Romania's Transition to Renewable Energy: Challenges, Opportunities and European Perspectives

Ghenadie Ciobanu[1], Mădălina Moncea[2], Maria Roxana Cosma[3] and Cătălin Ghinăraru[4]
[1) 4)] *National Scientific Research Institute for Labor and Social Protection, Bucharest, Romania.*
[2)] *Bucharest University of Economic Studies, Bucharest, Romania.*
[3)] *Technical University of Construction Bucharest, Bucharest, Romania.*
E-mail: gciobanu019@gmail.com; E-mail: monceamadalina17@stud.ase.ro
E-mail: roxana.cosma@utcb.ro; E-mail: ghinararu@incsmps.ro

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Abstract

The importance of renewable energies is undeniable today in the current situation of the energy crisis in Europe. The article presents Romania's transition towards renewable energy sources, analyzing the challenges, opportunities and European perspectives associated with this process. The main purpose of the research is to investigate the current situation of renewable sources in Romania and to propose strategies and models for an efficient energy transformation. The importance of energy storage in this process is also investigated and ways to optimize this aspect are proposed. The main results and discussions focus on the interdisciplinary approach to the field of renewable energies, highlighting the importance of collaboration between different scientific fields and industries. Also, a more complex managerial model is developed, specifically adapted to the needs and resources in Romania, and the concept of entropy is approached in the context of the transition to renewable energies. An innovative aspect of the research is the integration of blockchain technology in the development of the renewable energy industry, providing solutions for the efficient monitoring and management of energy production and consumption. These results have significant practical implications, contributing to the acceleration of the transition process towards renewable energy sources in Romania and to the optimization of their use. he research also provides a solid basis for developing energy policy and strategies at national and European level.

Keywords

Renewable Energy, sustainable development, interdisciplinary, entropic approach, blockchain technology.

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Introduction

Romania is currently at a critical moment in the field of sustainable development management, in the energy transition towards renewable sources becoming a focal point for discussion and action. Against the background of global energy crises and environmental imperatives, Romania faces a multitude of challenges and opportunities in search of a greener future. This introduction sets the stage by outlining the key themes and research findings explored in this study. The topic of energy is in the center of attention of researches and studies in the field. We would like to mention the authors Popescu at al. (2022) who identified the main steps taken by the EU in the energy transition process, underlining the importance of public authorities in modernizing the behavior of companies and consumers, the complexity of the energy phenomenon and the importance in creating the economy with low carbon emissions. The authors Voicu-Dorobanțu at al. (2021) presented the diagnostic methodology, case study of Romania, based on data at the national and local level, and presented the specific factors, regional trends related to the energy mix, energy production capacity, energy efficiency , pollution and the problem of employment. Bulmez et al. (2024) argue that: "policies are vital to mitigating the negative effects of climate change. The energy crisis in the EU affected by the war in Ukraine accelerates the need to promote energy policies. The EU has revised its energy strategy, and

priority is placed on climate change policies, because all measures involved reducing energy consumption and increasing renewable sources, contributing to the reduction of greenhouse gas emissions." The authors Buzogány, A., & Davidescu, S. (2022). The authors focused on the examination of the governance structures of the energy policy in Romania and reflected an overview of the characteristics of the Romanian energy system. They presented the historical perspective, the evolution of privatization, Europeanization, energy transition before the background of physical, political and societal structures. The authors mention that Romania is the largest producer of hydrocarbons in Central and Eastern Europe and has an evenly distributed energy mix (coal, gas, hydropower, indigenous nuclear energy, a great potential for renewable sources (solar and wind energy). However Romania's energy sector faces underinvestment in weak infrastructures, legacy of low energy prices, which block investments, various bureaucratic aspects, therefore the development of renewable energy sources is contested due to the increase in energy prices.

From the growing adoption of renewable energy among household consumers to policy interventions aimed at accelerating the transition, Romania's energy sector landscape is examined from several angles. In addition, insights from European Union directives, global energy trends and interdisciplinary research provide a holistic understanding of Romania's position in the broader context of sustainable development. By synthesizing diverse perspectives and empirical evidence, this introduction lays the groundwork for a nuanced exploration of Romania's renewable energy journey. Romania's energy landscape is undergoing a significant transformation, with an increasing focus on renewable energy sources (RES) to meet sustainability goals. This study explores Romania's renewable energy journey, examining the policy frameworks, objectives and technological innovations driving the transition. It emphasizes the importance of interdisciplinary collaboration and innovative approaches in achieving a greener and more resilient energy sector.

1. Review of the scientific literature

Considering Romania's confrontations with the challenges of sustainable development, the bibliographic study in the field of renewable energies is useful for studying and development opportunities.In the opinion of the authors (Ban et al., 2023) the challenges of sustainable development put in the foreground the energetic problems of the development of renewable energy sources, industrial and household consumers. The number of domestic consumers of energy from renewable sources in 2023 in Romania has reached over 63,000, but the process is slowing down. That research was conducted on a sample of 1098 valid responses. The author Filimon (2023) supports the slow energy transition towards renewable energy sources. EU companies can get help with the transition to producing energy from solar panels. Access to finance is the main obstacle. Absence of desalination systems, rainwater recovery systems, identified as natural resource conservation methods.

Lack of active online presence detailing the various activities of the companies. Lack of new technologies like applications for data reservation and live data visibility. The authors Moise et al. (2023) evaluate the villages in the mountain area of Sibiu County, Romania, as "smart" tourist villages, which represent that 78.2% of the locals use the Internet, own at least one smart device - 74%, and 60.16% of the energy used is renewable. The authors Cristea et al. (2022) claim: "as the technology behind solar photovoltaic systems has been significantly improved, along with the significant decrease in costs, grid-connected photovoltaic systems are becoming an important option to reach to a low-carbon energy transition. The high cost of electricity consumed at the Technical University of Cluj-Napoca was a good reason for the university to increase its energy efficiency by adopting and increasing energy consumption from renewable energy sources. The results indicated that the most viable distributed generation system is the one with a capacity of 100 kW, meeting approximately 23 percent of the university's electricity needs while reducing carbon dioxide emissions by approximately 460 tons. The authors Gaman et al. (2022) support the opinion of the necessity of the energy transition through the cooperation of the parties, of the promotion of decarbonization policies. The evaluation of the energy transition is proposed, perspective in the marginalized urban areas in Romania. and analyzed 37 local energy development strategies (electricity supply and heating), detected that communities in Romania showed limited interest in renewable energy, which may be related to the low level of awareness and education of residents from marginalized communities. The authors Tănasie et al. (2022) argue that Europe is in an energy crisis, exacerbated in large part by rising gas costs. Renewable energy is essential in this environment, to reduce Europe's dependence on imported energy; boosting renewables in Europe requires a "New Energy Pact", a coordinated effort across Europe to build more renewable energy capacity. We must mention that the purpose of this research is to examine the structure of renewable energy production in Romania between the years 2010 and 2020, and the employment of green (ecological) jobs produced by the renewable energy sector in Romania between 2010 and 2019. Markov chain application predicted that in 2025, employees in the hydropower industry will be in the largest proportion of the total average number of employees in the renewable energy production sector

in Romania (74.68%). Solar energy employees will be 14.31% of the average number of employees in the renewable energy production sector, biomass energy production employees will represent 5.8%, wind energy employees will be 5.2% of the average number of employees of the green energy sector. The authors Balugani et al., (2022) argue that Bio-based materials can help achieve a renewable circular economy, but their impact could be similar to that of non-renewable materials. In the case of biofuels, indirect land use change (ILUC) effects determine whether they can provide sustainability benefits compared to fossil fuels. ILUC modeling estimates have large uncertainties, which makes them difficult to include in a policy aimed at reducing environmental impact. The Renewable Energy Directive (RED) II reduced the uncertainties of ILUC estimation by shifting the focus from the environmental impact of ILUC to the risk of ILUC. Authors Mihai and Minea (2021) analyzed the contribution of the linear economy to the degradation of resources, environmental pollution in eastern Romania, the possible sources of environmental conflicts. The authors proposed sustainable and non-conflicting alternative routes, in connection with the circular economy, water conservation, clean energy transition, analysis of good practices, of local development paths in urban and rural environments. The authors Onete et al. (2023) argue that the new geopolitical realities have led the European Union to accelerate the transition to energy independence by 2030. The authors set out to present the benefits of the blockchain technology system, on the energy field, and how the alternative to reduce costs and massive amounts of electricity are even renewable sources. The authors Spunei et al. (2023) of the global energy crisis, the demand for electricity from renewable energy sources has been established as a priority. Compared to 2010, the installed capacity in power plants in Romania decreased due to the closure or conservation of some thermal power plants. This decrease was not significant because many renewable energy plants were put into operation.

The authors Rădulescu et al. (2022) emphasize Romania's transition to renewable energy as a response to the global energy crisis, emphasizing the prioritization of the source of electricity from renewable energy. The specific challenges and opportunities of this transition are discussed, integrating European perspectives to illustrate both the progress and the obstacles encountered by Romania in aligning with the EU's sustainability objectives. The authors Angheluta et al. (2019a) address the challenges of climate change and the importance of renewable resources within the European Union, highlighting how the latter represent an essential component in combating the negative effects of climate change. The paper highlights the vital role of renewable energy in reducing dependence on fossil fuels and reducing greenhouse gas emissions, in line with the EU's sustainability targets. The analysis provides a detailed insight into the progress and specific challenges facing Member States in adopting a cleaner and more sustainable energy mix, highlighting the urgent need for coordinated action and innovative investments to accelerate the transition to a green economy. The authors Diaconu et al. (2019) examine the development of renewable energy in the context of globalization, underlining the importance of a strategic approach for the effective integration of these sources into energy systems at a global level. They argue that innovative policies, advanced technologies, and sustainable financing are essential to promote the adoption of renewable energy in the face of contemporary energy and environmental challenges. Their analysis highlights how globalization can play a crucial role in accelerating the energy transition to more sustainable sources. The authors Angheluta et al. (2019b) analyze the progress of the European Union in achieving the energy targets from renewable sources, highlighting the efforts and strategies implemented to fulfill the sustainability commitments. Their study highlights the importance of effective policies and innovative investments in renewable technologies, showing that they are crucial to accelerating the energy transition and achieving greenhouse gas emission reduction targets.

Authors Apergis, N., Payne, J. E. (2010) analyzes the relationship between renewable energy consumption and economic growth for a group of twenty OECD countries in the period 1985-2005. The obtained results of the Granger causality indicated the bidirectional causality, which is between the consumption of renewable energy and economic growth both in the short term and in the long term. Author Charfeddine, L., & Kahia, M. (2019) analysis of the impact of renewable energies and the financing of CO2 projects; Investigating the impact of RE and FD on economic growth; The analysis using the PVAR (Panel Vector Autoregression) model, the impulse response function and the variance decomposition. The results show that renewable energy, financial development, have little explanatory power to explain the relationship between CO2 emissions and economic growth.

2. Research methodology

The research methodology for this study is designed to investigate and analyze the transition of renewable energy development in Romania, addressing aspects of the current situation of renewable sources, energy storage, managerial models, the interdisciplinary approach and the integration of blockchain technology.

The methodology includes the exhaustive review of the scientific literature on the renewable energy transition, data collection and analysis, on the installed capacity, production and development trends of different renewable energy sources in Romania, problems related to energy storage, within the transition to renewable energy. For the development of effective management, the interdisciplinary approach to the field of renewable energies, the collaboration between different scientific fields, industries involved in the transition to renewable energy in Romania with the development of a complex management model is welcome. Proposing the concept of the entropic approach in the context of the transition to renewable energy, identifying ways to reduce entropy in renewable energy systems. As well as in the activity of the economic and management system. A challenge is the integration of blockchain technology in the development of this branch, by identifying practical applications of blockchain technology in the effective monitoring and management of the production and consumption of renewable energy.

2.1. Evolution the renewable sources in the European Union countries

At the EU level, in 2022, the share of renewable energy sources in gross final consumption was 23.0%, decreased by 1.1 p.p. compared to the previous year 2021. And the consumption of renewable energy in absolute value increased by 1.4 million tons of oil equivalent (Mtoe) between 2021 and 2022, conditioned by the increase in solar energy production (+28%). Non-renewable energies decreased by (-2%), a situation caused by high gas prices, nuclear shutdowns, due to the increase in the relative share of renewable sources in total energy consumption. Sweden has the highest share of renewable energy, 66.0% of gross final energy consumption in 2022, based mainly on: hydrocarbons, wind, solid and liquid biofuels, heat pumps. In second place is Finland with a share of 47.9%, based on hydrocarbons, wind energy, solid biofuels. In third place comes Latvia with a share of 43.3%, largely dependent on hydrocarbons. In fourth place is Denmark with (41.6%) and Estonia with (38.5%) - they dominate wind renewables and solid biofuels. Portugal follows with (34.7%) based on solid biofuels, wind, hydro and heat pumps, Austria (33.8%), mainly uses hydrocarbons and solid biofuels.

Table no. 1. Share of energy from renewable sources (%)

	2013	2014	2016	2018	2020	2022
UE - 27	16,659	17,416	17,978	19,096	22,038	23,036
Belgium	7,671	8,038	8,744	9,472	13	13,759
Bulgaria	18,898	18,05	18,76	20,581	23,319	19,095
Czechia	13,927	15,074	14,926	15,139	17,303	18,195
Denmark	27,173	29,31	31,715	35,159	31,681	41,602
Germany	13,757	14,381	14,885	16,66	19,09	20,796
Estonia	25,356	26,13	29,232	29,97	30,069	38,472
Ireland	7,521	8,516	9,189	10,942	16,16	13,107
Greece	15,326	15,683	15,39	18,001	21,749	22,678
Spain	15,081	15,879	17,015	17,023	21,22	22,116
France	13,88	14,362	15,451	16,384	19,109	20,259
Croatia	28,04	27,817	28,266	28,047	31,023	27,924
Italy	16,741	17,082	17,415	17,796	20,359	19,131
Cyprus	8,428	9,144	9,833	13,873	16,879	19,429
Latvia	37,037	38,629	37,138	40,019	42,132	**43,316**
Lithuania	22,689	23,592	25,612	24,695	26,773	29,599
Luxembourg	3,494	4,471	5,364	8,942	11,699	14,356
Hungary	16,205	14,618	14,377	12,548	13,85	15,190
Malta	3,76	4,744	6,208	7,914	10,714	13,404
Netherlands	4,691	5,415	5,846	7,394	13,999	14,972
Austria	32,665	33,55	33,37	33,784	36,545	33,758
Poland	11,452	11,605	11,396	14,936	16,102	16,879
Portugal	25,699	29,508	30,864	30,203	33,982	34,677
Romania	23,886	24,845	25,032	23,875	24,478	24,140

Slovenia	23,16	22,459	21,975	21,378	25	25,002
Slovakia	10,133	11,713	12,029	11,896	17,345	17,501
Finland	36,63	38,633	38,943	41,185	43,939	**47,886**
Sweden	50,153	51,151	52,597	53,916	60,124	66,002

Source:Eurostat, 2023. Share of energy from renewable sources [nrg_ind_ren$defaultview]
https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ren/default/table?lang=en

Considering the European Environment Agency's estimates confirm that 22.5% of the energy consumed in the EU in 2022 is from sources, we would like to mention that the slight increase compared to 2021 is explained by the increase in solar energy. In order to reach the objective of 42.5% share of renewable energy sources for 2030, it is necessary to double the implementation rates of renewable sources from the last decade and transform the European energy system. The increase in renewable energy sources has various benefits for society. In 2023, changes were made to the Renewable Energy Directive (October 2023), one of the priorities is to increase the mandatory objective for 2030 from 32% to 42.5%, with the aim of reaching 45%. Therefore, the EU countries will contribute to the common objective, without introducing that objective into the legislation of each country. It is necessary to intensify efforts to comply with the new objective of the European Union for 2030, regarding the increase of the share of renewable energy sources in the final gross energy consumption of the EU by approximately 20 percentage points.

The analysis by energy sources highlights the high penetration of renewable sources in 2022, which were spent in the energy sector, with a weight of 40.7% of all electricity produced in the EU. In second place is the heating and cooling sector, with the share of renewable energy sources of 23.2%, and in transport, the share of renewable energy sources was 8.7%. The vast majority of renewable energy sources come from solid biomass, with implications for carbon stocks and biodiversity.

2.2. The current situation of renewable sources in Romania

Romania, as a country aligned to the "Energy Policy for Europe", developed the Energy Strategy for the period 2018-2030, in correlation with the energy objectives of the European Union reflected in the "European Strategy for sustainable, competitive and secure energy". Statistically, Romania's position is well presented in this paragraph, but from a statistical point of view, Romania is well presented, because a large part of this success is due to the consumption of hydro energy. We must mention that the production of renewable energy in Romania is significant, the country being ranked second in the region, after Poland, at a considerable distance from other European states.

The increase of 3.1% between 2000 and 2016 did not exceed the average established in Europe, but we can observe a 7.8% increase between 2015 and 2016, a moment that suggests the active involvement in the use of green energy in Romania in recent years. Due to the fact that the production of renewable energy in Romania is 6,550 ktoe, and the potential of 8,000 ktoe remains unexploited, with the creation of the possibility of exploitation in the future, the objective of the EU is to reduce domestic greenhouse gas emissions by at least 40% by the year 2030, compared to 1990, and the energy consumption from renewable sources should be 3256 % in 2030; interconnection of the electricity market at a level of 15% by 2030. To guarantee the achievement of the objectives, each member state was obliged to submit to the European Commission a Project of the Integrated National Plan in the field of Energy and Climate Change (PNIESC) for the period 2021-2030. In the PNESC Projects, the objectives and the national contributions for the achievement of the EU objectives regarding climate change are established. Regarding renewable energies, according to the recommendations of the European Commission, Romania will have to reach a share of at least 34%, the level was revised from the initially proposed share of 27.8% to a share of 30.7%.

2.3. Energy storage – for Romania's energy transformation

Supported by European funds and national co-financing, the development of the renewable energy sector in Romania is becoming more attractive for investors (national and international). As long as the desire and need for investment, together with the favorable regulatory framework, it leads the energy mix of the country in the direction of the development of the renewable energy sector, with net zero carbon dioxide emissions, and is a challenge in the development of the sustainable energy system. The recent evolution of Romania's electricity balance indicates the continuous reduction of net consumption, underlines the value of storing excess energy to mitigate waste. In addition to all these solutions, energy storage can reduce fluctuations, which are associated with special renewable energy installations, thus increasing grid stability, reducing the urgency of new grid infrastructures, or performing other necessary upgrades and transformations.

The development of energy storage in Romania is at the beginning, but the financing opportunities, presented in the National Recovery and Resilience Plan (PNRR) of Romania (Ministerul Investițiilor și Proiectelor Europene, 2023), the delivery of energy storage facilities and equipment is foreseen until the end of 2025, with a total installed capacity of at least 240 MW (or 480 MWh). The modernization fund until 2030 provides for the disbursement of EUR 13 billion by 2030, of which approximately EUR 10 billion is aimed at investments in green energy, it also presents provisions for the production of green hydrogen and its use in industrial appliances, its integration in the gas transmission network and energy storage potential. industriale, as well as its integration into the gas transport network and energy storage potential.

Romania has chosen to adopt a cautious approach regarding the level of ambition, taking into account the national particularities and the need for investments in SRE, both for the replacement of the capacities that reach the maximum duration of operation and for the new ones, in order to reach the targets assumed in the The National Integrated Plan in the field of Energy and Climate Change 2021-2030 (April 2020)-NIPECC, considering that Regulation (EU) 2018/1999 stipulates that in the future revisions of the NIPECC.

3. Results and discussion

3.1. The interdisciplinary approach to the field of renewable energies

The interdisciplinarity of renewable energies comprises: (1) Environmental science and biology: the development and use of renewable energies. In this direction, interdisciplinary research examines the effects on biodiversity, habitats, climate change, as well as ways to minimize them. Applicable in Romania's economy at the national, regional, and local level, it should address multiple aspects to assess the impact on biodiversity, habitats, climate change, as well as ways to minimize them. Proposing a real model could involve the following aspects: 1. Assessment of the resources and potential of renewable energies; 2. Impact analysis on biodiversity and habitats; 3. It involves field studies, ecological analysis and monitoring of species and ecosystems affected by renewable energy projects. 4. Climate change impact assessment includes estimates of reductions in CO2 and other greenhouse gas emissions due to the use of renewable energy sources. 5. Identifying impact minimization measures: may include ecological design practices, conservation of natural habitats and implementation of technologies with low environmental impact. 6. Stakeholder consultation and engagement: to ensure that diverse perspectives and concerns are considered in the renewable energy development process. 7. Monitoring and impact assessment: The model should also include mechanisms to monitor and assess real-time and long-term impacts of renewable energy projects on biodiversity, habitats, climate change. (2) *The interdisciplinary approach between engineering and technology,* applied the knowledge from different branches of engineering (electrical, mechanical, chemical, materials science). (3) *The approach between* digitization and the use of artificial intelligence of renewable energy sources. For planning operations to make effective strategic decisions in the management of this renewable energy source, we must be able to anticipate solar energy production according to weather conditions, seasonal cycles, other relevant factors. It is necessary to go through several steps: 1) *Data collection,* such as solar radiation, wind speed and direction, air and soil temperature, humidity, atmospheric pressure. That data can be collected from local weather stations or from sensors mounted directly in the solar park. 2) *Data analysis* and model building, we analyze the collected data to identify patterns and various correlations between meteorological variables and solar energy production. We build a forecasting model that uses this data to estimate future solar energy production based on anticipated weather conditions. *3) Validation and adjustment: ensuring the model is accurate and reliable*, it can be validated with historical data and by comparing predictions with actual solar energy production. 4) *Use in planning solar park operations,* such as scheduling maintenance and repairs, managing energy storage or delivery, pricing electricity based on production estimates. 5) *Optimization of consumption and distribution*. it can contribute to reducing energy losses and increasing the efficiency of the entire energy system. *6) Smart grid management,* enabling real-time monitoring and regulation of power flows to ensure system stability and reliability. *7) Interdisciplinary approaches between economics, management, public administration, and governance,* can examine the costs and benefits of using renewable energies, the impact on energy markets and local and global economies.

3.2. Develop a more complex managerial model

To develop a more complex managerial model that integrates the previously mentioned interdisciplinary approaches, we can structure the model around several dimensions and levels of governance. Here is such a model in more detail: Ensuring public consultation and involvement in the decision-making process and in the implementation of renewable energy projects, to promote their acceptability and sustainability in local communities. At local public level: 1. Concrete projects and innovation, promoting innovation and community initiatives in this field. 2. Education and awareness, at local level to inform and educate local communities about the benefits and opportunities offered by renewable energies. 3. Capacity building and

professional development of local skills in the field of renewable energies through training and education programs for professionals, entrepreneurs, and local communities. The complex managerial model would involve a close collaboration between different levels of governance and actors from different fields of expertise, to ensure a coherent and sustainable development of the renewable energy sector in Romania.

3.3. The entropic approach

The entropic approach in the management activity of the renewable energy sector can be innovative, based on the concept of entropy from physics and information science, with the following approach: 1. Measuring entropy in the energy system, entropy can be used to measure the degree of disorder or irregularity in the energy system. The more efficient and organized the system is in using renewable energies, the lower its entropy would be. 2. Optimizing energy efficiency, by applying entropic concepts, the model could be used to identify areas where energy efficiency can be improved in the renewable energy sector. This could involve identifying and reducing energy losses and optimizing renewable energy conversion and use processes. 3. Management of risk and uncertainty, with the help of entropy, used to evaluate the degree of uncertainty and risks associated with the implementation and operation of renewable energy systems.
By identifying and managing risks, the model can contribute to increasing the stability and reliability of the renewable energy sector. 4. The entropic model could be used to optimize the use of available resources and efficient capital allocation in the development.

3.4. Integrating blockchain technology into the development of the renewable energy industry

A model for the renewable energy industry in Romania using blockchain mainly for connecting to renewable energy sources: (1) Development of a renewable energy tracking platform: Implementation of a blockchain platform for tracking, verifying, production of renewable energy from sources solar and wind. Each unit of energy generated can be securely recorded on the blockchain, providing transparency and confidence in the origin and sustainability of this energy. (2) Peer-to-peer (P2P) transactions: Development of the P2P transaction system using the blockchain to allow owners of solar panels or wind turbines to directly sell surplus energy on the local market. This can create a more efficient and flexible market, encouraging local production and consumption of green energy. (3) Certification of origin of renewable energy: Using the blockchain to issue certificates of origin of renewable energy, attesting that the energy was produced from verified and sustainable sources. Certificates can be traded on a concrete market, providing an incentive mechanism for renewable energy producers. (2) Creation of a blockchain platform for crowdfunding in the field of renewable energy projects. (3) Smart grid management. Implementation of blockchain-based smart grids distribution. This will include functions such as consumption monitoring, optimization of distribution routes and management of charging and discharging of storage batteries, thus helping to increase the reliability and efficiency of the grid. The application of the blockchain model will have a significant role in the sustainable development of the renewable industry in Romania, contributing to increasing the use of green energy, reducing dependence on fossil energy sources and promoting a more sustainable and collaborative economy.

Conclusions

In conclusion, Romania's transition to renewable energy sources presents both challenges and opportunities on its way to sustainable development. Although significant progress has been made, particularly in the adoption of renewables among domestic consumers and institutions, barriers such as financial constraints, inadequate infrastructure and limited awareness persist. Addressing these challenges requires a multifaceted approach that encompasses policy interventions, technological innovations, Community engagement initiatives. Collaboration between stakeholders, both nationally and internationally, is crucial to overcoming these barriers and accelerating the pace of the energy transition. In addition, embracing the principles of the circular economy, capitalizing on bio-based materials, and capitalizing on emerging technologies such as blockchain can increase the resilience and sustainability of Romania's energy ecosystem. By charting a course towards a greener and more resilient future, Romania can position itself as a leader in the global transition towards renewable energy.

Romania is at a critical moment in its renewable energy trajectory, with ambitious targets set for 2030 and beyond. The country's commitment to increasing the share of renewable energy in its energy mix is evident through strategic planning, investment initiatives and policy reviews. Going forward, sustained efforts are needed to overcome challenges such as intermittency, grid integration and funding constraints. By adopting interdisciplinary approaches, adopting innovative solutions, encouraging international collaboration, Romania can accelerate its transition to a sustainable and resilient energy future, contributing both to national prosperity and to the management of the global environment.

References

Angheluta, S.P., Burlacu, S., Diaconu, A. and Curea, C.S., (2019). *The Energy from Renewable Sources in the European Union: Achieving the Goals.* European Journal of Sustainable Development, 8(5), p.57. https://doi.org/10.14207/ejsd.2019.v8n5p57.

Angheluta, S.P., Mitrita, M., Burlacu, S., Gole, I., Badea, C.G.(2019). *Climate Change and Renewable Resources in the European Union*. In: 34th International-Business-Information-Management-Association (IBIMA) Conference, Madrid, Spain. 13-14 November 2019. ISBN978-0-9998551-3-3, pp.1324-1336.

Apergis, N., & Payne, J. E. (2010). *Renewable energy consumption and economic growth: evidence from a panel of OECD countries.* Energy policy, 38(1), 656-660.

Balugani, E., Sumfleth, B., Majer, S., Marazza, D. and Thrän, D.(2022). *Bridging Modeling and Certification to Evaluate Low-ILUC-Risk Practices for Biobased Materials with a User-Friendly Tool.* Sustainability, 14(4), p.2030. https://doi.org/10.3390/su14042030.

Ban, O.-I., Dzitac, S., Simó, A. and Florea, A.(2023) *Romania Residents' Attitude Investigation toward the Transition to Renewable Energy Sources through Importance-Performance Analysis.* Sustainability, 15(20), p.14790. https://doi.org/10.3390/su152014790.

Bulmez, A. M., Brezeanu, A. I., Dragomir, G., & Năstase, G. (2024). *An Analysis of Romania's Energy Strategy: Perspectives and Developments since 2020*.

Buzogány, A., & Davidescu, S. (2022). *Energy Governance in Romania. In Handbook of Energy Governance in Europe* (pp. 993-1017). Cham: Springer International Publishing.

Charfeddine, L., & Kahia, M. (2019). *Impact of renewable energy consumption and financial development on CO2 emissions and economic growth in the MENA region: a panel vector autoregressive (PVAR) analysis.* Renewable energy, 139, 198-213

Cristea, C., Cristea, M., Micu, D.D., Ceclan, A., Tîrnovan, R.-A. and Șerban, F.M.(2022). *Tridimensional Sustainability and Feasibility Assessment of Grid-Connected Solar Photovoltaic Systems Applied for the Technical University of Cluj-Napoca*. Sustainability, 14(17), p.10892. https://doi.org/10.3390/su141710892.

Diaconu, A., Popescu, M.L., Burlacu S., Buzoianu O.C.A.(2019). *Strategic Options For The Development Of Renewable Energy In The Context Of Globalization.* In: Proceedings of the 13th International Management Conference: Management Strategies for High Performance. Bucharest, Romania. October 31st - November 1st, 2019. Bucharest, pp.1022-1029.

European Union (2023). *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001*, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652. [online] Available at: <https://eur-lex.europa.eu/eli/dir/2023/2413/oj>

Eurostat(2023).*Share of energy from renewable sources.* [online] Available at: <https://ec.europa.eu/eurostat/databrowser/view/nrg_ind_ren/default/table?lang=en>

Filimon, D.(2023). *Status of the Marinas' Development in the Southern Region of the Romanian Sea Coast: Implications for Sustainable Recreational Transport in the Black Sea*. Sustainability, 15(10), p.7979. https://doi.org/10.3390/su15107979.

Gaman, F., Iacoboaea, C., Aldea, M., Luca, O., Stănescu, A.A. and Boteanu, C.M.(2022). *Energy Transition in Marginalized Urban Areas: The Case of Romania*. Sustainability, 14(11), p.6855. https://doi.org/10.3390/su14116855.

Mihai, F.-C. and Minea, I.(2021). *Sustainable Alternative Routes versus Linear Economy and Resources Degradation in Eastern Romania.* Sustainability, 13(19), p.10574. https://doi.org/10.3390/su131910574.

Ministerul Investițiilor și Proiectelor Europene (2023). *National Recovery and Resilience Plan (PNRR) of Romania*. [online] Available at: < https://mfe.gov.ro/pnrr/>

Moise, G., Popescu, A., Bratu, I.A., Răducuță, I., Nistoreanu, B.G. and Stanciu, M.(2023). *Can We Talk about Smart Tourist Villages in Mărginimea Sibiului, Romania?* Sustainability, 15(9), p.7475. https://doi.org/10.3390/su15097475.

Onete, C.B., Budz, S., Bucur-Teodorescu, I., Chița, S.D., Sava, Ș. and Bucur, C.(2023). *The Relationship between Renewable Energy and Blockchain as a Sustainable Technology Tool*. Amfiteatru Economic, 25(64), pp.919-932. https://doi.org/10.24818/EA/2023/64/919

Popescu, C., Panait, M., Palazzo, M., & Siano, A. (2022). Energy transition in European Union—Challenges and opportunities. *Energy Transition: Economic, Social and Environmental Dimensions*, 289-312.

Rădulescu, C.V., Angheluță, P.S., Burlacu, S. and Kant, A.(2022). *Aspects Regarding Renewable Sources in the European Union.* European Journal of Sustainable Development, 11(3), p.93. https://doi.org/10.14207/ejsd.2022.v11n3p93.

Spunei, E., Minda, A.A., Piroi, I. and Șoanda, N.I.(2023). *Analysis of the Evolution of Electricity Production in Romania.* In: 2023 International Conference on Electromechanical and Energy Systems (SIELMEN) (pp. 1-5). IEEE. Craiova, Romania. 11 October 2023.

Tănasie, A.V., Năstase, L.L., Vochița, L.L., Manda, A.M., Boțoteanu, G.I. and Sitnikov, C.S.(2022) *Green Economy—Green Jobs in the Context of Sustainable Development.* Sustainability, 14(8), p.4796. https://doi.org/10.3390/su14084796.

Voicu-Dorobanțu, R., Volintiru, C., Popescu, M. F., Nerău, V., & Ștefan, G. (2021). *Tackling complexity of the just transition in the EU: Evidence from Romania*. Energies, 14(5), 1509.