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ARTIFICIAL INTELLIGENCE AND NATURE-INSPIRED OPTIMIZATION ON INTEGRATIVE CAPACITY OF RENEWABLE ENERGY IN THE WESTERN BALKAN

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Abstract: Two artificial intelligence models for the integration of renewable energy sources are developed within this research to contribute to the European Green Plan realization. The review of renewable energy natural potential, on one hand, and installed capacity, on the other hand, in the Western Balkans and twenty-eight European countries is done within this research, as well as emissions. The analyses show that the European countries, sometimes even with lower natural potential in renewables, have installed much more renewable capacities than the Balkans countries with much higher natural potential. According to this, the first artificial intelligence model is developed based on multi-criteria linear regression analysis. This model relies on the correlation between the relevant regressors, i.e. relevant input variables for twenty-eight European countries and the same regressors for a particular Balkans country. Its goal is to find the maximum possible integrative renewable capacity in a Balkans's country within the real socio-economic environment. The second artificial intelligence model is developed based on multi-criteria evolution genetic algorithms. Its goal is to find the maximum possible integrative renewable capacity within a real electric power system. Nature-inspired optimization is applied. From the framework of a given large number of generations, technical combinations of the degree of renewable energy sources integration, the best populations, i.e. combinations are selected. As nature selects from many generations and allows the best to survive and punishes the „weak", in our case, „weak" combinations are those failing to meet the given conditions and limitations of the real electric power system. A new methodology is offered. Theoretical general formulas are given for both models. Developed models are tested on a numerical experiment of solar energy integration in the Serbia case study. Analyses of sensitivity prove that both models are applicable for all renewable energy sources and countries or regions.

Keywords: Models, Artificial Intelligence, Nature-Inspired Optimization, Integration, Renewable Energy Sources, Circular Economy, the Western Balkans.

1. INTRODUCTION

The management of energetic potentials is one of the basic strategic issues of a country or region, which pretend to have independent functions in the energy sector. Within the scope of long-term planning, this issue may be considered through the concept of participation of renewable or non-renewable energy sources and does not depend on the fact whether the energy facilities are built using their investment funds or one of many possible concession arrangements. The answer to the set dilemma is obvious. Due to the Kyoto protocol and the aggregate of declarations, conventions, acts and agendas, the proclaimed sustainable development and climate change issue is feasible through the only strategic reasonable orientation towards renewable energy sources (RES).

Western Balkan countries have great potential for renewable energy sources [1]. Accordingly, orientation to the subject of RES higher integration can have a big contribution in achieving climate neutrality by 2050, declared by the European Green Plan and sustainability goals. The Western Balkan countries have a noticeable hydro potential due to the hilly geography. The region is also rich in wind and

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solar potential as well as biomass. The renewable potential is not fully used due to low economic development. This is a big problem because technically usable potential can be devalued during the time and due to environmental, social and political impacts. Holistic research is imperative.

This holistic research of artificial intelligence and nature-inspired optimization on the integrative capacity of renewable energy sources in the Western Balkan countries is presented through five parts, within this manuscript. The first part includes the review of the natural and integrated potential of renewable energy sources in the Western Balkan countries (WBc). This is compared with the same potential (natural and integrated) of twenty-eight European countries (Ec), that is, the EU and the United Kingdom (UK).

The second part develops a multi-criteria linear regression analysis (MCLRA) model providing all general formulas that describe the model. An accompanying numerical experiment is performed as well. The MCLRA model is extended by an economic method and social acceptance research to provide a holistic triangular approach and address the issue of maximum possible integrative renewable capacity in the Balkan countries within a real socio-economic environment. The model is tested on a numerical experiment of solar energy integration in the Serbian socio-economic system.

The third part includes nature-inspired optimization of renewable energy resources developed through the multi-criteria evolution genetic algorithms (MCEGA) artificial intelligence model. The goal of the MCEGA model development is to find the maximum possible integrative renewable capacity within the electric power system of a country. All general formulas are given and the model is tested on a numerical experiment of solar energy integration in the Serbian electric power system as a case study.

The fourth part is the discussion. It includes temporal and space validations. Since in the previous parts of the research the models are tested on the example of solar energy integration in a socio-economic and electric power system of Serbia, the validation of developed models for other renewable energy sources and other countries is carried out in this part of the research. Analyses of sensitivity and desk research are done to prove the extension and validation of developed models.

The fifth part of the research is a general conclusion and further research recommendation, although the parts containing models also include a particular conclusion.

The present situation in the Western Balkan countries is unacceptable regarding the existing emissions. Table 1 contains data1 on emissions in European countries (EU27 plus UK), compared with emissions in Western Balkan countries.

Table 1. Emissions of SO2, NOx and PM 2.5 in Western Balkan countries and EU27 plus UK

Emissions	SO2 (t/year)	NOx (t/year)	PM 2.5 (t/year)
European countries	992.248	795.358	11.946
Western Balkan countries	750.893	120.012	20.188

Since pollutions are always transboundary, emissions in the Western Balkan countries become a global problem. Sixteen coal-fired thermal power plants (TPP) located in the Western Balkan countries produce extreme high emissions compared to the emissions from EU27 plus United Kingdom, which has 250 active thermal power plants. Eight of the 16 TPPs are 8 of 10 the most polluting TPPs in EU27 plus United Kingdom [2]. This is one of the biggest reasons for strengthening regional cooperation in the field of renewable energy sources for sustainable development and climate change to achieve conditions of the European Green Plan in the Western Balkans. The data presented in Table 1 indicate the big differences in emissions in European countries and Western Balkan countries. At the same time, indicators from Table 2 show the big differences in installed renewable capacities between European countries and Western Balkan countries.

Although some European countries have a lower potential than Western Balkan countries, there is a higher degree of renewable energy integration. Regression is present. This suggests that the use of linear regression can give satisfactory results when developing a correlation model. It is also clear that several criteria can impact the degree of RES integration in a country. Therefore, linear regression should be a multi-criterion. Such a multi-criteria model of linear regression will be analyzed in the next chapter.

[1] HEAL (2017): „Boosting Health by Improving Air Quality in the Balkans", access July 15th 2021.

Table 2. Production in renewable energy (solar, wind and hydro) in Europe and the Western Balkans 2019-2020

Country	Ground PV (TWh)	Rooftop PV (TWh)	Onshore wind (TWh)	Offshore Wind (TWh)	Hydropower (TWh)
Austria	34.9	12.9	89.5	0.0	31.8
Belgium	19.0	12.5	0.9	7.6	0.2
Bulgaria	111.3	17.5	58.5	1.3	3.5
Croatia	12.8	9.0	23.6	11.7	5.5
Cyprus	11.0	5.7	2.4	0.0	0.0
Czech Republic	70.1	13.7	23.4	0.0	1.1
Denmark	41.2	6.2	40.1	112.6	0.0
Estonia	14.1	1.3	54.3	5.1	0.0
Finland	23.7	5.2	61.1	84.6	8.2
France	550.5	129.5	613.4	57.2	42.9
Germany	333.0	104.6	134.5	106.5	14.9
Greece	38.6	19.2	365.4	0.1	4.2
Hungary	133.9	18.0	86.4	0.0	0.2
Ireland	62.5	3.0	277.3	4.6	0.7
Italy	246.8	93.7	282.2	12.6	34.3
Latvia	26.1	1.5	123.5	60.9	1.2
Lithuania	40.3	3.0	144.2	11.8	0.4
Luxembourg	1.3	0.7	0.1	0.0	0.0
Malta	0.0	0.9	0.0	0.0	0.0
Netherlands	31.4	17.9	10.6	196.0	0.0
Norway	7.8	2.6	0.0	0.0	104.0
Poland	272.4	31.0	270.5	48.7	1.3
Portugal	29.3	25.7	48.2	0.0	5.4
Romania	274.5	35.9	201.1	27.4	14.5
Slovakia	35.5	9.1	21.3	0.0	4.1
Slovenia	3.8	2.7	1.9	0.0	3.1
Spain	376.2	69.3	1172.4	2.1	20.7
Sweden	46.5	7.9	343.2	119.7	47.4
Switzerland	15.5	10.2	0.0	0.0	0.0
United Kingdom	207.1	45.3	526.8	441.2	4.2
∑ European countries	3071.1	715.7	4976.8	1311.7	353.8
Albania	0.1	0.0	0.0	0.0	5.3
Bosnia&Herzegovina	0.0	0.0	0.0	0.0	6.1
Macedonia	13.1	2.3	0.0	0.0	1.2
Montenegro	0.7	1.2	0.0	0.0	1.8
Serbia	70.7	12.5	0.0	0.0	9.7
∑ Western Balkan	84.6	16.0	0.0	0.0	24.1
∑=∑Ec+∑WB	3155.7	731.7	4976.8	1311.7	377.9

2. MULTI-CRITERIA LINEAR REGRESSION ANALYSIS MODEL

2.1. Drafting the MCLRA model

The development of the multi-criteria linear regression analysis (MCLRA) model is presented in this chapter. The MCLRA model is also enlarged by the method of Levelized Cost of Electricity (LCOE) and by social acceptance research to allow holistic consideration of the possibility of a larger integration of RES.

Installing of new RES capacities for electricity production has slowed down worldwide. To explore this trend, assess opportunities for implementing RES potential, and determine whether a wider investment in

RES capacities is possible, a comprehensive artificial intelligence model is developed. The holistic “triangulation” approach encompasses a correlation multi-criteria model, an economic analysis, and a societal perspective.

First, in a linear regression analysis, the number and types of massive input variables were adjusted to maximize the level of explanation of the phenomenon and the significance of the input variables (regressors). The MCLRA model is first developed theoretically and subsequently tested on the numerical experiment of integration of solar energy in the Serbian socio-economic system. Calculating 255 combinations of eight types of input data, possible production of solar energy in the 29 countries was quantified. The calculated results were subjected to complex analyses of sensitivity. Second, the balance between the production cost and market price of electricity produced from photovoltaic panels was analyzed by the economic LCOE method.

Third, questionnaires and interviews revealed public opinion and expert opinion. Discussion of the current situation and positive practice internationally and in Serbia covers regulatory, financial, and economic aspects, including an investment risk assessment. In conclusion, interests and opportunities favour the wider implementation of solar energy facilities for the clean and renewable production of electricity.

2.2. Background for the research of the MCLRA model

Due to limited global resources, alarming pollution, and accelerating global warming development and implementation of renewable energy sources, in this chapter, solar energy is an imperative of modern science. To avoid the devastating effects, it is necessary to halve the carbon dioxide emissions by 2050 [1], which requires radical economic changes in favor of reducing the dependence on non-renewable energy sources and orientation towards renewable, such as solar energy.

Non-renewable resources and accompanying dirty technologies are nearing their end. The remaining recognized reserves of fossil fuels on Earth cover 46 years of oil consumption, 58 years of natural gas and nearly 150 years of coal for exploitation [2]. In Serbia, the reserves of coal, which is of very poor quality, are estimated to only 50 years [3]. If solar energy collected in a single year could be preserved and converted into electric energy, it would cover global energy consumption for the next 6000 years [4]. If only one-tenth of solar energy were collected and distributed, the problems of energy supply on Earth would disappear [5].

The current global population of 7 billion is estimated to reach about 10 billion by 2050 [6]. This growth will intensify the pressure on natural resources. Industrial developments and human lifestyles raise energy needs. Challenges of accelerating need for energy now require holistic research into opportunities for sustainable electricity production and wider use of free solar, clean, green energy. In some parts of the world, solar energy is the only possibility for energy production [7]. In this chapter, electricity production based on solar energy is considered in terms of a synergy of economic parameters function, environmental protection, and sustainable development.

The potential of solar energy is enormous; according to an estimate of the International Energy Agency (IEA) [8], about 885 million terawatt-hours (TWh) per year, which reach the surface of the Earth, is 4200 times greater than the global consumption in 2035. In one hour and 25 minutes, the sun sends to Earth the amount of energy the Earth consumes in a year. "The sun will be a fuel for the future" was written back in 1876 [9]. Many global problems can be addressed by researching the use of solar energy and all its innovative applications. This chapter includes technological, economical, and regulatory variables. A recent study [10] suggests solar-assisted modes with carbon capture and proves its technical and economic feasibility.

Responsible societies require clean electricity of good quality whose production will minimize pollution and allow sustainable development [11]. This chapter presents the research into opportunities for development and production of electricity from solar energy and compares positive practices of exploiting solar potentials in developed world and EU countries having lower potentials but a higher degree of exploitation.

Huge SPPs (solar power plants) are constructed: Shams 1 in the United Arab Emirates, Ivanpah in California, notable Solar Rail Tunnel in Belgium, Solar Bridge in London (Blackfriars Bridge)2. Besides, specific PV envelope design is often applied to commercial buildings in the last decade [12]. In the EU (especially in Germany, Italy, Spain, the United Kingdom, and the Czech Republic), between 2007 and 2014 [13], solar energy utilization increased considerably. Since 2014, however, investments in solar energy implementation decreased significantly [14]. According to a recent

[2] www.eex.com, access July 15th 2201.

study, high-interest rates in developing countries will have a negative effect on investments in solar power plants [15]. Some countries are introducing retroactive changes in existing supporting and stimulating measures for implementing solar energy [16]. This research is motivated by this reduced stimulus. The main question in this research is whether there is still room for wider implementation of free, clean, green energy that bathes the Earth.

This chapter is motivated by the conviction that solar potential for electricity production is underutilized even though it spares the environment. Many countries included solar energy in their energy policies [17]. Although particular methods are proposed for solving specific problems in solar energy implementation [18], more chapters are needed in which possible increases are calculated and analyzed on a country basis [18]. The main idea of this chapter is to establish methods and models for calculating predicted solar energy production, considering different input variables.

Three exact, quantitative methods allow the study of the underutilization of solar energy potentials for power production in this chapter. These methods cover technological, economic, and regulatory variables, including parameters of sustainable development, public opinion and expert opinion. First, the possibilities of expanding the use of solar energy have been explored by the purely economic method of the Levelized Cost of Energy (LCOE). Second, the method of multi-criteria regression analysis includes technological, energy, financial and economic factors and also indicators of sustainable development, simplicity degree of legislative procedures, and regulatory safety. Third, social acceptance is investigated by a questionnaire, combined with interviews exploring public opinion and expert opinion about the problems of solar energy implementation.

The following correlation dependencies for eight relevant input variables (regressors) [19] were analyzed:

– Feed-in Tariffs (FiT),
– Gross Domestic Product (GDP),
– Gross Domestic Product per capita (GDP per capita),
– Natural Solar Potentials (Insulation),
– Position on the World Business Doing List (BDL),
– Price of electricity in households with taxes and levies (PH t&l)
– Consumption by the Industry (CoI)
– Consumption by others, household and services (CoO)
– The analyses were based on literature data for 28 European countries and Serbia as a case study [20]. Input data for 2010, 2013, 2015 and 2016 were taken from relevant websites.

Due to a negative correlation between potentials and exploitation, studying this topic and domain worldwide becomes even more important. Undeveloped countries are, more than the EU, threatened by the effects of global warming, and ozone depletion [21]. In addition, non-renewable resources, primarily coal, are being depleted [22]. Countries need energy independence as a precondition for greater political independence. Economic development requires security for investors and legal regulations that support the business of solar programs.

The main goals of this research were to develop the MCLRA model, apply a triangulation approach, examine whether solar energy increase is possible and find domains in which solar energy can be implemented or expanded. The case study addresses a country with a relatively high solar potential that has so far invested little in solar panels. A secondary goal of this research was to examine obstacles and challenges that hamper the wider application of the solar concept of access to electricity. The educational goal of this chapter is to disseminate knowledge and encourage the implementation of solar energy in its various innovative solutions, for the sake of sustainable development and a sustainable economy.

2.3. Methods supporting the MCLRA model

Electricity is the basis of modern civilization and is essential for its development [23]. Electricity must be produced regardless of the means of production and the consequences. If the environment is to be able to absorb and neutralize immediate and cumulative negative effects, it is necessary to determine the maximum allowed negative impact of particular technologies for the production of electricity. This is one consideration.

Another consideration is the need for sustainable development. The present generation's right to development must not endanger the same right of future generations. Therefore, the production of electricity must be subject to certain limitations in the exploitation of available resources. Plausibly, the use of renewable energy sources is an optimal option that meets the principles of sustainable development and satisfies the need for electricity.

The research algorithm encompasses the following three methods: the multi-criteria linear regression (MCLRA), which investigates the relations among eight technological, energy, financial, economic, sustainability, and regulatory input variables; the LCOE method, which investigates the threshold of profitability for solar electricity; and 100 questionnaires combined with more than 52 interviews investigating pros, cons, and the social acceptability of solar energy.

It is a reasonable assumption that electricity needs will grow in the future. Given the constraints arising from the principle of sustainable development, it follows directly that electricity production can be expressed as a function of technology and principles of sustainable development. Mathematically, this approach can be represented by the following formula:

$$E = E(T, S) \quad (1)$$

Where,

E – Electricity production

T – Technology of electricity production

S – Sustainable development.

The formula (1) does not indicate the nature of dependence between technology and the principle of sustainable development in electricity production. It rather indicates that, in the production of electricity, negative impacts of technology for electricity production on sustainable development must be considered and certain restrictions should be introduced. In this approach, technology and sustainable development are equally important, and the relationship between the two may change with changing needs [25]. In electricity production, however, the principle of sustainability is usually ignored in the conflict of objectives. To improve the formula (1), a hierarchy of principles is introduced here. If the principle of sustainable development is made a fundamental one, then the formula for the production of electricity is as follows:

$$E = E[T(S)] \quad (2)$$

Formula (2) permits only the production of electricity whose technology meets the principles of sustainable development. If the conflict between economic principles and principles of sustainable development is recognized, it follows that the economic principle will prevail at the present level of civilization development. Electricity production technologies will be chosen depending on their economic effect rather than their compliance with principles of sustainable development. In such circumstances, the state inevitably manages the conflict between economic principles and principles of sustainable development. The state acts through subsidies to achieve acceptable profit margins and encourage investment in electricity production technologies that meet the principles of sustainable development.

Solar energy for electricity production is fully in compliance with the principle of sustainable development. The production technology is governed by the nature and physical laws of solar energy transformation into electricity. Because solar energy meets the conditions in formula (6), its implementation is imperative for sustainable development.

In this research, triangulation involves three methods. The first method uses a correlation model of multi-criteria linear regression (MCLRA) analysis [26]. The input variables represent the financial, economic, energy, and sustainable development considerations (FiT, GDP, GDP per capita, electricity prices, and electricity consumption), the country's natural solar potentials (insulation) and legislative procedures and regulations represented by the country's position on BDL. The output variable is the possible installed capacity of solar panels for electricity production. The second method of triangulation, the Levelized costs of energy, is purely economic. The third method of triangulation amounts to investigating the social acceptance of solar energy implementation. All three methods are explained in the following subsections.

2.3.1. The theoretical setting of the MCLRA model

The MCLRA model contains complex statistical analysis. It was chosen because it allowed predicting the value of output variables (possible installed capacity of solar panels) based on two or more values of input variables. In this chapter, there are eight statistically simultaneous independent input variables (also called regressors or predictors, or explanatory variables): FiT, GDP, GDP per capita, insulation, position on BDL, electricity price for homes including taxes and levies, electricity consumption by industry, and electricity consumption by homes and services, termed "other".

The MCLRA model is suitable for processing a system of multiple stochastic variables as predictors [27]. These variables figure in a recent analysis of solar potentials and possible electricity production [28]. The regression analysis model used here can be expressed in the following matrix form:

$$Y = A\Theta + \varepsilon \quad (3)$$

or, in a developed form:

$$Y_{ij} = x_j^T\Theta + \varepsilon_{ij} \quad (4)$$

where:

$$x_j^T = [x_{j0}\ x_{j1}\ x_{j2}\ \dots\ x_{j,u-1}] \quad (5)$$

$$\Theta^T = [\theta_0\ \theta_1\ \theta_2\ \dots\ \theta_{u-1}] \quad (6)$$

Solving the system of form equations (3) by the method of least squares, the following estimates of θ_j parameters are obtained:

$$t = N^{-1}A^TY,\ \ N = A^TA \quad (7)$$

where:
Y – The output variable vector
A – Matrix of coefficients with unknown parameters of dimensions *m* and *n*, where *m* is the number of equations and *n* is the number of unknown parameters
x_j^T – Transposed vector of input variables
Θ^T – Transposed vector of unknown parameters
$\widehat{\Theta}^T = t^T$ – Vector of estimated values of unknown parameters

The MCLRA model and analysis involved the following steps:

– The choice of input variables X1 = FiT, X2 = GDP, X3 = GDP per capita, X4 = potentials of solar radiation, X5 = position on BDL, X6 = electricity price for homes including taxes and levies, X7 = electricity consumption by industry and X8 = electricity consumption by homes and services.

– Output variable Y_i represents the installed capacities of solar cells.

– Regression model is set up for 28 EU countries and one developing country (Serbia) as a case study. When analyzing a set of all eight input variables, 28 equations with nine unknowns are solved.

– Estimating the values of the coefficient is $t = \Theta^T$.

– Using the coefficients, production capacities that could be installed in 28 EU countries and Serbia are calculated by the set regression model.

– Finding differences between capacities of solar cells that are installed and those that should be installed according to obtained coefficients in line with the EU countries, taken as reference.

The last two steps in the above list are calculated for the Serbia case study as follows:

$$Y'_s = \theta_0 + \sum_{i=1}^{n} \theta_i X_{iS} \quad (8)$$

$$\Delta_S = Y_s - Y'_s \quad (9)$$

where:
Y'_s – Capacity that should be installed in Serbia according to the regression model of the EU countries
Y_s – Installed capacity per country
n – Number of input variables
X_{iS} – Values of input variables for Serbia
Δ_S – Differences between capacities of solar cells that are installed and those that should be installed according to the model in this chapter.

The results were analyzed by processing all 255 possible combinations of input variables. Conclusions were drawn. The data on installed capacities for Ec were thoroughly analyzed by MCLRA at time t_0.

$$y_i = y_i(t_0) = \theta_0 + x_1(t_0)\theta_1 + x_2(t_0)\theta_2 + \cdots + x_n(t_0)\theta_n; i = 1{\sim}m \quad (10)$$

$$m_{max} = 28 \quad (11)$$

$$n_{max} = 28 - f \quad (12)$$

where:
f – number of degrees of freedom, which must be ≥1

To achieve reliable results in the MCLRA method, the following was done:

1. Several octets of input variables were tested, and the optimal octet was adopted.

2. The level of significance and the level of phenomenon explanation for all 255 combinations for all 28 EU countries were analyzed.

It was analyzed as follows:

$$v = C_8^1 + C_8^2 + C_8^3 + C_8^4 + +C_8^6 + C_8^7 + C_8^8 \quad (13)$$

where: v – number of variations and C_8^i – number of combinations for which $i = 1, 2, 3, 4, 5, 6, 7, 8$.

The statistical analysis was performed using average (y) and standard deviation (σ) to test the stability of the model concerning the exclusion of countries with extreme values, one at a time. Sensitivity analyses were done.

2.3.2. The LCOE method

The Levelized Cost of Energy method was applied to calculate the production price of solar energy and to discuss its impact on investment possibilities. The financial aspect of electricity production is critical when choosing technology [15]. Financial motives underlie human activity in the production of goods and services, including electricity. Electricity is a major driver of economic and investment activities. Expected profit is a measure of the cost-effectiveness of the project and a critical factor in decisions to make investments. The financial aspect of electricity production from solar energy is explored by the method of Levelized Cost of Energy [29], which is expressed by the following formula:

$$\mathrm{LCOE} = \frac{\text{Sum of costs during the plant's lifecycle}}{\text{Electricity produced during plant's lifecycle}} = \frac{\sum_{t=1}^{n} \frac{I_t + O_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{S(1-d)^t}{(1+r)^t}} \tag{14}$$

where:

- LCOE – Levelized cost of energy
- I_t – Investment cost per year t
- O_t – Operator cost per year t
- M_t – Maintenance cost per year t
- – Financial expenses per the year t
- S – Start-up electricity production in the first year
- d – Factor of decline in production per year
- r – Discount rate
- t – Particular year during plant's life expectancy
- n – Life expectancy of plant in years.

Regulatory domain refers to compliance with contracts between investors and buyers of electricity. The assumption is that in countries having a more efficient legal system, the costs of investments in solar energy production plants will be lower, and the time needed to obtain permits will be shorter so that the investment will be realized sooner. Assuming that investment costs are fixed and that maintenance and production costs remain the same during the lifecycle of a power generation plant, the formula (14) is simplified:

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{S(1-d)^t}{(1+r)^t}} = \frac{\sum_{t=0}^{n} \frac{(1+c)I}{(1+r)^t}}{equa} \tag{15}$$

where:

$$I = I_1 = I_2 = \cdots = I_n = I \tag{16}$$

$$M = M_1 = M_2 = \cdots = M_n = c * I_t \tag{17}$$

c represents maintenance costs as part of investment costs in year t. Research into the wider application of solar energy was done using the three aforementioned scientific methods. The methodological holistic approach [30] additionally includes induction, deduction, analysis, synthesis, and analogy [31]. This chapter cites examples of positive practices worldwide.

2.3.3. Questionnaires and interviews

Social acceptance is investigated by a questionnaire and follow-up public opinion surveys, and expert opinion on the problems of solar energy implementation. The questions elicited the participants' views about the awareness of, justification for, and usefulness of solar energy implementation [32]. This phase of experimental research was carried out in June and July 2021. In order to obtain reliable quantitative data, the questionnaires were completed by 109 respondents in two subgroups. The first subgroup consisted of 52 experts in solar energy; the second one consisted of 57 lay citizens, and all 109 responses were processed using statistical methods and software packages Microsoft Excel and SPSS for Windows 13.0 [1].

2.4. Research results

This research is partly motivated by a paradoxical situation in which some countries with relatively high solar potentials have less installed capacities than some developed EU countries such as Germany, Italy, the United Kingdom, and Spain, which have less solar potentials. This regression between potential and exploitation justifies the use of regression analysis, a complex statistical method that also allows the processing of massive amounts of data. The degree of PV (photovoltaic) panels installation depends not only on solar potentials, but also on economic, legal, and regulatory parameters and parameters of sustainable development. A multi-criteria (also known as multiple) regression analysis is appropriate because it enabled the inclusion of all of these parameters. Besides the multi-criteria analysis, the study also includes a purely economic method of uniform electricity costs (LCOE), which allowed testing the production price of electricity obtained from PV panels in market conditions in Serbia. The two quantitative methods are augmented by the third method – a combination of quantitative analysis of 109 questionnaires completed by experts and laymen, followed by qualitative interviews with a subset of ten professors, experts in solar energy. This holistic methodology, the three-pronged analysis, yielded significant results and useful conclusions. Research findings include the results of all three methods used (MCLRA, LCOE, and questioner with interview), also tested on a case study.

2.4.1. MCLRA results

The results of the regression model for the first combination of input variables (FiT, GDP, GDP per capita, insulation and BDL) are shown graphically in Figure 1 and they show the number of variant 1, that in Serbia with the current situation of FiT, GDP, GDP per capita and BDL, and according to existing potentials, it is possible to install another 934 MW of solar capacities.

Summarized results of exploring the possibility of building solar capacities that can be installed in Serbia according to the regression model are shown graphically in Figure 2.

The analysis of the results shown in Figure 1 and Figure 2 indicates that in Serbia in 23 variants, the combination of input variables (74%) has less installed capacity compared to the parameters of the model formed applied to 28 European countries, which means that the reasons for the larger installation of solar capacities in Serbia are dominant. In the eight variants, the combination of input variables (26%) of the regression model implies that Serbia has the potentials to develop the application of solar energy in electricity production by increasing FiT (*X1*) and/or GDP (*X2*) and/or GDP per capita (*X3*), and/or improving the position on BDL (*X5*). Regressor *X4* is constant and unchangeable. It is natural potential. These results indicate that in Serbia potentials for the development of solar capacities for electricity production are not sufficiently used and that there are possibilities for better implementation of solar energy through correction of indicators of technological, economic, legal regulatory and procedural improvements.

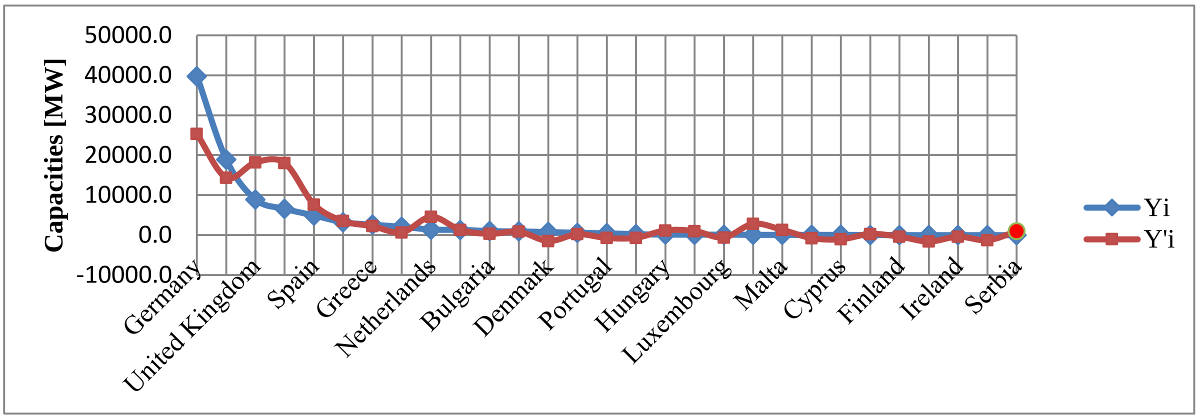

Figure 1. Solar capacities to be installed according to model [Y'i] and installed capacities [Yi] with simultaneous inclusion of all input variables

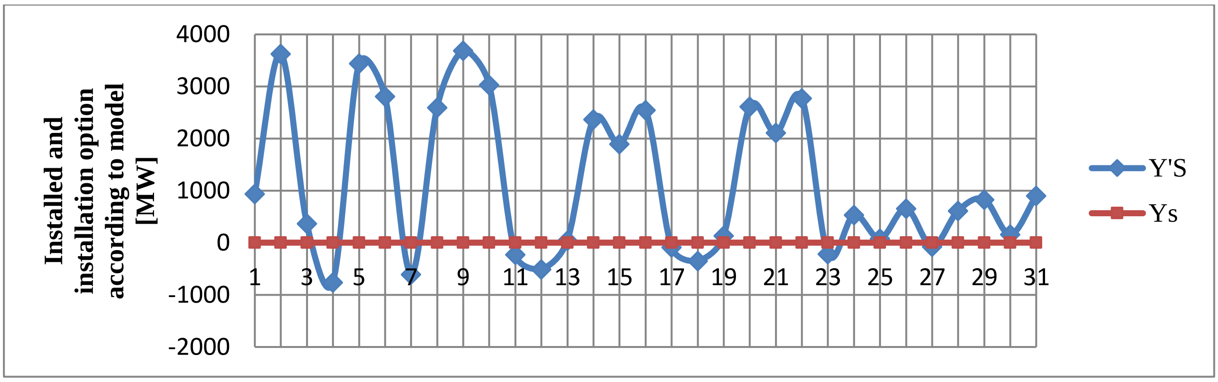

Figure 2. Ratio of solar capacities that can be installed in Serbia according to correlated regression model compared to EU countries [MW] for all variants

2.4.2. Sensitivity analysis

The stability of the MCLRA model developed here was verified by sensitivity analysis. The number of input variables was changed from five to eight. Additional input variables (regressors) were: electricity price for homes including taxes and levies (*X6*), electricity consumption by industry (*X7*), and electricity consumption by homes and services (*X8*). The results were stable.

The uncertainty of ±5% was also introduced in input variables *X1* through *X8*. Nine sets of input and output variables altered by ±5% around the initial values were calculated. All 255 combinations were examined and changes in the results were monitored. The sensitivity of results to alterations in input and output variables was tested. By applying the ±5%

alterations, the results somewhat change but the model remains stable and the results valid. The stability of the model was proved.

The statistical coefficient of determination quantifies the agreement between the phenomenon and the model. In other words, it shows the extent to which the model explains the phenomenon. It is higher than 95%. The level of explanation for installed solar capacity was calculated too. The level of explanation shows to what extent the phenomenon is included by the input variables selected. About three-fourths of the 255 combinations achieved levels exceeding 70%. The number of input variables and their composition was chosen properly. The 254th combination reached the level of 96%.

Since Germany, Italy, and the United Kingdom stand out by the values of installed solar capacities, the stability of the model was tested by excluding those extreme values from the mentioned countries. These three countries were variously excluded, one by one, and the entire calculation was performed for the remaining countries. The impact of these exclusions on the model was analyzed. The result shows that the model remains stable.

2.4.3. Results of the LCOE method – a case study

The economic analysis of cost-effectiveness by the LCOE method given by formula (19) rests on two assumptions:

First the average annual production will be realized corresponding to data for Serbia in the past period; and

Second - solar capacity is financed with a 20-year loan repaid in equal installments during the life cycle of the solar panels.

Inserting the following initial data:

– P = 1 MW = 1000 kW – installed power
– n = 20 – solar power plant lifecycle
– P_E = 0.20941 €/kWh – the price of electricity per kilowatt [1]
– I = 1,100,000.00 - initial investment [8] (1.1€/W)
– c = 0.01 (1%)
– d = 0.01 (1%)
– r = 0.025 (2.5%)
– I = 60,000 €/year
– S = 1,100,000.00 kWh (annual produced electricity based on installed power for Serbia)

into formula (15), formula (18) is obtained:

$$\mathcal{LCOE} = \frac{968{,}320\ €}{14{,}667{,}901\ \text{kWh}} = \frac{0.066\ €}{\text{kWh}} \quad (18)$$

This Levelized Cost of Energy is similar to market prices of electricity from leading producers in Serbia, namely, thermal and hydroelectric power plants [34]. This similarity expands the prospects of solar energy in Serbia. Investments in solar power generation remain insufficient, possibly because of the risks that further increase production costs from PV panels or because formula (15) simply defines the costs or omits certain costs. Low electricity prices in current market conditions in Serbia also inhibit the development of investments in solar power plants. In the literature [35], marketing barriers are identified as independent barriers.

The results of the questionnaire and the interview show positive public and expert attitude to higher integration of solar energy into the Serbian socio-economic system.

3. MCEGA MODEL

Multi-criteria evolution genetic algorithms (MCEGA) artificial intelligence model is developed within this chapter. It encompasses nature-inspired optimization of renewable energy resources integration within an electric power system. The goal of the MCEGA model development is to find the maximum possible integrative renewable capacity. The model is developed first theoretically by general formulas. After the theoretical mathematical analyses, the model is tested on the numerical experiment of a real electric power system, which considers all limitations and constraints. Solar energy integration in the Serbian electric power system is selected for a case study because the system includes a sufficient number of the reservoirs to provide stability of the system after introducing an intermittent resource.

The purpose of this MCEGA artificial intelligence model is to examine the effects of solar energy integration in an electric power system taking into account all costs arising from circular economy criteria. Four scenarios of solar power plant integration are analyzed. The methodology relies on nature-inspired optimization. The optimization is based on the costs of electricity production, including not only the costs of technology but also the costs of environmental protection and sustainable development, in line with circular economy principles. These costs are included in the model and the objectives are formulated accordingly. The objectives are based on the maximization of electricity production up to the level of demand, minimization of total electricity costs and minimization of greenhouse gas emissions. In addition, grid losses, as well as other limitations and constraints of the electric power system, are included in the model. The loss distribution is calculated in proportion to the distance between the supplier and the end-user. The solar power plant losses are zero because the plant is assumed to be located in a local community, close to consumers.

3.1. Motivation for MCEGA development and Circular Economy principals

Some of the most highlighted issues of the 21st century are resources, i.e. energy and environment, with the main and strongest impact on the conflict between the use of renewable and non-renewable sources. Growing populations, increased energy demand and profit as civilization goals versus CO2 emissions, environmental pollution, global warming and sustainability, are subjects of various studies [1]. All contemporary energy policies define the introduction of renewable energy sources as an imperative; however, objectively, all analyses have to take into account all costs rather than mere costs of technology and direct benefits, as was the case [2]. Optimization analyses should be made in the context of circular economy [3], respecting the right of all generations to equal use of resources. This may be achieved by the inclusion of the costs of recycling until reuse and environmental recovery to the zero state, a step forward dealt with in this chapter.

At the same time, there is a shortage of resources on the Earth for transforming into energy with the presently known technology. The existing technology causes unacceptable environmental degradation [4]. Intending to ensure the sustainable future of the Earth [5], scientists, engineers and decision-makers worldwide have defined limitations for all countries. In Europe, some requirements have been fulfilled about the Energy Policy 2020 [6], which has been replaced by a much stricter framework and limitations on emissions to serve the goals of EU Energy Policy 2050 [7].

The focus on renewable energy utilization is growing sharper due to its sustainability and contribution to greenhouse gas emission reduction. However, the highly stochastic, specific availability of hydro, solar or wind energy, given their variability and the issue of supply certainty, makes this issue more intricate. A holistic approach is required to achieve the synergy of all correlated elements of the system. Renewable energy cannot be introduced into an electric power system simply as a linear function. The electricity system has to be capable of covering the daily load at all times, even when there is no water, sun, or wind. In addition, water, solar and wind energy is not absolutely clean. There are still elements to be recycled after the end of the life cycle [8]. There are certain environmental impacts as well. Regardless of how these influences are smaller than the negative impact of thermal power plants (TPP), and however minimal they may be, they are taken into consideration in the optimization analyses in this chapter.

The subject of this chapter is research on wider solar energy use by nature-inspired optimization, intending to meet the criteria of circular economy, i.e. environmental management [9] and sustainable development in the holistic sense [10]. At the same time, stable electric power system operation is set as a condition to be fulfilled.

Sustainable development, even though defined in a simple way (as the right of the present generation to develop without violating the subsequent generation development) is quite complex in applications. From the aspect of the UN approach, it is divided into 17, sometimes mutually conflicting goals [11]. All those goals could be systematized in three large groups: social, environmental, and economic. Social aspects are researched in another chapter [12]. On the one hand, economic development needs the utilization of environmental resources, but on the other hand, the environment has to be protected, which means it limits the economic development. Social development means that people would be able to satisfy all their needs, including well-being and a clean environment. These two goals are directly conflicting. One of the sustainability goals (goal number 7) requires affordable and clean energy as the basis of contemporary civilization development. This means (bearing in mind that electricity is not available to 840 million people, according to a World Bank's current report [13]) that sources of electricity should be expanded. In addition, bearing in mind that electricity production causes significant greenhouse gas emissions, it is necessary to find solutions for their reduction, while increasing electricity production. SPP introduction opens up possibilities for this.

The circular economy is a new model of sustainable development and an instrument of environmental protection [14]. The European Union (EU) institutions are increasingly raising awareness of the importance of the circular economy (CE) agenda. According to the OECD report[3] 2020, global consumption of all materials is expected to double by 2060 [15]. The World Bank[4] estimates in its report that waste generation could increase by 70% by 2050, as compared to 2020 [16]. Therefore, governments, policymakers, engineers and scientists are faced with

[3] https://www.oecd.org/development/development-co-operation-report-20747721.htm, access July 25th 2021.

[4] https://www.worldbank.org/en/about/annual-report, access July 25th 2021.

the challenge to search for possibilities to use circular economy systems, such as better eco-designs, waste prevention, as well as the reuse and recycling of materials, whilst reducing waste and emissions according to EEA Report 2018 and the literature [17]. Only the sustainable, circular economic development models and their regenerative systems can minimize industrial waste, emissions, and energy leakages, as they can ultimately add value to the business as well as to our natural environment [18]. However, research on circular business models is nascent and the business literature pays limited attention to the challenges deriving from circular economy implementation [19].

New Energy Policy of the European Union 2050 (New Energy Policy, EU 2050) requires achieving an 80-95% greenhouse gas emissions reduction as compared to 1990 [20], which poses great challenges to mankind, given all the conflicting interests. This research includes the development of possible nature-inspired optimization models guided by circular economy principles. The optimal operation of solar power plants with different integrated capacities (0MW, 10MW, 60MW and 100MW) was considered by applying the evolutionary multi-criteria optimization algorithm. Numerous solutions were considered, as nature selects the best results in the course of evolution. Bad solutions are "punished" and excluded, just as nature punishes weakness and insufficiency.

Growing population and urbanization in developing countries have further increased the energy consumption and peaks in daily load patterns. Therefore, they are now faced with even bigger challenges to meet the requirements of the New EU Energy Policy 2050 [21]. Some of those countries, such as Northern Macedonia, which abounds with natural prerequisites for renewable energy integration, have already developed their strategic plans to meet the requirements of the EU Energy Policy 2050 [22]. Some countries, like Russia, have gas to export [23]; others, like Serbia, rely on lignite [24], which is rather poor quality with high CO2 emissions, the reserve of which is estimated to be low and almost entirely exhausted by 2050 [25].

"Energy for all" is one of the declared sustainability goals [26] and authors have found that the orientation towards wider integration of solar energy is one of the possible solutions to the existing problem. Solar energy is clean, renewable and free of charge. The power of the Sun absorbed by the Earth is 1.8 × 1011 MW. This is far higher than the total global current energy consumption [27].

In this chapter, an effort is made to create a new model for the analysis of solar energy integration into an electric power system, having considered technical and economic criteria, but also including quantified impact on the environment and sustainable development, and especially emissions. Although solar energy as a resource is clean, renewable and free of charge, there are still certain problems in its integration to be researched. This chapter deals with all real conditions and limitations of an electric power system and variability of daily load. The price of electricity per unit sold will include not only the costs of technology but also the environmental protection and sustainability costs in the sense of circular economy [28]. It means that all costs arising from the waste management system cycle, including recycling and reuse, will be included [29]. In this case, the user will pay not only the price per electricity unit (kWh) formed in the free market but also the costs of utilized resources (costs needed for environmental reclamation) and the costs of loss for future generations because of the resources which are now being depleted. In the optimization model, this attempt is expressed through the price, which burdens the costs of electricity production and consequently adversely affects the profit of the electricity producer.

3.2. Different scenarios

The methodology is based on different scenarios of introducing a renewable power plant in a local community and the electric power system of a country or region as a whole, with all inherent conditions and constraints. Simulation of the system operation (locally and in the electric power system as a whole) is made for three possible integrated capacities of renewable power plants (RPPs): 60MW, 300MW and 600MW. An RPP could be a solar, wind, or small hydropower plant or a plant powered from another renewable source depending on the country, region or location and availability of the natural potential of the local community.

All calculations were made for a system with and without a renewable power plant in a local community. The goal was to evaluate the differences and effects of renewable power plant integration in the local community. The benefits are analyzed and discussed from the aspect of both the local community and the whole system, for different integrated capacities.

The system operation was simulated based on real energy suppliers in the country, with their possible minimum and maximum production taking into account all actual conditions and constraints of the electric power system. The defined production target was to reach the consumption demand (presented as daily load), including grid losses resulting from energy transport. The 24-hour daily load pattern on the coldest winter day was selected to target the consumption requirements. The shapes of peaks, particularly pronounced during that season, were precisely covered by production.

3.3. Evolutionary multi-criteria genetic algorithm

The optimal operation of the electric power system is defined by the evolutionary multi-criteria genetic algorithm, as a decision-support system generator [30]. The input data are defined and organized within an Excel add-in that provides easy access to evolutionary multi-criteria optimization algorithms. The software is developed for solving problems in water engineering practice, to close the gap between the achievements in the optimization technology and the successful use of the decision-support system in practice [31]. This chapter contemplates the new adjustment of existing software of complex electric power systems such as the electric power system of the whole country, which is comprised of different power plants and consumption requirements defined by the 24-hour daily diagram of different loads.

At the same time, the novelty is that the impacts on the environment and sustainable development (in the broadest sense of the word) are not left to be discussed separately or after the implemented optimization and selection of solutions:

They are included together and, at the same time, with technical and economic criteria in the optimization model.

They are included in optimization as quantitative data.

They have equal weight in deciding on the choice of the optimal solution, having a direct impact on solution selection.

In this model, they also have more weight because greenhouse gas emissions are singled out as a special criterion.

After the testing, 20 dominant results were found a sufficient module to be presented as a result of a robust optimization framework. 50,000 (fifty thousand) generations composed of daily consumption requirements on an hourly basis (24h), versus production of all different power plants in the country (24 power plants), for four different scenarios of the additional solar power plant integrated capacity (0MW, 10MW, 60MW and 100MW) were calculated. For easier visualization, a huge number of results was systematized and graphically presented by a newly developed algorithm. We operated with 576 data on energy production, emissions, technology costs, environmental costs, sustainability costs and losses for 24 PP in 24h.

3.4. The goal

The main goal of the research presented in this chapter was to study the impact of renewable solar energy integration on the local community and within the power supply system of the country. Hypotheses were tested and proved in a case study of a real electric power system.

The optimal operation of 23 or 24 different power plants in the selected electric power system was found by the evolutionary multi-criteria genetic algorithm, introducing two objective functions and related constraints. The goal was to maximize the production up to the level of demand, minimize CO2 emissions, and minimize the costs of energy production. The novelty is that the electricity production costs were considered as per circular economy principles. They were calculated as the sum of:

– Technology costs,
– Environmental protection costs,
– Sustainability costs (since the circular resources usage was considered) and
– The costs incurred due to losses in the distribution network.

Technology costs include all the costs arising from the technology process of electricity production, including maintenance and refurbishing. Environmental protection costs include all costs arising from all mitigation measures of direct environmental impact in the process of electricity production from solar energy. Sustainable costs in this chapter include all the additional costs of decomposing all used materials and reusing them to the zero-waste level. The costs of distribution network losses are very high in Western Balkan countries due to the bad cable connections and old materials used. Thus, the costs incurred due to losses in the distribution network have also to be calculated because it increases the total cost of electricity production. A graphical presentation for the calculation of electricity production cost is given in Figure 3.

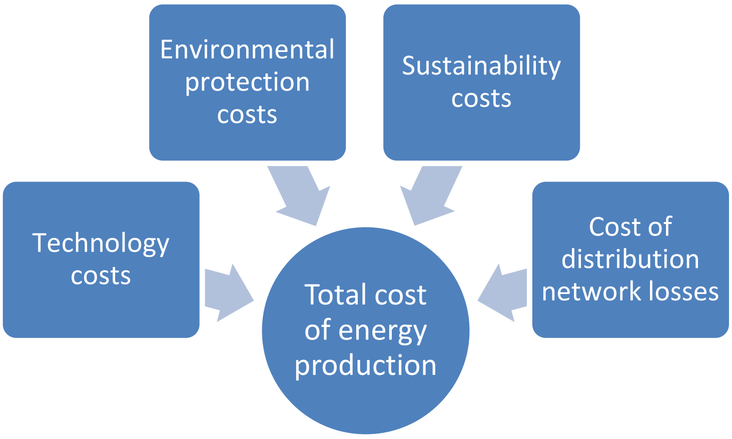

Figure 3. A holistic approach to optimization of electricity production costs

3.5. Methodology of the MCEGA model development

This research includes the development of possible nature-inspired optimization models. The purpose of this MCEGA artificial intelligence model is to research the effects of solar energy integration in an electric power system taking into account all costs arising from circular economy criteria. Four scenarios of solar power plant integration are analyzed. The methodology relies on nature-inspired optimization. The optimization is based on the costs of electricity production, encompassing not only the costs of technology but also the costs of environmental protection and sustainable development, as per circular economy principles.

These costs are included in the model and the objectives are formulated accordingly. The objectives are based on the maximization of electricity production up to the level of demand, minimization of total electricity costs and minimization of greenhouse gas emissions. In addition, grid losses, as well as other limitations and constraints of the electric power system, are included in the model. The loss distribution is calculated in proportion to the distance between the supplier and the end-user.

The solar power plant losses equal zero because it is assumed that the plant is located in a local community, close to consumers. The optimal operation of solar power plants with different integrated capacities is considered applying the evolutionary multi-criteria optimization algorithm. Numerous solutions are considered, just as nature selects the best results in the course of evolution. Bad solutions are "punished" and excluded, just as nature punishes weakness and insufficiency.

Economic benefits are analyzed and calculated in addition to all financial constraints and costs arising from the waste management system, including recycling and reuse. The use of the resource is not linear in this case. The proposed methodology implies performing some critical tasks such as data acquisition[5], data processing [31] and determining an adequate objective function with the goal of electricity production costs minimization and emissions reduction.

If all of the existing energy sources (thermal, hydro, nuclear, wind, solar, etc.) in one country have their respective outputs marked as:

$$X_1, X_2, \dots, X_k, \dots, X_n \quad (19)$$

and costs from particular sources are:

$$C_1, C_2, \dots, C_n \quad (20)$$

then the functions of energy production could be defined as:

$$Y = \sum_{i=1}^{n} C_i * X_i \rightarrow \min \quad (21)$$

wherein:

– Y – costs of total energy production;
– C_i – costs of energy production per each source;
– X_i – amount of energy produced from each source, and
– n – total number of electricity sources.

The first objective function (total sum of electricity production costs) in the optimization model could be formulated as:

$$C = \sum_{i=1}^{n} C_i \rightarrow \min \quad (22)$$

wherein

$$\forall C_i \rightarrow \min \quad (23)$$

[5] https://ourworldindata.org/, access July 27th 2021.

Electricity production costs shall be expressed as follows:

$$C_i = C_i(T_i,\ E_i, S_i) \quad (24)$$

wherein:

T_i – costs of technology per kWh of electricity produced;

E_i – environmental costs per kWh of electricity produced, and

S_i – sustainability costs per kWh of electricity produced.

Energy production per source is limited as follows:

$$X_i \leq \varepsilon_i \quad (25)$$

$$\varepsilon_i = \varepsilon_i(K_i, En_i, S_i) \quad (26)$$

wherein:

K_i – Capacity of i^{th}electricity source;

El_i– Environmental limitations for i^{th} electricity source and

Sl_i – Sustainability limitations for i^{th} electricity source.

The position of the local community as a possible location for renewable power plant installation may be different within the system. The distances between the local community and particular energy sources are consequently different, and there is a difference in grid losses. The goal is to minimize the losses. Losses could be defined as follows:

$$L = \sum_{i=1}^{m} k * d_{ij} = k * \sum_{i=1}^{m} d_{ij} \quad (27)$$

wherein:

– L – total amount of electricity losses in the system;

– k – coefficient of losses (expressed as losses of kW per km $\left[\frac{kW}{km}\right]$ assuming that losses are proportional to the distance from the electricity source to the user) and

– d_{ij} – the distance between the j^{th} electricity source and i^{th} user.

Total losses in the electric power system are defined as the difference between the total production and total distributed electricity and, accordingly, they can be calculated or estimated quite accurately. The coefficient of losses could be then calculated as follows:

$$k = \frac{L}{\sum_{i=1}^{m} d_{ij}} \quad (28)$$

Other limitations related to the capacity of the source are:

$$K_i = \sum_{i=1}^{n} X_i\ (t) \leq \max(K_i) \quad (29)$$

This means that one source, the same as all sources together, is not able to produce energy above its capacities. Starting from the assumption that equilibrium is necessary for the electric power system (the demand and production, inclusive of electricity losses, have to be equal), this equation reads:

$$\sum_{i=1}^{n} X_i = \sum_{i=1}^{m} Z_i + L \quad (30)$$

wherein Z_i is i^{th} user and m is the total number of users.

The demand (D) in this context is the sum of amounts of electricity distributed to end users, and it is a dynamic value that depends on daily and seasonal variations. This is expressed as

$$D(t) = \sum_{i=1}^{m} Z_i \quad (31)$$

It also implies that the sources of electricity will adapt to the demand. The difference in the equilibrium state of the electric power system caused by non-equality of the demand, production and time-dependent losses could be expressed as follows:

$$\Delta(t) = D(t) + L(t) - \sum_{i=1}^{n} X_i\ (t) \quad (32)$$

The value of $\Delta(t)$ causes a decrease in the quality of distributed electricity and must be made up by either an increase of electricity production or by electricity import.

- t – the hour of the day and
- $\sum_{i=1}^{n} X_i\ (t)$ – sum of electricity produced within the hour t.

Further limitations in the model are assumed:

$$X_i \in (0.20 * X_i^{max}, X_i^{max}) \quad (33)$$

$$\Delta \rightarrow \min\ (\Delta \leq 5\%) \quad (34)$$

which means that the sources are utilized between 20% and 100% of their maximum capacity. In the case of the electric power system imbalance, it will not exceed 5% per each hour of the day. In order to reduce the wear and tear of equipment and to ensure smooth operation of each plant, an additional constraint was introduced to penalize solutions with big changes in operations. The optimal integrated capacity for the local community was searched through four different scenarios of integrated capacity. The first objective function shall be modified as follows:

$$Y(t) = \sum_{i=1}^{n} C_i * X_i(t) \rightarrow \min \quad (35)$$

The second objective function expresses the goal to minimize emissions of GHG, i.e. equivalent CO_2:

$$EM = \sum_{i=1}^{n} EM_i \rightarrow \min \quad (36)$$

wherein EM represents total daily emissions of the electric power system, i.e. from all PPs.

The scientific community can replicate our findings using the given objective functions and the software available at request. Input data for the presented case study are taken from the Public Electric Utility of the country, as well as from relevant global websites[6]. Information regarding software settings is presented in Appendix A, which is available for replication.

3.6. Results and discussion on the MCEGA model

Solar energy implementation is selected as a case study of energy supply for the local community, although other renewable are also applicable. Hence, due to local conditions, solar energy is considered the most appropriate energy for the case study in this research. The results obtained by solar power plants incorporation are discussed and compared with other types of energy at national and community levels.

Solar energy is clean, renewable and free of charge. 1.8 × 1011 MW is the power from the Sun captured by the Earth. This is many times higher than the current total quantity of energy consumption in the world [27], so we can expect a new technology of more efficient solar energy production to be found by 2050 within further researches.

Serbia is selected as a location for the research because it is a country with a specific situation in coming 2050, relating to the main present resources availability and because it has an average solar potential in the European continent presented by insulation of 1400 kWh/m^2/year [27]. Also, it is an agricultural country already organized in many local communities [32], with the good possibility of local power plant implementation within the system or as an isolated system. At the same time, since introducing additional capacities such as solar or wind capacities requires adequate reserves of water reservoirs and hydropower plants, as a rotating reserve in an electric power system, one can say that this condition is also fulfilled. Therefore, consideration of a Serbian electric power system, as a case study for the research of wither integration of solar renewable energy, is an absolutely good choice. Presently, there is constraining in solar energy implementation in the system. It is related to the quality of energy and its applicability within the peaks of the daily pattern of electricity supply, which is presented in Figure 4.

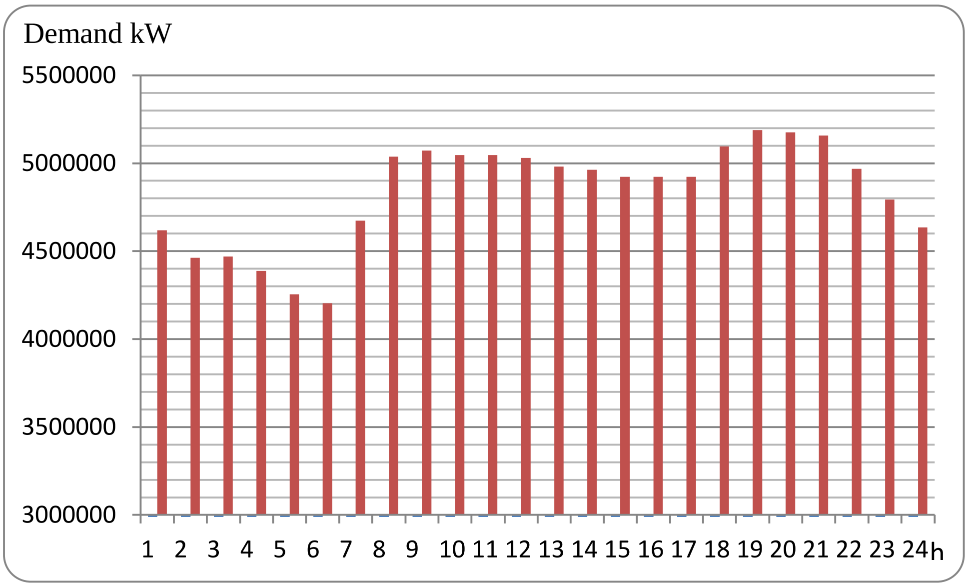

Figure 4. The daily pattern of electricity demand per hour – daily load

The daily pattern of electricity demand per hour is considered as the daily load of the coldest winter day because the peaks are the sharpest during that period. Accordingly, if the combination of power plants is successful in covering the daily pattern of electricity demand on that day, it will be also successful on other days within the production year.

Every solar power plant can be incorporated in the electricity supply system of the country if there is a supporting quantity of renewable hydropower stored in reservoirs, which is therefore named and known as “green accumulators” [1]. This condition is met in Serbia and it is an additional motive for selecting this location and this renewable resource as

[6] https://www.electricitymap.org/map, http://www.eps.rs/eng, access August 25th 2021.

a case study for the research. The correlation coefficient between the emission and cost of SPP 0 MW, 10 MW, 50 MW and 100 MW of installed capacities (denoted as 1, 2, 3 and 4 respectively) is given in Figure 45. All results are related to the complete energy system of a case study. The correlation coefficient is negative because CO_2 emission decreases, since the solar power plants investment increase.

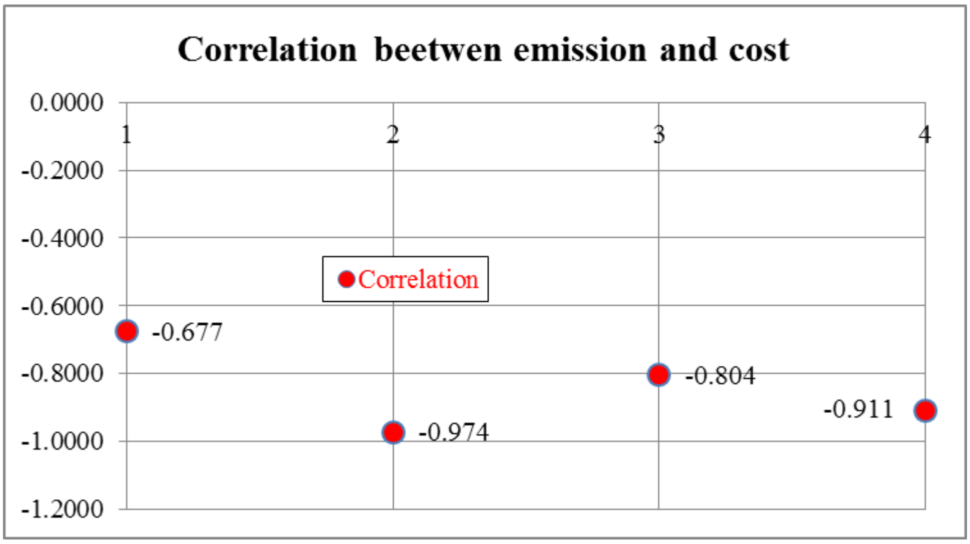

Figure 5. The correlation coefficient between emission and cost for four scenarios

This diagram shows that the optimal installation of SPP in the present stage of the electricity system and consumption is 10MW. It means that the model is well developed and tuned because the results adequately present the actual situation in the electricity system of the case study. In the next diagram (figure 6), the total cost is presented in millions of euros of electricity production of a complete energy system, for all 20 generations analyzed within the evolutionary multiple objective genetic algorithms. The results of the installation of SPP of 10MW within the system are presented in Figures 6, 7 and 8.

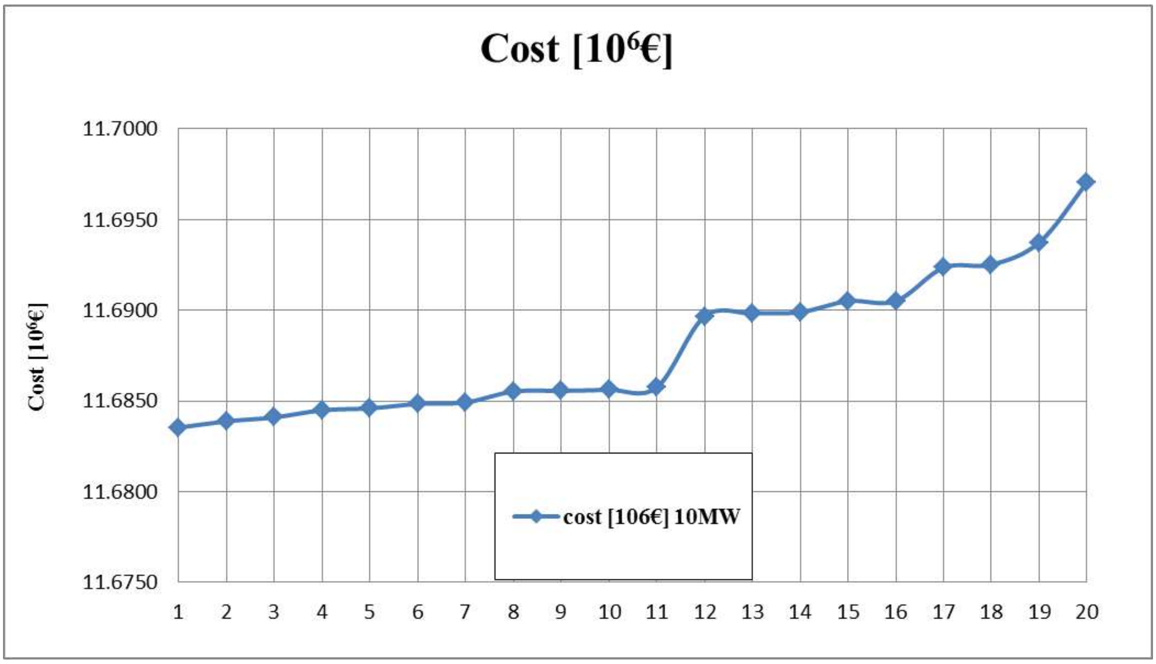

Figure 6. The total cost of energy production of an electricity system with 10MW of SPP

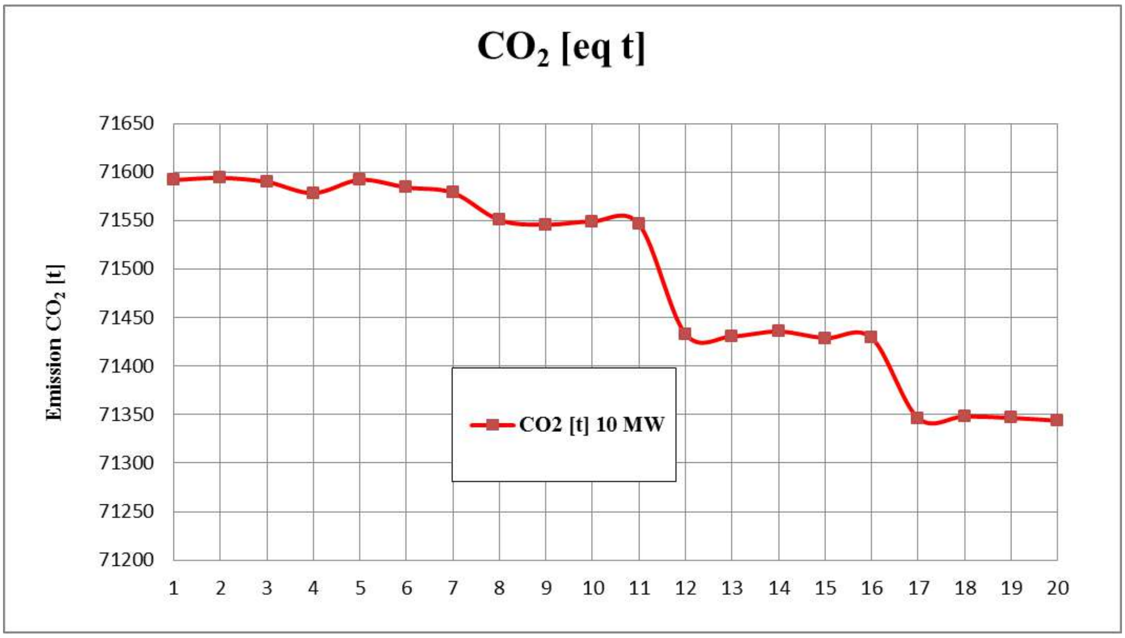

Figure 7. Total CO_2 emission (eq t) in an electricity system with 10MW of SPP

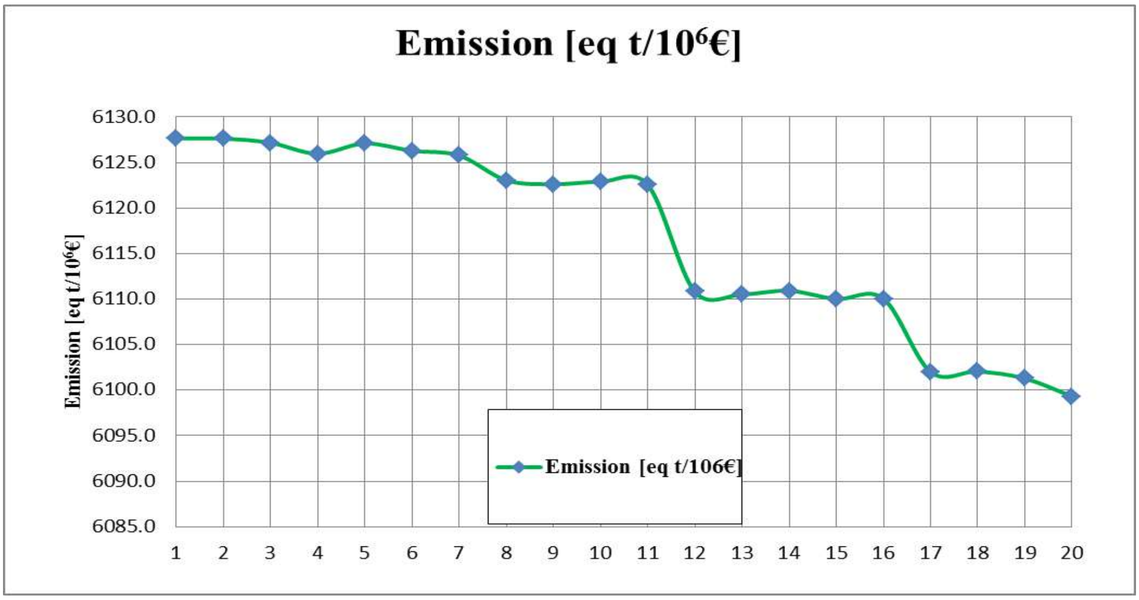

Figure 8. Total emission (eq t/10^6 €) in an electricity system with 10MW of SPP

Normalized values are also given (Figure 9) because of obviousness and better presentation of the results. Normalized results are obtained by the following formula:

$$\eta_i = \frac{x_i - \bar{x}}{\sigma_x} \quad (37)$$

Normalized values are given for SPP of 10 MW for both functions:

– total cost of energy production within the electric power system; and

– total emission of the considered electric power system within the country.

The total cost of energy production within the whole electric power system is above average because the circular economy and sustainability principles are introduced. The cost is not calculated as technology cost only, which is the most common practice within optimization models. The circular economy and sustainability principles as well as the responsibility for future generations obliged us to include the environmental cost and sustainability cost. In the presented calculation, the total energy production cost contains the costs incurred due to losses in the electrical distribution grid as well.

Summarized results for the four scenarios are given in Figure 10.

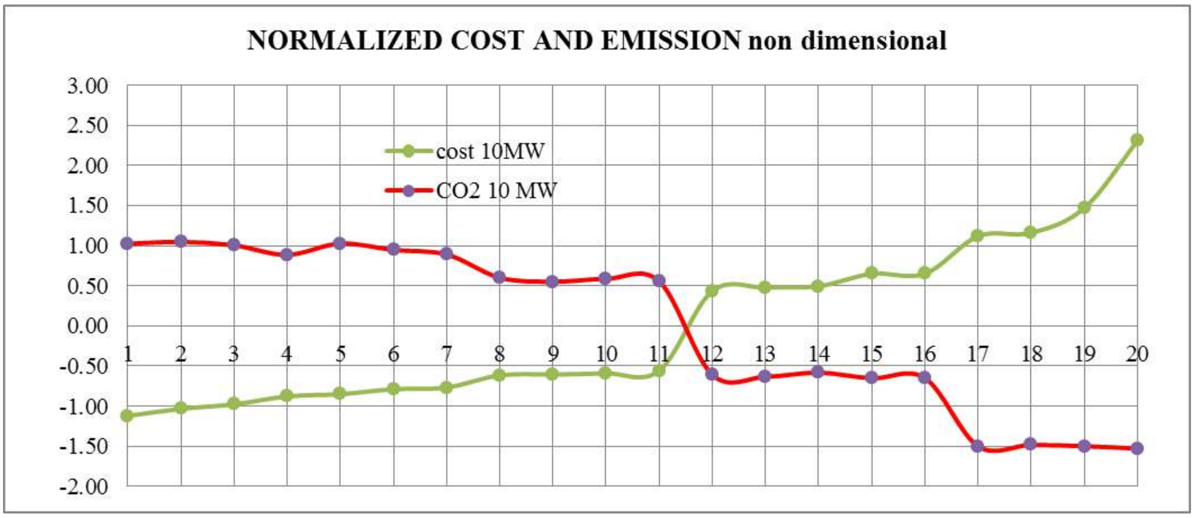

Figure 9. Normalized cost and emission non-dimensional for 10MW of SPP installation

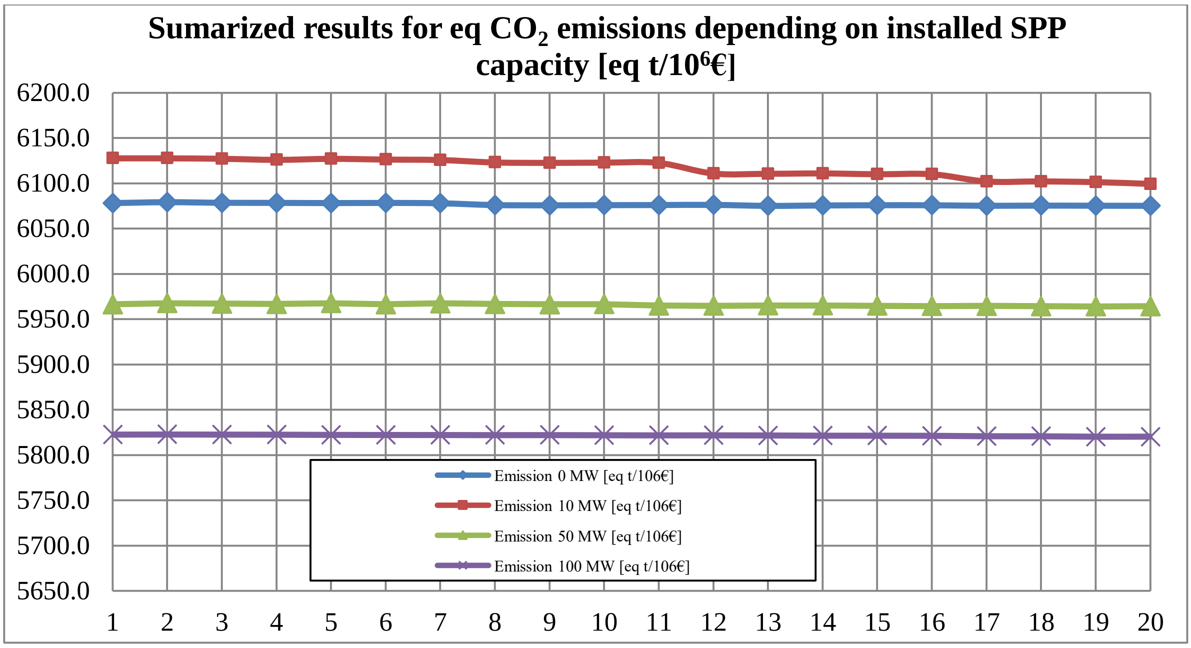

Figure 10. Summarized results for eq CO_2 emissions (eq t/10^6 €) for all four scenarios

The last diagram shows that emissions are decreased with increased installation of SPPs. It means that with higher solar energy installations a system is closer to the sustainable set, as it is defined in the literature [34]. The same conclusion can be valid for a whole system, or renewable micro-grid (MG) [34] if we consider a local community with installed SPP as a decentralized energy option. The fact that emissions increase between 0 and 10 MW can happen because the input of 10MW of a new solar power plant is too small an installation to change big thermal block in their engagement, within the system. It can be a matter of further research.

The results suggest that increased installation of solar power plants (50MW and 100MW) provides greater benefits for the local community and the whole system regarding cost and decrease in CO_2 emissions. Taking into account the limitation of coal reserves and New EU Energy Policy 2050, requirements relating to the emission reductions, the results and conclusion of the justification of investment in solar energy implementation are even more on the side of feasibility.

4. DISCUSSION

Of the global renewable energy sources, hydropower plants account for 16% in electricity production [36] All other renewable sources –

photovoltaic panels; wind energy; biomass in solid, liquid and gaseous state; geothermal energy – account for only 1% of the electricity production [37]. In 2015, the commissioned renewable energy power plants worldwide had a capacity of only 65 GW. In 2016, only 53 GW worth of renewable sources [38] were.

There is still plenty of room for improvements in the solar power industry. Taking into consideration the current efficiency of photovoltaic panels, these renewable sources can undoubtedly be a sole or an additional source of energy in various environments, such as places devoid of civilization infrastructure: remote cottages, islands, high mountains, and other places without power lines. In the period 2008 – 2013, which is only five years, prices of photovoltaic panels worldwide have fallen by a factor of 3.5 [39]. The profitability of investing in photovoltaic systems increases with the increase in the price of electricity,

To stimulate the implementation of solar photovoltaic panels, the EU countries used to heavily subsidize solar power production to cover a portion of purchase prices, so that producing energy and selling it to the network became profitable. As the subsidies have stagnated in recent years, however, the extent of installing panels in households and investment in new fields of electricity has also decreased. The profitability of investment in photovoltaic panels at today's efficiency and prices without incentives is still uncertain. Therefore, incentives by states and/or energy companies remain necessary for the continued growth of this mode of electricity production. Opportunities for new developments can be sought in more efficient technology solutions and lowering PV costs.

Combining solar methods with one another and with non-solar methods [40] offers additional opportunities. Solar-powered cosmic devices, such as modules on satellites, are inspiring possibilities.

The atlas of solar and wind energy potentials in Serbia [41], shows that Serbia and other Balkan countries have high solar potentials. Nevertheless, this potential is utilized little in Serbia and not at all in Albania. Solar thermal plants are few, and research is meager. Since photovoltaic (PV) technology is expensive, existing facilities in some of the Balkan countries are subsidized through grants and international projects [42].

The solar energy potential of Serbia exceeds that of Central Europe by about 30%. With more than 2000 h/year of sunshine, which exceeds many EU countries, the intensity of solar irradiance in Serbia is among the highest in Europe [12]. The average daily energy in kWh/m2 of overall radiation for a flat surface range between 1.1 in the north and 1.7 in the south during winter, and between 5.4 in the north and 6.9 in the south during summer [43]. In comparison, the corresponding values for the respective territories of Germany and Serbia are approx. 1000 and 1400 kWh/m2. [44]. The most favorable areas in Serbia have many sunny hours, with annual irradiance of ca. 50% of total possible irradiance. All fossil fuels currently consumed in Serbia can be replaced by capturing only 0.1% of solar energy. Such considerations motivate this research.

Research into investing in renewable energy sources in Serbia [45] suggests public-private partnership as a promising funding mechanism. Using this mechanism for solar capacities would require greater involvement of the state and local governments, which should recognize special challenges in solar energy production projects and dynamics of change [46].

The current procedure for building solar power plants in Serbia includes the following main steps: acquiring the right to use natural resources, selection of locations, review of valid planning documents, review of the location data, energy permits, connection to the power grid, location permits, environmental impact assessment, technical documentation, building permit, facility construction, technical inspection, and granting various other permits. Acquiring the status of a privileged electricity producer extends the procedure further [33].

The procedure regarding technical conditions for connecting the photovoltaic power plant to the network follows the technical standards of the EU because Serbian legislation is partly taken over by the EU. The current legal framework must satisfy both Serbian laws and European directives. The two should be aligned, clarified, and worked out. Serbian and international investment banks will probably be financing electricity production from RES rather than coal mines and coal-fired power plants [34].

The Ministry of Energy of the Republic of Serbia (RS) is fostering the installation of solar power plants. The involvement of foreign and international banks will open up favorable opportunities for expanding power production from solar power plants in Serbia. Electricity production from solar and other renewable energy sources in cooperation with conventional sources contributes to the independence, reliability, and quality of delivered electricity.

The main obstacles to the development of solar energy in Serbia are low current electricity prices and the reluctance of the state utility company to issue licenses to privileged producers. Photovoltaic panels are most used by three categories of users:

– households distant from electro distributive grid,

– successful enterprises and,
– advertisers.

Serbia lags in several aspects of developing solar projects. Long-term political, legal, and economic stability; committed strategic orientation; political consensus about the desirability of solar energy; and experienced administrative staff are insufficient or lacking. Various governmental incentives compatible with market principles are also necessary.

The state and local governments should encourage more investments in solar and other renewable energy sources. Current incentives are so limited, that they cannot be considered a priority [45]. Serbia can increase PV panel capacities by legislation supporting the strategic framework of public utility companies and public-private partnerships [47]. Serbia should adopt models and smart practices from Europe and the wider world to create conditions for greater investments in electricity production from PV panels. Investment in solar energy raises total electricity production and improves the entire economy.

Results of this study could be used for practical applications in calculating potential solar energy production in different countries and analyses of relevant input variables, i.e., parameters that significantly affect that production.

Further research may deal with analyzing both: the decentralized renewable energy options vs. centralized energy generation, their respective advantages and disadvantages, and similar studies on regional, national or local levels. In addition, social and institutional components of sustainability may be very important areas to consider in future research.

The obtained results show that it is also possible to develop a nature-inspired model of genetic algorithm for the research of effects of integrating new solar capacities in the electric power system. The new model includes not only the technology costs but also the environmental protection costs, sustainable development costs and grid losses while taking into account all conditions and constraints in a real system and daily load. The model is theoretically presented in chapter 2, while chapter 3 includes the result and discussion on numerical analyses, the sensitivity analysis, correlation and regression for a set of dominant results. All these analyses confirmed the credibility and stability of the results. Accordingly, hypothesis 1 has been proved.

The analysis of all numerical and graphical results shows that the introduction of additional solar capacities in the electric power system yields benefits through the reduction of total costs of the system and reduction of GHG emissions from the whole system, thus proving hypothesis 2. Total costs of the system are reduced, although the costs of production per one kWh from the solar plant are additionally burdened with the costs of environmental protection, costs of sustainable development and those incurred due to losses in the distribution network. Grid losses in solar plants are taken as zero, because it is assumed that electricity would be used in the local community, i.e. at the point of production. This is advantageous for the local community and the electric power system as a whole.

With the introduction of solar power plants in the system, as decentralized sources, not only the benefits in terms of reduced costs and emissions are achieved, but also the quality of independent electric power supply to local communities is gained. In the latest literature [35], solutions with the grid-interactive system have been analyzed and proved in practice, where the local community may use the produced energy for its own needs, but may also contribute it to the grid and use the power from the grid as required. In chapter [36], heuristic optimization is performed applying the nature-inspired glowworm swarm algorithm. In most countries, a local community that contributes electricity from its solar plant to the system may qualify for state and federal incentives [37]. The existence of decentralized solar capacities yields benefits both on the local level and on the level of the whole electric power system.

In every country, the electric power system consists of various sources of supply: nuclear plants, thermal, hydro, solar, winds, etc. Solar and wind power plants are intermittent [38]. Their introduction to an electric power system requires backup and storage reservoirs [39]. Therefore, the introduction of solar plants in the system cannot be treated as a linear function. It is necessary to use a new holistic model, such as the one developed in this chapter, for example, which simulates the operation of the electric power system and takes into account all actual conditions and constraints of the real system. That is exactly what the analysis of numerical results from Figures 4, 7, 8 and 9 proves. There is a limit value up to which the integration of SPP capacities reduces emissions and costs. With further increase of SPP capacity, GHG emissions start growing. Logically, the costs would grow as well, in case a vaster introduction of SPP, as a privileged producer, forces out run-of-the-river hydropower plants, as they are in the literature [40]. Hydropower plants, particularly the storage and pumped storage plants, not only produce cheaper electricity but also ensure the certainty of the electric power system operation. They are the necessary rotating (operating) reserve and green storage reservoirs of the system [41]. Their role grows even more important nowadays, when the goal of introducing larger solar and wind power capacities, as intermittent sources, is set.

The results of chapter three suggest that the vaster integration of solar power plants provides holistic energy, economic, environmental and sustainability benefits, however, with certain limitations. The ultimate question is: what level of emissions and costs is acceptable? In this case study, this is between 50MW and 100MW. The question for further research is: should the SPP capacities be increased up to the level of the initial value of the system costs (when 0MW SPP is integrated into the system), or should they remain on the level of limit values? The additional introduction of solar capacities into the electric power system raises the issue of the system's certainty and stability given the intermittent nature of SPPs. This is why the introduction of SPPs into the system is examined in this chapter through genetic algorithms while observing all conditions and constraints of a real, complex electric power system.

At the time of writing this chapter, no penalties for tons of carbon dioxide emitted are still being charged in the country taken as an example. The introduction of these penalties is inevitable in the near future. In addition, the price of penalties is continuously increasing in the world market. This will have an impact on the outcome and conclusions in this chapter. The optimal degree of solar energy integration will be higher. The importance of introducing solar capacities, or other renewable energy capacities, will become even more pronounced.

Further research can be directed towards resolving intermittency and, consequently, even more extensive use of solar energy. Scientists, engineers and decision-makers suggest resolving the issue of intermittency of solar power plants in the future by changing the mindset, responsibility and habits of consumers as well as by dynamic pricing incentives, as shown in the literature [42]. The aim is to harmonize the electricity consumption time with the time when solar power plants (SPPs) operate – when there is sunshine, or in the case of wind farms, when wind power plants operate – when there is wind.

There is an additional opportunity for resolving the issue of intermittency to allow the large-scale introduction of renewable energy sources into the power system. This also implies smart grids and smart meters [43]. Increasing the capacity of water-storage reservoirs and pumped storage systems may have a positive effect on possibilities for increasing the share of solar capacities in a country [33]. Other approaches facilitate and harmonize the integration of SPPs. In the literature, they are referred to as "energy to heat" [44], "energy to electricity [45]" and "energy to hydrogen" [46]. All of them represent different methods of solar energy storage. The latest literature shows different ways of battery storage, both utility-scale [47] or small scale as home batteries [48] or mobile batteries used in electric vehicles [49]. Naturally, these storage methods may refer to the energy storage from both solar and wind power plants. The optimal capacity of the batteries is investigated using a genetic algorithm referred to in the literature [50].

Further development in solar power integration may certainly be expected in the future. This is supported by the latest research campaigns that tend to:

– upgrade the efficiency of transforming solar power into electricity,
– improve the materials used to build photovoltaic (PV) panels,
– extend the PV lifetime,
– reduce the production prices of PV and related equipment,
– improve battery storage capacities and performances,
– advance in all related technologies.

Having in mind all the specified trends, if the model developed in this chapter were to be applied, it would be reasonable to expect a future increase in the optimal sustainable degree of solar capacities integration up to which both the emissions and costs decline.

The main goal of the research presented in this chapter is to assess the benefits of renewable energy implementation for CO2 reduction and the costs of electricity production, as well as the qualitative advantages of such a decentralized option for a local community. The effects of diversification of resources on the entire power supply system of a country are undeniable. Theoretical hypotheses are tested and proved on a case study of a real electric power system. The optimal operation of different power plants was considered using the evolutionary multi-criteria optimization algorithm. The aim is to satisfy the total demand presented by the daily pattern of consumption while minimizing CO2 emissions and electricity production costs.

The application of the new optimization model developed in this paper enables decision-makers to make higher-quality planning documents and resolve strategic issues concerning easier and faster introduction of new energy sources into the system. Such decisions cannot be correct or sustainable if they are profit-driven only.

5. CONCLUSION

Renewable energy sources are significant in the Western Balkan countries. In most cases, renewable energy sources in the Western Balkan countries are bigger as a potential, than the corresponding potential in the European countries. However, the renewable energy sources in European countries have a higher degree of integration than within the Western Balkan countries. Within this research, it is investigated which input variables are relevant for the definition of the degree of integration in a country.

Two mathematical artificial intelligence models were developed within this research. The first one was the MCLRA – multi-criteria linear regression analysis model. Its purpose was to calculate the maximum possible integrative capacity in a Western Balkan country in correlation with European countries. The second model was the MCEGA – multi-criteria evolution genetic algorithms artificial intelligence model, which was developed to investigate how the certain renewable energy potential introduced in a real electricity power system impacts energy production costs and how it changes greenhouse gas emissions. The greenhouse gases were calculated as equivalent *t* of carbon dioxide.

The theoretical postulate of both models was created and tested on numerical examples of solar energy. Possible maximum installation of solar energy within a real socio-economic system of a Western Balkan country was investigated within the Republic of Serbia. Accordingly, the second model was tested on the case study of solar energy integration in the Serbian electric power system, calculating the total energy production cost and the total greenhouse gas emissions.

Although increasing renewable energy production compatible with sustainable development and preservation of the environment is imperative, installing new solar capacities has been slower lately in every country and every region. Clean and free solar energy is underutilized. This study finds room for higher investments in solar energy based on further research and greater implementation.

The postulate here is that economics cannot be the only guide in decision-making. That is why the holistic study within this research covers technology, economics, regulations, social, and sustainability input variables and their impact on the maximum degree of renewable energy integration.

The research conducted in chapter two improves the methodological knowledge within the triangulation approach. The MCLRA model was developed, extended, and adjusted to a massive input of variables from 28 countries and tested in a case study. The main academic contribution of this chapter is combining three different methods to model and explain the phenomenon mathematically. An interplay of problems related to the possible production of solar energy, in four different years, with a variety of input data. The level of explanation of the phenomenon with five and eight inputs reached as high as 96% of the variables proving that the results and conclusions are valid and stable.

The model was tested by developing 255 combinations of input variables in extensive calculations covering the years of 2010, 2013, 2015 and 2016 for 28 EU countries and a case study. In complex analyses of sensitivity, feed-in tariffs were varied along with other input variables, with and without statistically extremes values. These analyses proved the stability of the developed model and the validity of the results. The convergence of all calculated graphs proves the stability of the model.

Input variables in the regression model included technological, financial, economic, legal, regulatory, and procedural elements, and took into consideration requirements of sustainable development. The results were further tested and confirmed in a case study, which confirmed that PV panels could be more widely used in Serbia.

The LCOE economic analysis indicated that costs of electricity production from PV panels were comparable with market prices of electricity. When, however, risks and profits are included, the production costs exceed the market prices of major electricity producers in Serbia. Solar electricity can be made more competitive in Serbia by either lowering the cost of solar production or raising the market price of electricity. The near equality of production cost and selling price hampers the wider implementation of solar energy. The similar situation is in most Western Balkan countries. At the same time, the production price of energy will be reduced, thanks to technological improvements, and the selling price of energy will increase. Both parameters will affect the possibility of a broader integration of solar energy and other types of renewable energy sources, both in Serbia and other countries of the Western Balkans. This conclusion is valid for other renewable energy sources too. The questionnaire and interview showed considerable awareness of the importance of wider use of solar energy and a keen interest in investing in solar energy despite current obstacles and problems.

More research is needed. Every step in the algorithm could be the subject of further research. Further research into input variables could reveal aspects obscured by official statistics. A more comprehensive explanation of installed solar capacities might include subtler considerations:

– feed-in tariffs could be high but available to relatively few producers so that the market is barely affected;

– GDP per year could be high but unevenly distributed over the population;

– GDP per capita could be high but lower among the population installing solar devices or among the investors in these devices.

– willing investors may face alternative projects involving renewable sources other than solar;

– countries having higher insulation may lack resources (GDP or GDP/c) to invest in solar capacities;

– doing business list includes the availability of electricity but this availability does not control the ranking of countries in the list, with its significance possibly varying over time;

– electricity prices may be high but electricity consumption may be too low to drive the installation of solar capacities,

– electricity prices may be high but the supply may be sufficient to cover the needs without additional solar capacities; and

– electricity consumption may be insufficient to drive the installation of new solar capacities.

Challenges among the growing population, worsening pollution and lacking energy require more research into technological, economic, and regulatory aspects of using free, clean and green solar energy.

According to the research conducted, it is also concluded that it is possible and very useful to develop the nature-inspired, multi-criteria model of genetic algorithms, which may be used as a support to energy policymakers. The novelty is in the complexity of the model that operates with conditions and constraints from a real electric power system, satisfying the demands and including all technology, environmental and sustainability costs, as well as losses of distribution network, simultaneously and at the beginning of the decision-making process. Considering the limited amount of non-renewable coal reserves and the EU Energy Policy 2050 requirements regarding the reduction of emissions through introduction of renewable sources, the results obtained in this research may help decision-makers develop better plans and strategies.

The introduction of solar capacities reduces the costs and emissions to a certain level. The developed models may be useful as a decision-support system generator for the integration of all renewable energy resources in any country.

The result of the research within the Serbian energy system showed that the emissions and costs are the highest when there is no SPP in the electric power system selected for the case study (scenario 1 – 0 MW SPP). The emissions are lowered by the integration of a higher degree of SPP installation (scenario 4). Production costs are decreased to a certain level to slightly increase afterward. In any case, the developed model enables the decision-maker to choose the adequate solution from the “Pareto” front, i.e. from a set of dominant results regarding costs and emissions: either according to the pre-defined requirement to reduce emissions to a particular level and then determine the costs of that variant, or to determine the possible emissions reduction based on available funds. Further research may be conducted in higher integrated capacities of SPPs.

Solar energy integration is selected for the case study of power supply to the local community, although other renewable options are applicable as well. Due to local conditions, solar energy is considered the most appropriate energy for the case study in this research. Nevertheless, the results obtained for solar energy may apply to wind, hydro and other renewable energy sources. Contemporary approaches strive for reduction in emissions, which indicates that the growing costs of electricity production will be justifiable.

The presented research has a broader context and applicability. The developed models apply to any energy source and they contribute to faster implementation of the European Green Plan in the Western Balkans. The methodology for calculation of maximum possible integration in socio-economic system of one country and calculation of optimal integration of solar energy in the entire real electric power system, as well as the calculation of the costs and effects on greenhouse gases reduction can be extended to other locations, countries, demand curves and renewable energy sources. Developed models help better understand the renewable energy integration within the socio-economic system and electric power systems.

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ВЕШТАЧКА ИНТЕЛИГЕНЦИЈА И ПРИРОДОМ ИНСПИРИСАНА ОПТИМИЗАЦИЈА О ИНТЕГРАТИВНОМ КАПАЦИТЕТУ ОБНОВЉИВЕ ЕНЕРГИЈЕ НА ЗАПАДНОМ БАЛКАНУ

Сажетак: У оквиру овог истраживања развијена су два модела вештачке интелигенције за интеграцију обновљивих извора енергије са циљем да се допринесе реализацији европског зеленог плана. У оквиру овог истраживања урађен је преглед природних потенцијала обновљиве енергије, с једне стране, и инсталираних капацитета, с друге стране, у земљама Западног Балкана и у двадесет осам земаља Европе и емисија. Анализе показују да су европске земље, иако понекад имају мањи природни потенцијал у обновљивим изворима енергије, инсталирале много више обновљивих капацитета од балканских земаља, које имају много већи природни потенцијал. Везано са тим, развијен је први модел вештачке интелигенције на основу вишекритеријумске линеарне регресионе анализе. Овај модел се ослања на корелацију између релевантних регресора, односно релевантних улазних варијабли за двадесет осам земаља Европе и истих регресора за одређену балканску земљу. Његов циљ је да се пронађе максимални могући капацитет обновљивог ресурса који се може интегрисати у једној балканској земљи, у стварном друштвено-економском окружењу. Други модел вештачке интелигенције развијен је на основу вишекритеријумских еволуционих генетских алгоритама. Његов циљ је да се одреди максимални могући капацитет интеграције обновљивих ресурса, у оквиру стварног електроенергетског система. Примењена је оптимизација инспирисана природом. Из оквира датог великог броја генерација, заправо техничких комбинација степена интеграције обновљивих извора енергије, бирају се најбоље популације, односно комбинације. Као што природа бира из низа бројних генерација и омогућава најбољима да преживе, а кажњава „слабе“, тако и у нашем случају „слабе“ комбинације су оне које не испуњавају дате услове и ограничења стварног електроенергетског система. Нуди се нова методологија. За оба модела дате су опште теоријске формуле. Развијени модели тестирани су на нумеричком експерименту интеграције соларне енергије у студији случаја у Србији. Оба модела су примјењива за све обновљиве изворе енергије и све земље или регионе.

Кључне речи: модели, вештачка интелигенција, оптимизација инспирисана природом, интеграција, обновљиви извори енергије, кружна економија, Западни Балкан.

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