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A COMPARATIVE STUDY OF PRIMARY ENERGY PRODUCTION AND ENERGY DIVERSIFICATION IN SERBIA AND SLOVENIA*

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Abstract

The way a country generates its primary energy shapes its economic trajectory, the stability of its supply and its environmental footprint, which is why understanding this structure has become a central concern of our time. Against this backdrop, this paper traces how primary energy production evolved in two geographically close yet developmentally distinct countries: 1.Serbia, classified as developing, and 2. Slovenia, classified as advanced, across a ten-year span from 2014 to 2024. Secondary data drawn from the official statistical offices of both countries were examined through descriptive statistics, trend analysis and Pareto charts. The findings point to two markedly different energy models. Serbian production is dominated by coal throughout the entire period, reflecting a heavy concentration on non-renewable sources, whereas Slovenian production rests on a more balanced combination of three pillars - nuclear energy, solid fuels and renewables. This confirms that Slovenia has reached a higher degree of diversification, while Serbia remains tied to fossil fuels. The study adds to the comparative literature on national energy structures and underscores the need for Serbia to accelerate diversification and strengthen investment in renewable sources. Although the analysis carries certain limitations, it offers useful guidance for energy policy and opens avenues for future research grounded in broader datasets and more sophisticated analytical models.

Keywords: *energy, production, structure, renewable sources, diversification, Pareto analysis, Serbia, Slovenia*

1. INTRODUCTION

Energy is considered to be one of the most important factors of the modern civilization. As stated by the United Nations "energy is central to nearly every major challenge and opportunity the world faces" (United Nations, 2025). Nowadays, energy is known to have an important role in everyday environment and is closely connected to economic growth and living standards of societies (Siirola, 2014). A subcategory of energy, known as primary energy, refers to energy which is derived from both renewable and non-renewable sources in its initial form, before any conversion or transformation (European Parliament, 2018; Bilardo et al., 2022). Primary energy production includes solid fossil fuels, natural gas, crude oil, nuclear energy, renewable energy, renewable energy sources, peat and non-renewable waste (Zhao et al., 2023; Kosowski, 2024). They can be further transformed into secondary energy sources, like electricity (Zhao et al., 2023). Although energy itself offers substantial benefits, it still has serious downfalls. Energy production negatively impacts human health and the environment in three main ways: air pollution, accidents, and greenhouse gas emissions. Even though every energy source has its

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negative impact, fossil fuels by far have the biggest negative impact on both the environment and human health (Ritchie, 2020). Fossil fuels emit the most greenhouse gasses per unit of energy, whereas both nuclear energy and renewable energy are far better options (Radosavljević et al., 2022). Given the anticipation of further growth in primary energy demand, it is necessary to utilize all available energy sources efficiently, including coal (Balat, 2009). As the most cost-effective fuel source globally, coal maintains a dominant position in the global market for electricity production (Radosavljević et al., 2022). Coal is often seen as a necessary alternative choice in situations where cleaner and cheaper energy sources cannot meet the demand (Balat, 2009). Unfortunately, since it does emit the most amount of greenhouse gasses, it is considered to be the biggest cause of global warming (Radosavljević et al., 2022). On the other hand, renewable energy is produced from indigenous natural resources that are continuously restored and are environmentally friendly. Global investments in research and development have further made renewable energy more accessible, available and acceptable (Gökgöz & Güvercin, 2018).

However, the geographical positioning and the market imbalance make it difficult for developing countries, where Serbia is currently listed, to have access to modern energy services (Legro et al., 2009; International Monetary Fund, 2023). Furthermore, energy consumption is rising dramatically, due to population expansion, developments in different industries and the countries' efforts to improve their living standards (Albayrak, 2010). This rising trend is present around the world, due to industrialisation and urbanisation, which additionally contributes to the increase of waste generation (Ouda et al., 2016), indicating that advanced countries, such as Slovenia (International Monetary Fund, 2023), are also affected. Consequently, energy production has significantly increased over the past three decades in order to meet this growing demand worldwide (United Nations Department of Economic and Social Affairs, 2024).

2. LITERATURE REVIEW

Energy has a strong connection with problems and opportunities on a global level, including issues regarding affordability, supply security, resilience, environmental pollution, climate change, and global sustainability. On the other side, the energy sector has a role in the development of new technologies and industries and can create opportunities for sustainable energy production, especially in regions where drastic economic growth is recorded. (Pfenninger, 2014). The importance of incorporating both traditional and renewable sources, in order to achieve diversification of primary energy production, which has direct influence on reducing the risk of supply disruptions is acknowledged by Shipkovs et al., (2011). Having said that, previous academic literature has covered the topic of primary energy consumption (Bozsik et al., 2023) and production, with a focus on the importance of sustainable and multiple energy systems around the world (Shalaeva et al., 2020), on European countries level (Kosowski, 2024; Balaras et al., 2022) and in the case of European Union countries (Dacko et al., 2020). Furthermore, renewable energy production and its production in European regions has become relevant in academic research (Perpiñá Castillo et al., 2024; Trębska & Gromada, 2017). Shalaeva et al. (2020) analyzed the changes of energy production and consumption in the period between 1990 and 2018 by world regions, with one of the conclusions being that, due to climate policy changes, the coal consumption in Europe achieved a declining rate over time. Further analysis, on a dataset including European countries, from 1990 to 2020 was conducted by Kosowski (2024), who examined the changes in primary energy production in these countries in terms of their sources and effects on energy security and sustainability. Kosowski (2024) grouped European countries by their similarities into multiple clusters. Extracted from results obtained in 1990, Serbia was categorized into "Coal Countries" cluster, and Slovenia "Coal Countries with Nuclear Components". Three decades later, in 2020, Serbia was still considered as the predominantly "Coal" country, while Slovenia obtained a change in its primary energy production and got

categorized as a part of the "Nuclear Countries" grouping. Energy situation (Brkić, 2018), potential for the growth of renewable energy sources (Dragović et al., 2019) and the status of Serbia regarding waste to energy process (Bajić et al., 2015) are explored by authors. Previous studies assessed patterns of energy consumption, energy efficiency indicators across economic sectors and reviews relating energy efficiency policies and measures (Al-Mansour, 2011), the future chances of Slovenia lowering the levels of fossil and nuclear sources by the year of 2050 (Senegačnik & Sekavčnik, 2024) and energy management in Slovenia, with a focus on renewable sources, nuclear energy and decrement of coal use (Crnčec, 2022). Given the previously stated, primary energy production is a relevant and important topic for further academic research, and this paper aims to give contribution by analyzing primary energy productions of two geographically close countries, Serbia and Slovenia, which are differently categorized in terms of their levels of economic advancement and this paper aims to fill the identified research gap in current literature. While both Serbia and Slovenia have been individually analyzed in the existing literature, no direct comparative analysis of their primary energy production structures over the 2014-2024 period has been conducted. In this paper, descriptive statistics, trend analysis and the Pareto chart are applied in order to give detailed comparison of primary energy productions between these countries and to confirm key energy sources for each of them using the newest datasets available.

3. DATA AND METHODOLOGY

The purpose of this research is to compare secondary data obtained from the official national statistical databases of Serbia and Slovenia. The analysed dataset includes the period from 2014 to 2024 and includes primary energy production by source, ensuring comparability between two countries. The methods of analysis that were used throughout this research were descriptive statistics, trend graph and Pareto plot. All data regarding primary energy production in Serbia and Slovenia were retrieved from the databases of the Statistical Office of the Republic of Serbia (2024) and the Statistical Office of the Republic of Slovenia (2024). The available statistical data are presented according to Eurostat standards and the International Energy Agency, which gives the opportunity to cross examine data from different countries, supporting the analysis conducted in this paper (Statistical Office of the Republic of Serbia, 2024; Statistical Office of the Republic of Slovenia, 2024). Descriptive statistical methods and SPSS version 26.0.0.0 software was used to summarise the dataset, which helped provide an overview of the primary energy production in both Serbia and Slovenia. The results of descriptive statistics provide data of the number of samples (N), mean value (Mean), median (Med), minimum values (Min), maximum values (Max), range (R), standard deviation (SD) and coefficient of variation (CV) for both analysed countries. The importance (dominance) of each source was assessed using a Pareto analysis as a tool useful to showcase and identify the relative importance of problems. It contains both bars and lines, where bars represent individual values and the curved line presents the cumulative total of the sample. A cut off line is also included where the most vital factors sit under it. In the context of the primary production in Slovenia and Serbia, the cut off line was approximately 80% which follows the Pareto principle 80/20 that states that roughly 80% of the effects come from 20% of causes (Pyzdek, 2021). In some cases, the cut off line exceeds 80% in order to obtain the most important sources in a logical manner. Additionally, a trend graph covering a ten-year period was created to illustrate changes in primary energy production over time.

4. RESULTS AND DISCUSSION

The results of the analysis reveal dominant energy sources and indicate differences in the dynamics and structure of primary energy production between Serbia and Slovenia. Firstly, descriptive statistics were performed and the results are presented in Table 1 and Table 2. Based on the obtained results (Table 1), it can be stated that the total mean value of non-renewable

primary energy sources, consisted of coal, oil and oil derivatives, natural gas, non-renewable industrial waste and non-renewable municipal waste (326930.36), is significantly higher than renewable energy sources in Serbia (99482.82), which includes wood fuel, hydro energy, geothermal energy, biogas, renewable industrial waste, solar photovoltaic energy, wind energy and renewable municipal waste. Coal achieved the overall highest mean value (270294.82).

Table 1. Descriptive statistics - Serbia (in TJ)

Energy source	N	Mean	Med	Min	Max	R	SD	CV (%)
Coal	11	270294.82	276720	227048	302127	75079	29599.09	10.95
Oil and oil derivatives	11	40376.09	38990	35940	50592	14652	4652.40	11.52
Wood fuel	11	56346.36	49151	45395	68918	23523	11111.27	19.72
Hydro energy	11	39227.91	38819	33388	47090	13702	4106.99	10.47
Natural gas	11	15963.82	16247	11000	21207	10207	3620.81	22.68
Geothermal energy	11	166.82	215	61	257	196	82.61	49.52
Biogas	11	1321.73	1190	215	2587	2372	900.12	68.10
Renewable industrial waste	11	91.36	93	73	105	32	10.93	11.96
Non-renewable industrial waste	11	191.27	51	34	1613	1579	471.61	246.57
Solar photovoltaic energy	11	105.09	48	22	586	564	163.96	156.02
Wind energy	11	2145.36	3234	0	4875	4875	1948.62	90.83
Non-renewable municipal waste	11	104.36	0	0	1083	1083	325.16	311.57
Renewable municipal waste	11	78.18	0	0	813	813	244.12	312.24

The obtained results from Table 2 show that nuclear energy sources, which are in this case represented by nuclear energy (64181), obtained the highest total mean value in the Slovenian dataset. Renewable energy sources, which include: renewable energy, hydro energy and geothermal energy, had a total mean value of 48856.45, while non-renewable energy sources: solid fuels, natural gas, crude oil and petroleum products, obtained the lowest total mean value (33809.64).

Table 2. Descriptive statistics - Slovenia (in TJ)

Energy source	N	Mean	Med	Min	Max	R	SD	CV (%)
Nuclear	11	64181	63016	61124	69459	8335	3280.84	5.11
Solid	11	33592.64	34252	24504	39433	14929	5053.42	15.04
Renewable	11	27620.09	27235	24222	30585	6363	2151.85	7.80
Hydro	11	16561.91	16936	11335	21929	10594	2873.71	17.35
Geothermal	11	4674.45	3888	2925	8936	6011	1935.82	41.41
Natural gas	11	200.91	164	92	546	454	127.29	63.36
Crude oil	11	16.09	16	4	37	33	9.10	56.58
Petroleum products	11	0	0	0	0	0	0	0.00

Figure 1 illustrates the trends in primary energy production by source in Serbia during the period from 2014 to 2024. The analysis confirms that coal remained the dominant source of primary energy production throughout the entire period. Other energy sources, including hydro energy, oil derivatives and renewable energy sources contributed significantly less to the overall energy structure. Although certain variations can be observed over time, the overall structure of energy

production in Serbia remained strongly dependent on conventional energy (non-renewable) sources such as coal.

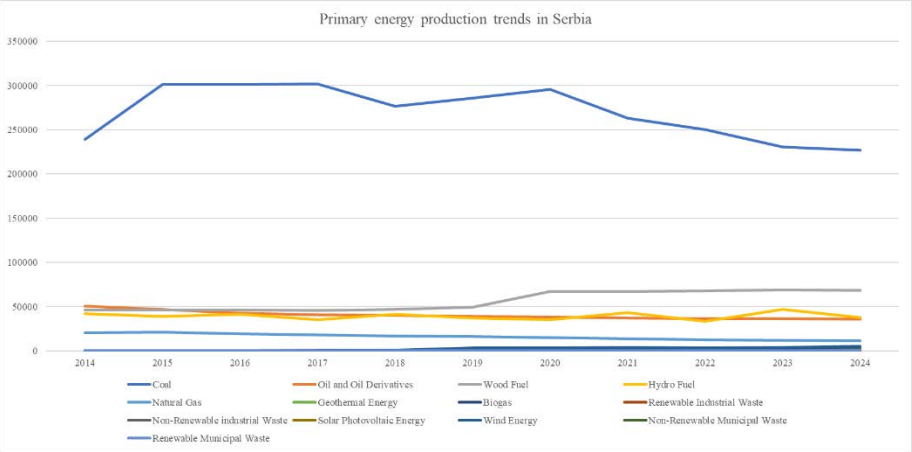

Figure 1. Primary energy production trends in Serbia

The analysis of Figure 2 presents a diversified energy structure, with nuclear energy representing the dominant source throughout the entire period. Although certain fluctuations can be observed over time, solid fuels and renewable sources of energy contributed significantly to total energy production. Overall, the analysis indicates a relatively stable energy production structure with increasing importance of sustainable energy sources. The results indicate that Slovenia achieved a higher level of diversification in primary energy production compared to Serbia, whose energy sector remains largely dependent on fossil fuels, mostly coal. Such dependence may have negative environmental implications due to high greenhouse emissions and reduce the sustainability of the energy sector. Therefore, greater investment in renewable energy sources and diversification of energy production could contribute to a more sustainable energy system in Serbia. Trend analysis illustrated the dynamics of primary energy production during the observed period, whereas Pareto analysis provides a clearer understanding of dominant energy sources and their cumulative contribution to the energy sector.

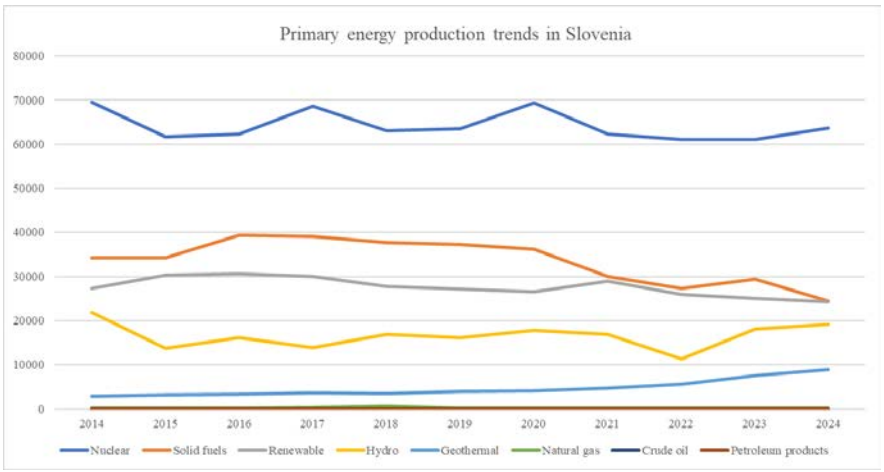

Figure 2. Primary energy production trends in Slovenia

Figure 3 and Figure 4 present the Pareto analysis of primary energy production sources in Serbia for 2014 and 2024. In both years that limit the period under consideration, coal remained the

dominant energy source, accounting for the largest share of total primary energy production. The pareto diagrams show that a small number of energy sources contributed to the majority of total production, indicating a concentrated energy structure. Although slight changes can be observed between 2014 and 2024, Serbia continued to rely heavily on fossil fuels, particularly coal. Such dependence may present environmental challenges, suggesting the need for greater development of renewable energy sources in the future.

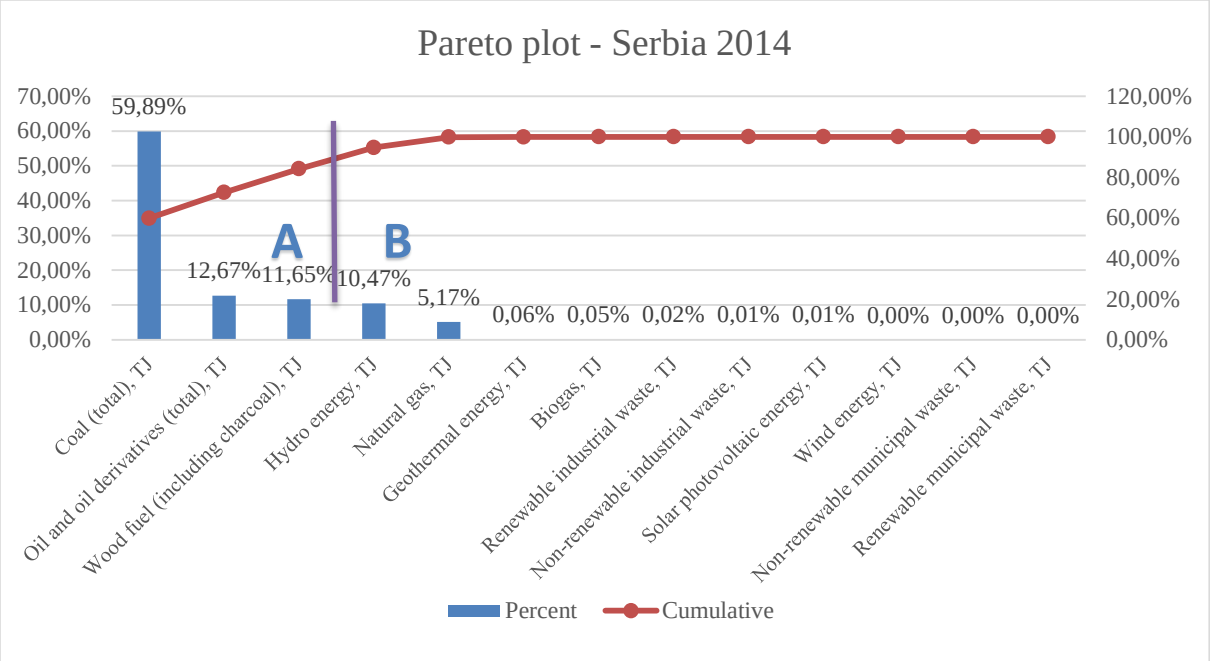

Figure 3. Pareto plot - Serbia 2014

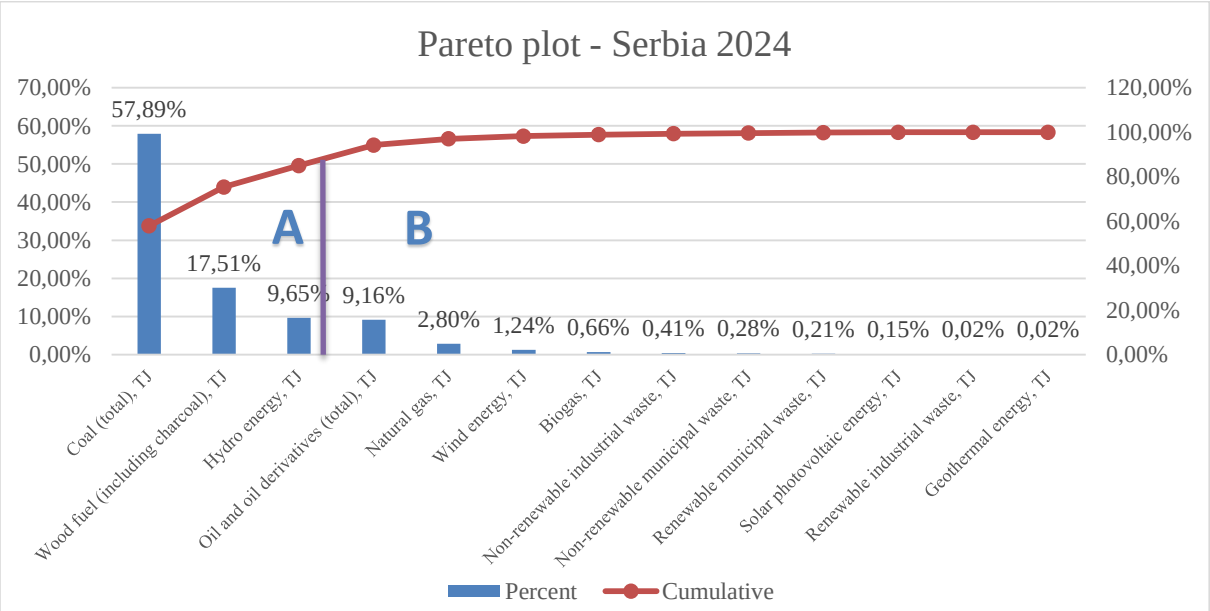

Figure 4. Pareto plot - Serbia 2024

Figure 5 and Figure 6 show the Pareto analysis of primary energy production sources in Slovenia for 2014 and 2024. Results indicate that nuclear energy, solid fuels and renewable source of

energy contributed significantly to total primary energy production. Unlike Serbia, where one source is dominant, Slovenia demonstrates a more balanced distribution of energy production.

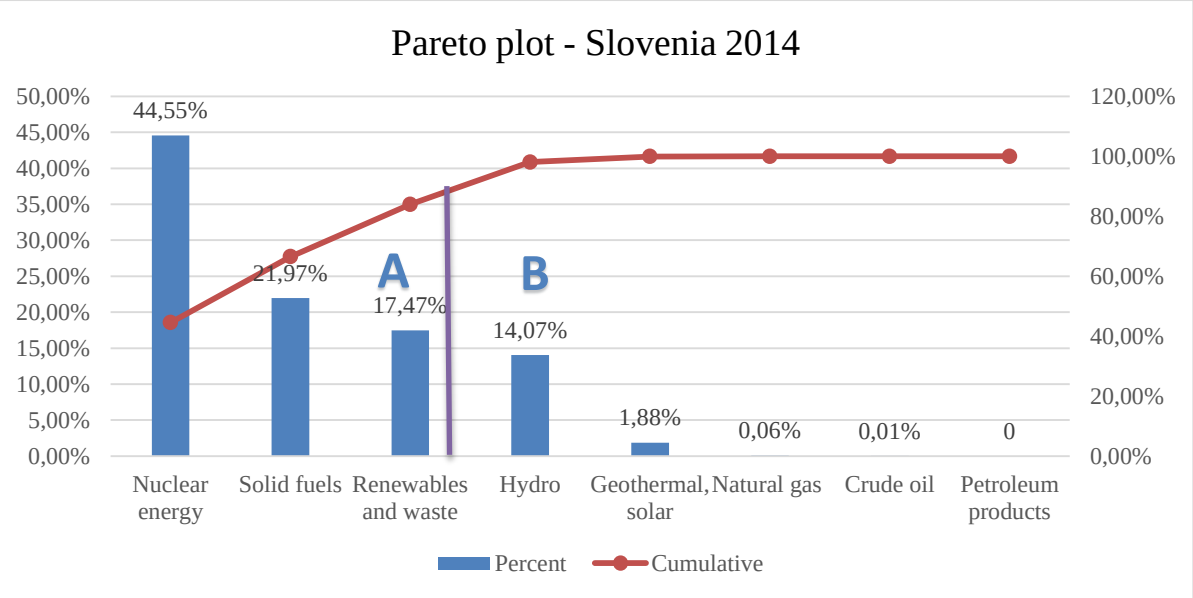

Figure 5. Pareto plot - Slovenia 2014

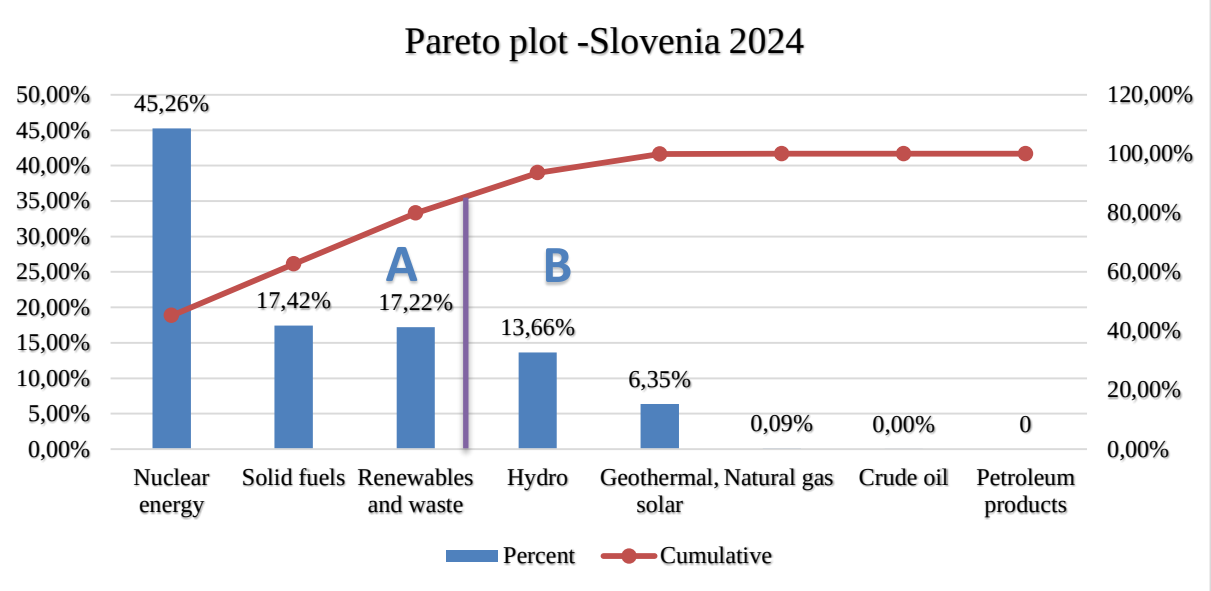

Figure 6. Pareto plot - Slovenia 2024

A more structured comparison between the two countries can be drawn by grouping the analysed energy sources into three categories: non-renewable, renewable and nuclear. Regarding non-renewable sources, Serbia exhibits an overwhelming dominance of coal, which alone contributes the majority of total primary energy production, complemented by oil and oil derivatives and minor amounts of natural gas, non-renewable industrial waste and non-renewable municipal waste. In Slovenia, non-renewable sources are also present, primarily in the form of solid fuels, with marginal contributions from natural gas and crude oil; however, their relative share is considerably lower than in Serbia and is consistent with broader European decarbonisation trends. With respect to renewable sources, Serbia's renewable portfolio is led by hydro energy and wood fuel, while wind, solar photovoltaic, biogas and geothermal energy remain marginal contributors despite some growth in recent years. Slovenia displays a comparatively more stable

renewable structure, anchored by renewables, hydro and geothermal energy, which together provide a more consistent contribution to the overall energy mix. The most pronounced difference between the two countries lies in the third pillar - nuclear energy. Slovenia's primary energy production is led by nuclear energy, which provides a stable, low-carbon baseload throughout the entire analysed period and accounts for the highest mean value among all sources. Serbia, by contrast, produces no nuclear energy, leaving a structural gap in low-carbon baseload capacity. This three-pillar comparison further confirms that Slovenia's energy mix benefits from the complementarity of nuclear, renewable and non-renewable sources, while Serbia's structure remains highly concentrated on a single non-renewable source, indicating a higher concentration of energy production in Serbia compared to Slovenia.

The structural difference between the two countries with respect to nuclear energy invites a brief reflection on the broader academic debate. On one side, several studies emphasise the systemic advantages of nuclear capacity in low-carbon energy systems. Aszódi et al. (2023), based on high-time-resolution electricity supply models for fifteen European countries with nuclear capacity, find that scenarios retaining nuclear power achieve the lowest CO_2 emissions, while phase-out scenarios increase emissions and storage requirements even when compensated by additional solar and wind capacity. Hjelmeland et al. (2025), using the EMPIRE model for European power systems, similarly show that the role of nuclear becomes more pronounced as baseload demand increases, with higher nuclear shares contributing to lower system-wide needs for storage, transmission, curtailment and land use. On the other side, studies emphasise the economic and timing challenges associated with new nuclear capacity. Steigerwald et al. (2023), through a Monte Carlo cost analysis of nineteen small modular reactor concepts, find that none are profitable under their tested assumptions, with median levelized costs of electricity starting at 116 USD/MWh, suggesting that significant cost reductions would be required for new nuclear projects to be economically competitive with alternative low-carbon technologies. The differing positions of Serbia and Slovenia with respect to nuclear capacity place the two countries on different sides of this ongoing academic and policy debate, and the choices each country makes regarding the future structure of its primary energy production represent an open area for further research.

5. CONCLUSION

This paper gives contribution by providing descriptive statistics, trend analysis and Pareto chart analysis for primary energy production comparison of a developing country, Serbia and advanced country, Slovenia. The results present changes in primary energy production between years 2014 to 2024. In the case of Serbia, the most dominant primary energy source is coal throughout the analyzed period. However, the second and third most dominant sources had changed over the decade: oil and oil derivatives have been exceeded by hydro energy, while wood fuel maintained its position in the most influential Pareto zone (A) in both cases. There were no drastic changes in the Pareto A zone for Slovenia: minimal variations were noticed, nevertheless the three dominant sources remained throughout the decade: nuclear energy as the most dominant, followed by solid fuels and renewables and waste. While this study is limited by its descriptive nature and reliance on secondary data from two countries, it provides valuable insights for energy policy decision-makers. Future research should expand the geographical scope and employ dynamic models and inferential tests to deepen the understanding of these relationships.

KOMPARATIVNA STUDIJA PROIZVODNJE PRIMARNE ENERGIJE I DIVERZIFIKACIJE ENERGETSKIH IZVORA U SRBIJI I SLOVENIJI

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Izvod

Način na koji jedna zemlja proizvodi primarnu energiju oblikuje njen ekonomski razvoj, stabilnost snabdevanja i uticaj na životnu sredinu, zbog čega je razumevanje ove strukture postalo jedno od ključnih pitanja savremenog doba. Polazeći od toga, u radu se analizira razvoj proizvodnje primarne energije u dve geografski bliske, ali razvojno različite zemlje: Srbiji, koja se svrstava u zemlje u razvoju, i Sloveniji, koja se smatra razvijenom zemljom, u periodu od deset godina (2014-2024). Korišćenjem sekundarnih podataka prikupljenih iz zvaničnih statističkih izvora obe zemlje, sprovedene su deskriptivna statistička analiza, analiza trendova i Pareto analiza. Rezultati ukazuju na postojanje dva značajno različita energetska modela. Proizvodnjom energije u Srbiji tokom celog posmatranog perioda dominira ugalj, što ukazuje na visoku zavisnost od neobnovljivih izvora energije. Nasuprot tome, energetska proizvodnja u Sloveniji zasniva se na uravnoteženijoj kombinaciji tri ključna izvora – nuklearne energije, čvrstih goriva i obnovljivih izvora energije. Ovi nalazi potvrđuju da je Slovenija dostigla viši nivo diverzifikacije energetskih izvora, dok Srbija i dalje ostaje snažno oslonjena na fosilna goriva. Rad doprinosi komparativnim istraživanjima nacionalnih energetskih struktura i ukazuje na potrebu da Srbija ubrza proces diverzifikacije i intenzivira ulaganja u obnovljive izvore energije. Iako istraživanje ima određena ograničenja, ono pruža korisne smernice za kreiranje energetske politike i otvara prostor za buduća istraživanja zasnovana na obuhvatnijim skupovima podataka i naprednijim analitičkim modelima.

Ključne reči: *energija, proizvodnja, struktura, obnovljivi izvori, diverzifikacija, Pareto analiza, Srbija, Slovenija*

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