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COUPLED ENERGY AND ENVIRONMENTAL TRANSITION – POSSIBILITIES AND CONSEQUENCES

DOI: 10.5937/PIM25035G

Abstract:
The concept of the coupled energy and environmental transition is presented and discussed. Two transition goals are considered: carbon-free electricity generation and sustainable development. Appropriate indicators are used to indicate the transition's development. The intermittent renewable energy sources are considered for increasing carbon-free electricity generation. Presented concept shows the relation between improvements in forestry and possible further use of coal for electricity generation with simultaneously fulfilled imposed limit of carbon dioxide emission. The relation is given in the analytical form. The aim is to contribute to the options for sustainable development of undeveloped and developing countries. The example of Serbia is also presented and discussed.

Keywords: *Energy transition, Environmental transition, Sustainable development*

Introduction and problem definition

On the global level, significant differences emerged among individual countries regarding the basic concept of energy transition. Underdeveloped and developing countries have a legitimate desire to develop their economies as soon as possible and to reduce their lag behind developed countries. The increase in consumption of primary energy per capita is necessary for their development. The fastest and for many of the countries the most suitable way to increase the consumption of primary energy per capita is directly related to the increase in the consumption of fossil fuels, primarily coal, and, therefore, to the increase in carbon dioxide emissions. Exploitation of coal and its use for electricity enables underdeveloped and developing countries to provide the necessary employment and the level of their gross domestic product. In this resolution, the countries rely on the theoretical concept of sustainable development.

The countries gathered in the BRICS group give priority to sustainable development defined as “the human right to development” with an emphasis on the “fundamental role of energy security for achieving the

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goals of sustainable development" [1]. This further led to the affirmation of the principle of "common but differentiated responsibility and the respective capabilities of individual countries for the implementation of the United Nations Framework Convention on Climate Change and the Paris Agreement" [1]. On the other hand, developed countries, gathered in the G7 group, demand that "inefficient" subsidies for fossil fuels be abolished and that "private and public, domestic and international financial resources" should be mobilized in the fight against climate change [2].

Using natural carbon dioxide sinks, particularly the forests, to remove carbon dioxide from the atmosphere can be of great importance for ensuring the sustainable development of underdeveloped and developing countries. The absorption of carbon dioxide by forests could enable the continuation of the use of solid fossil fuels, i.e. a notably slower abandonment of its use and thus significantly contribute to the sustainable development of a specific country, simultaneously fulfilling the condition for carbon dioxide emission.

Natural carbon dioxide sinks are: forests and biomass on land, but also biomass in seas, oceans and continental waters. In addition to sinks, forests are also sources of carbon dioxide. Actual carbon dioxide sink capacity of the forest is determined by the difference between absorbed and emitted carbon dioxide. According to data published in the literature [3], in the period of their research all the world's forests absorbed approximately twice as much carbon dioxide as they emitted. The ability to absorb carbon dioxide, per the unit of land surface, is mainly determined by two key factors, i.e. the age of the forest and the way the forest is managed [4]. The key role of forest maintenance and management in the process of increasing the capacity of forests as carbon dioxide sinks is emphasized in the literature [3, 4]. According to data published in [4], the most powerful forests in terms of absorptive capacity are able to absorb up to 100 times more carbon per hectare than the least powerful forests.

1. Energy transition

Relying on the general definition of transition given by Lurbach and Rothmans [5], energy transition can be defined as the process of transformation of the energy system from the equilibrium state determined by the initial configurations of its structures: energy, technological, organizational and personnel, to another equilibrium state with different configurations of these structures. This structure concept can be applied to each of the energy subsystems, namely: to power system, thermal energy system, natural gas system, liquid fuel system, solid fossil fuel system and biomass system [6]. Energy end technology transition of power systems is subject of the further considerations.

In the development of energy transition theory and practice so far, two main goals of energy transition have been formulated and set, as two higher order requirements; these are: elimination, i.e. drastic reduction of carbon dioxide emissions during energy transformation processes and ensuring sustainable development.

In energy transition toward selected transition goal, different transition trajectories are possible. Different transition trajectories require different engagement of resources for the transition realization. At the same time, each transition trajectory enables different effects to be achieved. For example, in energy and technology transition of a power system toward carbon-free electricity generation, different transition trajectories require different investments, but also condition and different power system's dispatchability [7]. Therefore, defining the transition trajectory represents one of the most important and complex steps in the process of designing the energy transition. The change of the already chosen transition path during the transition process, can be characterized as the result of political compromises, bearing in mind the opinion of Pastukhova and Westphal [8] that the energy transition is a policy-driven process.

In the power system in transition, two basic groups of electric energies can be distinguished. The first is electricity produced without the emission of carbon dioxide from the primary energy of wind and sun. This is non-dispatchable energy because its amount depends on weather conditions. The second is the remaining electrical energy produced by dispatchable technologies from various primary energies (see Fig. 1). In current practice, the most commonly used transition path towards the goal of minimizing carbon dioxide emissions is to increase the share of electricity produced from primary wind and solar energy at the expense of reducing the share of electricity produced from other primary energies. Another possible transition path, towards the same goal, is to increase the share of electricity produced by dispatchable technologies without carbon dioxide emissions, primarily nuclear power plants. However, for the energy transition of underdeveloped and developing countries, the transition trajectory towards the goal - the achievement of sustainable development respecting the goal of minimization carbon dioxide emission - is very important, and for this they usually need the continuation of fossil fuel use. Bearing in mind the above, the energy structure of the power system can be defined by the following equation.

$$\lambda_{i-RES} = \frac{E_{i-RES}}{E_{i-RES} + E_{DIS}} = \frac{E_{i-RES}}{E_{tot}} \quad (1)$$

Here, $E_{i\text{-}RES}$ represents the electrical energy produced in one year by variable renewable energy sources i-RES (wind and sun), while the remaining secondary electricity produced by dispatchable technologies is denoted as E_{DIS}. The basic energy characteristic of the power system is the annual load duration diagram. Figure 1 shows the load duration diagram, mostly typical for European power systems in the energy transition. Here, the total electricity produced for a year from primary wind and solar energy ($E_{i\text{-}RES}$) corresponds to the green area, while E_{DIS}, corresponds to the orange area. More will be said about the energy E_f, which is indicated by the hatched area in Fig. 1, and which, in principle, can belong to either the $E_{i\text{-}RES}$ energy or the E_{DIS} energy.

The result of the power system's energy transition process, as well as of the energy system is expressed by appropriate energy transition indicators. The indicators also quantify the movement of the transition process toward the set goal. Are the indicator's numerical values getting closer to the goal and how much, or are they moving away from the goal? In the second case, according to [Shlaile and Urmecer] [9], it would represent the defeat of the transition. However, this second case is especially important when, as a transitional goal, sustainable development is set. Different indicators of energy transition are used in practice. Among the most commonly used indicators are: energy trilemma and energy intensity, which can be defined in different ways. In addition, to indicate the degree of development of the energy transition process, the already mentioned indicators of the structure of the power system, or the energy subsystem, also are used.

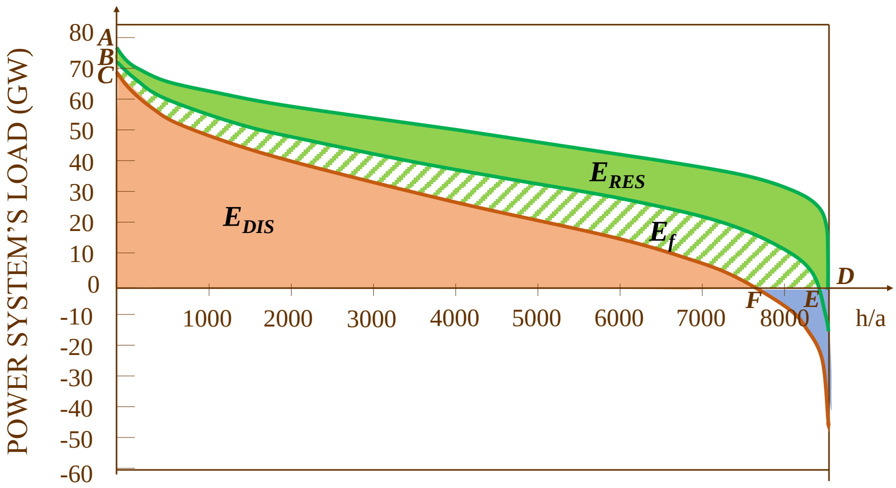

Figure 1. *Options for electricity generation without increase of carbon dioxide emission in energy transition*

The energy transition should be fair, both in terms of rights and responsibilities, and in terms of requests for achieving procedural and distributive justice, as formulated by Nevell and Mulvaney [10]. A just energy transition defined on these basic principles should be represented in the concept of each energy transition project.

2. Environmental transition

Environmental transition, analogous to energy transition, can be defined as the transition of the environment system of a country from the initial state of the environment defined by appropriate indicators, to another, according to those indicators a better and higher quality state of the environment. If during this transition occur a deterioration of the indicators, then, instead of improvement, there is a degradation of the environment, which represents the defeat of the transition and the reflection of the existence of an opposite process.

The most important mechanisms for improving the environment system are the improvement of forest potential, on the one hand, and the management of industrial, urban and agricultural waste, on the other hand. Improvement of forest potential can be achieved by improved management of existing forests and planting of the new ones. In this way, it is possible to increase the capacity of forests to absorb carbon dioxide, which further enables the continued use of part of the primary energy of fossil fuels and, on that basis, the maintenance of higher employment, which ultimately contributes to sustainable development.

The basic indicator of the capacity of the carbon sink in a country is the degree of afforestation σSf, which is defined as the ratio of the area under forest to the total area of the observed country, according to the equation:

$$\sigma_{Sf} = \frac{S_f}{S_{tot}} \tag{2}$$

The next very important indicator is the absorption capacity of the forest q_{fCO2} (in t/km^{2}a). It represents the amount of carbon dioxide, expressed in tons, that is absorbed by one square kilometer of a certain forest in a year. The appropriate indicator at the country level is defined as the average value of the absorption capacity of all forests $\bar{q}_{fCO2}$ (t/km^{2}a) in the observed country and, according to [11], is determined by the equation:

$$\bar{q}_{fCO2} = \frac{1}{S_f} \cdot \sum_{i=1}^{n} q_{fCO2i} \cdot s_{fi} \tag{3}$$

Here q_{fCO2i} and s_{fi} (in km^2) denote the carbon dioxide absorption capacity and the area of the *i*-th part of the total forest area, respectively, in the observed country.

3. Coupled energy and Environmental transition

With the known average value of the forests' absorptive capacity in a country $\bar{q}_{fCO2(1)}$, as well as with known forested surface σ_{Sf0}, can be determined the effect that these forests have on reducing the level of anthropogenic originated carbon dioxide, which is graphically shown in Fig. 2. The total amount of carbon dioxide of anthropogenic origin is divided into the part that forests absorb and on remaining part, Fig. 2. An increase in afforestation by $\Delta\sigma_{Sf}$ can produce the same effect as an artificial reduction in carbon dioxide emissions by $\Delta_1 CO_2$ obtained by replacing part of fossil fuel power plants with carbon-free generation (see Figure 2). Here, for the sake of simplicity, the same absorption capacity of new forests as existing forests has been assumed, although young forests, in principle, have a higher absorption capacity than existing ones.

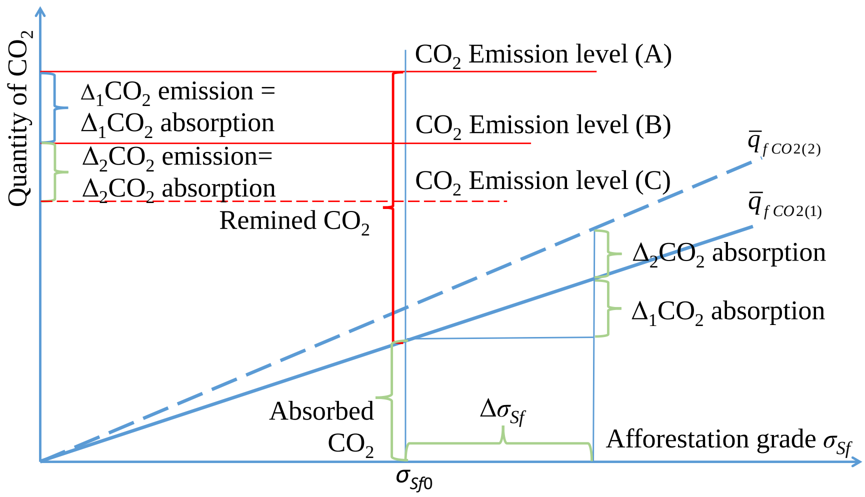

Figure 2. *Graphical interpretation of the afforestation effect on CO_2 content in a countries' atmosphere*

Improved forest management and maintenance can further improve the average value of the forests' absorption capacity in the considered cofuntry to the value of $\bar{q}_{fCO2(2)}$. In that case, an increase in the absorptive capacity of forests by $\Delta_2 CO_2$ could be achieved. The same effect of reducing carbon dioxide emissions could be achieved by replacing an additional part of fossil fueled power plants with the i-RES. In other words, increased afforestation and improved forest management, can enable the continuation of the exploitation of power plants on solid fossil fuel whose total annual carbon dioxide emission is determined by the equation:

$$\Delta CO_{2f} = \Delta_1 CO_2 + \Delta_2 CO_2 \tag{4}$$

In order to illustrate the concept of coupling the ecological and energy transition, the energy transition process is conditionally divided into two transition intervals. Here, the term "transition interval" represents a period of several years, during which certain transitional changes were made in the power system. The electrical energy $E_{i\text{-}RES}$, which in the last year of the previous transition interval is produced for one year by all i-RES sources corresponds to the green area (ADEBA) in the power system's annual load duration diagram, shown in Fig. 1. In the next transition interval, it is necessary to provide an additional amount of carbon-free electricity E_f, which corresponds to the hatched area

(BEFCB) in Fig. 1. At first glance, this can be achieved by a corresponding increase in the installed capacities of i-RES. However, this can also be achieved by fossil fuel power plants, provided that afforestation is increased and forest management is improved, which together would enable an overall increase in carbon dioxide absorption by ΔCO_{2f}. Thus, we obtain the general equation of the coupled energy and environmental transition in the form:

$$E_f = K_{CO2} \cdot \Delta CO_{2f} \tag{5}$$

Here, ΔCO_{2f} is determined by equation (4), while K_{CO2} is a constant whose numerical value depends on the chemical composition of the coal, which is used for electricity generation and on the electricity generation efficiency. If, on the basis of a corresponding study, can be concluded that by increased afforestation and improved forest management can be achieved the increase in annual carbon dioxide absorption by ΔCO_{2f}, then the corresponding amount of electricity that can be produced by coal-fired power plants, is determined by the equation (5). The inverse problem also can be considered.

By increasing the surface of the land covered by forests, as well as by improving forest management, it is possible to extend the operation of power plants on solid fossil fuel, including appropriate coal production that correspond to the energy amount E_f. Thus, instead of the costs of closing mines, paying severance pay to workers who lose their jobs and investing capital to create new jobs, we have the continuation of the work of workers in mines and associated power plants, with an appropriate gros domestic product and without increase the amount of anthropogenic originated carbon dioxide in the atmosphere.

4. Example of Serbia

The Energy Development Strategy of the Republic of Serbia [12] foresees in the year 2040, a decrease in the share of lignite-fired thermal power plants to about 55%, of those from the year 2021, that is for about 10700 GWh of their electricity generation, at the expense of increasing production from i-RES, with the aim of reducing carbon dioxide emissions. This implies a corresponding decrease in the number of employees in coal mines and thermal power plants, but also a decrease in GDP in the areas of coal mines and thermal power plants. All this for the sake of reducing carbon dioxide emissions in Serbia.

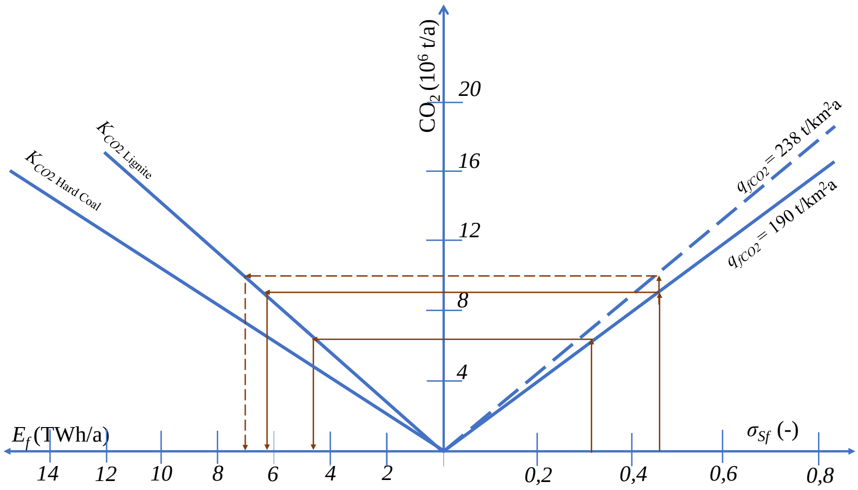

Figure 3. *Graphical interpretation of the afforestation effect on a carbon-free electricity production with coal fired power plants in Serbia*

All forests in Serbia, with assumed average absorption capacity equal to the average world's forests absorption capacity of 190 t/km^2, can absorb about 5,2E6 tons of CO_2 per annum. With the K_{CO2}=0,846MWh/t of CO_2, which corresponds for Nicola Tesla lignite-fired power plants (see also and Fig. 3), from Eq. (5) follows the electricity amount of about 4,3E6 MWh. This amount represents about 40% of the electricity generation reduction foreseen by The Energy Development Strategy of the Republic of Serbia. Simultaneously this figure amounts about 22% of the annual electricity generation of Nikola Tesla A and B thermal power plants (total installed capacity of 3000 MW) in 2019 [13]. However, if the surface under forest in Serbia is increased for 40%, and in addition if forest's maintenance and management is improved for 25%, the value of ΔCO_{2f}=2,6E6 t_{CO2}/a probably could be reached. With K_{CO2}=0,846, from Eq. (5) the value of E_f =2,2E6 MWh, can be calculated. Altogether these figures give about 64% of the foreseen reduction from the Energy Development Strategy of the Republic of Serbia [12].

Graphical interpretation of the coupled energy and environmental transition for the case of Republic of Serbia is presented in Fig. 3. For the purpose of the comparison lignete and hard coal in the coupled transitions, in Fig. 3 is presented line that coresponds to the Aleksinac hard coal, for which is K_{CO2} =1,056.

The figure of 190 t/km^2 is based on the assumption that the absorption capacity of Serbian forests is equal to the world average. Precise determination of the capacity of Serbian forests to absorb carbon dioxide should be performed within the framework of a complex scientific research project. That project should have two parts. In the first part, the necessary recordings on the ground should be carried out and, if the need dictates it and the possibilities allow, satellite images. On the basis of these studies, the sectors of areas under the forest with similar carbon dioxide absorption capabilities should be determined, as well as the average absorption capabilities of each of the defined sectors.

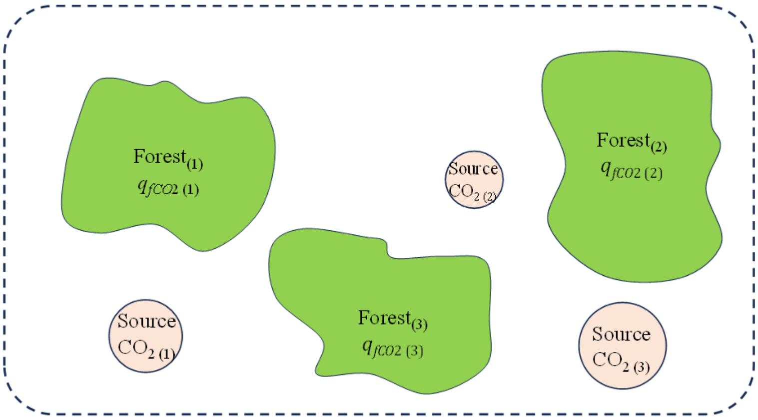

Figure 4. *Schematical presentation of the CO_2 sources and forests' distribution*

In the second part of the scientific research project, it is necessary to develop a specific mathematical model for calculating the possible and most likely absorption of carbon dioxide emitted from various industrial emitters in Serbia. Here, in addition to the emission intensity of individual emitters and the absorption capacity of individual sectors of the forest area and their spatial distribution, as is schematically presented in Fig. 4. The movement of air masses with carbon dioxide should be also taken into account. One of the results of such a project would be software for calculating carbon dioxide absorption in Serbian forests in real time.

5. Comparing countries regarding carbon dioxide emissions

The specific emission of carbon dioxide is the simplest indicator for comparing different countries in terms of carbon dioxide emissions. It is defined as the ratio of the emitted amount of carbon dioxide and the population of the observed country, that is, in analytical form as:

$$\mu_{CO2} = \frac{M_{CO2\_Em}}{P_{Ct}} \tag{6}$$

The emission of carbon dioxide at the country level indicates the part of the anthropogenic emission of carbon dioxide that the observed country "spills over" to other countries, that is, to the global level. This indicator is defined as the ratio of the difference between emitted and absorbed carbon dioxide and the number of inhabitants of the observed country, or in analytical form as:

$$\mu_{CO2Sf} = \frac{\left(M_{CO2\_Em} - M_{CO2\_Abs\,f}\right)}{P_{Ct}} = \frac{M_{CO2\_Em}}{P_{Ct}} \cdot \left(1 - \frac{M_{CO2\_Abs\,f}}{M_{CO2\_Em}}\right) = \mu_{CO2} \cdot (1 - \Theta) \tag{7}$$

Here, M_{CO2_Em} (in t/a) denotes the amount of anthropogenic carbon dioxide emitted in one year in the observed country, M_{CO2_Abs} (in t/a) denotes the annual amount of anthropogenic carbon dioxide absorbed by forests in the same country, P_{Ct} is the population of that country, μ_{CO2} is defined by Eq. (6), while Θ represents the ratio of annual amounts of absorbed and emitted carbon dioxide.

Assuming the general case when certain parts of the country's total forest area have different absorption capacities, then the ratio of annual amounts of absorbed and emitted carbon dioxide Θ will be determined by the following equation:

$$\Theta = \frac{M_{CO2\_Abs\,f}}{M_{CO2\_Em}} = \frac{\sum_{i=1}^{n} q_{fCO2i} \cdot s_{fi}}{M_{CO2\_Em}} = \frac{\bar{q}_{fCO2} \cdot S_f}{M_{CO2\_Em}} \tag{8}$$

Here, q_{fCO2i} (in t/km^{2}a) and s_{fi} (in km^2) denote the average amount of absorptive capacity and the area of the *i*-th part of the total forest area S_f, respectively. For a country with a sufficiently large area under forest and a relatively low emission of anthropogenic carbon dioxide, may be $\Theta > 1$, which results in a negative numerical value of the carbon dioxide emission indicator defined by Eq. (7). Such a country is a net absorber of carbon dioxide, in contrast to countries with a positive numerical value of this indicator, which are net emitters of carbon dioxide. A country for which $\Theta = 1$ will be emission neutral, i.e. neither will it “spill” its carbon dioxide to other countries, nor will it absorb carbon dioxide emitted by other countries.

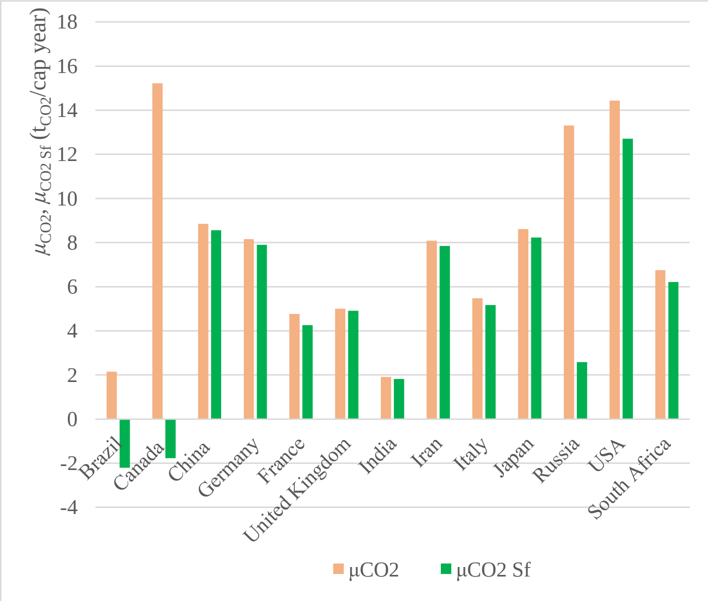

Figure 5. *Calculated values of the relative carbon dioxide per capita and carbon dioxide emission indicator for selected group of countries, according to data from [14, 15 and 16]*

In Fig. 5 is presented a comparative view of the specific carbon dioxide emission μ_{CO2} and of the indicator of carbon dioxide emission at the state level μ_{CO2Sf}, for a selected group of countries that includes some of the countries from the BRICS group and the countries of the G7 group, according to Grković [11]. The comparative view is obtained with the numerical value of $\bar{q}_{fCO2}$=190t/km^{2}a that approximately corresponds to the average absorption capacity of forests at the global level, calculated according to the data published in the literature [14, 15 and 16]. From Fig. 5 it can be seen that for some countries there are no big differences between μ_{CO2} and μ_{CO2Sf}, while for other countries from the selected group (Brazil, Canada, Russia) the difference between the numerical values of these two indicators is significant. According to the μ_{CO2Sf} indicator, the USA is the largest emitter, Russia and India, are among the smallest ones, while Canada, together with Brazil, are carbon dioxide absorbers. It is to underline that previous analysis is performed under the assumption that carbon dioxide absorption capacity of all forests in each country is equal to average world's forests absorption capacity. However, such an assumption represents a pertinent approximation.

6. Conclusions

Coupling environmental transition that comprises increase in the forest area and improvement forests' management with energy transition towards significant reduction of carbon dioxide emission potentiates, to the certain extend, continuation of electricity generation in coalfired power plants, simultaneously satisfying envisaged carbon dioxide limitations.

Continuation of electricity generation in the coalfired power plants is very important for undeveloped and developing countries. In this case, greater employment in the sectors of coal and electricity production from coal can be enabled and, on that basis, a higher gross domestic product, compared to the energy transition trajectory toward increased participation of i-RES in the electricity generation.

Presented analytical procedure for coupling energy transition and environmental transition is demonstrated on the case of Serbia.

Finaly, it can be outlined that coupled energy and environmental transition can contribute to the environmental justice.

Disclaimer (Artificial intelligence)

Author hereby declares that no generative AI technologies such as large language models (ChatGPT, COPILOT, etc.) and text to image generators have been used during writing or editing this manuscript.

Conflicting interests

Author hereby declares that there have been no conflicting financial interests or personal relationships that could influence the creation of the presented work.

REFERENCES

[1] XIV BRICS Summit, available at: http://brics2022.mfa.gov.cn/eng/dtxw/202206/t20220624_10709295.html (16.08.2022.).

[2] G7 Leaders' Communiqué, Elmau, 28 June 2022, available at: https://www.governo.it/sites/governo.it/files/2022-06-28-abschlusserklaerung-eng-web-data.pdf, accessed on 16.08.2022.

[3] Harris N. and Gibbs D. Forests Absorb Twice as Much Carbon as They Emit Each Year, available at: https://www.wri.org/insights/forests-absorb-twice-much-carbon-they-emit-each-year (Forest, 21.05.2024.)
[4] Moseman A., Harwey C. and Terrer C., How many new trees would we need to offset our carbon emissions?, MIT, (2024), available at: https://climate.mit.edu/ask-mit/how-many-new-trees-would-we-need-offset-our-carbon-emissions (Forest, 21.05.2024.)
[5] Loorbach D. and Rotmans J., Managing transitions for sustainable development, in Understanding Industrial Transformation. Views from different disciplines. Olshoorn, X. Wieczorek, A. J. Dordrecht, Springer, 2006. www.drift.eur.nl.
[6] Grković V.: Transition and post transition: energy and technology, Society of engineers in Zrenjanin and City national library in Zrenjanin, Serbia, 2024 (in Serbian)
[7] Grković V. and Doder Dj., On competitiveness of power systems in technology transition, Proceedings, (Editors: P. Stefanović and D. Cvetinović), Power plants 2021, Belgrade, Srbija, 2021, pp. 238-252.
[8] Pastukhova M., Westphal K., Governing the global energy transformation. In "The Geopolitics of the Global Energy Transition"; Springer: Berlin, Germany, 2020; pp. 341–364.
[9] Schlaile M. P. and Urmetzer S., Transitions to sustainable development. In W. Leal Filho, A.M. Azul, L. Bandli, P.G. Özuyar, and T. Wall (Eds.), Encyclopedia of the UN Sustainable Development Goals: Decent Work and Economic Growth, Cham, Springer, 2019. https://doi.org/10.1007/978-3-319-71058-7_52-1
[10] Newell P., Mulvaney D., The political economy of the "just transition". Geogr J. 179, (2013),132–140. https://doi.org/10.1111/geoj.12008
[11] Grković, V. 2024. "Contribution to Comparison Different Countries Regarding Carbon Dioxide Emissions". Journal of Energy Research and Reviews 16 (7):30-36. https://doi.org/10.9734/jenrr/2024/v16i7360.
[12] Strategy of the development of energetics of Republic of Serbia until 2040 year with projections until 2050-year, draft, (in Serbian), available at https://www.mre.gov.rs/extfile/sr (21.08.2024.)
[13] Electro energy portfolio of EPS, 2019.
[14] https://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions_per_capita (21.05.2024.)
[15] https://www.worldometers.info/world-population/population-by-country/ (21.05.2024.)
[16] Ritchie H. (2021) – Forest area, Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/forest-area (21.05.2024.)