European Energy Transition: A Comparative Analysis of Renewable Energy, Electricity Consumption, Emissions, and Energy Dependence in Romania and the European Union

Iavorschi Eugen
Faculty of Electrical Engineering and Computer Science, Department of Electrical Engineering
"Stefan cel Mare" University of Suceava
Suceava, Romania
eugen.iavorschi@student.usv.ro

Milici Dan Laurențiu
Faculty of Electrical Engineering and Computer Science, Department of Electrical Engineering
"Stefan cel Mare" University of Suceava
Suceava, Romania
dam@usm.ro

***Abstract*—Against the backdrop of accelerating climate change, growing energy demand, and the need to reduce dependence on energy imports, assessing the effectiveness of the energy transition has become a major challenge for European energy policies. Although renewable energy sources have expanded rapidly across Europe, uncertainties remain regarding their impact on energy consumption, greenhouse gas emissions, and energy security. In this context, the present study examines the relationships between renewable electricity generation, electricity consumption, energy import dependency, and environmental performance in the European Union (EU), with a particular focus on Romania. The research employs the most recent European energy and environmental indicators related to renewable energy generation, electricity consumption, external energy dependency, greenhouse gas emissions, and air pollution. The methodology is based on a comparative analysis between Romania and the EU average, using graphical representations and statistical analyses of key indicators. The results highlight a continuous increase in the share of renewable energy in electricity generation, accompanied by a gradual reduction in external energy dependency. However, the expansion of renewable energy sources has not resulted in a proportional decline in greenhouse gas emissions and air pollution levels. Furthermore, electricity consumption remains strongly influenced by economic activity, seasonal factors, and climatic conditions. The study also emphasizes the growing importance of decentralized energy generation and prosumer participation in the development of future energy systems. This research contributes to a better understanding of the interactions between renewable energy development, energy security, electricity demand, and environmental sustainability, providing relevant insights for policymakers involved in the European energy transition.**

Keywords— renewable energy, energy efficiency, solar energy, electricity storage systems, european energy sector, climate neutrality, greenhouse gas emissions.

I. INTRODUCTION

The growth of the global population and the intensification of urbanization processes have led to a significant increase in worldwide energy demand [1]. In this context, the development of concepts associated with energy sustainability, such as renewable energy, green energy, and sustainable energy systems, has become essential for addressing the challenges generated by continuously increasing energy consumption. These approaches aim to reduce dependence on non-renewable resources and to mitigate the economic and environmental impacts associated with the use of fossil fuels [2]. At the same time, the promotion of low-emission energy sources contributes to the reduction of carbon emissions and greenhouse gases, generating positive effects on environmental protection and public health [3].

The EU has adopted ambitious strategic objectives regarding the reduction of greenhouse gas emissions, targeting the achievement of climate neutrality by 2050. In order to accomplish this objective, multiple legislative initiatives and energy policies have been implemented, including the latest revision of the Energy Efficiency Directive (EED) EU/2023/1791 [4] and the Renewable Energy Directive (RED III) EU/2023/2413 [5]. This regulatory framework supports the development of Renewable Energy Communities (REC), collaborative structures that facilitate cooperation between consumers and producers for the local generation, use, and distribution of renewable energy. Through these measures, citizens are actively integrated into the energy and climate transition process, acquiring a central role in the management and operation of energy communities.

To ensure continued progress toward achieving the established energy and climate objectives, the European Commission is developing a new strategic framework dedicated to renewable energy development for the next decade, scheduled for adoption by the end of 2026. Achieving these objectives requires sustained and coordinated involvement from EU Member States. However, differences related to energy resource availability, geographical location, as well as historical and geopolitical contexts generate distinct approaches regarding energy security and national energy policy priorities [6].

At the same time, the Russia-Ukraine conflict has accelerated the process of redefining European energy strategies, leading to the intensification of measures aimed at climate neutrality and strengthening the energy transition [7]. In parallel, geopolitical tensions and conflicts in the Middle East have generated significant disruptions in global energy markets, increasing energy price volatility and risks associated with supply security [8]. Consequently, the use of renewable energy sources has expanded considerably, while the EU's dependence on energy imports from the Russian Federation and the Middle East has become a major issue not only in the energy sector, but also in the spheres of foreign policy and European security, highlighting the structural vulnerabilities associated with fossil fuel dependence [9].

XXX-X-XXXX-XXXX-X/XX/$XX.00 ©20XX IEEE

An increasing number of studies emphasize the need to differentiate between types of energy resources, giving particular attention to renewable energy sources due to their contribution to sustainable development and the achievement of climate objectives [10]. Research findings indicate that renewable electricity generation can support long-term economic growth, although short-term effects remain influenced by the level of energy infrastructure development and the efficiency of the institutional framework [11]. The expansion of renewable energy use represents a central component of the decarbonization process of fossil fuel-dependent energy systems. The integration of low-emission energy technologies into the energy mix contributes to reducing carbon dioxide (CO_2) emissions, lowering the carbon footprint associated with economic activities, and limiting greenhouse gas (GHG) emissions, which are considered major drivers of anthropogenic climate change [12].

II. Dynamics of the European Energy System and Energy Dependence

A. Energy Imports in EU

Energy represents an essential factor for economic development and social progress, playing a decisive role in the operation of production, distribution, and consumption infrastructures across nearly all sectors of the economy, including the residential sector, transportation, and industrial activities [13]. Over recent decades, meeting energy demand has relied predominantly on the exploitation of fossil fuels, leading to an intensification of environmental impacts through increasing pollutant and greenhouse gas emissions [14]. Although these resources have been widely utilized due to their energy efficiency and technological maturity, their environmental and climatic impacts highlight the unsustainable nature of the current energy model in the long term [15].

Recent transformations of energy systems have become a central factor in shaping global economic, environmental, and security challenges [16]. In this context, energy holds a strategic role in the development of EU foreign and security policies. Despite the progress achieved in expanding renewable energy sources, Member States continue to exhibit a high level of dependence on energy imports, with a significant share of energy consumption being covered by resources originating from outside the EU [8].

Statistical data for 2024 regarding available primary energy, presented in Figure 1, indicate that the EU covered approximately 43% of its energy demand through domestic production, while the remaining 57% was supplied through energy imports.

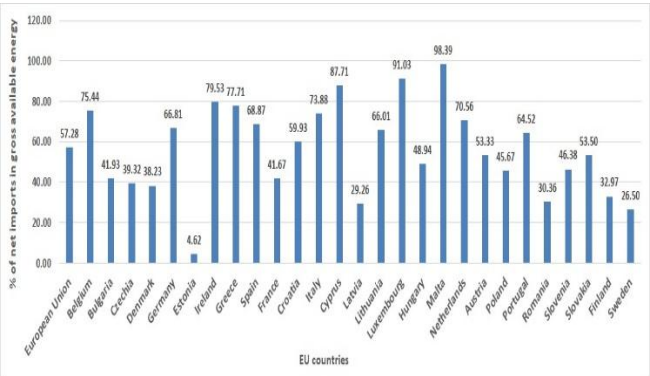

Fig. 1. Energy imports dependency rate-EU countries (% of net imports in gross available energy, based on terajoules) [17]

The energy import dependency indicator reflects the extent to which an economy relies on external energy resources to satisfy domestic consumption, being calculated as the ratio between net imports and gross inland energy consumption. At the EU level, the energy import dependency rate reached 57% in 2024, indicating that more than half of the EU's energy demand was covered through net imports. Significant differences can also be observed among Member States, with the highest dependency levels recorded in Malta (98%), Luxembourg (91%), and Cyprus (88%), while Estonia reported one of the lowest values, at approximately 5%.

The data presented in Figure 2 highlight the persistence of a high level of EU dependence on energy imports throughout the analyzed period.

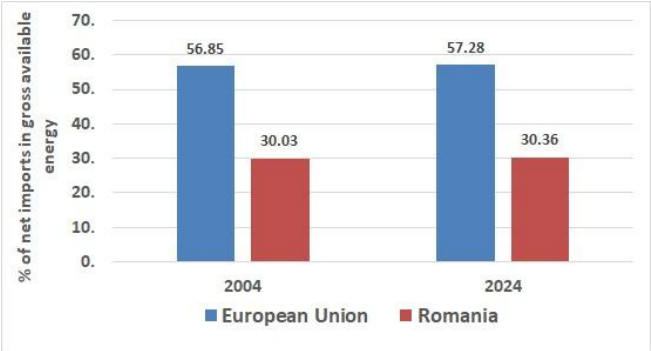

Fig. 2. Energy imports dependency rate-EU&Romania (% of net imports in gross available energy, based on terajoules) [17]

The share of net imports in gross available energy within the EU increased slightly between 2004 and 2024, indicating the persistence of a significant structural dependence on external energy resources despite European policies aimed at promoting the energy transition, diversifying energy supply sources, and expanding renewable energy generation capacities. The high level of energy import dependency reflects the structural characteristics of European energy consumption, driven by substantial demand from the industrial, transport, and residential sectors, as well as by the gradual decline of conventional energy resources available within the EU. In this context, imports of natural gas, crude oil, and petroleum products continue to play a crucial role in supporting the functioning of the European economy. The persistence of similar dependency levels at the two points in time analyzed suggests that the expansion of renewable energy sources and the implementation of energy efficiency measures have not yet been sufficient to substantially reduce the EU's reliance on external energy supplies.

Compared with the European average, Romania exhibits a considerably lower level of external energy dependency, with values remaining relatively stable at approximately 30% in both 2004 and 2024. This situation reflects the existence of a diversified energy mix and the availability of significant domestic energy resources, including natural gas, hydropower, and nuclear energy, which contribute to limiting the need for energy imports. Furthermore, Romania's position below the EU average indicates a relatively higher degree of energy security and lower vulnerability to fluctuations in international energy markets.

The stability of this indicator in Romania can be attributed both to the maintenance of domestic energy production capacities and to the gradual development of renewable energy sources. Nevertheless, the absence of a significant reduction in energy dependency over the last two decades suggests that the energy transition process has not yet resulted

in a substantial decrease in the need for external energy resources, either at the European or the national level.

In the context of the accelerating European energy transition and the need to reduce dependence on external energy imports, Romania has undertaken important steps toward strengthening energy security and diversifying domestic energy sources. A major strategic initiative is the development of the Neptun Deep project, the largest natural gas extraction project and the first deep-water offshore development in Romania, located in the Black Sea approximately 170 km from the Romanian coastline. Situated within Romania's exclusive economic zone and covering an area of approximately 7,500 km², the Neptun Deep perimeter is estimated to contain around 100 billion cubic meters of natural gas, according to data provided by the OMV Petrom-Romgaz partnership. Natural gas production is scheduled to commence in the first half of 2027, and the estimated production capacity could exceed Romania's current annual natural gas output by approximately ten times [18]. The implementation of this project has the potential to significantly reduce Romania's external energy dependency and contribute to strengthening both regional and European energy security.

At the same time, Romania is pursuing strategic investments in the nuclear energy sector through the deployment of Small Modular Reactors (SMR), which are regarded as an innovative technology for the generation of clean and reliable energy. The SMR project, developed in partnership with NuScale technology, will be located in Doicești, Dâmbovița County, on the site of a former coal-fired power plant, thereby supporting the decarbonization process and the repurposing of conventional energy infrastructure. Small Modular Reactors are advanced nuclear reactors with a generating capacity of up to 300 MWe per reactor, while each NuScale module has an individual capacity of 77 MWe. The planned Doicești power plant will consist of six modules, reaching a total installed capacity of 462 MWe [19].

The development of SMR technology is considered an important solution for replacing coal-fired power plants that are being progressively phased out across the EU, while making use of existing energy infrastructure and Romania's extensive experience in the safe operation of nuclear power plants. Furthermore, the implementation of these strategic projects demonstrates Romania's commitment to strengthening energy independence, reducing CO_2 emissions, and accelerating the transition toward a sustainable, low-carbon energy system.

B. Energy Structure of EU and Romania

In 2024, approximately 66% of the total available energy in the EU was utilized as final energy consumption, mainly for the residential, industrial, and transport sectors. The remaining 34% was associated with losses resulting from electricity generation and distribution processes, the energy required for the operation of energy infrastructures, and non-energy uses such as asphalt and bitumen production.

The structure of final energy consumption in the EU was dominated by petroleum products, which accounted for approximately 37% of the total, followed by electricity (23%), natural gas and manufactured gases (20%), and the direct use of renewable energy sources, including biomass, solar thermal energy, geothermal energy, and biogas, representing around 12%. In addition, derived heat, such as district heating, contributed approximately 5%, while solid fuels accounted for about 2% of final energy consumption.

The effective share of renewable energy in total consumption exceeded the level of direct use, reaching approximately 25%, due to the inclusion of electricity generated from renewable sources such as hydropower, wind energy, and solar photovoltaic energy.

The data presented in Figure 3 highlight significant differences between the structure of final energy consumption in the EU and Romania in 2024.

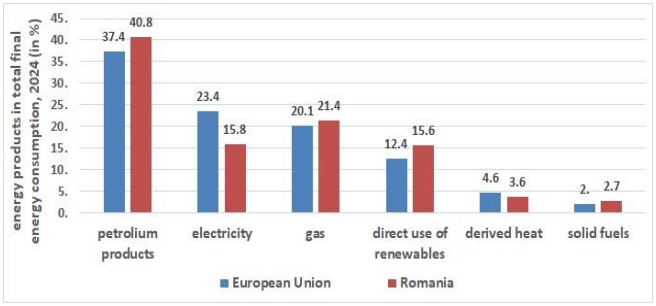

Fig. 3. Energy products in total final energy consumption, 2024 (in %) [17]

Petroleum products represent the primary energy source in both cases; however, their share is higher in Romania (40.8%) compared to the EU average (37.4%), indicating a greater dependence on liquid fuels. The EU records a higher share of electricity consumption (23.4%) compared to Romania (15.8%), a difference associated with the varying degree of economic electrification. In contrast, natural gas contributes similarly in both energy structures, accounting for approximately 20-21% of total consumption.

The direct use of renewable energy sources is higher in Romania (15.6%) than at the EU level (12.4%), highlighting their more significant role in national final energy consumption. In addition, solid fuels account for a slightly higher share in Romania, while derived heat has a limited contribution in both cases. Romania maintains a greater dependence on conventional fuels but utilizes direct renewable energy sources to a larger extent compared to the EU average.

In 2024, electricity accounted for approximately 23% of final energy consumption within the EU and was generated from a diversified energy mix. The largest contribution to electricity production originated from renewable energy sources, which provided approximately 48% of total generation, followed by fossil fuels with a share of around 28%, and nuclear energy, which accounted for approximately 23% of production.

Among renewable sources, wind energy made the largest contribution to electricity generation, representing approximately 17% of the total, followed by hydropower (13%), solar photovoltaic energy (11%), and biofuels, which contributed nearly 6%.

The data analyzed in Figure 4 indicate that European electricity production is supported by a diversified energy mix, in which fossil fuels hold the largest share (28.2%), followed by nuclear energy (23.3%) and renewable sources, particularly wind energy (17.5%), hydropower (13.2%), and solar energy (11%).

In Romania, fossil fuels represent the primary source of electricity production, accounting for 33.4%, above the European average, which indicates a higher dependence on conventional resources. At the same time, hydropower has a significantly larger contribution in Romania (26.7%) compared to the EU level (13.2%), reflecting the important role of hydropower resources in the national energy mix.

Wind and solar energy record lower shares in Romania than at the European level, suggesting a lower degree of development of these technologies. Overall, Romania relies to a greater extent on fossil fuels and hydropower, while the EU presents a more diversified energy mix from the perspective of renewable energy sources.

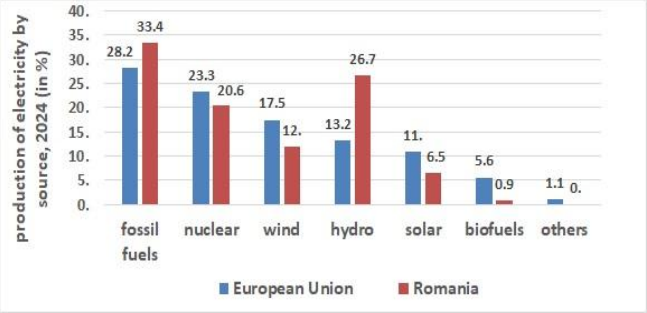

Fig. 4. Production of electricity by source, 2024 (in %) [17]

III. Energy Transition and Its Implications for Energy Consumption and Emissions

A. *Electricity Production and Consumption in EU and Romania*

The data presented in Figure 5 highlight the evolution of the share of renewable energy in total net electricity production in Romania and the EU throughout 2025.

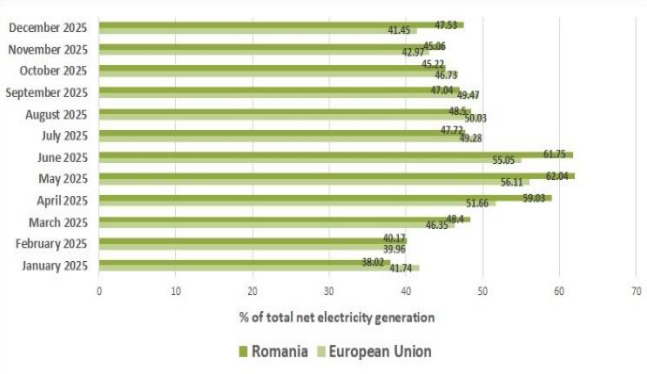

Fig. 5. Renewable energy in net electricity generation, 2025 (% of total net electricity generation) [20]

At the European level, the values remain consistently higher than those recorded in Romania during most of the analyzed months, reflecting a higher degree of renewable energy integration within the European energy mix. During the first part of the year, both Romania and the EU recorded moderate values, followed by a significant increase during the spring and early summer months. The highest shares were observed in May and June 2025, when the EU exceeded the 60% threshold, while Romania reached values of approximately 56-62%. This evolution is associated with favorable conditions for hydropower production and electricity generation from wind and solar sources.

After the peak period, a gradual decline in the share of renewable energy can be observed during the second half of the year, both at the European and national levels. In the final months of 2025, the values decreased below 50%, with Romania recording levels of approximately 41-47%, while the European average remained slightly higher.

The analyzed data emphasize the seasonal nature of renewable energy production and confirm that the EU exhibits a higher level of renewable energy integration compared to Romania, although both energy systems display similar evolutionary trends throughout the year.

The developments presented in Figure 6 illustrate the evolution of electricity consumption in 2025, expressed as a percentage change compared to the same period of the previous year, for both the EU and Romania. The graph indicates significant fluctuations throughout the year at both the European and national levels, reflecting the influence of economic, climatic, and seasonal factors on electricity demand.

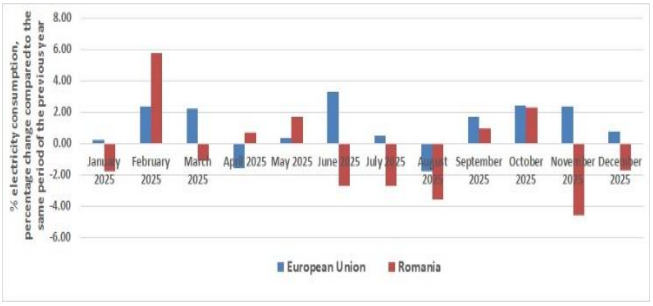

Fig. 6. Electricity consumption, percentage change compared to the same period of the previous year, 2025 (in %) [20]

At the EU level, electricity consumption recorded predominantly moderate positive variations, with higher values observed in February, June, October, and November, suggesting a relatively stable upward trend in energy demand. The decreases observed in August and April were limited in magnitude, indicating low consumption volatility at the European level.

In the case of Romania, the variations were more pronounced, highlighting a higher sensitivity of electricity consumption to economic and seasonal factors. The most significant increase was recorded in February 2025, when consumption exceeded 5% compared to the same period of the previous year. In contrast, the summer months and the first part of winter showed significant decreases in consumption, with more pronounced negative values than the EU average.

During the winter months, such as November, December, and January, the negative consumption variations may be explained by milder weather conditions compared to the same period of the previous year, reducing the energy demand for heating. In addition, the winter holiday period is frequently associated with reduced industrial and commercial activity, contributing to a decline in total electricity consumption.

The decreases in electricity consumption recorded during June, July, and August may also be explained by the increase in energy production from photovoltaic systems installed at residential and commercial levels. During the summer period, favorable weather conditions characterized by a high number of solar radiation hours allow prosumers to cover a significant share of their electricity demand from self-generated energy sources.

As a result, the amount of electricity drawn from public distribution networks decreases, which is reflected in a reduction in nationally reported electricity consumption. This phenomenon is amplified by the growing number of prosumers and the expansion of installed photovoltaic capacities in Romania in recent years.

Overall, the graph suggests that the evolution of electricity consumption in the EU remained relatively stable in 2025, while Romania exhibited more pronounced fluctuations, indicating a higher variability of electricity demand influenced by seasonal, climatic, and economic factors.

The results presented in Figure 7 indicate moderate fluctuations at the European level and significantly more pronounced variations in Romania, suggesting a higher sensitivity of national energy consumption to economic, climatic, and seasonal factors.

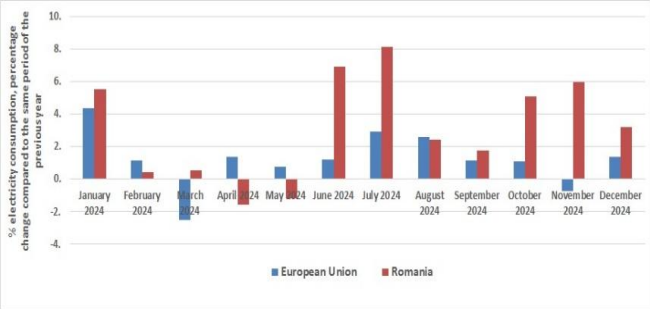

Fig. 7. Electricity consumption, percentage change compared to the same period of the previous year, 2024 (in %) [20]

La nivelul EU, Within the European economy, electricity consumption exhibited predominantly moderate positive variations throughout most of the analyzed months, with the highest values recorded in January, July, and August. In contrast, March and November showed slight decreases compared to the corresponding period of the previous year, suggesting a relatively stable evolution of energy demand at the European level.

In Romania, consumption fluctuations were considerably more pronounced, with significant increases observed in June and July compared to the previous year. These developments may be associated with high summer temperatures, the intensive use of air conditioning systems, and the expansion of economic and commercial activities. Furthermore, the elevated values recorded during the October-January period indicate an increase in energy consumption specific to the cold season, a phenomenon that was more pronounced in 2024.

Figure 7, corresponding to the year 2024, highlights significant increases in electricity consumption in Romania during the summer months, particularly in June and July, when variations exceeded 6-8% compared to the same period of the previous year. These developments may be associated with high temperatures and the intensive use of air conditioning systems. In contrast, Figure 6 shows that in 2025 Romania recorded decreases in electricity consumption during the summer months, especially in June, July, and August. This evolution suggests the increasing influence of distributed renewable energy generation, particularly through photovoltaic systems installed by prosumers, which reduce the amount of electricity drawn from the public grid during periods with high solar radiation. During the cold season, electricity consumption in Romania is significantly influenced by climatic conditions and fluctuations in low temperatures.

At the European level, both graphs indicate a more stable evolution of electricity consumption compared to Romania, with moderate percentage variations throughout the two analyzed years. However, Figure 6 reveals a more pronounced downward trend in consumption during certain months of 2025 compared to 2024, an evolution that may reflect both the energy efficiency measures implemented at the European level and the increasing adoption of renewable energy sources and self-consumption practices.

B. Emissions and Pollution in the Context of the Energy Transition

The statistical data presented in Figure 8 highlight the evolution of emissions expressed in tonnes per capita for the EU and Romania during the 2020-2025 period. At the EU level, the values remained relatively stable throughout the analyzed interval, with moderate fluctuations between approximately 1.77 and 2.10 tonnes per capita. Following the higher levels recorded during 2020-2021, a slight downward trend can be observed in the subsequent years; however, no significant long-term changes are evident.

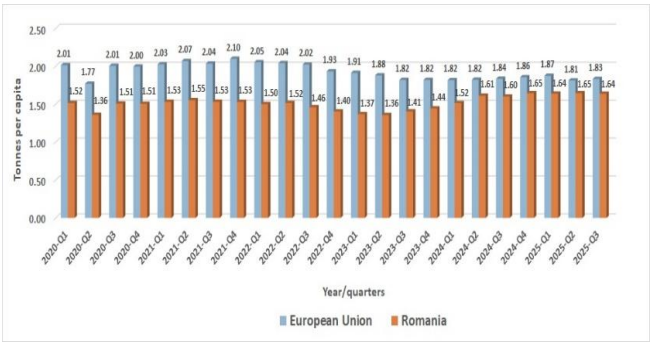

Fig. 8. Tonnes per capita 2020-2025, greenhouse gases (CO2, N2O in CO2 equivalent, CH4 in CO2 equivalent, HFC in CO2 equivalent, PFC in CO2 equivalent, SF6 in CO2 equivalent, NF3 in CO2 equivalent) [20]

In the case of Romania, greenhouse gas emissions per capita remained consistently below the EU average throughout the analyzed period, ranging between approximately 1.36 and 1.69 tonnes per capita. This relatively low level may be attributed to the structure of the national energy mix, characterized by the significant contribution of hydropower and nuclear energy, as well as by a lower per capita energy consumption compared to the European average. Nevertheless, a gradual upward trend in emissions can be observed beginning in 2023, with values recorded during 2024-2025 exceeding those reported in the 2020-2022 period. This evolution suggests an intensification of economic activity and energy demand, which has partially offset the environmental benefits associated with the expansion of renewable energy sources.

The comparative analysis reveals that, at both the European and national levels, emission reductions have not progressed at the same pace as the expansion of renewable energy generation capacity. Although the share of renewable energy in electricity production has increased significantly in recent years, greenhouse gas emissions have remained relatively stable, exhibiting only moderate semester-to-semester fluctuations. This situation highlights that while the deployment of renewable energy sources contributes to the diversification of the energy mix and the reduction of dependence on fossil fuels, its impact on total emissions is simultaneously influenced by growing energy consumption, economic activity, and the accelerated electrification of the economy.

Furthermore, the results suggest that the positive effects of the energy transition on emission reductions are likely to materialize over a longer time horizon than that required for the expansion of renewable generation capacities. Consequently, achieving European climate objectives depends not only on increasing the share of renewable energy but also on implementing complementary measures aimed at improving energy efficiency, reducing fossil fuel consumption, and decarbonizing energy-intensive sectors,

particularly industry, transport, and heating systems. Therefore, the development of renewable energy sources represents a necessary condition for emission reduction, but not a sufficient one in the absence of broader structural transformations of the energy system and consumption patterns.

The data analyzed in Figure 9 highlight the evolution of average nitrogen dioxide (NO_2) concentrations during the 2024-2025 period for the EU average and the city of Bucharest.

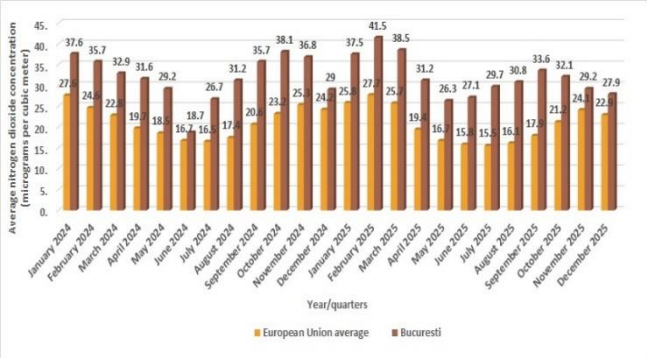

Fig. 9. Nitrogen dioxide concentrations in EU average and Bucuresti capital city, monthly averages, experimental statistics, (micrograms per cubic meter) in 2024-2025 [20]

Throughout the analyzed period, the values recorded in Bucharest remained consistently above the European average, reflecting a higher level of urban pollution associated with road traffic, industrial activities, and energy consumption.

In the European context, NO_2 concentrations exhibited moderate seasonal fluctuations, with higher values during the winter months and early spring and lower levels throughout the summer period. A similar pattern can also be observed in Bucharest; however, the amplitude of the variations is more pronounced, with concentrations frequently exceeding 30-40 $\mu g/m^3$ during the cold season.

The comparative analysis indicates that pollution levels did not experience a significant reduction during the analyzed period, remaining relatively constant at both the European and local levels. Despite the increasing share of renewable energy sources in electricity generation and the acceleration of the energy transition, the effects on reducing emissions and atmospheric pollution remain limited in the short term.

This evolution suggests that the expansion of renewable energy production has not automatically led to a decrease in greenhouse gas emissions and atmospheric pollutants, but has instead been accompanied by an increase in total available energy consumption. Consequently, the positive environmental impact of renewable energy depends not only on the expansion of production capacities, but also on reducing fossil fuel-based consumption, improving energy efficiency, and transforming high-emission sectors, particularly transportation and industry.

IV. Conclusions

• The study confirms the strategic role of renewable energy sources in supporting the energy transition process, strengthening energy security, and reducing external energy dependency within both the EU and Romania.

• Despite significant progress in renewable energy deployment, the EU continues to exhibit a high level of energy import dependency, highlighting the need for further investments in domestic renewable generation capacities and energy infrastructure modernization [21].

• Compared with the EU average, Romania benefits from lower external energy dependency due to the availability of domestic energy resources and the important contribution of hydropower to the national energy mix.

• Fossil fuels continue to play a significant role in electricity generation and final energy consumption, while the EU demonstrates a more diversified renewable energy structure, particularly through wind and solar energy integration.

• The increase in renewable electricity generation during the analyzed period was not accompanied by a proportional reduction in greenhouse gas emissions and atmospheric pollution, indicating that growing energy demand and economic activity continue to offset part of the environmental benefits of renewable energy expansion.

• Electricity consumption remains strongly influenced by economic, seasonal, and climatic factors, while the growing number of prosumers and distributed photovoltaic systems contributes to reducing electricity demand from public grids during periods of high solar irradiation.

• REC and prosumer-based models are expected to play an increasingly important role in enhancing energy independence, promoting decentralized energy production, and supporting the transition toward a low-carbon economy.

• Important research gaps remain regarding the interactions between renewable energy deployment, energy consumption, prosumer development, and greenhouse gas emission reductions, particularly in the context of distributed energy systems.

• Future research should focus on integrated assessment models linking renewable energy production, energy consumption, energy efficiency, and emissions, as well as on evaluating the role of emerging technologies such as energy storage, green hydrogen, and digitalized energy management systems in accelerating the energy transition.

References

[1] M. G. M. Abdolrasol, M. A. Hannan, S. M. S. Hussain, T. S. Ustun, M. R. Sarker, and P. J. Ker, "Energy Management Scheduling for Microgrids in the Virtual Power Plant System Using Artificial Neural Networks," Energies, vol. 14, no. 20, p. 6507, Oct. 2021, doi: 10.3390/en14206507.

[2] Z. Farooq, A. Rahman, S. M. S. Hussain, and T. S. Ustun, "Power Generation Control of Renewable Energy Based Hybrid Deregulated Power System," Energies, vol. 15, no. 2, p. 517, Jan. 2022, doi: 10.3390/en15020517.

[3] E. Iavorschi, L. D. Milici, I. Taran, and Z. Israeli, "Sustainability of the European Energy System: The Evolution of the Energy Transition, Renewable Energy, and Energy Conservation," Sustainability, vol. 18, no. 8, p. 4046, Apr. 2026, doi: 10.3390/su18084046.

[4] European Commission, "Energy Efficiency Directive EU/2023/1791" Available online: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en?utm_source=chatgpt.com, (accessed on accessed on 5 May 2026).

[5] European Commission, "Renewable Energy Directive EU/2023/2413." Available online: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en?utm_source=chatgpt.com, (accessed on accessed on 6 May 2026).

[6] A. Javed, M. Shabir, F. Rao, and M. S. Uddin, "Effect of green technological innovation and financial development on green energy transition in N-11 countries: Evidence from the novel Method of Moments Quantile Regression," Renew. Energy, vol. 242, p. 122435, Apr. 2025, doi: 10.1016/j.renene.2025.122435.

[7] Y. Li, M. W. Hanif, M. Wen, A. K. Khoso, and W. M. Khoso, "Geopolitical risks and the global renewable energy transition:

Implications for energy security and economic resilience," Energy Reports, vol. 15, p. 108875, Jun. 2026, doi: 10.1016/j.egyr.2025.12.012.

[8] G. Dincă, I.-C. Netcu, and C. Ungureanu, "Renewable Energy Transitions in the EU: A Comparative Panel Data Perspective," Energies, vol. 18, no. 18, p. 4836, Sep. 2025, doi: 10.3390/en18184836.

[9] J.-L. Wang, J.-J. Fan, Y. Liu, H.-T. Guo, and M.-Y. Guo, "Geopolitical turbulence in the Middle East: Reshaping global energy landscape?," Pet. Sci., Mar. 2026, doi: 10.1016/j.petsci.2026.03.050.

[10] A. Raza, M. Alharthi, M. Shakeel, and M. I. Khan, "Nexus between CO2 emissions, economic growth, and energy consumption with special reference to BRICS: A panel data approach," Energy Nexus, vol. 20, p. 100556, Dec. 2025, doi: 10.1016/j.nexus.2025.100556.

[11] M. F. Sharaf, A. M. Shahen, and R. E.-S. A.-G. Issa, "Rethinking Growth in the Gulf: The Role of Renewable Energy, Electricity Use, and Economic Openness in Oil-Rich Economies," Sustainability, vol. 17, no. 19, p. 8949, Oct. 2025, doi: 10.3390/su17198949.

[12] G. De Carne, S. M. Maroufi, H. Beiranvand, V. De Angelis, S. D'Arco, V. Gevorgian, S. Waczowicz, B. Mather, M. Liserre, V. Hagenmeyer, "The role of energy storage systems for a secure energy supply: A comprehensive review of system needs and technology solutions," *Electr. Power Syst. Res.*, vol. 236, p. 110963, Nov. 2024, doi: 10.1016/j.epsr.2024.110963.

[13] X. Y. Hu and L. Smith, "From fossil fuels to green growth: rethinking new models through digital innovation, labor force and sustainable investment," Front. Environ. Sci., vol. 13, Oct. 2025, doi: 10.3389/fenvs.2025.1614744.

[14] M. Sohaib, A. Majeed, J. Liu, and J. Oláh, "The role of renewable energy in mitigating carbon emissions: Insights from China's energy consumption patterns," Energy Strateg. Rev., vol. 61, p. 101860, Sep. 2025, doi: 10.1016/j.esr.2025.101860.

[15] P. Atănăsoae, R. D. Pentiuc, and L. D. Milici, "High-Efficiency Cogeneration: A Viable Solution for the Decarbonization of Cities with District Heating Systems," Energies, vol. 18, no. 7, p. 1581, Mar. 2025, doi: 10.3390/en18071581.

[16] M. de la E. Mata Pérez, D. Scholten, and K. Smith Stegen, "The multi-speed energy transition in Europe: Opportunities and challenges for EU energy security," Energy Strateg. Rev., vol. 26, p. 100415, Nov. 2019, doi: 10.1016/j.esr.2019.100415.

[17] Eurostat, "Energy in Europe - 2026 edition." Available online: https://ec.europa.eu/eurostat/web/interactive-publications/energy-2026, (accessed on accessed on 10 May 2026).

[18] Free Europe Romania, " Countdown to Neptun Deep: Black Sea gas to enter the market in 2027, but the Romanian government has yet to clarify its intended use." Available online: https://romania.europalibera.org/a/tara-in-service-neptun-deep-gaze-marea-neagra/33695971.html, (accessed on accessed on 08 June 2026).

[19] Nuclearelectrica, " The SMR Project (Small Modular Reactor)." Available online: https://nuclearelectrica.ro/snn/proiecte-de-investitii/proiect-smr/, (accessed on accessed on 08 June 2026).

[20] Eurostat, "European Statistical Monitor." Available online: https://ec.europa.eu/eurostat/cache/dashboard/european-statistical-monitor/#/, (accessed on accessed on 13 May 2026).

[21] E. Iavorschi, L. D. Milici, V. C. Ifrim, C. Ungureanu, and C. Bejenar, "A Literature Review on the European Legislative Framework for Energy Efficiency, Nearly Zero-Energy Buildings (nZEB), and the Promotion of Renewable Electricity Generation," Energies, vol. 18, no. 6, p. 1436, Mar. 2025, doi: 10.3390/en18061436.