermal energy cost includes cost of crude oil, plant operation and maintenance, and it amounts to 0.026 $/kWh. CO_2 emission factor for crude oil of 74.7 kg/GJ is adopted and the calculated CO_2 emission for the plant is 0.287 $kgCO_2$/kWh.

4.1.2. Scenario II

The additional electricity production from the hydro potential is predicted in *scenario* II. Additional thermal energy is obtained as in the *scenario* I, whereas the useful thermal energy is produced in biomass industrial power stations. The planned power plant hydro power plant proposes group of new medium size hydro power plants ($>10\,MW_e$) with total installed power of 280 MW_e [16]. Their share in total needed energy is 30%. Hydro power plant efficiency of 90% and specific investment cost of 2000 $/kW are adopted [17]. The projected annual supply of electricity to Belgrade is 270 GWh. Only direct CO_2 emission of 0.00014 $kgCO_2$/kWh released during the operation and maintenance of hydro power plant is taken into consideration in the paper [18]. The biomass industrial power stations ($P_{in}=33\,MW_t$) satisfy 26% of total energy demand projected for 2015. Specific investment cost of plant construction is 200 $/kW, while the busbar cost of thermal energy is 0.015 $/kWh [19]. CO_2 emission factor for biomass of 79.5 kg/GJ is adopted, and CO_2 emission of 0.178 $kgCO_2$/kWh is calculated for the plant [14].

4.1.3. Scenario III

The additional production of electricity and thermal energy from a new gas-fired cogeneration plant (CHP) is predicted in the *scenario* III. The share of electricity and thermal energy produced of this plant in the total projected demand is 60%. Estimated specific investment cost of the new CHP is $C_{inv}=860$ $/kW, and busbar cost of energy is 0.043 $/kWh. Carbon dioxide emission is 0.181 $kgCO_2$/kWh. Also, the production of useful thermal energy in

Table 6
Scenarios of Belgrade energy system development for 2015

Scenario I 'business-as-usual'	*Scenario* II	*Scenario* III	*Scenario* IV	*Scenario* V
CPP ('Kolubara B'), coal	Hydro power plant	CHP, gas	PP (NGCC), gas	Import
City HP, gas	City HP, gas	Industrial power stations, crude oil	Gas distribution network	Gas distribution network
Industrial power stations, crude oil	Industrial power stations, biomass	Motor fuels (90%)	Solar collectors	Industrial power stations, gas
Motor fuels	Motor fuels	Fuel cells (10%)	Industrial power stations, gas	Motor fuels (90%)
–	–	–	Industrial power stations, biomass	Fuel cells (10%)
–	–	–	Motor fuels	–

industry sector from the crude oil-fired industrial power stations is predicted as in the *scenario* I [20,21].

4.1.4. Scenario IV

Scenario IV provides for additional supply of electricity by natural gas combined cycle power plant (NGCC PP). The additional final thermal energy is obtained from gas distribution system, and water heating is realized by solar collectors (household and industry sectors). The useful thermal energy in industry is produced in gas and biomass industrial power stations (13.9% and 11.8%), whereas smaller portion is obtained from solar collectors (0.3%). New gas-fired PP (NGCC) is planned, $P_{\text{ins}} = 200\,\text{MW}_{\text{e}}$, and its participation in production of total energy is 31%. The projected busbar cost of electricity is 0.054 \$/kWh. CO_2 emission factor for gas of 50.33 kg/GJ is adopted, and CO_2 emission of 0.213 kgCO_2/kWh is calculated for the plant [14]. By 2015, it is expected that new 150,000 thermal energy consumers will be connected to gas distribution network. This system participates with 30% in supply of total projected energy needed. The projected thermal energy cost is 0.067 \$/kWh. CO_2 emission of 0.181 kgCO_2/kWh is calculated. Gas-fired industrial power stations participate with 13.9%, while biomass-fired industrial power stations participate with 11.8% in total energy production.

4.1.5. Scenario V

Instead of building new thermal power plants, import of electricity is adopted as a solution in *scenario* V. As in the case of previous scenario, supply of final thermal energy is provided by the gas distribution network, while supply of useful thermal energy is provided by the industrial gas-fired power stations. Motor fuels consumed in the sectors of transportation and industry include total amount of used petrol, diesel, and fuel oil. Participation of motor fuel energy (thermal energy base) in total energy supply is 14%. The projected amount of motor fuels which satisfy the increased needs in 2015 in relation to those in 2010 is $54.7\ 10^6$ l in public transport, suburban traffic and transportation of passenger cars as well. Predicted average cost of motor fuels is 2.9 \$/l, while the CO_2 emission coefficient of 71.025 kg/GJ for motor fuels is adopted and CO_2 emission of 0.256 kgCO_2/kWh is calculated [14]. *Scenarios* III and V, besides the motor fuels, predict introduction of fuel cells that would replace 10% of total additional motor fuels amount needed in 2015 in the sector of public transport.

4.2. Procedure of math modeling for determination of general sustainability index

The chosen indicators numerically reflect essential property of the observed scenario, while the criteria show the scenario's quality within the indicator limits. In assessment of sustainability of considered scenarios, the method of multi-criteria analysis is used. In decision-making process, the aim of this method is to determine the influence of mutual relations between all criteria on the sequence of list priorities of considered scenarios.

For assessment of sustainability scenarios three indices are used, while each of them is defined by four sub-indices. The first level of calculation includes normalization of all sub-indices numerical values for each ESPR. Linear normalized function $q_i(x_i;\Theta)$, $\Theta = 1$ is adopted in this paper. The value of weight coefficient is introduced to determine influence of specific criteria [22].

Agglomerated values are obtained by using of linear agglomeration function:

$$I_{\text{agi}} = \sum_{i=1}^{m} w_i q_i, \tag{1}$$

where I_{agi} is the agglomerated values of indices, w_i the weight coefficient for sub-indices, and q_i the normalized values of sub-indices.

The second level of calculation considers normalization of all indices for each scenario and under conditions of pre-defined constrains that represent non-numerical information about interrelation between criteria. Also, synthesis function for general index sustainability (GIS) calculation is used on this level:

$$\overline{Q}_{+}(q;I) = \frac{1}{N(I;m,n)} \sum_{s=1}^{N(I;m,n)} Q_{+}(q;w^{(s)}), \quad w^{(s)} \in W(I;m,n), \tag{2}$$

where $\overline{Q}_{+}(q;I)$ is the average value of GIS, q the criteria, $N(I;m,n)$ the number of elements of the set $W(m,n)$, w the weight coefficient, $W(m,n)$ the infinite set of all possible weight coefficients, m the number of criteria, n the positive integer, and I the non-numerical and inexact information.

Numerical values of energy sub-indices for defined scenarios are shown in Table 7. These data present input values for mathematical model which calculates the average value of GIS.

4.3. Analysis of obtained results

Estimate of Belgrade energy system sustainability includes assessmnet of economical, social, and ecology aspects, as an integral parts of sustainability. In this paper the influence of using few indices is examinated, in reference to sub-indices in defining priority of examinated scenarios.

At first, numerical values of sub-indices are defined for discussed scenarios (Table 7), then the method of multi-criteria analysis based on fuzzy sets synthesis technique is applied. Procedure of math modeling that is based on the fuzzy sets synthesis technique is briefly described in Section 4.2.

The results of model are expressed in the form of GIS and based on that, comparison of examined scenarios in terms of sustainability are done (Figs. 3a, 4a, 5a). GIS is defined as the synthesizing additive function that expresses of all normalized values of indices considered by ESPR and weighting coefficients in the conditions of predefined constraints.

Table 7
Values of sub-indices of EISD for scenarios I–V, 2015

Indicator	1. EcInd				2. SoInd				3. EkInd			
Sub-indicator	EcIec	EcIinv	EcIef	EcIei	SoIeh	SoIsi	SoIni	SoIwh	EkI_{CO_2}	EkI_{CO_2}	EkI_{NO_x}	EkI_{NO_x}
Units	\$/kWh	\$/kWh	%	kWh/\$	kWh/househ	%	kWh^{-1}	h/kWh	kg/kWh	kg/cap.	kg/kWh	kg/cap.
Scenario I	0.0743	0.0255	66.48	0.0349	323.41	0.184	6.977 × 10E−8	4.059 × 10E−4	0.279	30.198	0.00141	0.163
Scenario II	0.0750	0.0120	73.32	0.0348	323.41	0.184	8.428 × 10E−8	2.456 × 10E−4	0.137	13.237	0.00023	0.023
Scenario III	0.0730	0.0150	69.65	0.0590	625.33	0.300	5.566 × 10E−8	3.226 × 10E−4	0.212	35.036	0.00044	0.078
Scenario IV	0.0780	0.0240	70.89	0.0310	592.29	0.287	6.190 × 10E−8	3.021 × 10E−4	0.212	19.453	0.00043	0.043
Scenario V	0.0900	0.0220	54.29	0.0340	592.13	0.290	5.567 × 10E−8	2.340 × 10E−4	0.136	12.939	0.00029	0.031

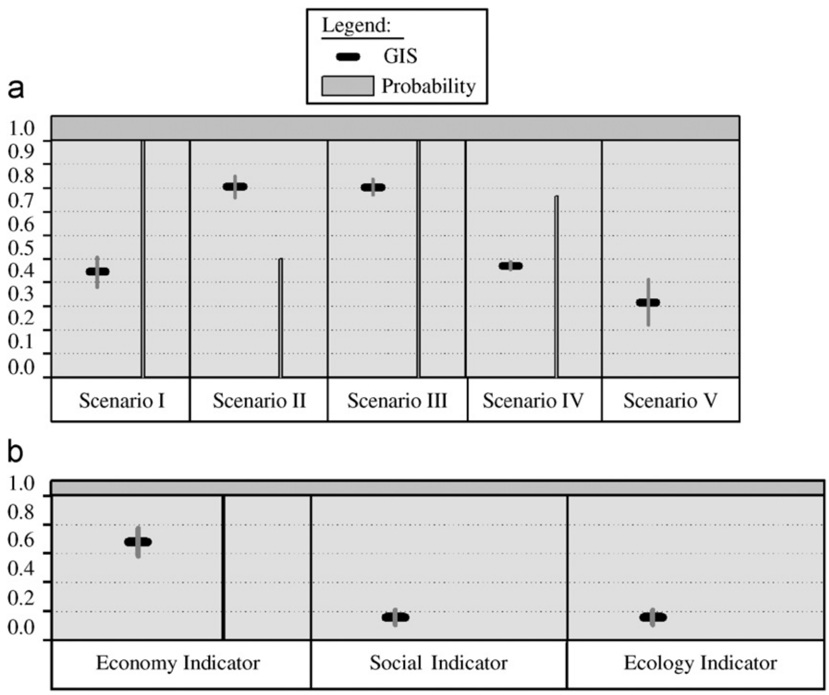

Fig. 3. (a) Priority list of Case A and (b) value of weight coefficients.

The weight coefficients express relative weight of specific criteria and show the importance of specific criterion q_i in defining the general index $\overline{Q}_+(q;I)$, (Figs. 3b, 4b, 5b). When the values of w_i are increasing, the specific criteria q_i has more influence on value of GIS.

Three distinctive cases (A, B, C) are presented, and constrains that give priority to one of the energy indices are defined for each case. Assigning a different priority to certain indicator results in different rating of scenarios in sustainability assessment. Application of multi-criteria evaluation enables selection of the best scenario in terms of sustainability according to defined constrains and in that way gives help experts in decision-making.

Case A: *Constrain* 1. EcInd(condition 1)>SoInd(condition 1) = EkInd(condition 1):

$$\mathrm{EcInd(EcIec > EcIinv = EcIef = EkIei)}$$
$$\mathrm{> SoInd(SoIeh > SoIsi = SoIni = SoIwh)}$$
$$\mathrm{= EkInd(EkI^{(1)}_{CO_2} > EkI^{(2)}_{CO_2} = EkI^{(1)}_{NO_x} = EkI^{(2)}_{NO_x})}.$$

In Case A, constrain 1 is defined so to give priority to the economy indicator (value of weight coefficient is 0.68), while the other indices have the same value of weight coefficient (0.16), Fig. 3b. In the process of sub-indices agglomerations, according to the defined conditions, following has priority: economy sub-indicator of energy cost (EcIec), social sub-indicator of energy use per household (SoIeh) and ecology sub-indicator of CO_2 emission per energy produced $EkI^{(1)}_{CO_2}$, respective agglomerated indices are obtained. For example, the following agglomerated values of indices, for scenario II are obtained: $I_{ag}(\mathrm{EcInd}) = 0.799$, $I_{ag}(\mathrm{SoInd}) = 0.235$, $I_{ag}(\mathrm{EkInd}) = 0.977$; and for scenario III: $I_{ag}(\mathrm{EcInd}) = 0.779$, $I_{ag}(\mathrm{SoInd}) = 0.789$, $I_{ag}(\mathrm{EkInd}) = 0.345$.

Fig. 3a shows priority list for defined constrain. If economy indicator has priority, it is noticeable that *scenarios* II and III are in the first place on the list. *Scenario* V is last on the list. Fig. 3a shows that the GIS that presents the quality of given scenario, for scenarios II and III have the value of 0.804.

Case B: *Constrain* 2. SoInd(condition 2)>EcInd(condition 1) = EkInd(condition 4):

$$\mathrm{SoInd(SoIsi > SoIeh = SoIni = SoIwh)}$$
$$\mathrm{> EcInd(EcIec > EcIinv = EcIef = EkIei)}$$
$$\mathrm{= EkInd(EkI^{(2)}_{NO_x} > EkI^{(1)}_{CO_2} = EkI^{(2)}_{CO_2} = EkI^{(1)}_{NO_x})}.$$

In Case B, constrain 2 is defined so as to give priority to the social indicator (value of weight coefficient is 0.68), while economy and ecology indices have the same value of weight coefficient (0.16), Fig. 4b. In the process of sub-indices agglom-

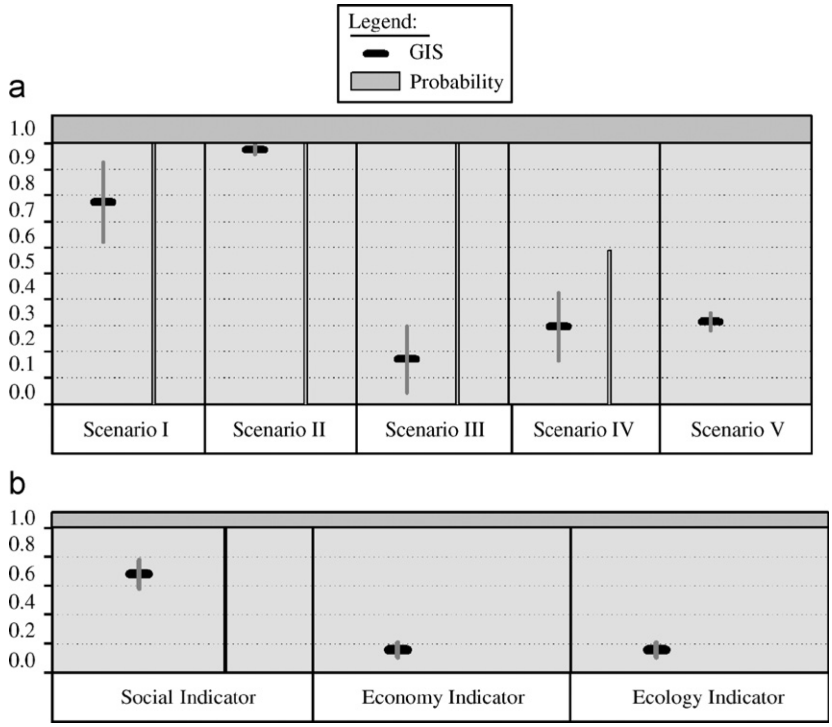

Fig. 4. (a) Priority list of Case B and (b) value of weight coefficients.

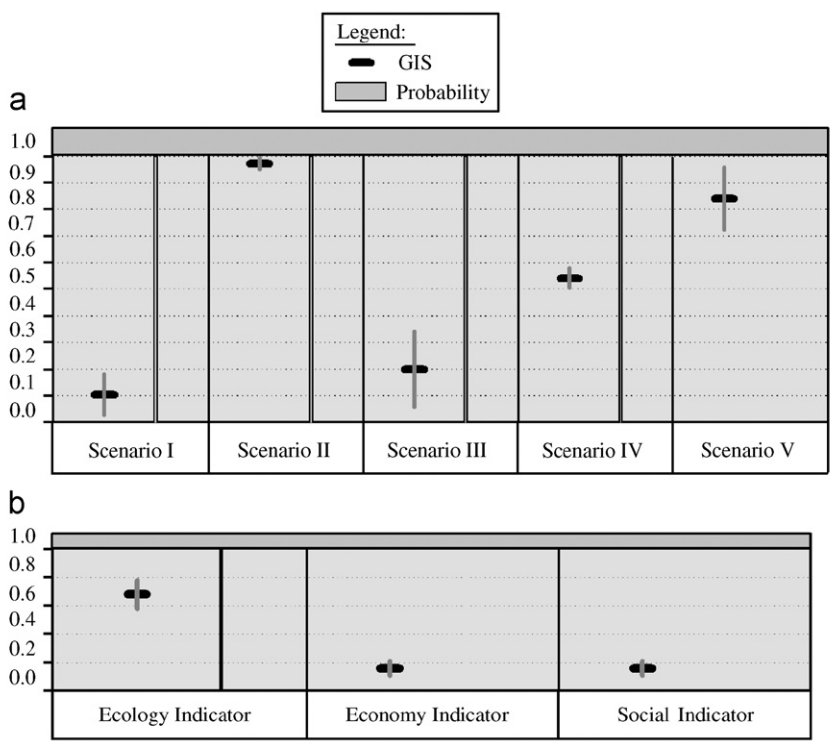

Fig. 5. (a) Priority list of Case C and (b) value of weight coefficients.

erations, according to the defined conditions, following has priority: social sub-indicator of share of household income spent on fuel and electricity (SoIsi), economy sub-indicator of energy cost (EcIec) and ecology sub-indicator of NO_x emission per capita ($EkI^{(2)}_{NO_x}$), respective agglomerated indices are obtained. For example, following agglomerated values of indices, for scenario I are obtained: $I_{ag}(SoInd) = 0.675$, $I_{ag}(EcInd) = 0.653$, $I_{ag}(EkInd) = 0.0063$; and for scenario II: $I_{ag}(SoInd) = 0.755$, $I_{ag}(EcInd) = 0.799$, $I_{ag}(EkInd) = 0.944$.

List of priorities for the Case B is presented in Fig. 4a. If priority is given to the social indicator, it is noticeable that *scenarios* I and II show the best level of sustainability. Group of scenarios III, IV, and V is at the bottom of the GIS rating list as the scenarios with the respective sustainability level. *Scenario* III which is in the previous case at the first place, in this case ranks the last. The derived value of GIS, that presents the quality of given scenario, for scenarios I and II are 0.774 and 0.976, respectively (Fig. 4a).

Case C: *Constrain* 3. EkInd(condition 2) > EcInd(condition 1) = SoInd(condition 4):

$$\begin{aligned}&\mathrm{EkInd}(\mathrm{EkI}^{(2)}_{\mathrm{CO_2}} > \mathrm{EkI}^{(1)}_{\mathrm{CO_2}} = \mathrm{EkI}^{(1)}_{\mathrm{NO}_x} = \mathrm{EkI}^{(2)}_{\mathrm{NO}_x})\\ &> \mathrm{EcInd}(\mathrm{EcIec} > \mathrm{EcIinv} = \mathrm{EcIef} = \mathrm{EkIei})\\ &= \mathrm{SoInd}(\mathrm{SoIwh} > \mathrm{SoIeh} = \mathrm{SoIsi} = \mathrm{SoIni}).\end{aligned}$$

In Case C, constrain 3 is defined so as to give priority to the ecology indicator (value of weight coefficient is 0.68), while economy and social indices have the same values of weight coefficients (0.16), Fig. 5b. In the process of sub-indices agglomerations, according to the defined conditions, following has priority: ecology sub-indicator of CO_2 emission per capita ($\mathrm{EkI}^{(2)}_{\mathrm{CO_2}}$), economy sub-indicator of energy cost (EcIec), and social sub-indicator of number of working hours per energy production (SoIwh), respective agglomerated indices are obtained. For example, following agglomerated values of indices, for scenario II are obtained: $I_{\mathrm{ag}}(\mathrm{EkInd}) = 0.977$, $I_{\mathrm{ag}}(\mathrm{EcInd}) = 0.799$, $I_{\mathrm{ag}}(\mathrm{SoInd}) = 0.733$; and for scenario V: $I_{\mathrm{ag}}(\mathrm{EkInd}) = 0.960$, $I_{\mathrm{ag}}(\mathrm{EcInd}) = 0.122$, $I_{\mathrm{ag}}(\mathrm{SoInd}) = 0.872$.

GIS rating list of priorities for defined constrain is presented in Fig. 5a. At the first place of the GIS rating list are *scenarios* II and V, while *scenarios* I and III are on the lower position. *Scenario* I takes first place of the priority list in the previous case (Case B), but when priority is given to the ecology indicator, *scenario* I takes last position. Fig. 5a shows that GIS, that presents the quality of given scenario, for scenarios II and V are 0.972 and 0.840, respectively.

5. Conclusion

Nowadays, Belgrade presents very important consumer of various energy forms. Determination of Belgrade energy needs regarding three greatest consumer sectors is defined by simulation model of MAED. For the predicted energy needs, scenarios that meet better understanding, tracking, and analyzing of sustainable development are created.

In the scope of each scenario, ESPR that should satisfy predicted differences in energy consumption for the time intervals until 2020 are determined. In sustainability assessment of presented scenarios, EISD are determined. Each energy indicator is defined by the set of sub-indices that express different aspects or consequences of production or energy consumption.

In the paper, analysis of five sustainability scenarios for the year of 2015 is defined by application of multi-criteria assessment method. This method of analysis excludes human factor in estimation of sustainability scenarios by importing the constrains as non-numerical information. Three characteristic cases are defined and presented to show the influence of indices and sub-indices on choice of the most proper scenario for the defined indices and their constrains.

Further development of this method should be focused to better defining and determining of sustainability indices that are values variable in time and space. Also, use of different kinds of agglomerated functions for GIS determination should be observed.

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