Between Stability and Sustainability: Nuclear Energy in Romania's Energy Mix

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Abstract: The transition to green energy is a priority of the European Union in fighting climate change and aiming to reach open strategic autonomy, especially today when the world has entered a period of high uncertainty regarding energy security. Since the transition to green energy implies costs, resources, and new technologies, nuclear power generation could represent the buffer between the current situation and the desired one. This paper aims to analyse whether nuclear energy could represent such a buffer for Romania, which still relies on electricity imports due to the variability of internal production, considering our country's advantages in this field, namely resources of uranium and existing nuclear capacities.

Key-Words: - nuclear energy, solar energy, wind energy, sustainability, stability

JEL Classification: C40, F18, Q42

1 Introduction

In 2022, the European Parliament voted to classify nuclear energy as green or sustainable on a proposal from the European Commission (2022) since atomic energy does not directly produce carbon dioxide emissions, ensures energy security, does not cause more harm to human health or the environment than other electricity production technologies already included in the taxonomy, the significance of nuclear industry in Europe and as a political compromise among the Union`s member states. The decision has been criticised because of the issues related to nuclear waste management, the high costs of developing new production capacities, and the consequences of the accidents in Chornobyl and Fukushima.

The scientific debate surrounding nuclear energy's viability, safety, and impact is heterogeneous. Some researchers highlight the potential benefits of atomic energy, while others underscore the looming threats and challenges.

Supersperger et al. (2011) consider nuclear power unreliable, expensive, and unsafe for the North African countries that would remain dependent on imports to produce nuclear energy. Renewable energy is a better solution because it allows North African nations to build and maintain their infrastructure.

Naimoğlu (2022) analysed the impact of Nuclear Energy Consumption (NEC) and energy imports on CO_2 emissions in 10 emerging economies from 1990-2019, confirming the Environmental Kuznets Curve (EKC) hypothesis. The findings underlined the potential of nuclear energy to reduce pollution, the significance of renewable energy for environmental quality, and the need for technological advancements in energy efficiency.

Rotblat (1978) argues that the push towards nuclear energy increases the risk of nuclear warfare due to the widespread availability of plutonium while creating an imbalance of power, where developing countries become heavily dependent on more prosperous nations for nuclear resources. The author suggests that the ideal solution is to focus on alternative, renewable energy sources, like solar, to gain energy independence and minimise the risks of nuclear energy.

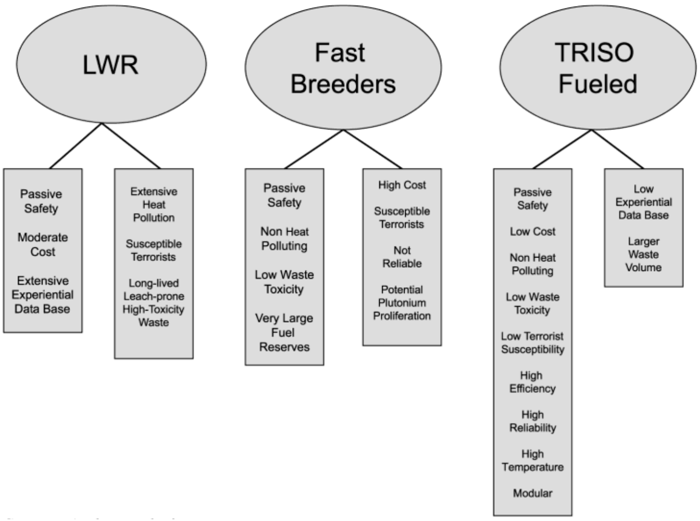
According to Heffron and Nuttall (2017), Scotland's energy debate focuses mainly on nuclear and renewable energy, while the country relies mostly on fossil fuels. If Scotland becomes a member of the EU, it may have to shut down its fossil fuel power plants due to EU regulations and agreements. The Scottish Government promotes renewable and fossil fuels, neglecting nuclear energy.

Hollomon et al. (1975) argue that a nuclear plant can displace 2.5 times its energy output in oil equivalents compared to an oil-fired plant due to the inefficiency of converting oil into electricity. When considering future demand and accounting for energy inputs in constructing nuclear and oil-fired plants, atomic energy can displace even more oil. The exact amount depends on the parameters of the oil system, with the displacement from the first case serving as a minimum estimate.

According to Yi-Chong (2011), Australia could increase its uranium exports due to Asia's growing nuclear power industry. Australia must strengthen the Nuclear Non-Proliferation Treaty framework to ensure safety and improve its protection measures, especially in the region. Australia's approach to nuclear fuel and used fuel management needs careful consideration, with an emphasis on regional cooperation and skill development.

Schaffer (2007) analyses the advantages and disadvantages of three types of nuclear reactors: light water reactors (LWR), fast breeders and TRISO. The LWRs offer passive safety, moderate cost and an extensive experiential database but suffer from extensive heat pollution and are susceptible to terrorist threats. Fast breeders also provide passive protection and produce low waste but are costly, unreliable, and vulnerable to terrorism. TRISO-fueled reactors have passive safety, low cost, and non-heat polluting features but have an insufficient experiential database, producing a larger volume of waste (Figure 1).

Figure 1: Principal reactors advantages and disadvantages



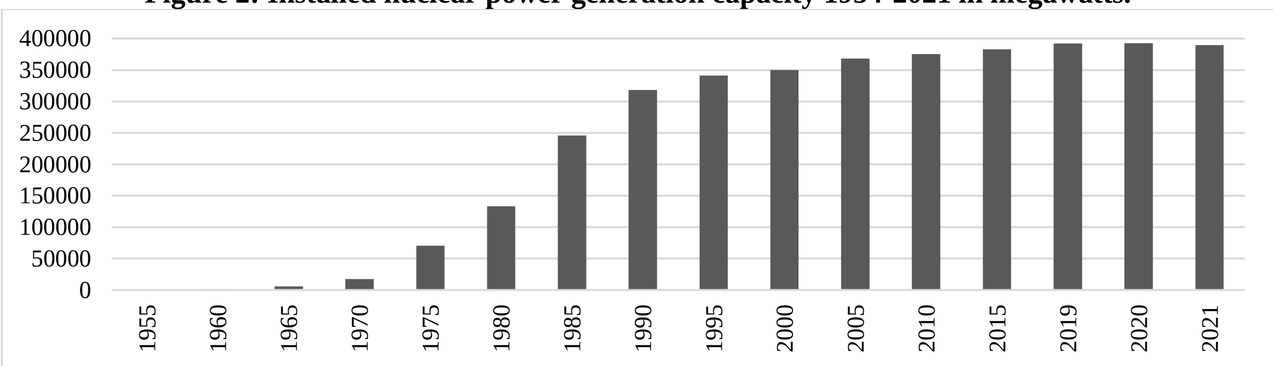
Source: Schaffer (2007)

The EU considers nuclear energy transitional between fossil fuels and green energy sources. Such transition can provide stable and reliable baseload power, essential for stabilising the grid while renewable sources are being integrated. However, it poses significant challenges, particularly regarding safety and waste disposal. Therefore, adopting a comprehensive approach that includes new green energy sources, technological advancements, strict regulations, and international cooperation is crucial to ensure its effective and safe use.

2 Zooming out nuclear energy

Worldwide, installed nuclear power generation capacity grew rapidly between 1955 and 1990, from five gigawatts in 1955 to 318,253 megawatts in 1990. Afterwards, the development was slower due to various factors, such as safety concerns, economic challenges, regulatory changes, and competition from alternative energy sources, in the context of the transition to the green economy (Figure 2).

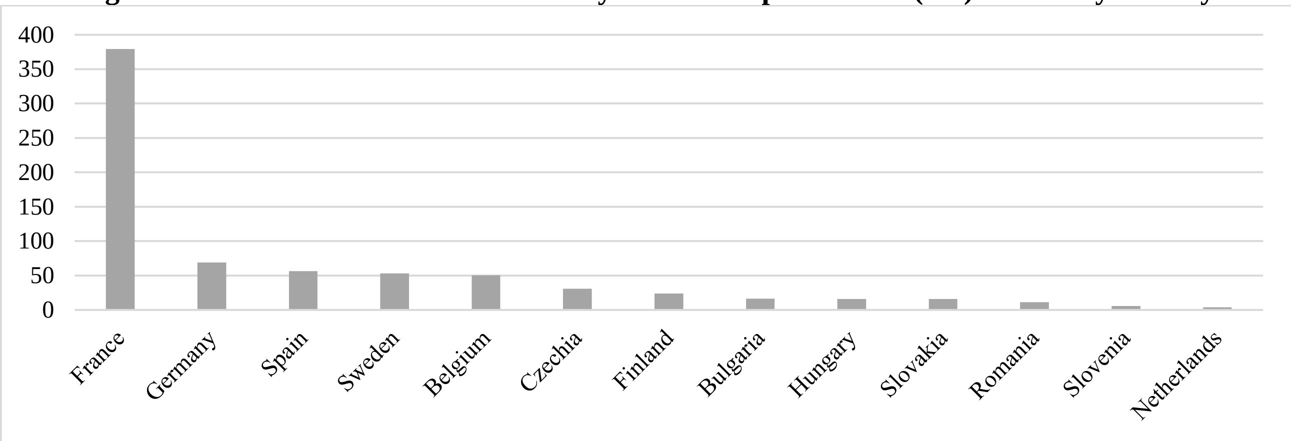
Figure 2: Installed nuclear power generation capacity 1954-2021 in megawatts.



Source: Statista (2023a).

The capacity peaked in 2020 (392,612 megawatts), entering a decline in 2021 (389,508 megawatts).
In the EU (Figure 3), the largest producer of nuclear power in 2021 was France (379.4 terawatt-hours), followed by Germany (69 terawatt-hours) and Spain (56.6 terawatt-hours).

Figure 3: Generation of Nuclear electricity in the European Union (EU) in 2021 by country



Source: Statista (2023b).

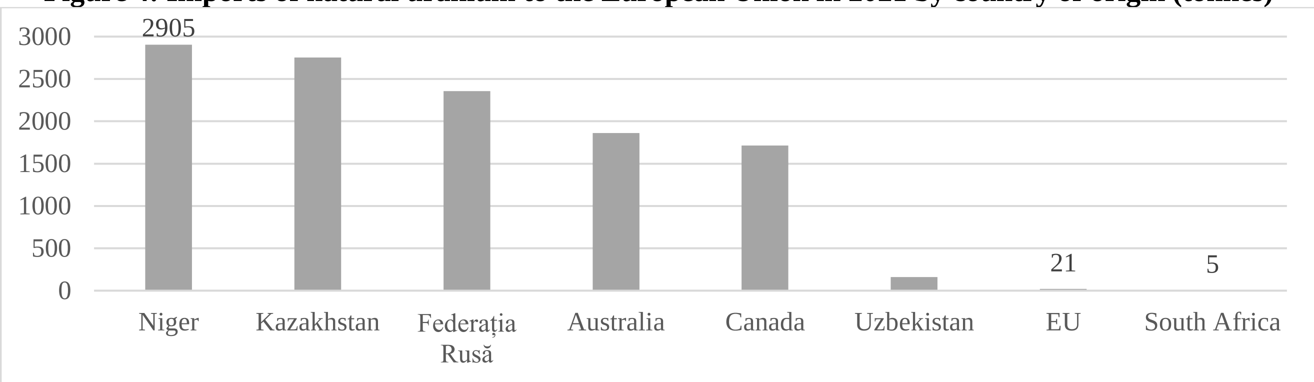
Romania produced 11.3 terawatt-hours of nuclear electricity, while Slovenia produced 5.7 and the Netherlands 3.8.

Regarding raw materials for nuclear fuel, the EU depends on imports.

According to Statista (2023c), the EU's leading source of natural uranium is Niger, from which it imported a total of 2,905 tonnes in 2021, followed by Kazakhstan (2,753 tonnes of natural uranium) and Russia (2,358 tonnes). Smaller quantities (Figure 4) were imported from Australia (1,860 tonnes), Canada (1,714 tonnes) and Uzbekistan (162 tonnes).

Only 21 tonnes of natural uranium is supplied from within the EU, a negligible contribution to domestic consumption needs. The EU also imports 5 tonnes of natural uranium from South Africa and a further 17 tonnes from sources not identified in the statistics.

Figure 4: Imports of natural uranium to the European Union in 2021 by country of origin (tonnes)



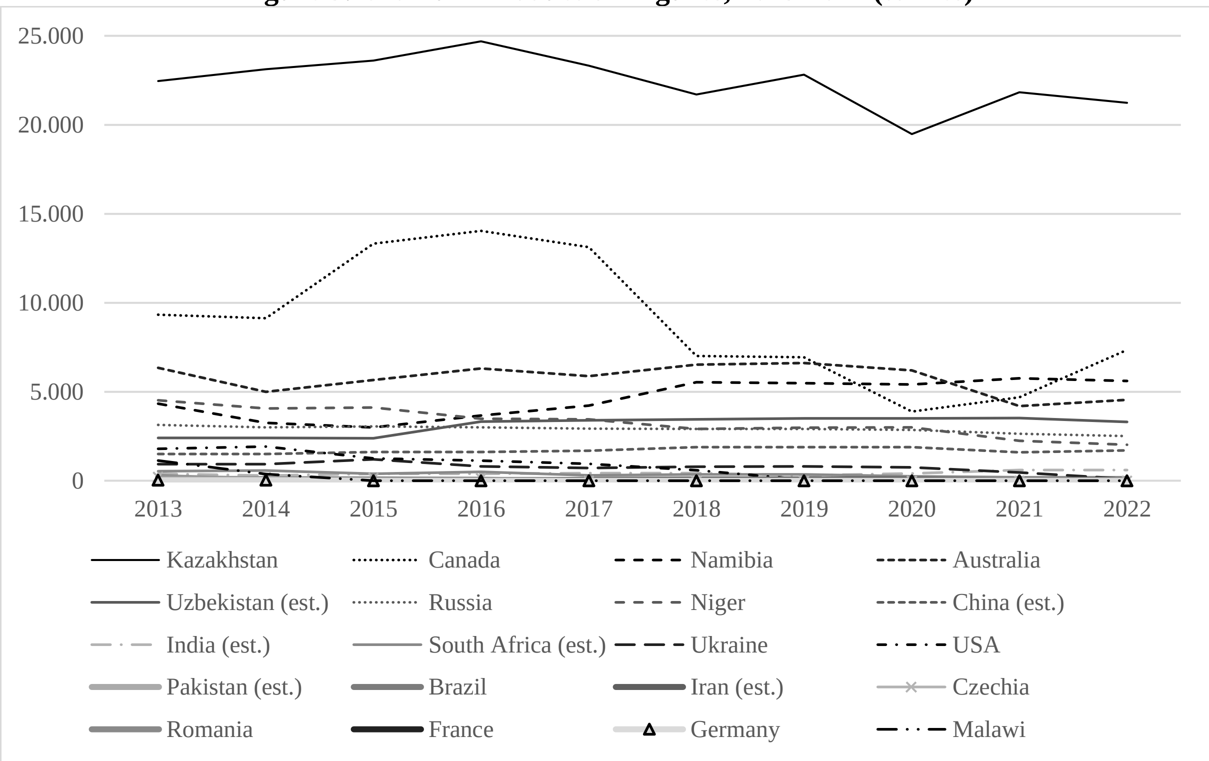
Source: Statista (2023c).

The analysis of the level of production of natural uranium exporting countries and EU imports (Figures 4 and 5) reveals that in 2021 the EU imports from Niger exceeded the output of that year (129.23%) and some stocks from previous years. The tensions in Niger this year could have a very negative impact on nuclear energy in the EU.

From the Russian Federation EU imported 89.5% of its production in 2021, from Australia (44.37%), from Canada 35.5%, from Kazakhstan (12.62%) and from South Africa (2.60%).

According to the data provided by the World Nuclear Association (2023), in 2013, only a few European countries produced uranium (Figure 5), namely Czechia (215 tonnes), Romania (77 tonnes), France (5 tonnes), and Germany (27 tonnes).

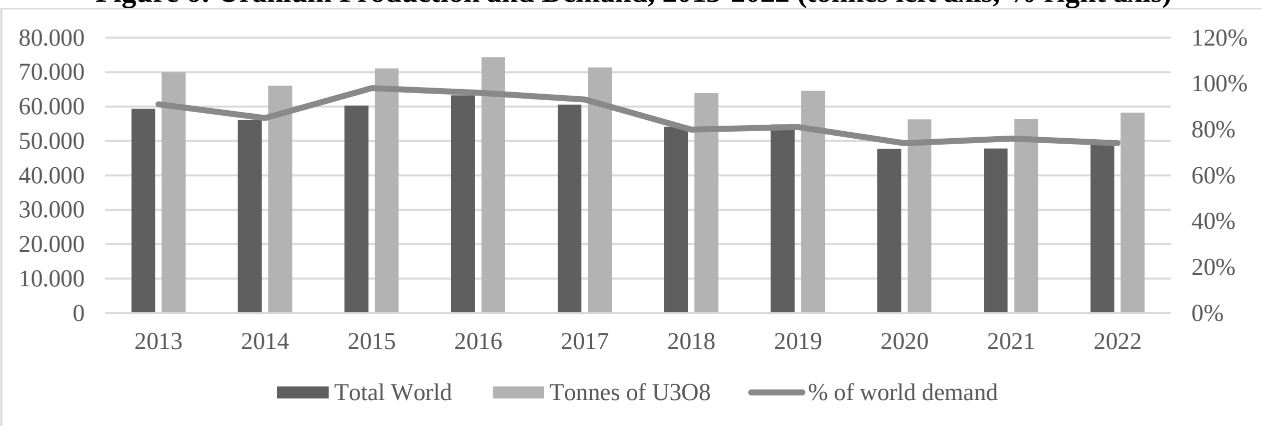
Figure 5: Uranium Production Figures, 2013-2022 (tonnes)



Sursa: World Nuclear Associacion (2023).

In 2016, only Czechia (138 tonnes) and Romania (50 tonnes) were still listed with natural uranium production. Since that year, no EU country has had any domestic production.

Figure 6: Uranium Production and Demand, 2013-2022 (tonnes left axis, % right axis)



Sursa: World Nuclear Associacion (2023).

A significant point is that in 2022, total natural uranium production only supplied 74% of the world's demand (Figure 6). Therefore, no global equilibrium exists between supply and demand, with countries competing for domestic requirements.

Considering the uncertainties regarding the uranium supplies from Niger and the war in Ukraine that led to the sanctions against Russia, in order to ensure its uranium imports, the EU needs to diversify its sources of natural uranium supply in a highly competitive market.

Since the EU is looking for open strategic autonomy, in the case of nuclear resources, the picture could be promising, looking at the resources available within the Union, and a more diversified sources of imports. Regarding the European uranium identified recoverable resources (Table 1), Czechia ranks first with (120,000 tonnes), followed by Spain (93,600 tonnes) and Slovakia (43,700 tonnes). Portugal has (18,500 tonnes), Italy (18,300), Hungary (13,500), Romania (13,200). The lowest resources of uranium have Slovenia (7,600 tonnes), Germany (7000), Greece (7000) and Finland (2,400 tonnes).

Table 1. Identified recoverable resources in the EU*
(as of 1 January 2019, tonnes U, rounded to nearest 100 tonnes)

Country	<USD 40/kgU	<USD 80/kgU	<USD 130/kgU	<USD 260/kgU
Czechia	-	-	900	119200
Finland	-	-	1200	1200
Germany	-	-	-	7000
Greece	-	-	-	7000
Hungary	-	-	-	13500
Italy	-	6100	6100	6100
Portugal	-	4500	7000	7000
Romania	-	-	6600	6600
Slovakia	-	12700	15500	15500
Slovenia	-	-	-	7600
Spain	8100	28500	28500	28500
Total	8100	51800	65800	219200

Source: IAEA, NEA (2020).
* It refers to the quantity of uranium that has been discovered and is considered technically and economically feasible to extract with the existing technology and under current market conditions.

The EU imports in 2021 amounted to 11,795 metric tonnes (Statista, 2023c), and the total uranium resources discovered and extractable in the Union are around 344,900 metric tonnes, representing the demand in 2021 for 29 years on. Under these conditions, and current production capacities, nuclear power production could be an actual buffer in the transition to entirely green energy, until new clean technologies will be able to replace it.

2 Analysing nuclear energy's importance in Romania's energy mix.

To analyse the importance of nuclear energy in Romania, we selected a data set comprising the energy production in Romania by sources on the 15th of October 2023, during the day, so all the energy sources are included in the research. The data is available on the webpage of Transelectrica, the Romanian Transmission and System Operator, which plays a vital role in the Romanian electricity market (Table 2).

Table 2: The production of electricity in Romania by source, in Megawatts, 15th of October 2023 Daylight

Coal	Hydrocarbons	Water	Nuclear	Wind	Solar	Biomass	Balance*
781	1147	1150	1385	792	4	49	-508
818	1118	1114	1389	794	4	48	-530
825	1135	1142	1385	783	9	49	-511
818	1117	1155	1383	786	17	49	-467
820	1125	1151	1383	805	35	50	-434
864	1125	1131	1384	834	57	49	-490
892	1133	1141	1386	811	82	50	-479
912	1131	1114	1389	780	105	48	-483
906	1120	1099	1388	756	133	50	-535
916	1129	1103	1391	704	157	50	-512
941	1137	1133	1396	675	191	51	-525
934	1138	1116	1394	635	215	52	-660
941	1139	1143	1392	573	243	51	-647
934	1143	1140	1390	527	269	51	-594
940	1140	1143	1389	480	283	51	-481
941	1146	1144	1393	443	314	49	-548
941	1146	1144	1393	443	314	49	-548
943	1173	1171	1390	417	374	50	-721

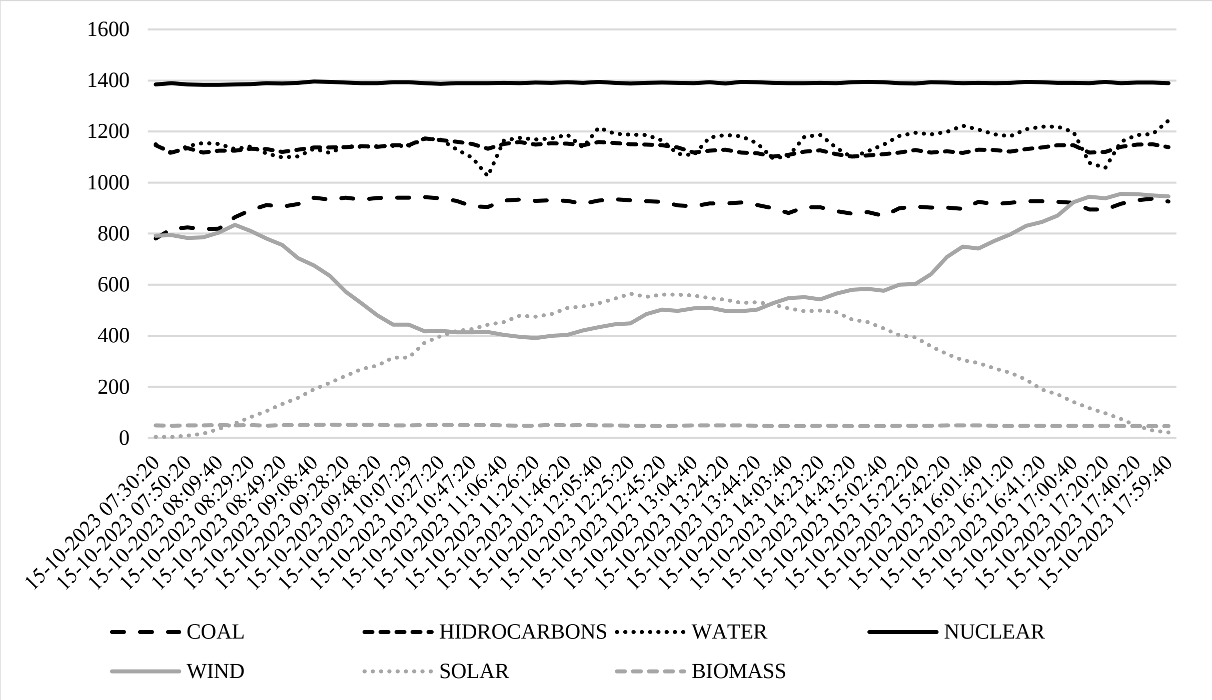
Coal	Hydrocarbons	Water	Nuclear	Wind	Solar	Biomass	Balance*
938	1166	1169	1387	420	398	51	-742
928	1160	1130	1390	413	419	50	-754
907	1152	1097	1389	413	426	50	-702
904	1133	1025	1390	415	443	50	-633
930	1152	1165	1391	404	453	49	-815
933	1159	1175	1390	396	479	48	-893
929	1149	1169	1392	391	475	48	-939
931	1154	1173	1391	400	485	51	-506
928	1153	1188	1393	403	509	49	-921
917	1146	1138	1391	421	515	50	-900
930	1159	1215	1394	434	528	49	-1055
935	1155	1191	1391	445	545	49	-994
931	1150	1188	1388	449	565	48	-1055
927	1149	1187	1391	485	553	48	-1044
925	1146	1165	1392	503	561	46	-994
911	1138	1113	1391	498	561	48	-958
907	1117	1107	1389	507	558	49	-976
918	1125	1177	1393	510	547	49	-1009
918	1129	1186	1388	497	541	49	-945
922	1118	1182	1394	496	529	49	-899
912	1115	1154	1393	502	531	48	-862
900	1102	1095	1391	527	522	47	-831
881	1109	1104	1390	547	507	47	-864
903	1121	1180	1390	551	496	47	-925
903	1126	1186	1391	543	499	48	-947
888	1111	1136	1389	565	492	48	-873
878	1102	1099	1393	580	464	46	-763
884	1106	1122	1394	584	453	47	-861
870	1111	1149	1393	577	429	47	-776
899	1118	1183	1390	600	402	48	-836
906	1127	1195	1388	603	394	48	-751
902	1117	1189	1393	641	359	48	-779
902	1122	1199	1392	709	328	49	-784
897	1116	1223	1389	749	304	49	-864
925	1129	1208	1391	742	293	49	-766
916	1127	1189	1390	772	272	48	-732
921	1121	1181	1391	797	256	47	-576
927	1131	1209	1394	831	228	48	-621
927	1138	1219	1393	846	189	48	-573
925	1146	1219	1391	871	171	47	-583
921	1147	1198	1391	923	141	48	-551
894	1117	1078	1389	945	117	47	-257

Coal	Hydrocarbons	Water	Nuclear	Wind	Solar	Biomass	Balance*
895	1120	1058	1394	938	96	48	-270
917	1140	1160	1390	956	74	47	-322
931	1149	1186	1392	955	46	47	-255
937	1150	1190	1392	950	29	46	-188
926	1139	1243	1389	946	22	47	-274

Source: Transelectrica (2023).
*Balance is the difference between consumption and production.

To better understand the selected data, we generated Figure 4 to visually represent each source.

Figure 4: The production of electricity in Romania by source, in Megawatts



Source: Transelectrica (2023).

Figure 4 represents the energy production from various sources over the day of 15th October 2003, during the day. The nuclear source was the most stable energy production, remaining relatively constant over the analysed time. It has the highest average production (1390 MW) and a very low standard deviation (3 MW), indicating a very stable and consistent energy production (Table 3). On the 15th of October 2023, the nuclear source accounted for 25% of the total production, followed by water (21%), and hydrocarbons (20%). Wind energy represented only 11% of the total production, while solar just 6% and biomass 1%.

Table 3: Descriptive statistics

Descriptive statistics	*Coal*	*Hydrocarbons*	*Water*	*Nuclear*	*Wind*	*Solar*	*Biomass*
Mean	908	1134	1156	1390	626	323	49
Standard Deviation	34	16	42	3	181	187	1
Minimum	781	1102	1025	1383	391	4	46
Maximum	943	1173	1243	1396	956	565	52
Sum	59023	73709	75126	90378	40688	21010	3160
Count	65	65	65	65	65	65	65

Source: Author`s calculation.

Hydrocarbons and hydropower show a bit more variation in energy production. Hydrocarbons seem to decrease slightly, while water has some fluctuations but is generally stable.
Wind and Solar show the most variation and instability in energy production. The energy production from these sources is lower than the others, and their outputs fluctuate more frequently and with greater intensity.

Considering stability, coal and nuclear sources are the most consistent. Regarding variability or fluctuation, wind and solar affect total energy production more due to their less predictable energy outputs. Regarding environmental impacts, hydrocarbons would have a considerable effect due to emissions, while wind and solar would have less environmental impact.

To improve the variability of the energy supply, it is important to address the unpredictability of wind and solar sources through energy storage solutions or better grid management.

4 Conclusion

Nuclear energy is a significant component of the national energy mix due to its stability and low carbon footprint.

Given Romania's existing nuclear facilities and domestic uranium resources, nuclear power could be a reliable baseline energy source, reducing dependency on energy imports, considering the variability in production from renewable sources such as wind and solar, which still need to provide consistent outputs.

However, the reliance on nuclear energy has its challenges.

Since the internal uranium production in the European Union is insufficient to meet the demand, the member states should diversify their uranium supply in a very competitive market affected by instability and conflicts in some of the significant uranium-producing countries or produce it internally, given the identified and recoverable resources in the member states.

Even though nuclear power is considered green, there are still challenges regarding the used fuel and the high costs of developing new nuclear power capacities that need to be addressed by the EU when setting new atomic capacities.

Considering the pros and cons, nuclear energy can be a significant buffer in the transition towards the green that could be aligned with the Union`s goal of reaching open strategic autonomy and environmental sustainability.

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