

CHAPTER 8

THE CURRENT STATE AND FUTURE TRENDS OF THE ENERGY SYSTEM IN SERBIA

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The issue of energy seems more relevant than ever. A systematic review of the literature and available sources was undertaken in order to find an answer to the research question: "What is the current state of the energy system in Serbia and what the perspective is?" The aspiration of the authors is a comprehensive (as far as possible) review of the Serbian energy system through its important parts. Serbia, like the rest of the world, faces giant challenges in the energy field: the use of fossil fuels, the slow development of renewables, and low-emission fuels. Steady growth in consumption and demands.

This research is study about complex energy system issues and its potential new directions for the future in Serbia, with comparative analyses of region: Croatia and Bulgaria. Research shows that Serbia has progress and innovative solutions, as well as natural potential, but also that it stumbles on outdated technologies.

Keywords: *Fossil fuels, Renewables, Electricity, Nuclear power, Carbon capture, Decarbonization.*

INTRODUCTION

Renewable energy sources (RES) represent the main support of energy independence in the future of Serbia. Serbia has good RES potential:

hydropower, wind energy, geothermal energy, biomass energy, solar energy. An interesting area of research is the review of nuclear capacities, which represent a clean source of energy, but with certain additional risks. Climate change and energy crises were the main reasons for seeking new approaches in solving problems in the field of energy (Radonjić, 2023).

In addition to relying on RES, the transition to using these sources requires bridging the interruption in the supply of RES while the period of building nuclear capacities can be a decade. In that case, the issue of energy obtained from hydrogen is also important, which in the ideal case of obtaining energy from hydrogen, this type of energy should meet the criteria of efficiency, ecological suitability, profitability and speed of production (Seović et al., 2023). Arsić and Vučinić point out that the elimination of unsustainable treatment becomes a necessity (Arsić & Vučinić, 2022), which is in line with the European Green Deal that proposed Europe as an energy-neutral continent by 2050. In February 2024, the European Commission (EC) presented its assessment for the climate goals of the EU until 2040.

The implementation of modern energy technologies into the existing energy system, as a rule, aims to improve the process of energy transition, which is defined through the matrix: decarbonization, decentralization, digitalization and democratization of the energy sector (Parović, 2023). By reviewing Serbia's energy mix, it is clear that fossil fuels play a significant role, accounting for 42.9% and development of RES is slow and unpredictable. The development of RES requires investments, and the same applies to nuclear energy (Jovanović&Pavlović, 2025).

The Commission recommended a reduction of net greenhouse gas emissions in the EU by 90% by 2040 compared to 1990 (EC, 2024). In order to achieve this, EU countries as well as other European countries are investing efforts in the field of green resources. It is a fact that the energy sector plays a key role on Serbia's path to EU accession, serving as a link between economic development, sustainability and compliance with EU standards, which is essential for the broader goals of integration and regional stability (Brkić, 2023). Serbia has the comprehensive new legal framework from 2021 directed to the energy sector. Reducing negative energy trends implies an unambiguous process of energy transition (ET). The transformation of the existing energy system is accompanied by: an increase in the share of RES, an increase in energy efficiency, as well as a decrease in energy consumption (Golušin et al., 2012).

The negative impacts of energy sources based on coal, gas and fossil fuels can be beneficial and challenging for the development of a country's economy, but they are also a reason for the development of energy from

renewable energy sources (RES) which contributes to wider human development goals (Pavlović&Jovanović, 2024).

The implementation of ET is not only an energy-economic issue, but also has other implications: social, ecological, psychological and existential (Đuran et al., 2013; Bošković et al., 2023). The use of renewable energy sources can also be a source of harmful effects on the environment. This significantly slows down the development and implementation of RES-related projects.

The causes of obstacles in development and use can be: lack of political support, low income and expensive investments, conflict of interests, tax policy, complex knowledge for the application of technologies. The experts assert that safety is of utmost importance in the research phase. The administrative approach is present in decision-making, while adoption of a project often depends on political reasons. In the implementation of the adopted project, the infrastructure has the greatest impact on the usage of resources (Štrbac et al., 2023). The diverse and numerous obstacles should certainly not be excluded from consideration of RES application in order for the system in Serbia to become an optimal energy system (Beke Trivunac et al., 2014).

MATERIALS AND METHODS

The starting point is the analytical method through the IEA database, the IRENA database, which is further developed by additional collection and systematization into the author's research with the use of other official and relevant data (state data, the World Bank database, etc.).

The paper examines the situation related to absorbing, using and storing carbon, with the aim of decarbonisation. A comparative analysis of electricity production from RES: wind energy, hydropower, solar energy and biofuels was also considered. The aim of the work also included the positioning of the results of the development points of the energy system of Serbia, as well as the discovery of its weak points in the global and regional frameworks. Through this study, a comparative analysis of electricity production from different energy sources in Serbia with the countries of the selected region: Croatia, Bulgaria and Hungary was carried out.

RESEARCH AND DISCUSSION

Total electricity production

The electricity sector of Serbia, which is particularly important for the entire economy and society, is one of the biggest polluters of the environment, as electricity production is mainly based on fossil fuels (mainly domestic lignite, gas, and oil) (Jovanović et al., 2023).

The total production of electricity in Serbia is growing from year to year. A well-known problem with electricity production is that the production is based on coal. By recent data, 62,29% of total production is from coal, but it is on downward trend. The hydropower potential is valuable in a development of energy strategy of Serbia. Hydropower and wind energy have a constantly growing share in the energy mix of Serbia.

The capacities of solar energy as RES stagnate. Table 1 shows the IEA's energy data survey for electricity generation.

Table 1. Electricity production in Serbia with trend in GWh

Type of source	2019	2020	2021	Trend
Total production	37600	37956	38235	+1.6%
Coal	25658	26494	23820	-7.1%
Hydropower	10198	9748	11984	+17.5%
Wind	898	975	1084	+17.1%
Solar PV	13	13	13	/
Biofuels	138	192	247	+44.1%

Source: Author's research based on IEA database

Total electricity production growth in Serbia in the period 2019-2021 by 1.6% and shows increased demands.

Table 2. Total electricity production in selected countries in GWh with trend

Country	2019	2020	2021	Trend
Serbia	37600	37956	38235	+1.6%
Croatia	12760	13385	15210	+16.1%
Bulgaria	44276	40754	47568	+7.4%
Hungary				

Source: Author's research based on IEA database

As the Table 2 shows, Serbia has the lowest trend growth in total energy production. Croatia has the highest percentage increase in the observed period.

Coal-based electricity production

Table 3. Coal-based electricity production in selected countries in GWh with trend

Country	2019	2020	2021	2022	Trend
Serbia	25658	26494	23820	23546	-8.9%
Croatia	1639	1215	1456	1558	-5.1%
Bulgaria	17224	13532	17085	21785	+20,9%
Hungary	4184	3826	3105	3064	

Source: Author's research based on IEA database

Table 3 shows the progress of selected countries in reducing electricity generation from coal. Coal-based electricity production in Serbia is in decline. Croatia and Hungary has achieved a significant reduction, while Bulgaria has regress.

RES electricity production

The focus on renewable energy utilization is growing sharper, due to its sustainability and contribution to greenhouse gas emissions reduction. But 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 (Stevović et al., 2021). It is possible to reduce the share of coal in the production of electricity, by energy transition and wider application of RES.

Table 4. Renewable energy share of electricity production

Country	2019	2020	2021	2022	Trend
Serbia	28.0	27.03	33.1	28.1	+0.1
Croatia	65.4	63.9	69.2	62.9	-2.5
Bulgaria	16.9	18.3	21.7	19.1	+2.2
Hungary	13.7	15.8	19.1	21.4	+7.7

Source: Author's research based on IRENA database

According to the authors' research, based on data from the IRENA Report (IRENA, 2024), in period 2019-2022 Hungary has the highest growth

trend in RES share in electricity production, followed by Bulgaria, while Serbia compared to the selected countries, has the lowest growth trend, Croatia has negative trend.

Wind energy

Wind energy is a valuable potential with an increasing share which does not require additional consumption of conventional fuels. In Serbia there are suitable locations for the construction of wind generators. Now in Serbia operate 9 wind farms with a total of 158 wind generators, primarily in the plains of Vojvodina. Four wind farms are under construction and 23 are planned.

The use of wind generators is accompanied by certain negative effects. These effects can be division into those that arise during their production, normal operation, possible system failures as well as at end-of-life disposal. Does not exist direct emission of toxic substances in progress normal operation, but still there is an impact on life environment during the operation of the converter: noise, infrasound, reflection, shadows, landscape impact, effect to birds, effects to fauna, occupying space, end-of-life disposal (Jovanović & Baroš, 2023). In addition to the negative effects, the use of wind energy requires large investments.

Table 5. Wind energy in selected countries in GWh with trend

Country	2019	2020	2021	2022	Trend
Serbia	898	975	1084	949	+5.6%
Croatia	1467	1721	2062	2138	+45.7%
Bulgaria	1317	1477	1434	1499	+13.8%
Hungary	729	655	664	610	-16.3%

Source: Author's research based on IRENA database

Largest amount of wind energy in GWh has Croatia, with 2138 in 2022, Hungary shows weakest result (610), but the trend is weak in Bulgaria. The data show that Hungary is not committed to obtaining energy from this source.

Biofuels

Bioenergy represents the largest renewable source of energy, based on several feedstock types. Mostly exploited feedstock includes residues from forestry (fuel wood, wood chips, sawdust), crops cultivated specifically for the purpose of energy production, wastes and agricultural residues (Pušić et al., 2024).

In the Republic of Serbia, there are conditions for the production of biofuels - bioethanol and biodiesel. Biodiesel is suitable alternative for petroleum diesel, and raw materials for bioethanol production include: cereals, millet, potatoes, sugar beet molasses and maize.

Table 6. Biofuels energy in selected countries in GWh with trend

Country	2019	2020	2021	2022	Trend
Serbia	138	192	247	252	+45.2%
Croatia	878	978	1099	1128	+28.4%
Bulgaria	1776	1697	2588	2243	+26.2%
Hungary	2090	1988	2070	2008	-3.9%

Source: Author's research based on IEA database

The use of biofuels shows the largest growth in the share of total electricity production in the observed period. According to research in Table 6 - Serbia has the highest growth trend in the use of biofuels in the observed period of the selected countries, but the lowest number in the amount of energy produced. Bulgaria produces the largest amount of energy from biofuels, after Bulgaria there is Hungary by the amount of energy by with negative trend, while Croatia is in the middle in terms of production volume, and showed the average growth trend (+28.4%).

Hydropower

Serbia has 16 hydropower plants with 51 units, which accounts for almost 38.4% of total power potential of Electric power industry of Serbia. Electricity is generated in Djerdap HPPs Branch, Kladovo, and Drinsko-Limske HPPs Branch, and Bajina Bašta.

The extraordinary potential of renewable water energy is also represented by small hydropower plants that can be installed on watercourses and become “privileged” energy producers.

Table 7. Hydropower energy in selected countries in GWh with trend

Country	2019	2020	2021	2022	Trend
Serbia	10198	9748	11984	9274	-9.06%
Croatia	5932	5810	7228	5574	-6.03%
Bulgaria	3382	3320	5067	3833	+13.33%
Hungary	219	244	212	178	-18.72%

Source: Author's research based on IEA database

Data in Table 7. Shows growing trend in hydropower production in Bulgaria, while in terms of the amount of energy produced, Serbia has the highest value. The trends in Serbia and Croatia are negative, while the worst results by both criteria are found in Hungary.

Solar energy

Serbia is a rich country in global radiation energy that can be used for renewable solar energy sources: north-west and south-east Serbia have great potential. Solar energy is an immediately usable, clean, and renewable ecological resource, which is a great advantage over fossil fuels.

Therefore, more and more work is being done on systems that convert solar energy into electricity, both for small-scale domestic and large commercial fields of solar panels so as to make a great contribution to the stability of the operation of public power grids (Arsić et al., 2023).

According to research data, this solar energy has a relatively low share in the total electricity production in Serbia. Thus, there is no official capacity improvement in the observed period, but efforts are being made.

Table 7. Solar power energy in selected countries in GWh with trend

Country	2019	2020	2021	2022	Trend
Serbia	13	13	14	16	+18.75%
Croatia	83	95	148	152	+45.39%
Bulgaria	1417	1468	1466	2094	+47.7%
Hungary	1497	2459	3796	4732	+316%

Source: Author's research based on IEA database

According to the data from Table 7, the study of observed countries, Serbia, although it has great potential, does show progress of 18.75%. Croatia and Bulgaria achieve progress in trend in solar energy use of total electricity production, while Hungary receives the greatest total energy from solar energy and great progress of +316%.

Nuclear energy

The energy of water, sun, wind, energy from geothermal sources, biomass and biogas is used for the production of electricity, thermal energy and fuel. Apart from RES, the potential in distancing from fossil energy sources is presented and the total alternative energy sources.

Primary energy can be obtained from non-renewable energy sources, ie fossil fuels and nuclear fuels, as well as renewable energy sources. More and more is in the discussion the nuclear energy as an alternative source of energy, even though it is a non-renewable source, nuclear energy, due to its low consumption (high energy density) and high productivity in the obtained energy, can also be viewed in this way.

Uranium has characteristics that can strengthen a country's security of supply when nuclear is part of its energy mix. Uranium is a uniquely concentrated source of energy, so the required quantities are much smaller than for coal or oil; a 1 GWe power plant requires about 20-30 tons of manufactured nuclear fuel per year compared to over 3 million tons of coal (Brkić, 2023).

Table 8. Nuclear electricity generation in GWh with trend

Country	2019	2020	2021	2022	Trend
Serbia	-	-	-	-	-
Croatia	-	-	-	-	-
Bulgaria	16555	16625	16486	16462	-
Hungary	16288	16055	15990	15812	-

Source: Author's research based on IEA database

The trend in nuclear energy production in Hungary and Bulgaria is stable. Nuclear power plants represent a large part of the energy system in the production of electricity in these countries. Serbia and Croatia do not have nuclear potential on their territories (for now) but there are announcements in the case of Serbia around 2035. y.

According to data from the European Nuclear Society (ENS), there are 167 active nuclear reactors and 10 under construction in Europe. In terms of electricity globally generated by nuclear energy in 2023, France holds the top position with a share of 64.8%, followed by Slovakia (61.3%) and Hungary (48.8%), then Finland (42%).

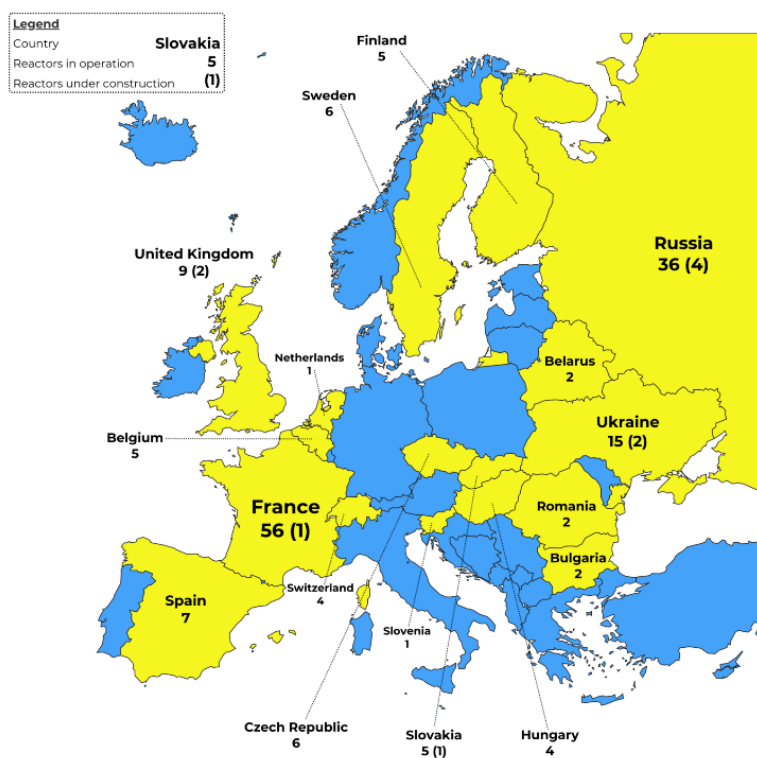


Figure 1. Map of nuclear power plants in Europe

Source: ENS, 2024

In the surrounding countries of Serbia, 4 reactors are operational in Hungary, 2 in Romania, 2 in Bulgaria and 1 in Slovenia. According to official announcements Serbia could also have its own nuclear future, while Croatia is a co-owner of the Krško nuclear power plant located in Slovenia with a 50% share.

Potential energy used from alternative, especially renewable sources, is often available in forms that are not suitable for direct use, which requires conversion to another form of energy. Nuclear energy is not dependent on the above external factors, while equally striving towards carbon neutrality of the future of energy production (Rajković et al., 2024). It is considered that the decarbonization of the electricity supply system would include, in addition to renewable energy sources, nuclear energy obtained from advanced nuclear technologies.

The pursuit of sustainable development has taken centre stage on the global agenda. One of the most promising avenues in this endeavour is the continuous advancement of renewable energy technologies (Ostergard et al., 2023). Wind energy is a valuable potential with an increasing share

which does not require additional consumption of conventional fuels. In Serbia there are suitable locations for the construction of wind generators (Jovanović&Pavlović, 2024). The trend of total electricity consumption in Serbia is slightly increasing. Coal-based electricity production is decreasing, but significantly less than in Croatia.

Total RES is also in progress in Serbia. The research data that are not encouraging and the some author's views regarding the barriers in the implementation and participation of renewable energy sources in the electricity production system are certainly worrying. Compared to developed countries, Serbia has a weak dynamic of RES development, but it has significant natural potentials.

The approach to the environment and climate change is strategically defined in a number of policies pertaining to the water management, sustainable use of resources, renewable energy resources and energy efficiency, and risk management in Serbia. Together with the other Western Balkans economies, signed the Sofia Declaration on the Green Agenda for the Western Balkans which refers to following: climate, energy, circular economy, depollution ect.

Serbia has established new legislation in the field of energy: The Energy Act ("Official Gazette of the RS", No. 145/2014, 95/2018 - other law and 40/2021), Act on the Use of Renewable Energy Sources ("Official Gazette of RS", No. 40/2021), Law on the Use of Renewable Energy Sources ("Official Gazette of RS", No. 40/2021). The Law on the Use of Renewable Energy Resources represents the foundation for investment in construction solar power plants and wind farms. More and more industrial consumers opt for the construction of solar systems power plant for own purposes (with return on investment within 5-7 years). Serbian Ministry of Agriculture, Forestry and Water Management offers grants for the acquisition and installation of new equipment with the intension to to use renewable energy sources and improve energy efficiency.

CONCLUSION

Serbia's energy system is the backbone of the economy, but also the source of progress in green development. Sustainability would be a prerequisite. Serbia has a significant energy potential of most renewable energy sources.

However, this potential is poorly utilized due to the dominance of outdated technologies, especially in the energy sector. The modernization of the energy sector, but also the increase of capacity, is certainly an ongoing process, so the opening of new capacities in the thermal power

plants Kostolac 3 is expected as early as next spring, the first additional capacity that Serbia will receive after 35 years. The increase in capacity is again accompanied by technology from non-renewable energy sources, but with respect to emissions.

Energy transition and decarbonisation in Europe can serve as models for all countries of the Western Balkans. The use of renewable energy sources in total energy production is constantly increasing in Serbia, mainly due to hydroelectric power plants and the use of biomass, in the form of pellets. Green technologies are within reach, but development is stuck in certain parts of the energy system (construction of solar power plants and biogas plants, production of biodiesel).

Nevertheless, certain efforts are being made (construction of the first wind farms), which inspires hope for the imminent progress of the energy transition in Serbia.

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