INTERDISCIPLINARY RES INTEGRATION MODELS FOR SUPPORTING DECARBONIZING SOCIETY PROJECTS

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Abstract
This paper deals with problem solving process of renewable energy sources integration in society that strives to create new decarbonizing environment. New Energy Policy 2050 defines a number of development projects, within transition from nonrenewable to 100% renewable energy in use. In order to create a new value in environmentally clean society, by respecting not only profitable projects, two models are here developed. Interdisciplinary created input variables are incorporated. Circular economy principals are respected as main project's philosophy. The goal was to research possible degree of renewable energy integration in socio economic community and within the real power system. The models are presented theoretically by objective functions. They are tested numerically on case study, as well. The question is: are all countries capable to change its energy supply system towards this goal? When and how project society can fulfill this hard strategic task. Developed models can help decision makers and stake holders for better understanding of necessary steps towards new valuable decarbonizing society. The results also indicate the limits of renewable energy integration in present society and consequently further researches, changes in consumer awareness and measures required to achieve absolute renewable energy integration, as a global mutual value.

Keywords: Circular economy, Decarbonizing society, Global value, Interdisciplinarity, Models, Renewable energy

1. Introduction

Some of the most highlighted issues of the 21st century are the projects related to resources, energy and environmental management, with the main and strongest impact on the conflict between the use of renewable energy sources (RES) and non-renewable sources. This problem affects the future of the Globe. People and the environment are endangered by non renewable sources utilization. High CO_2 emissions from non renewable resources jeopardize the health of the Earth population and increase global warming.

That is why new RES projects are requested, with the goal to create a new value of decarbonizing society. Growing populations, increased energy demand and profit, as civilization goals, versus CO_2 emissions, environmental pollution, global warming and sustainability, are subjects of various projects [18].

All contemporary energy policies define the introduction of renewable energy sources as a project's imperative; however, if one wants to be objective, all renewable energy projects have to consider all costs, and not only the costs of technology and direct benefits of [19], as used to be the case. Optimization analyses should be made in the context of circular economy philosophy [5], respecting the right of all generations to equal use of resources. This may be achieved by inclusion of the costs of recycling until reuse and environmental recovery to the zero state, and that step forward is contemplated in this paper, as an imperative principle for new project society. The ideas elaborated in this research are expected to help in overcoming problems in order to accelerate the phases of energy transition.

At the same time, there is a shortage of resources on the Earth for transforming into energy with the presently known technology [11]. The existing technology causes unacceptable environmental degradation [8]. World's scientists, engineers and decision-makers have defined limitations for all countries, so as to ensure sustainable future of the Globe [7]. In Europe, some requirements have been fulfilled with regard to the Energy Policy 2020 [9], which has been replaced by much stricter framework and limitations on emissions to serve the goals of EU Energy Policy 2050 [1].

Projects of renewable energy sources integration (RES projects) have a very important role to play in reducing green house gases pollution and creating a decarbonizing society. In order to discuss the upcoming necessary energy transition as efficiently and precisely as possible, it is necessary to determine how much RES technical potential of one country is economically usable within the current legal-regulatory and socio-economic framework. A complex issue is interdisciplinary researched by the developed model of triangulation approach, which consist from multidimensional linear regression model, levelized cost of electricity method and social acceptance investigation. Based on comparisons with European countries, the interdisciplinary model, in addition to the natural potential of RES, the investment, GDP, GDP per capita, legal regulatory framework, government incentives, economic prices of a particular RES, electricity selling prices in households, consumption for industry and others are considered.

The social acceptability of such projects is seriously taken into account, as well as the degree of involvement and information of local communities on direct and indirect benefits locally and regionally. After quantifying the unused potentials, a simulation model was developed for adding the degree of RES in power system of the society, with a step towards respecting the principles of the circular economy. The goal is to increase the environmental, energy and economic benefits for all stakeholders, which is analyzed and discussed through four scenarios. Developed models are generating support in project society which strives to the new values of decarbonizing society. They help decision makers and creators of development strategies for RES integration, within national plans to combat climate change. Since the pollution knows no borders, more international and cross border projects that create new values of decarbonization for society are needed. The involvement of all countries, decision makers and stakeholders is required.

All previous background leads us to the clear research question: what project's principals, approaches and models can help to decision makers in higher integration of RES in order to decarbonize society.

1.1 Circular Economy Principals

Circular economy is a new tool of sustainable development and an instrument of environmental protection projects [4]. The European Union (EU) institutions are increasingly raising attention to the importance of the circular economy (CE) agenda. According to the OECD report[1] 2020, global consumption of all materials is expected to double by 2060. The World Bank[2] makes an estimate in its report that waste generation could increase by 70% by 2050, as compared to 2020.

Therefore, governments, policy makers, engineers and scientist are faced with the challenge to search for possibilities to use circular economy systems within the projects, such as better eco-designs, waste prevention, as well as the reuse and recycling of materials, whilst reducing waste and emissions as per EEA Report 2018, and according to literature [3]. Only the circular economy's sustainable 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 [17]. Yet research on circular business models is nascent and the business literature gives limited attention to the challenges deriving from circular economy implementation in projects [6]. Within this research, circular economy principles are incorporated in models developed to support projects of decarbonizing society.

1.2 Interdisciplinary approach

In order to achieve new values in the global society the interdisciplinary approach is applied. All input variables are not only from technical, or economic fields. They covered the different fields, starting from the social acceptance, by different stimulation measures, over natural renewables potential, to the legal regulatory normative, or position on world business doing list.

2. Methodology

The methodology here applied encompasses interdisciplinary triangulation model and multidimensional models of genetic algorithms, based on interdisciplinary approach and circular economy principals, explained in the following text.

2.1 Interdisciplinary Triangulation Model

Starting from the natural solar potential and analyzing the impact of relevant financial, economic and legal regulatory parameters, including criteria of sustainable development, the correlation model of multidimensional linear regression (MDLR) was developed for 28 European countries, in order to define planning possibilities in Serbia, which is selected as a case study. The Levelized Cost of Electricity method was applied to calculate production price of RES and to discuss its impact on investment possibilities. The current situation and positive practice in the world and in the EU, perspectives in Serbia, regulatory, financial and

[1] https://www.oecd.org/development/development-co-operation-report-20747721.htm, (January, 2021.)
[2] https://www.worldbank.org/en/about/annual-report, (January, 2021.)

economic aspect, including the aspect of investment risks, are also discussed. Mix method survey-interview is applied for investigation of social acceptance.

Project of solar energy integration is selected for a case study, since it has the most recognizable difference between the natural potential and realized investment projects between Serbia and a model of European countries.

The Levelized cost of electricity (LCOE) method was applied to calculate production price of solar energy and to discuss its impact on investment possibilities. The financial aspect of electricity production is critical when choosing technology. Financial motives underlie human activity in production of goods and services, including electricity. Electricity is a major driver of economic and investment activities. Expected profit is a measure of 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 LCOE, which is expressed by the following formula:

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

where:

- LCOE – Levelized cost of electricity
- I_t – Investment cost per year t
- O_t – Operation cost per year t
- M_t – Maintenance cost per year t
- F_t – Financial expenses per 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 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 (1) is simplified:

$$\mathrm{LCOE} = \frac{\sum_{t=0}^{n} \frac{I_t + M_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{S(1-d)^t}{(1+r)^t}} = \frac{\sum_{t=0}^{n} \frac{(1+c)I}{(1+r)^t}}{\sum_{t=0}^{n} S\frac{(1-d)^t}{(1+r)^t}} \quad \ldots(2)$$

where:

$$I = I_1 = I_2 = \cdots = I_n = I \quad \ldots(3)$$

$$M = M_1 = M_2 = \cdots = M_n = c * \mathrm{I_t} \quad \dots (4)$$

c represents maintenance costs as part of investment costs in year t.

So, research into projects of wider application of solar energy can be done using the three aforementioned scientific methods. The methodological holistic approach additionally includes induction, deduction, analysis, synthesis, and analogy.

Research algorithm of triangulation model is presented on Fig. 1.

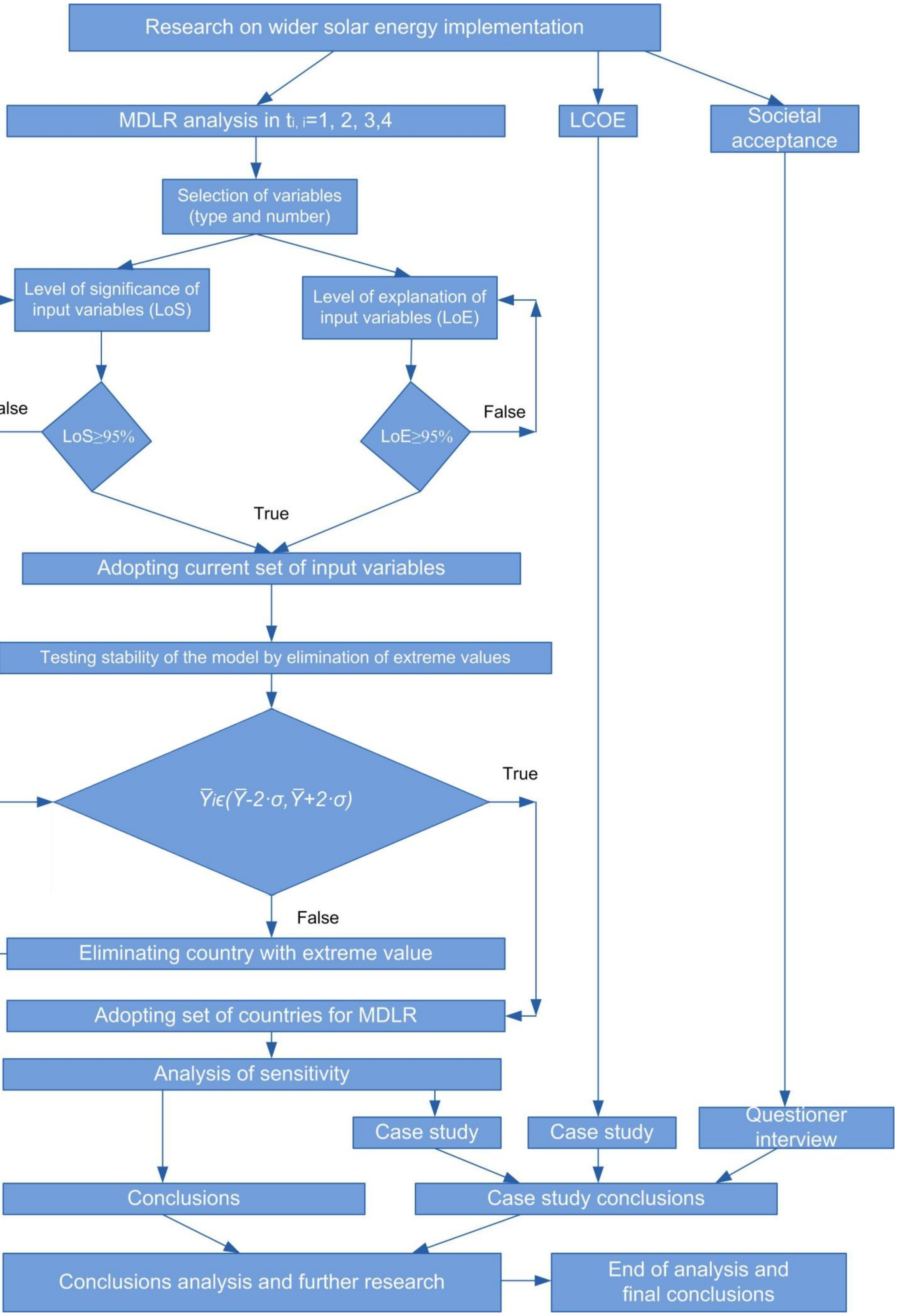

Fig. 1 Research algorithm of triangulation model

Three project's orientations are graphically visible on Fig. 1. presenting the algorithm for RES project integration. The algorithm is consisting main research directions, covering managerial, technological, environmental, economic, regulatory and social dimension:

- Multidiobjective linear regression analyses
- Levelized cost of electricity and
- Social acceptance survey

Research algorithm of triangulation model is created with the goal to clarify and to prove the interdisciplinary covering of all the aspects relevant for decision makers and for better shape the future of the RES project integration.

2.2 Multidimension Models of Genetic Algorithm

New model for higher integration of green energy is developed based on nature inspired optimization, in order to support clean development projects. Different scenarios are researched of RES integration into power system in the transition to be green and decarbonizing society. Green energy as a new imperative merges with principles of circular economy. In order to validate the impact of additional integration of RES, a model with four scenarios of renewable energy plants integration has been developed. Four levels of integration in a system were analyzed: 0MW, 60MW, 300MW and 600MW. The benefits of that integration on total energy production cost and to total emission of green house gases were calculated. The green renewable energy integration model relies on artificial intelligence and nature-inspired optimization [15]. 50000 generations, i.e. 50000 combinations of possible engagement of power plants within the energy system were developed by evolutionary multiobjective genetic algorithm, merging and respecting circular economy principals. The novelty is that the costs of technology are charged also by the costs of environmental protection and by the costs of sustainable development. These costs are included in the model at the beginning of a decision making process. The objectives are formulated accordingly. The goal was to increase the electricity production up to the level of demand, and on the same time to minimize total electricity production costs and to minimize greenhouse gas emissions. Grid losses and other limitations and constraints of the electric power system are also included into the model. The losses within the distribution are calculated by the method of proportion to the distance between the supplier and the end energy user. Since it is supposed that the renewable energy power plants are located in a local community, close to consumers, there are no additional charges on it, related to grid losses.

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

$$X_1, X_2, \dots, X_k, \dots, X_n \qquad \text{...(5)}$$

and costs from particular sources are:

$$C_1, C_2, \dots, C_n \qquad \text{...(6)}$$

then the functions of energy production could be defined as:

$$Y = \sum_{i=1}^{n} C_i * X_i \rightarrow min \qquad \text{...(7)}$$

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:

$$\mathrm{C} = \sum_{i=1}^{n} C_i \rightarrow min \qquad ...(8)$$

wherein

$$\forall C_i \rightarrow min \qquad ...(9)$$

Electricity production costs shall be expressed as follows:

$$C_i = C_i(T_i,\ E_i, S_i) \qquad ...(10)$$

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.

The first objective function shall be modified as follows:

$$Y(t) = \sum_{i=1}^{n} C_i * X_i(t) \rightarrow min \qquad ...(11)$$

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

$$EM = \sum_{i=1}^{n} EM_i \rightarrow min \qquad ...(12)$$

wherein EM denotes total emissions of the electric power system, from all PPs in one day.

The scientific community can replicate our findings using the given objective functions and the software which is available on request. Input data for the presented case study are taken from the Public Enterprise Electric Power Industry of Serbia, as well as from relevant global websites[3]. Information regarding settings of the algorithm is also available on request for replication purposes.

3. Results

3.1 Results of Interdisciplinary Triangulation Model

The research subject of this chapter is related to development opportunities for implementation projects of solar potentials for electricity production in Serbia as a case study. The aim of this research was to prove that there is room for wider investment in solar

[3] https://www.electricitymap.org/map, http://www.eps.rs/eng (January, 2021.)

capacities in Serbia. Research findings encompass the results of all three methods used (multidimensional linear regression model, LCOE, and questioner with interview).

3.1.1 Results of Multidimensional Linear Regression Model

The research method defined the following input variables for 28 European countries and Serbia: FiT (*X1*), GDP (*X2*), GDP per capita (*X3*)[2], natural solar potentials (*X4*), position of each country on BDL according to World Bank (WB) reports (*X5*), electricity price for homes including taxes and levies (*X6*), electricity consumption by industry (*X7*), and electricity consumption by homes and services, marked as others (*X8*). The output is installed capacities of solar cells (*Yi*). The BDL variable was taken from International Finance Corporation (IFC) and World Bank's Ease of Doing Business index. The regression model developed in this research yielded results in Table 1.

Table 1
Input variables and output variable for the MDLR analysis for 28 European Union countries.

Country	*X1* FiT €c/kWh	*X2* GDP Bill €	*X3* GDP pc €	*X4* Insolation kWh/m^2/y	*X5* BDL Position -	*X6* Price home €c/kWh	*X7* Industry consumption TWh	*X8* Other consumption TWh	Yi "Should be installed" MW
Germany	11.93	3494.898	42326	1100	17	29.49	224.88	278.57	39763.0
Italy	13.00	1852.499	30294	1600	50	24.39	112.67	163.96	18924.0
United Kingdom	12.80	2649.893	40412	900	7	21.54	93.01	206.03	8918.0
France	13.68	2488.284	38537	1300	29	16.79	116.45	307.23	6578.0
Spain	15.68	1252.163	27012	1850	32	23.40	76.05	149.92	4921.0
Belgium	20.40	470.179	41491	1040	42	22.39	37.99	42.13	3228.0
Greece	9.00	195.878	18078	1750	61	17.69	12.67	37.73	2613.0
Czech Rep.	0.00	193.535	18326	1100	27	13.97	22.81	30.22	2083.0
Netherlands	2.00	769.93	45210	1025	28	19.16	34.25	67.11	1405.0
Romania	16.25	186.514	9439	1300	36	13.11	20.53	21.42	1325.0
Bulgaria	10.70	50.446	7091	1400	39	9.50	8.95	19.03	1021.0
Austria	11.50	387.299	44561	1000	19	19.96	25.27	32.67	935.3
Denmark	3.00	302.571	53243	1000	3	30.55	8.37	22.11	782.5
Slovakia	9.89	90.263	16648	1200	33	15.12	11.61	12.16	591.1
Portugal	14.50	205.86	19759	1700	25	22.82	15.48	30.02	460.0
Slovenia	6.50	44.122	21370	1250	30	16.10	6.20	6.44	257.4
Hungary	10.97	117.065	11903	1250	41	11.36	15.40	19.72	137.7
Sweden	1.50	517.44	51604	900	9	18.63	50.28	71.98	130.0
Luxembourg	26.40	60.984	105829	1080	59	17.67	3.06	3.04	125.0
Poland	0.00	467.35	12309	1100	24	14.31	49.48	75.23	86.9
Malta	15.00	10.463	24298	2000	76	12.63	0.42	1.70	73.2
Lithuania	14.00	42.776	14899	1025	21	12.50	3.31	5.96	73.1
Cyprus	3.40	19.931	23425	1900	45	18.98	0.46	3.63	69.5
Croatia	23.00	49.855	11858	1500	43	13.15	3.43	11.67	44.8
Finland	0.00	239.186	43492	800	13	15.41	37.89	39.87	14.7
Estonia	5.37	23.476	17896	950	12	12.97	2.06	4.75	4.1
Ireland	13.00	307.917	65871	900	18	24.40	9.84	15.19	2.1
Latvia	12.45	27.945	14141	950	14	16.43	1.70	4.65	1.5

As Fig. 2 shows, some of the countries installed more, while other countries installed less solar capacities than the optimum obtained by the MDLR model. Convergence of the two curves proves the stability and validity of the MDLR model developed here.

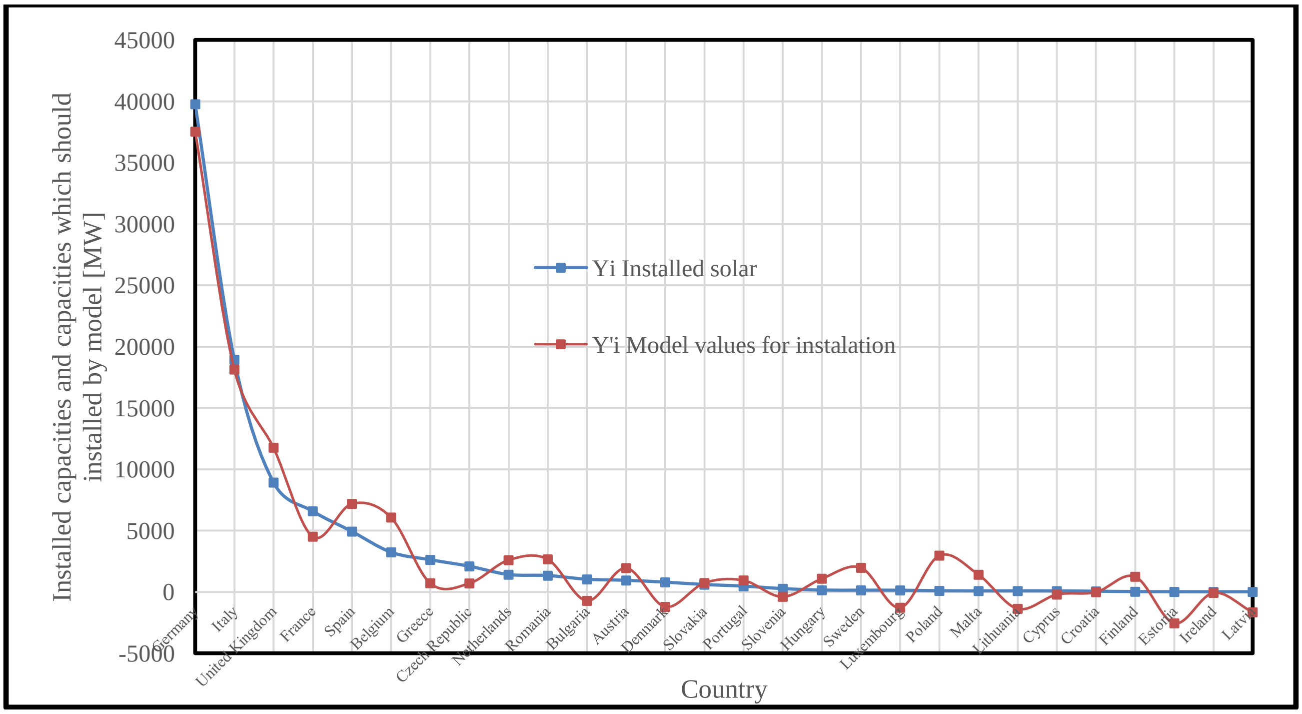

Fig. 2 Capacities that are installed and capacities that should be installed, calculated by the MDLR model

After having developed and validated the MDLR model in studies of 28 European countries and several subsets of the 28 countries, the model was further tested in a case study of a single country. Serbia is a developing country in which thermal power plants supply 70% of consumed electricity. Worse yet, these plants burn coal of poor quality, a dirty technology. Serbian coal reserves are estimated to last only about 50 years [13].

Bleak prospects of fossil fuels in Serbia, a typical developing country, necessitate considerations of renewable sources of energy, such as solar source. Because this country has unused solar potential, it was chosen for a case study of the model developed here.

Again, all 255 combinations of all eight input variables were analyzed. First, coefficients in the MDLR model for each input variable (*X1*, *X2*, *X3*, *X4*, *X5*, *X6*, *X7*, and *X8*) were separately determined. Next, a total of 255 combinations of two, three, four, five, six, seven, and eight input variables were calculated. When all eight input variables were analyzed, a system of 28 equations with nine unknowns was solved. For each combination of input variables, the output variable, *Y*, was determined for all 28 EU countries and Serbia. The difference between solar capacity that is installed and capacity that should be installed is shown in Fig. 3.

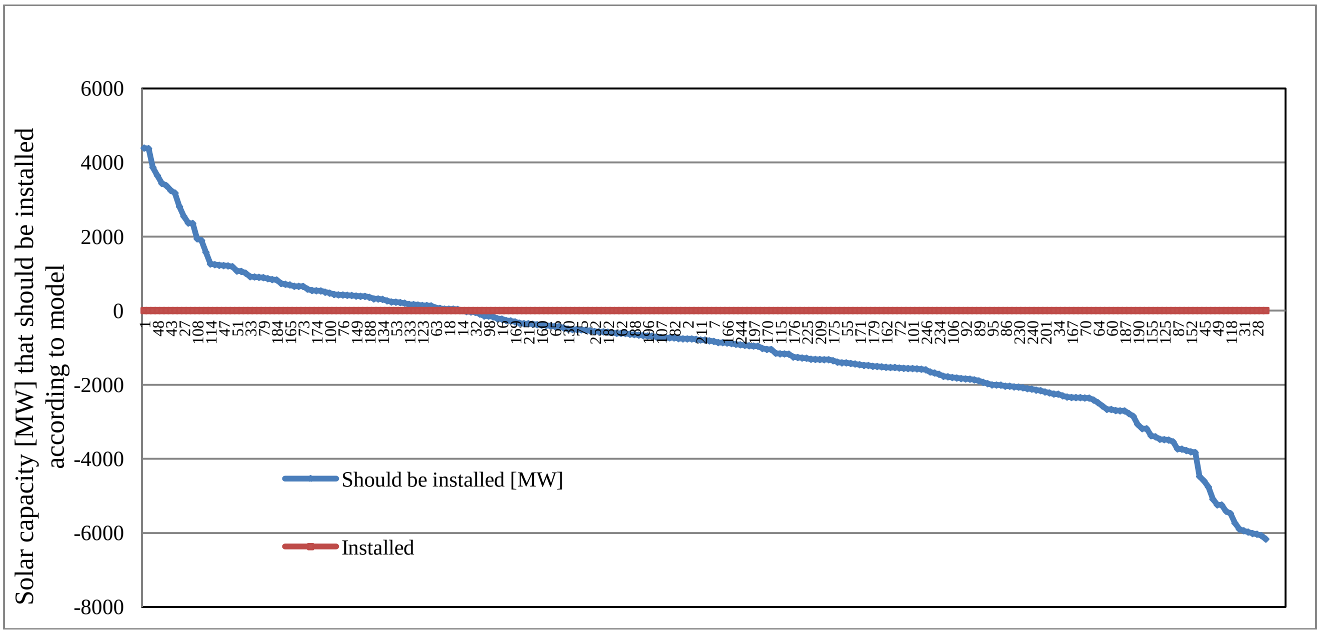

Fig. 3 The "should be installed" solar potential in Serbia according to MDLR model (the vertical axis) for various combination of input variables (the horizontal axis)

An analysis of the results in Fig. 3 shows two scenarios. In 30% of the combination, 73 of them, of input variables Serbia has lower installed capacity than that calculated by the MDLR model for 28 European countries. Under this analysis, Serbia needs more installation of solar capacities. In 70% of the combinations, 182 of them, of input variables Serbia has higher capacity than that calculated by the MDLR model for 28 European countries.

In conclusion, there are possibilities for new projects of greater implementation of solar energy, through technological, economic, legal, regulatory, and procedural improvements in Serbia. The country can develop the application of solar energy for electricity production by increasing one or more of the following: FiT, GDP, GDP per capita, consumption, and prices. Improving the position on BDL also would help.

3.1.2 Results of LCOE Method for Case Study

The economic analysis of cost-effectiveness by the LCOE method given by formula (2) rests on two assumptions: first, that the average annual production will be realized corresponding to data for Serbia in the past period; and second, that solar capacities are financed with a 20-year loan repaid in equal instalments to during the life cycle of the solar panels [16]. Inserting the following initial data:

- P = 1 MW = 1000 kW – installed power
- n = 20 – solar power plant lifecycle
- P_E = 0.20941 €/kWh – price of electricity per kilowatt
- I = 1,100,000.00 - initial investment (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 (produced electricity based on installed power for Serbia annually)

into formula (2), formula (13) is obtained:

$$LCOE = \frac{968{,}320\ €}{14{,}667{,}901\ \text{kWh}} = \frac{0.066\ €}{\text{kWh}} \qquad \ldots(13)$$

This value of LCOE is similar to market prices of electricity from leading producers in Serbia, namely, thermal and hydroelectric power plants. This similarity expands the prospects of solar energy in Serbia. Investments in solar power generation remains insufficient, possibly because of the risks that further increase production costs from PV panels or because formula (2) defines the costs simply, or omits some costs. Low electricity prices in current market conditions in Serbia also hamper development of investments in solar power plants.

3.1.3 Results of Questionnaire and Interview

A questionnaire is conducted on a representative sample of 109 respondents, addressed the possibility of enhancing production of electricity from solar PV in Serbia. Subsample *a*, of average age 59, consisted of 52 experts in solar energy, 51 of whom are doctors of science. Subsample *b* of average age 37, consisted of 57 respondents differing in education, age, and gender, were randomly selected. Women made up 3% of subgroup *a*, and 50% of subgroup *b*. Of the respondents in subgroup *b* 37% graduated from college, 33% from secondary school, and 30% from elementary school.

Respondents in subsample *a* knew technical details about Kladovo SPP and smaller installed solar plants in Serbia. Fully 93% of them stated that Serbian legislation generally follows relevant EU regulations. Surprisingly, respondents in subsample *b*, were fairly knowledgeable about solar energy: 68% of them knew of some installed solar power plants in Serbia. Evidently, informing the public and raising awareness about the importance of solar energy had some effect.

Serbia is striving to harmonize its legislation with that of the EU. Remaining inconsistencies and ambiguities, however, destabilize the market. According to the World Bank's Ease of Doing Business index, Serbia occupies the 47th place on BDL, in the moment of this research implementation. In subsample *b*, the opinion is divided on whether Serbian legislation concerning solar energy application in follows the EU legislation: 53% of the respondents agreed, and 47% disagreed.

From subsample *a*, 92% would invest in solar energy projects in Serbia; 87% would do so abroad, too. In subsample *b*, 68% would invest in the construction of a solar power plant if they had the funds; 81% would do so in a foreign location. The two most common locations chosen were Africa for its high potential and EU countries for their legal and financial stability.

In free responses, 61% from subsample *b* said that investment, application, and development of solar energy are impeded by corruption. Position of Serbia on BDL is consistent with this view. Arguably, corruption is one of the factors affecting procedures for construction and investment licenses, thus influencing the position on BDL.

The previous answer by subsample *b* may be related to an answer by 87% of subsample *a*, that the market as a whole is unstable. So, the results of this mix method survey-interview show that the societal support for solar development is very strong in Serbia.

3.2 Results of Multidimensional Model of Genetic Algorithm

The optimal operation of the electric power system is defined by the evolutionary multiobjective genetic algorithm, as a decision-support system generator. Additional algorithms are also developed for the purpose of graphical user interface that allows easy visualization of an enormous number of results and better understanding and checking of decision-support applications.

A different number of generations was performed to find the optimal solution in the process of software use. The first one was formed randomly, within a set of limited values $X_i \in (0.20 * X_i^{max}, X_i^{max})$.

The results are graphically presented in the coordinate system in Fig. 4, where costs are indicated on the abscissa and the emissions on the ordinate. The costs are expressed in € and emissions in tons, for similarity of scales. The results show that the worst case scenario is when there is no SPP in the electric power system. That entails the highest emissions and the highest costs of electricity production. The optimal scenario is reached in between the installed capacity of SPP of 300MW and 600MW. The lowest emissions are achieved with installed capacity of 300MW, and the lowest costs are reached with installed capacity of 600MW. Since the difference in emissions is not significant, additional analyses of results are presented in further text, for clarification purposes.

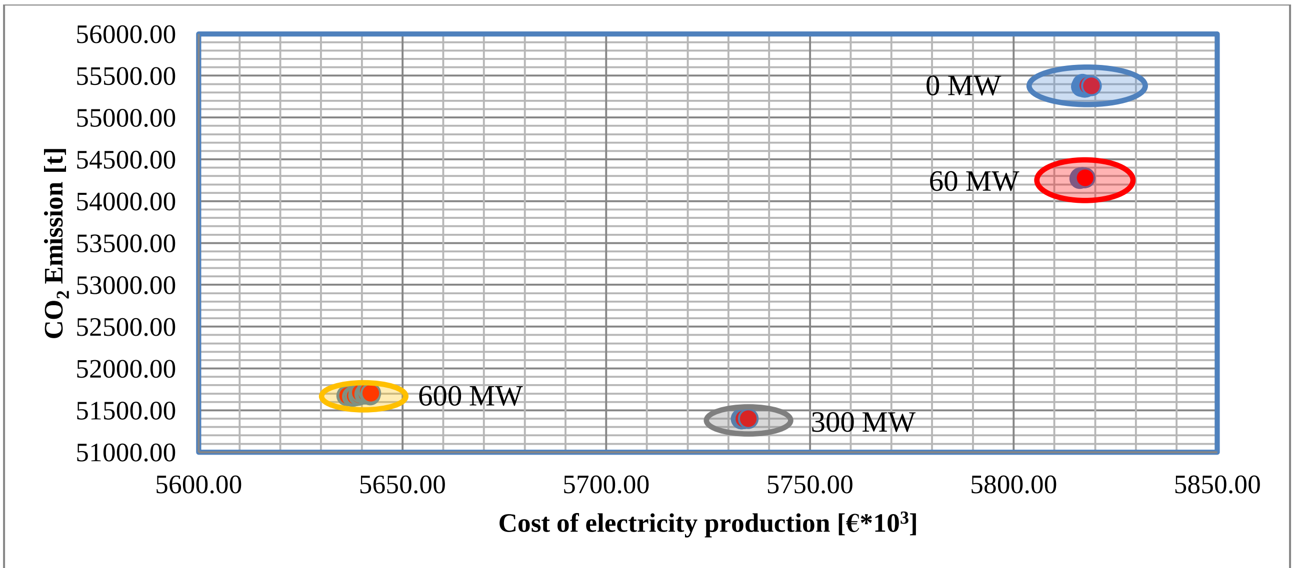

Fig. 4. Four scenarios of costs/emissions relationship (with different installed capacities of SPP: 0 MW, 60 MW, 300 MW and 600 MW)

This diagram shows that the optimal installed capacity of SPP is to be searched between 300MW and 600MW, in the present status of the electric power system and consumers.

20 dominant results on costs for different installed capacities of SPP, for each particular scenario of SPP - 0MW, 60MW, 300 MW and 600 MW integrated in the system, are presented in Figures 5. Since they are all similar or the same within one scenario, it means that the calculation entered the stable zone within 50,000 generations[4]. Such a result may be considered stable and final.

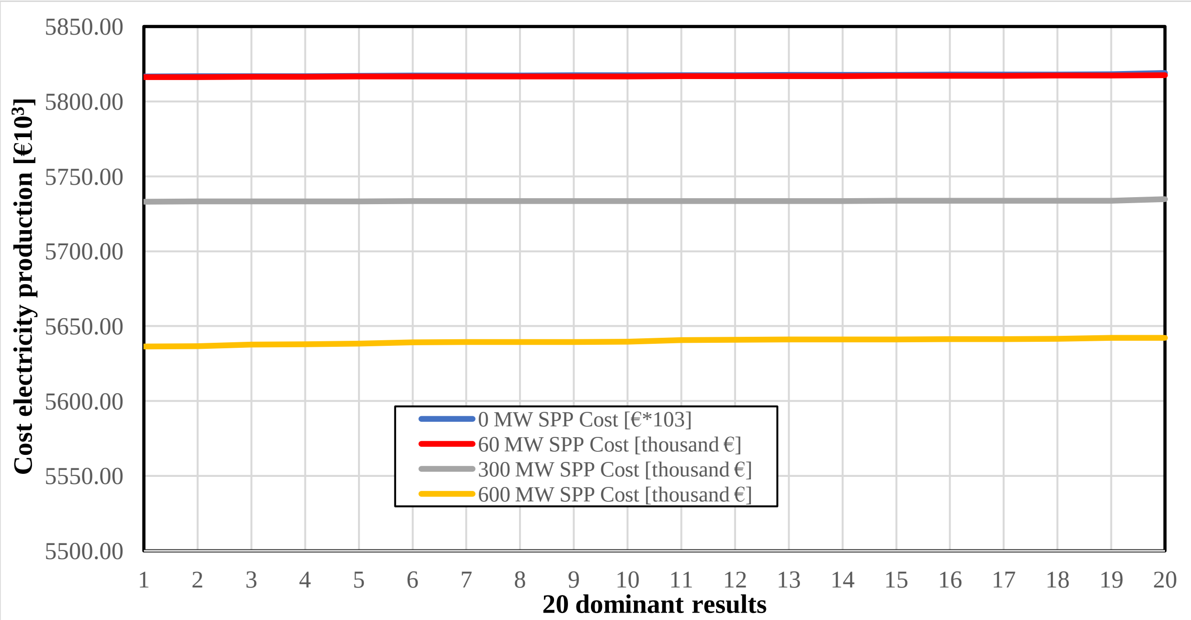

Fig. 5. Total electricity production costs of the electric power system for 0MW, 60MW, 300MW and 600MW SPP implementation

The diagram in Fig. 5 shows the total costs (expressed in 10^3 euros) of electricity production for the entire electric power system. 20 dominant results are presented. The results show that the lowest electricity production costs are achieved with integration of a 600MW SPP. The results are obtained by evolutionary multiobjective genetic algorithms, optimized within 50,000 generations. The fact that the line is almost straight means that after 50,000 possible combinations of solutions, it reached the level of an optimal project solution. The stability of results has been confirmed. The Fig. 5 is graphical visualization of the developed model stability.

4. Discussion

Evidently, there is still plenty of room for improvements in the projects of power renewable industry. Already with the current efficiency of, for example photovoltaic panels, these projects of 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. As the price of electricity increases, the profitability of investing projects in photovoltaic systems also increases.

[4] All inputs, Excel sheets and auxiliary calculations are available on request

To stimulate the projects for integration of RES, European countries used to subsidize purchase prices greatly, so that producing energy and selling it to the network became more profitable. As the subsidies have stagnated in recent years, however, the extent of projects for installing e.g. photovoltaic panels in households and investment in new fields of electricity have decreased. Profitability of investment projects in the panels at today's efficiency and prices, is growing more and more every day. Incentives by states and/or energy companies are always stimulating and welcomed for continued growth of this mode of electricity production. Opportunities for new development projects can also be sought in more efficient technology solutions and lowering PV costs. Serbian and international investment banks probably will be financing projects of electricity production from RES rather than projects of electricity production from coal mines and coal-fired power plants [14].

The main impediments to higher number of development projects for RES in Serbia are low current electricity prices and reluctance of the state utility company to issue licenses to privileged producers. Projects of RES are mostly used by three categories of users:

- households remote from electro distributive grid;
- successful enterprises; and
- advertisers.

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

The state and local governments should encourage more investments in solar and other renewable energy projects, taking care of sustainability [20]. Current incentives are so limited, that they cannot be considered a priority. Serbia can increase projects of RES by legislation supporting strategic framework of public utility companies and public-private partnerships [10]. Serbia should adopt models and smart practices form Europe and the wider world to create conditions for greater investments in electricity production from RES. Investment in RES raises total electricity production, improves the entire economy and creates benefits of reducing GHG emissions locally and globally.

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

The analysis of all numerical and graphical results shows that the introduction of additional solar capacities in the electric power system yields benefits through reduction of total costs of the system and through reduction of GHG emissions from the whole system. 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 and costs of sustainable development. 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 for the electric power system as a whole.

With 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 [12], solutions with 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 most countries, a local community which contributes electricity from its solar plant to the system may qualify for state and federal incentives [2]. The existence of decentralized solar capacities yields benefits both on the local level and on the level of the whole electric power system.

The results suggest that vaster installation of solar power plants provides holistic energy, economic, environmental and sustainability benefits, however, with certain limitations. The ultimate question is: which level of emissions and costs is acceptable? In this case study, the optimum is between 300MW and 600MW. 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 installed in the system), or should they remain on the level of limit values? Additional introduction of solar capacities into the electric power system raises the issue of system's certainty and stability, given the intermittent nature of SPPs. That is why the introduction of SPPs into the system is researched in this paper through genetic algorithms, while observing all conditions and constraints of a real, complex electric power system.

6. Conclusion

The results of developed models for RES integration projects, show that the emissions and costs are reduced by a greater degree of RES integration. Interdisciplinary approach also supports projects of faster RES integration. Developed models contribute to more correct analyses in the decision making process, towards actions for decarbonization of society, green systems and green economy, which is undoubtedly the new global value. Economics shouldn't be the only guide in decision making. This holistic study covers technology, economics, regulations, societal, and sustainability arguments.

Presented research has a broader context and applicability in project society. Developed models are applicable to any energy source. Methodology for optimal RES installation, as well as the effects of carbon dioxide reduction in the entire electric power system, can be extended to the projects related to other locations or demand curves. This paper also improves the methodological knowledge. Development of such models speeds up the transition to a responsible project society that strives for a clean decarbonized environment.

Based on developed interdisciplinary models and triangulation approach applied, it was concluded that the interest and opportunities for projects of wider solar energy implementation in Serbia exists. Investment in research and development projects in solar and others RE capacities are feasible. Energy, economic, social and environmental benefits are realized. Methodology offered here is applicable to different project's phases, especially in the strategic planning and conceptual designs.

Solar energy implementation is selected for the case study of decarbonized power supply to local community, although the projects of other renewable options are applicable as well. Anyhow, the results obtained for solar energy indicate that the methodology may be applied for integration of wind and other RES projects. Contemporary approaches presented in this research are important and significant for the development of projects in the field of decarbonization of the energy sector.

Considering the analyses and results above presented one can answer on a research question that the right principals for achievement of decarbonizing society are circular economy principals and right approach is interdisciplinary approach. The developed triangulation models and MDGA model can help in projects of decarbonization on the Globe.

Further research may deal with analyzing projects of decentralized renewable energy options vs. centralized energy generation, their respective advantages and disadvantages, and similar studies on regional, national or local level. In addition, social and institutional components of sustainability may be very important areas to consider in future research. The number of projects and researches in this area should be increased.

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References

1. Association, E. W. E.: EU Energy policy to 2050. EWEA. (2011)
2. Botterud, A., & Auer, H.: Resource Adequacy with Increasing Shares of Wind and Solar Power: A Comparison of European and US Electricity Market Designs. Economics of Energy & Environmental Policy, 9(2), 71-99. (2020)
3. Camilleri, M. A. A.: Circular Economy Strategy for Sustainable Value Chains: A European Perspective. Global Challenges to CSR and Sustainable Development, 141. (2021)
4. Charles Jr, O. H., Schmidheiny, S., & Watts, P.: Walking the talk: The business case for sustainable development. Routledge. (2017)
5. Charles, R. G., Davies, M. L., Douglas, P., Hallin, I. L., & Mabbett, I.: Sustainable energy storage for solar home systems in rural Sub-Saharan Africa–a comparative examination of lifecycle aspects of battery technologies for circular economy, with emphasis on the South African context. Energy, 166, 1207-1215. (2019)
6. De Angelis, R.: Circular economy and paradox theory: A business model perspective. Journal of Cleaner Production, 285, 124823. (2021)
7. Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M. C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., & Noble, I.: Policy: Sustainable development goals for people and planet. Nature, 495(7441), 305-307. (2013)
8. Holden, E., Linnerud, K., & Banister, D.: The imperatives of sustainable development. Sustainable Development, 25(3), 213-226. (2017)
9. Klessmann, C., Held, A., Rathmann, M., & Ragwitz, M.: Status and perspectives of renewable energy policy and deployment in the European Union—What is needed to reach the 2020 targets? Energy policy, 39(12), 7637-7657. (2011)
10. Mirjana, B., Uroš, R., Dragana, S., Erna, Z., & Miloš, N.: Local people's attitudes towards quality of environment in Serbia–B&H cross-border region. Arhiv za tehničke nauke/Archives for technical sciences(14). (2016)
11. O'Shea, T., Golden, J., & Olander, L.: Sustainability and earth resources: life cycle assessment modeling. Business Strategy and the Environment, 22(7), 429-441. (2013)

12. Patel, N., Gupta, N., Kumar, A., & kumar Verma, A.: Multifunctional grid interactive solar photovoltaic systems: A comprehensive review. International Journal of Renewable Energy Research (IJRER), 8(4), 2116-2130. (2018)
13. Stević, I.: Strategic orientation to solar energy productionand long term financial benefits. Arhiv za tehničke nauke/Archives for technical sciences(17). (2017)
14. Stević, I., Kirin, S., & Bozić, I.: Artificial intelligence and nature-inspired optimization on integrative capacity of renewable energy in the Western Balkan. Contemporary materials, 12(2). (2021)
15. Stevovic, I., Mirjanic, D., & Petrovic, N.: Integration of solar energy by nature-inspired optimization in the context of circular economy. Energy, 235, 121297. (2021).
16. Stević, I., Mirjanić, D., & Stević, S.: Possibilities for wider investment in solar energy implementation. Energy, 180, 495-510. (2019)
17. Suárez-Eiroa, B., Fernández, E., Méndez-Martínez, G., & Soto-Oñate, D.: Operational principles of circular economy for sustainable development: Linking theory and practice. Journal of cleaner production, 214, 952-961. (2019)
18. Sun, H., Samuel, C. A., Amissah, J. C. K., Taghizadeh-Hesary, F., & Mensah, I. A.: Non-linear nexus between CO_2 emissions and economic growth: A comparison of OECD and B&R countries. Energy, 212, 118637. (2020)
19. Tanoto, Y., Haghdadi, N., Bruce, A., & MacGill, I.: Reliability-cost trade-offs for electricity industry planning with high variable renewable energy penetrations in emerging economies: A case study of Indonesia's Java-Bali grid. Energy, 227, 120474. (2021)
20. Toljaga-Nikolić, D., Todorović, M., Dobrota, M., Obradović, T., & Obradović, V.: Project management and sustainability: Playing trick or treat with the planet. Sustainability, 12(20), 8619. (2020)