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Review

The Energy Transition in Bulgaria: An Analysis of Economic, Social, and Environmental Perspectives on State-Owned Companies

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Abstract

As a member state of the European Union, Bulgaria is committed to decarbonisation and the achievement of sustainable development goals. The country has a well-established energy sector and is a net exporter of electricity produced from diverse sources. Electricity generation relies mainly on two key pillars: lignite-fired Thermal Power Plants (TPPs) and the Nuclear Power Plant (NPP) in Kozloduy. This study examines the status of Bulgarian state-owned energy companies (SOEC) and their capacity to respond to the challenges of a sustainable transition towards low- or zero-emission electricity production. The study contributes to the existing literature by providing insights from a comparative analysis of state-owned thermal and nuclear power generation in Bulgaria, examined through the lens of sustainable development. From a practical standpoint it contributes by outlining possible pathways for the sustainable transformation of carbon-intensive TPPs. The analy-sis is based on key sustainability indicators covering the three pillars of sustainable development—economic, social and environmental performance. It includes not only an assessment of the financial performance of state-owned thermal power plants and the nuclear power plant over the past five years but also selected social and environmental indicators. The findings suggest that nuclear energy production in Bulgaria is largely consistent with the core principles of sustainability, while coal-based thermal power plants face increasing economic pressures and contribute to significant environmental impacts. The results highlight the need to transform the coal-based electricity sector into a more economically viable and socially responsible alternative, such as low-carbon generation technologies including nuclear energy.

Keywords: energy transition; decarbonisation; thermal power plants; nuclear energy; sustainability; Bulgaria

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1. Introduction

The need for a rapid but at the same time just transition to sustainable energy systems is one of the most significant challenges of the 21st century. The main complexity comes not only from the need to reduce emissions but also from managing the transition in such a way that employees and entire regions are not left behind. As Sartor points out, phasing out coal can be achieved without serious economic or social disruptions, but it demands early planning, strong policy coordination, and active support for the affected communities and industries. These challenges, therefore, could be addressed from multiple perspectives. The concept of sustainable development (SD) also can be used as a standpoint for studying the challenge of overcoming the dependence on the use of fossil fuels as a source of energy [1].

A significant challenge and one of the top priorities today is achieving the sustainable development goals (SDGs) by 2030 mainly due to growing concerns about climate change, in which electricity generation plays a significant role [2–4]. In his study Luis Berga describes electricity as a vital resource needed for the functioning of society, economic prosperity, and sustainable development on a global scale [3]. The link between sustainable development and energy became a major global concern at the 2002 Johannesburg World Summit on Sustainable Development [5].

From the perspective of the environmental pillar of SD, the problems are related not only to environmental pollution and climate change but also to the excessive use of water and land, loss of wildlife habitats, and harm to public health. From an economic point of view, a number of challenges can be pointed out. On the one hand, they are related to the fact that fossil fuels are limited resources and are not expected to be sufficient to meet global demand by the middle of the 21st century [6]. On the other hand, they can lead to economic instability, which may arise as a result of fluctuations in their prices and geopolitical dependence. Social challenges are mainly related to negative public attitudes towards unemployment and social inequality.

However, there is a growing awareness among the community that the transition from burning harmful fossil fuels to sustainable energy sources can help overcome these problems. It is evident from the above that decarbonisation of the electricity system is crucial for mitigating the effects of climate change, which is one of the main sustainability challenges [7].

A strategic approach to achieving sustainable development is the selection of the most appropriate energy systems within the electricity mix [8].

The importance of addressing the correlation between economic activities and environmental impact derives from the fact that energy production is one of the most significant economic activities ensuring the normal functioning of human society. A number of authors have studied the relationship between energy sources and systems and sustainable development. In their study Kolagar et al. [9] pointed out that, in order for them to have a positive impact and to be considered sustainable, they have to meet the following requirements: to be renewable or inexhaustible; to ensure efficient production and usage with minimal waste of resources; to be economically resilient; to be diversified and reliable; to be just and cost-effective; to be accessible and available; and to cause minimal harmful impacts on the environment and society.

According to Yasar Demirel, the impact of climate change on energy consumption depends on the scenarios which are described as possible future climate conditions resulting from different energy production and consumption patterns [10]. He frames climate change scenarios in the context of energy systems and environmental impact highlighting the interrelationship between energy use, greenhouse gas emissions, climate change scenarios, and environmental and technological measures.

Therefore, the most important factors affecting energy use include population growth, which increases energy demand, and the use of heating and cooling systems, which will increase due to changes in extreme weather conditions. As a result, electricity production per unit of carbon dioxide emitted into the atmosphere, equivalent to the amount of carbon, will increase.

Sustainable transition strategies usually focus on three main technological shifts: reducing energy use on the demand side, improving efficiency in energy production, and gradually replacing fossil fuels with renewable sources and low-carbon nuclear energy [11,12]. Going further shows that while sustainable development is typically based on three pillars—social, economic, and environmental—energy sustainability is more effectively assessed through a broader five-dimensional approach, which also includes technical and institutional (or political) aspects [12].

With growing trends in urban consumption and production practices, it can be noted that the need for action against climate change can only be achieved by promoting action across all three pillars of SD. The energy transition varies across countries, as it is shaped by specific social and economic conditions. At the same time, it is a complex process due to the involvement of multiple actors with diverse and often competing interests [13]. There are different paths that countries can take to mitigate the hazardous impacts of climate change. But the most important thing for the transition to be technically and economically viable is the necessity to be supported by appropriate policies that guide the shift toward a more sustainable energy and electricity system [14,15].

A possible pathway for transitioning to reduced global energy-related emissions has been proposed by the International Energy Agency (IEA) and consists of five strategies, namely, increasing energy efficiency in industry, construction, and transportation; decreasing the use of the least efficient coal-burning power plants and outlawing further construction; increasing investment in renewable energy technologies and a hierarchical cancellation of fossil-fuel subsidies to end-users; and cutting methane emissions in oil and gas production. Furthermore, by monitoring and disseminating awareness about energy saving, households will become increasingly more energy-aware and climate-conscious.

Also, as Meltem Ucal and George Xydys cite in their article "Multidirectional Relationship between Energy Resources, Climate Changes and Sustainable Development: Technoeconomic Analysis" the forecast by the IEA for the period 2015–2025 is that the intensity of CO_2 emissions from electricity generation will decrease by 32% in China, 34% in the US, 35% in India, 42% in the European Union, and 47% in Japan [16]. Moreover, a number of studies point out that the green transition is crucial because it offers a path to SD through a sustainable energy future [6].

Cherp et al. describe the energy transition as a transformation process that takes place within the respective national, interlinked systems. Technoeconomic systems refer to the energy flows involved in energy production and consumption, coordinated by energy markets. Sociotechnical systems are represented by knowledge, practices, and networks of energy technologies. Energy policy is represented in political systems, and unlike other authors, its role in energy transitions in the 21st century is highlighted [17].

The ability to meet current and future electricity demand in a safe and efficient way, using clean energy sources and appropriate technologies, defines technical sustainability in electricity generation [18]. The main cause of environmental damage not only at the organisational level but also at the worldwide level is the unsustainable production and consumption of energy resources [19].

Accordingly, in their study, Philip Wong and Joseph Lai emphasise the need to introduce increasingly rigorous methods for assessing the impact of energy policies on reducing harmful emissions, as it has a strong impact on different economic sectors, including finance and education. The main problems identified in the study are related to ensuring compliance with energy efficiency standards, varying levels of public awareness, and securing funding for energy transition projects, which often require significant investments in infrastructure, technology, and human resources [20].

Oliveira, Nogueira and Madaleno emphasise that the transition to a wider use of renewable energy sources is associated with favourable economic outcomes, such as economic growth. Capital accumulation, labour force participation, and higher education are identified as key drivers of economic growth, while institutional and financial variables appear to have a more limited impact [21]. This finding is consistent with recent empirical evidence showing that improvements in energy efficiency—supported, for example, by the expansion of digital infrastructure—can contribute to more sustainable and economically efficient energy systems [22].

This confirms that in order to be effective, the energy transition process requires a thorough knowledge and understanding of the political and economic context in different countries. In energy systems where state-owned energy companies (SOECs) control key strategic assets, governments have strong influence over capital allocation, technological processes, and the long-term design of energy infrastructure.

The energy transition process in France in the early 1970s is often cited as a good example of a successful transition from oil to nuclear power generation through a state-led rapid expansion programme. As a result, by 2024, nuclear power will provide around 67% of the electricity mix in France, contributing to one of the most decarbonised energy grids in the world. Similarly, according to Yang et al., China's approach to renewable energy is also characterised by significant government incentives and a substantial role for state-owned enterprises [23].

These cases show that in counties with strong SOECs, their role can be recognised not only as market players but also as instruments of public policy. Benoit [24] shows that they can often operate with a mandate to provide reliable and cheap electricity, which can limit their ability to respond to carbon pricing when tariffs are regulated. However, they also provide direct tools—through shareholder control, financing, and strategic guidance—to make investment decisions in line with decarbonisation goals.

Furthermore, in the literature they are increasingly acknowledged as important actors in decarbonisation scenarios not only for their important position in energy systems but also for their significant emission footprint. In their article "Greenhouse gas emissions from state-owned enterprises: A preliminary inventory", Alex Clark and Phillipe Benoit [25] show that a significant share of global greenhouse gas emissions related to electricity generation and fossil fuel production are attributed to the SOECs. At the same time, SOECs have control over a large share of low-carbon production capacity, including renewables and nuclear power, positioning them as both major contributors to pollution and potential enablers of decarbonisation.

Ownership structure is an important factor influencing climate performance. Mayer and Rajavuori explain that state ownership can either reinforce carbon-intensive development or support climate mitigation, depending on how governments align company mandates with national climate priorities [26].

Similarly, Clò, Ferraris and Florio find that the structure of ownership (state-owned vs. private) influences how companies respond to the environmental rules and sticking to those rules does not automatically guarantee better environmental outcomes. SOECs may behave differently from private companies when faced with environmental regulation. They can remain financially stable and afford to earn slightly lower profits than private firms because they pursue broader goals and often balance profitability with broader social objectives [27].

Empirical evidence on whether SOECs perform better or worse than private companies on environmental sustainability outcomes is not coherent.

Andrew Meyer and Grzegorz Pac, analysing Eastern European energy companies show that ownership alone is not the main factor that determines the environmental performance and the institutional context and regulatory structure play a crucial role as well [28].

According to what has been said so far it is obvious that SOECs are not automatically considered as a barrier or enabler of decarbonisation. Their impact depends on how ownership, regulation and political commitment to climate goals work together and on whether governments actively use their power to steer them towards a low-carbon transition.

Based on what has been discussed so far, it is evident that identifying long-term sustainable solutions in the energy sector is becoming increasingly important both nationally and internationally. The challenge, though, is that at the beginning of the 21st century, the world is exhausting its usable fossil fuel energy, and renewable energy sources are not yet sufficiently developed to offer a complete and flexible alternative. Therefore, the use of nuclear energy for electricity generation is also an alternative for reducing resource requirements to a more sustainable level that should be considered.

With respect to the environmental, social and economic context, the capacity of the different countries may differ. In order to find the optimal solution in terms of sustainable energy sources at a given moment, it is necessary to conduct an in-depth study and analysis of the status and potential capacity in the country to be addressed. In this regard the objective of the study is to investigate the current status of Bulgarian state-owned energy companies and their capacity to address the challenges and requirements associated with a sustainable transition to low- or zero-emission electricity production. Key sustainability indicators have been considered regarding the three pillars of sustainability. The analysis encompasses the annual financial results of state-owned TPPs and NPPs over the last five years, as well as social and environmental performance.

To address these challenges, the present study provides an integrated assessment of the sustainability of Bulgaria's electricity sector from economic, environmental, and social perspectives. The paper contributes to the literature on energy transition in three main ways. First, it analyses the sustainability performance of Bulgaria's state-owned energy companies, which remain key actors in the national electricity system and play an important role in shaping decarbonisation strategies. Second, the study introduces a territorial comparison between two municipalities strongly shaped by different energy technologies—Radnevo, whose economy is closely linked to coal mining and thermal power generation, and Kozloduy, where nuclear energy represents the dominant economic driver. This comparison allows the analysis to capture the regional socio-economic implications of the energy transition. Third, the study examines how ownership structures and institutional frameworks influence possible decarbonisation pathways in a coal-dependent electricity system.

This study therefore investigates the sustainability of Bulgaria's electricity sector from economic, environmental, and social perspectives and explores possible transition pathways for transforming coal-dependent electricity generation.

Analysing financial performance, emissions, and socioeconomic impacts, the study outlines the key differences between the two technologies and their impact on the energy transition. The outcomes demonstrate that while coal-fired power generation is subject to increasing economic and environmental pressures, nuclear energy provides a more stable and low-carbon alternative in the Bulgarian context. In this way, the study offers a comprehensive analysis of how the changes that define the transition have been shaped, as well as the role of state-owned enterprises in managing them.

The European Green Deal and the 2050 climate-neutrality target call for significant changes in EU Member States that still use coal. Bulgaria is one of the countries that has been particularly affected. Lignite-fired capacity in the Maritsa-Iztok complex (Radnevo Municipality, Stara Zagora Region) still accounts for 41% of national electricity generation, complemented by nuclear output from the Kozloduy Nuclear Power Plant. With this in mind, the planned decrease in coal mining and in some coal power plants will have significant effects on the power system and the economy. About 15,000 people work directly in the complex, and over 30,000 work indirectly there as well [29].

In this context, the TPP Maritsa-Iztok 2—Bulgaria's and the Balkans' largest state-owned thermal power plant, with an installed capacity of 1620 MW across eight units—is particularly important. It is crucial for Bulgaria's energy guarantee, and the EU's decarbonisation policies have made it a high priority. Beyond its system role, the plant is a vital part of the community. It provides direct and indirect employment to thousands of households in the region. The future of Maritsa-Iztok 2 is significant for the just transition and vice versa. It is vital to find a balance between protecting the environment, ensuring sufficient energy, and helping the communities that will be affected.

The TPP Maritsa Iztok 2 has been included in the list of the biggest polluters participating in Europe's carbon dioxide emissions trading scheme (ETS). Overall, harmful emissions generated from various economic activities in Bulgaria are shown in Figure 1.

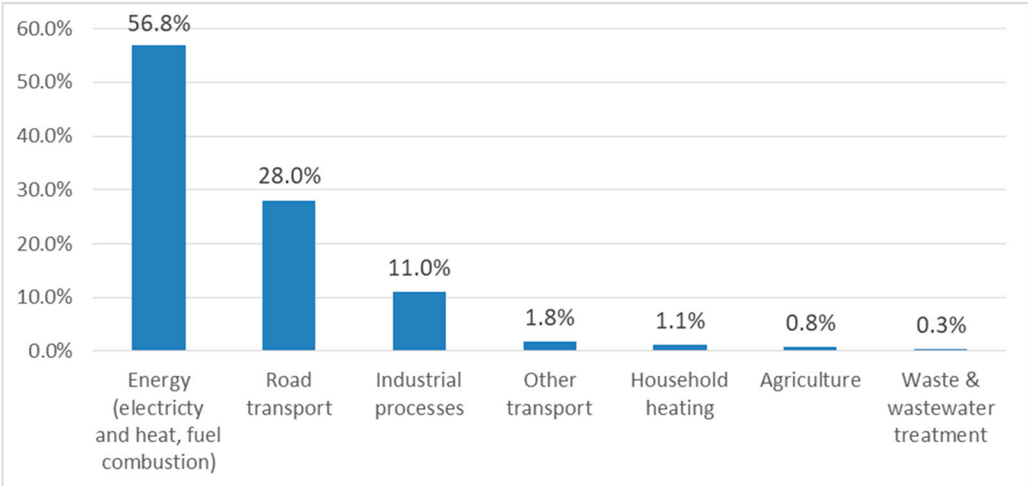

Figure 1. Emissions of harmful substances into the air from main economic activities for 2023. Own work. Source: National Statistical Institute (NSI) [30].

2. Methodology

This study adopts a qualitative case study approach based on secondary data analysis. Such an approach is considered appropriate because it allows an in-depth examination of the Bulgarian electricity sector within the broader context of sustainable development and the European Union's decarbonisation objectives. Case study methods are widely used to analyse complex and context-dependent processes such as national energy transitions, where institutional, economic and social factors interact in specific national contexts [31].

The analysis relies on publicly available secondary data, an approach widely recognised as methodologically rigorous in qualitative research. Secondary data analysis allows researchers to examine institutional and statistical information that exists independently of the research process, which reduces the risk of subjective influence on the data generation stage and improves the reliability and traceability of the information used. [32–34].

The empirical material used in the study consists of several categories of sources. These include national and European policy documents and regulatory frameworks related to energy transition and decarbonisation; statistical data from Eurostat, the Bulgarian Ministry of Energy and other official institutions; as well as annual financial statements and publicly available reports on the environmental and social performance of state-owned Thermal Power Plants (TPPs) and the Kozloduy Nuclear Power Plant (NPP). The use of official statistical sources ensures comparability and reliability of the analysed information in accordance with established principles governing public data reporting. The documents used in the analysis were selected according to three main criteria: institutional reliability of the source, relevance to the research question, and comparability of the data across the analysed time period. Preference was given to official statistical datasets, regulatory documents, and publicly available company reports that provide consistent information on economic performance, environmental indicators, and sector development. The overall analytical process used in the study is summarised in Figure 2, which illustrates the sequence from data collection and analytical categorisation to comparative assessment and identification of structural determinants shaping the energy transition.

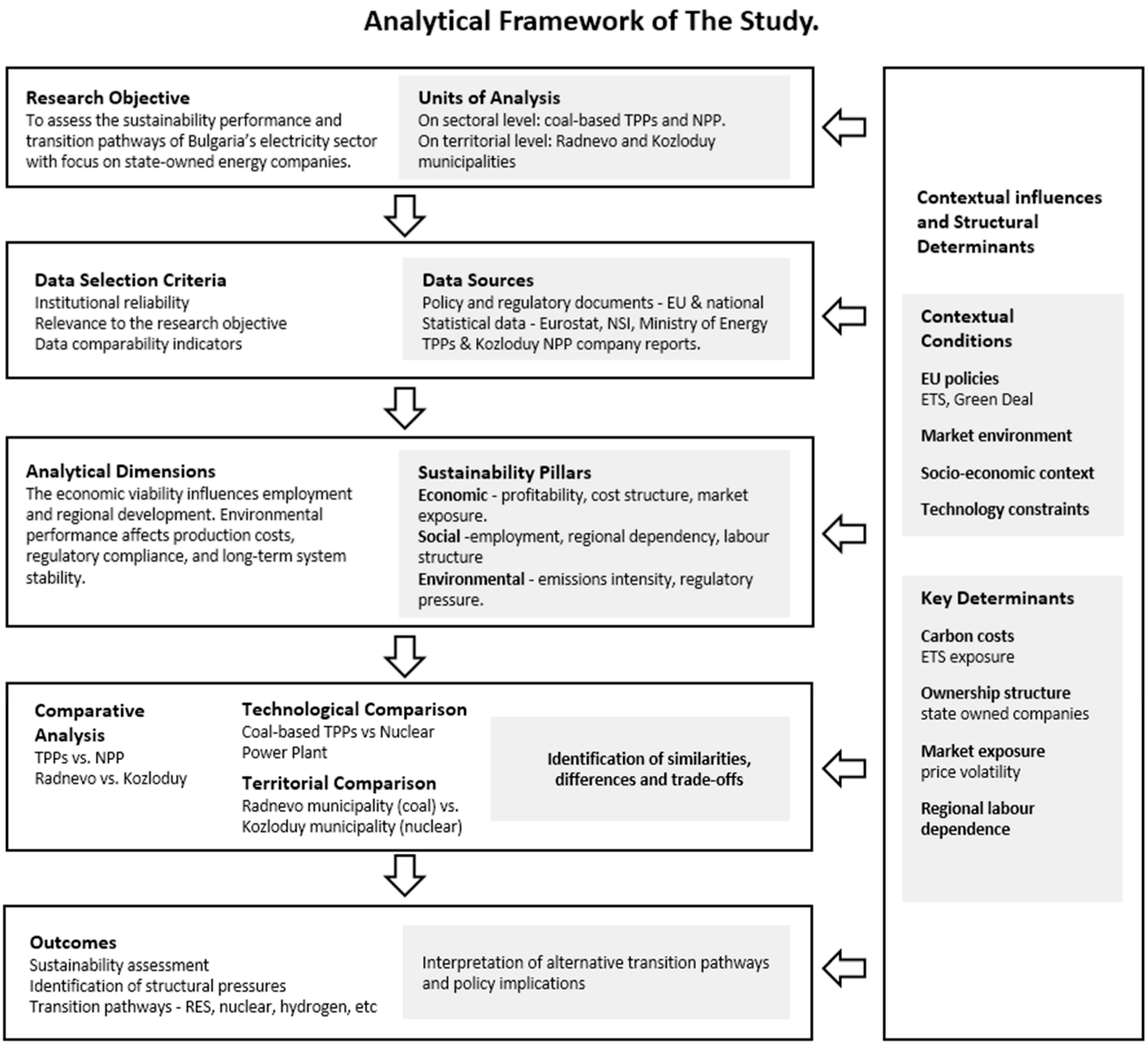

Figure 2. Analytical framework of the study. Sequential process linking data, sustainability indicators, comparative analysis, and structural determinants to policy implications. Own work.

Financial data were analysed primarily through publicly available annual reports and aggregated financial results of state-owned electricity generation companies. The analysis focuses on long-term profit and loss trends rather than short-term market fluctuations, allowing the study to identify structural economic pressures affecting coal-based and nuclear electricity generation [35].

Document analysis is particularly suitable in this context because the materials examined were produced independently of the research process and were not created specifically for the purposes of this study. As a result, the information contained in these documents is less likely to be influenced by the researcher's interpretation or by interaction between researchers and respondents, which may occur in methods based on interviews or surveys. This contributes to increasing the objectivity and consistency of the analytical process [32].

This aspect is particularly important because energy transition and decarbonisation policies are politically sensitive and often controversial issues, where direct engagement with stakeholders may lead to additional bias related to their institutional, economic, or political interests.

The analytical results were organised within the sustainability framework in order to evaluate the economic, social and environmental implications of different transition pathways for carbon-intensive electricity generation.

The collected data are examined through the analytical framework of the three pillars of sustainability—economic, social and environmental performance. Within this framework, the economic dimension considers the financial performance and market exposure of electricity generation companies; the social dimension focuses on employment structures and regional labour-market dependency; while the environmental dimension examines emissions intensity and regulatory pressures related to decarbonisation policies. The analysis compares the financial performance of state-owned thermal and nuclear power plants, examines regional socio-economic indicators for coal-dependent municipalities, and evaluates environmental pressures associated with decarbonisation policies. By analysing the key factors influencing the performance of different electricity generation technologies, the analytical approach moves beyond a purely descriptive assessment. Specifically, the study examines how economic outcomes are shaped by market conditions, price dynamics, and carbon-related costs; how environmental performance is influenced by emissions intensity and regulatory requirements; and how social impacts are determined by employment structures and regional economic interdependence. By integrating these dimensions, the analysis captures the interactions and trade-offs between economic resilience, environmental pressures, and social sustainability within the energy transition process and outlines the key interrelationships underlying the differences between thermal and nuclear power generation.

The temporal scope of the analysis covers the most recent five-year period for the financial performance of state-owned energy companies, while selected statistical and socio-economic indicators are used to illustrate broader structural trends within the Bulgarian electricity sector. In addition to sector-level analysis, the study incorporates a territorial comparison between the municipalities of Radnevo and Kozloduy. These municipalities represent two distinct local economic structures shaped by different energy technologies—coal-based thermal power generation and nuclear power production—allowing the analysis to capture the regional socio-economic implications of the energy transition.

By combining institutional documents, statistical indicators and territorial comparison, the methodological approach provides a comprehensive framework for evaluating the structural challenges facing Bulgaria's electricity sector and for identifying possible pathways for the sustainable transformation of carbon-intensive electricity generation.

This integrated analytical approach makes it possible to connect sector-level developments with regional socio-economic dynamics and institutional policy frameworks shaping the energy transition.

3. Limitations

Although the data were obtained from reliable and traceable sources, document analysis is not without limitations. The study is limited by the fact that it is based on publicly available information. The available materials may reflect selective or institutionally aligned perspectives [36]. Such documents are typically produced for purposes other than research and may therefore not fully address the specific research questions [32] and the complexity of a company's internal processes or the perspectives of all relevant stakeholders. While these limitations are not fundamental weaknesses, they should still be recognised and acknowledged. Nevertheless, the findings may provide useful insights for other Central and Eastern European energy systems where state-owned enterprises play a dominant role in electricity generation.

4. Discussion

4.1. The Bulgarian Power Sector

Bulgaria's power system is characterised by a diversified energy mix including lignite coal, nuclear energy, natural gas, hydropower, and a growing share of renewable sources such as solar and wind. Historically, lignite production in the Maritsa-Iztok basin near Stara Zagora has played a central role in the regional economy, shaping employment structures and industrial development. Major power plants such as Maritsa-Iztok 2, AES Galabovo, and ContourGlobal Maritsa-Iztok 3 remain important components of the national electricity system. However, these assets face increasing economic and regulatory pressures related to the EU's decarbonisation policies and the rising cost of carbon allowances under the EU Emissions Trading System.

Nuclear power represents a central component of Bulgaria's electricity system (Figure 2). The Kozloduy Nuclear Power Plant, operating two VVER-1000 units, provides approximately 41% of the country's electricity generation. Discussions on expanding nuclear capacity include the potential construction of additional units at Kozloduy and the possible deployment of small modular reactor (SMR) technologies. These developments reflect Bulgaria's broader effort to balance decarbonisation objectives with energy security and system reliability.

Figure 3 shows the different financial profiles of state-owned TPPs and NPPs over the period 2013–2024. TPPs have been chronically loss-making for almost a decade, with the only profitable deviation occurring in 2022. This single increase in profits is due to two short-term factors: a sharp increase in the electricity prices (from around BGN 90/MWh (EUR 46/MWh) in 2020 to a peak of BGN 560/MWh (EUR 286/MWh) in 2022) and significantly higher electricity production induced by the energy supply crisis. Beyond this rarity, TPPs are highly dependent on market shocks and the regulatory environment, which highlights their low structural resilience.

The cost pressure on thermal power plants is further increased by the EU Emissions Trading System (ETS), which requires the operators to purchase allowances for every ton of CO_2 they emit. Given the highly carbon-intensive nature of lignite-fired power generation, ETS costs can represent a significant share of total production costs, which has a substantial impact on profit margins. In comparison, nuclear power is not subject to such costs, thereby contributing to its relatively more stable financial performance.

The nuclear power plant has been steadily profitable, with only a few temporary dips (Figure 4). These were mainly caused by slightly lower electricity prices in 2016, limits on how much energy they can sell on the free market (since about 30% is sold at lower regulated prices), and the high costs of modernisation in 2017 and 2019, when the first 30-year licences had to be renewed. These modernisations lead to longer planned repairs, lower capacity utilisation rates, and correspondingly lower revenues.

This comparison illustrates the significant difference between the two types of technology. Thermal power plants are strongly dependent on external factors such as price fluctuations in electricity and regulatory requirements, which limit their long-term financial sustainability. In comparison, nuclear energy offers higher stability and predictability, which strengthens its role as a reliable low-carbon energy source in the electricity system.

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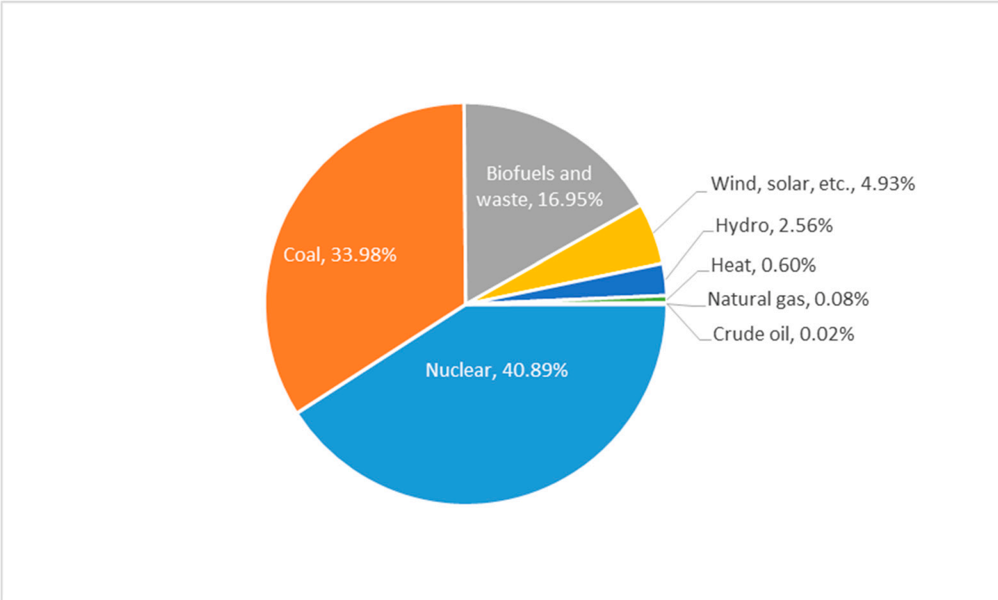

Figure 3. Domestic energy production, 2023. Own work. Source IEA [37].

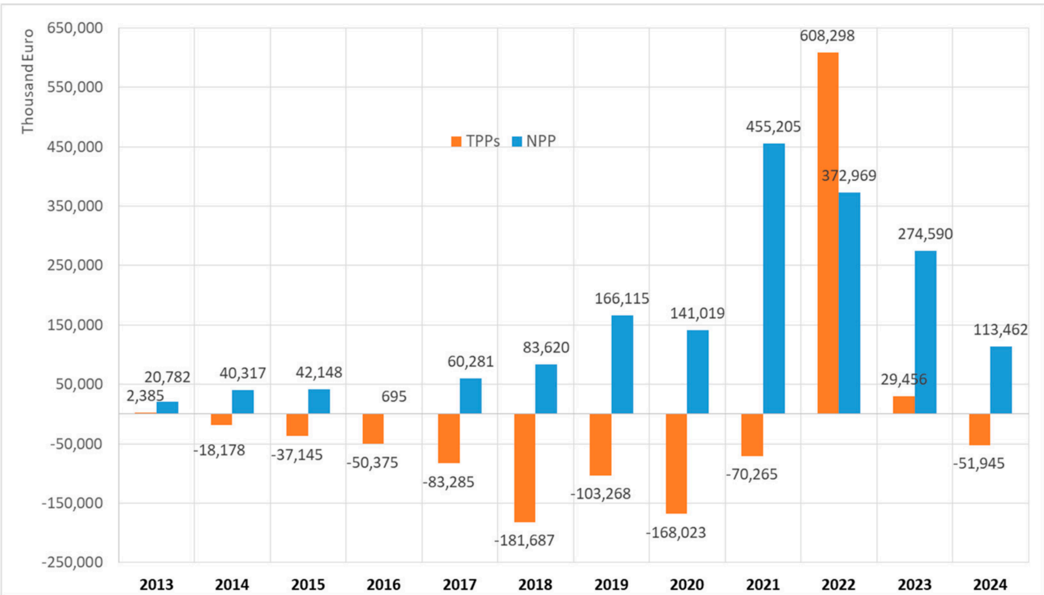

Figure 4. Profits and losses of state-owned thermal power plants and the only nuclear power plant in Bulgaria, in millions of euros. Own work. Source: public-accessible data on the BEH internet site, bgenh.com [38].

Hydropower is an excellent option because it is flexible and balanced, even though it has a moderate overall share. Gas-fired generation is still rather limited, but it could grow with combined-cycle projects. Renewable energy capacity in Bulgaria has expanded significantly in recent years, particularly in solar photovoltaic installations. By 2024, solar PV capacity is expected to exceed 3 GW, while wind installations surpass 700 MW. This expansion has been driven primarily by private investment and policy incentives associated with the European Green Deal.

Bulgaria has traditionally been a net exporter of electricity within Southeast Europe, supplying neighbouring countries such as Greece, Romania, Serbia, North Macedonia and Turkey. However, the gradual reduction in coal-based generation raises questions regarding the long-term balance between domestic supply, export capacity, and the need for additional investments in grid modernisation, storage capacity and regional market integration.

4.2. Maritsa-Iztok 2 and the Just Transition

Within Bulgaria's national just transition programming, the Maritsa-Iztok complex (the Maritsa-Iztok complex includes four coal power plants, but only one of them—Maritsa Iztok-2—is state-owned. The other two major stations, Maritsa Iztok-1 (AES) and Maritsa Iztok-3 (ContourGlobal), are privately operated, while the fourth plant and the large mining company Mini Maritsa-Iztok support the complex's overall operation. This mix of public and private ownership shapes both the region's energy role and its economic transition challenges.)—and specifically TPP Maritsa-Iztok 2—stands at the core of energy and employment dynamics in the Stara Zagora Region. The notion of a "just transition" denotes a socially oriented approach to ecological and energy transformation in which the shift to a low-carbon economy should not exacerbate social inequalities; the emphasis is on employment protection, reskilling, social security, and meaningful community participation (https://www.ilo.org/publications/guidelines-just-transition-towards-environmentally-sustainable-economies, accessed on 10 December 2025). Originating in US trade union debates of the 1980s, the concept is now institutionalised both in International Labour Organisation (ILO) instruments and in the European Commission's strategic architecture through the Just Transition Mechanism (https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/finance-and-green-deal/just-transition-mechanism_en, accessed on 10 December 2025).

In Bulgaria, the concept is implemented through Territorial Just Transition Plans (TJTP) for the three regions most affected by the phase-out of coal-fired power plants: Stara Zagora, Pernik, and Kyustendil. The overall goal of the TJTP is to minimise the socioeconomic consequences of this transition, which primarily affects the Maritsa-Iztok basin. Thousands of workers in these regions are employed directly in mining and electricity production and indirectly in related supply chains. Planned interventions include targeted investments in new low-carbon activities, requalification programmes, and employment support. There are also measures for developing SMEs and infrastructure projects to improve connectivity and the business environment. These projects are developed with stakeholder participation and social dialogue as cross-sectoral principles. The effectiveness of these measures depends on reliable management, careful planning, secure financing, and the development of local institutional capacity.

The concept of a "just transition", originating in trade union debates and now embedded as a guiding principle, frames these interventions. Under Bulgaria's Recovery and Resilience Plan (RRP) [39], coal-based power generation is to be discontinued by 2038, a target also affirmed by a Parliamentary Resolution of 12 January 2023.

4.3. Social Risks, Pricing and Institutional Dependencies

Under the planned reforms, around BGN 3 billion (≈EUR 1.5 billion) from the European Commission's Regional Development Program 2021–2027 is earmarked for the implementation of the TJTP. European Commission estimates indicate that the closure of coal-fired power plants could affect over 20,000 direct jobs and over 56,000 people in total, including those indirectly affected. The most vulnerable region is Stara Zagora, where up to 80% of employment is functionally linked to mines and thermal power plants; significant job losses are also expected in Pernik and Kyustendil [40].

Coal policy in Bulgaria is characterised by enduring interests that go beyond energy considerations. Alongside the needs of the system, the sustainability of the coal sector is fuelled by strong political and economic configurations in which security of supply is presented as a significant argument: "the only reliable local resource" [41]. Empirical studies show that insufficient stakeholder participation undermines trust and public support, while

Bulgarian workers are more pessimistic about requalification than in other comparable contexts [42]. Given the strong dependence on the Maritsa-Iztok complex, the goal of transition by 2038 faces weak participation mechanisms and fragile trust among local actors—factors that may delay implementation and increase the social cost of transformation.

Local economies in coal-affected regions are highly dependent on the sector; thousands of jobs, both directly and indirectly, hinge on coal mining and related activities. In the face of information and participation deficits, communities often lack meaningful avenues to influence decisions, reproducing low trust among the state, business, trade unions, and citizens, and generating resistance—both passive (apathy, distrust) and active (protests, project blockage). This resistance can be identified in populist statements, political hesitation on difficult decisions, fear of job losses, depopulation and economic insecurity. The lack of timely and effective communication with the local communities fosters tensions and can delay or even block the transition [43].

A second structural factor is social pressure to maintain low-regulated household tariffs. Bulgaria keeps some of the lowest prices in the EU (set by the energy regulator), yet regulated tariffs are often below average production costs. The result is chronic indebtedness across the value chain: for instance, the state utility NEK purchases electricity at roughly EUR 92/MWh while selling to households at about EUR 37/MWh. Despite low end-user prices, around 30% of households report difficulties paying bills regularly—an indicator of widespread energy poverty.

Support for state-owned enterprises and local actors is a third key mechanism. TPP Maritsa-Iztok 2 and Mini Maritsa-Iztok receive substantial subsidies via preferential tariffs, intra-group loans from BEH, and direct budget injections; by various estimates, the annual volume exceeds EUR 450 million, rising with EUA prices. Such support is often opaque and clientelistic in effect—securing political backing and limiting the risk of mass worker protests. In this context, trade unions remain a powerful collective actor, capable of rapid mobilisation and slowing reforms [41].

The Stara Zagora region is heavily dependent on the Maritsa-Iztok complex. Both the regional and local economies are highly dependent on the sector, and thousands of jobs depend on coal mining. Communities often do not receive sufficient information or a real opportunity to influence decisions, which leads to a lack of trust between the state, business, trade unions, and citizens. This is precisely why there is resistance, both passive and active.

4.4. Radnevo and Kozloduy—Municipal Comparison

Radnevo has emerged as an intense industrial centre, with exceptionally high added value and substantial export revenues, thanks to its coal mines and thermal power plants. Kozloduy, at first glance, reports very low export values, but this is a statistical distortion: the electricity produced at the Kozloduy Nuclear Power Plant is marketed through the Electricity System Operator (ESO) and the Independent Bulgarian Energy Exchange (IBEX), meaning that the value is not recorded as direct municipal export. At the same time, Kozloduy stands out for its high expenditures on the acquisition of fixed assets, indicating investment activity and infrastructure renewal.

Kozloduy is a national leader in average wages (2nd place in Bulgaria), due to the nuclear power plant, while Radnevo is also among the top performers (4th place), relying on coal-based energy. Radnevo has more employees overall, underlining the importance of the mining and energy industries for local employment.

Both municipalities experience negative natural growth, but the decline is sharper in Radnevo, −12.9‰ (vs. Kozloduy −5.1‰). Kozloduy has a significantly higher share of the working-age population—67.6% versus 61.8%, which indicates a more favourable demographic structure (Table 1).

Radnevo has an impressive provision of hospital beds (26 per 1000 inhabitants), ranking among the highest in the country, while Kozloduy is closer to the national average. Both municipalities face challenges in the field of education, a high share of the population with low education levels and poor student performance in mathematics at the national external assessment. Radnevo lags even further behind Kozloduy in terms of educational outcomes.

Table 1. Comparative socio-economic indicators for Kozloduy and Radnevo municipalities (2023–2024). Own work. Source: https://265obshtini.bg [44].

	Kozloduy	Radnevo
Export revenues (2023)	BGN 1.3 million (EUR 664 million) 196/265 place	346.6 million BGN (EUR 177 million) 37/265 place
Expenditures for acquisition of fixed assets (2023)	118.4 million BGN (EUR 60.5 million) 35/265 place	280.9 million BGN (EUR 339.5 million) 16/265 place
Employees under labour contract (2023)	7459 persons 49/265 place	10,405 persons 37/265 place
Average gross monthly wage (2023)	3421 BGN (EUR 1749) 2/265 place	2803 BGN (EUR 1433) 4/265 place
Share with primary or lower education (2021)	27.4% 59/265 place	30.4% 81/265 place
Average National External Assessment in Mathematics, 7th grade (2024)	29.6 points/100 159/265 place	27.6 points/100 181/265 place
Share of illiterate (9+ years, 2021)	135/265 place	151/265 place
Hospital beds per 1000 inhabitants (2023)	6/1000 persons 73/265 place	26/1000 persons 8/265 place
Net migration rate (2020–2024)	−0.3% 186/265 place	−0.1% 152/265 place
Share of working-age population (2021)	67.6% 2/265 place	61.8% 90/265 place
Natural growth rate (2024)	−5.1‰ 32/265 place	−12.9‰ 151/265 place

4.5. Provided Measures in the Territorial Just Transition Plan—Stara Zagora

The TJTP sets out an integrated package of measures aimed at the energy transition and the socio-economic transformation of the region. The strategic focus is on restructuring the Maritsa-Iztok energy complex, which is central to the national power system. A gradual reduction and cessation of coal-mining activities are envisaged, accompanied by land reclamation and repurposing of freed areas.

The infrastructure transformation is the second pillar. The plan foresees low-emission industrial parks, logistics zones and new production activities to replace the dominant coal sector. A flagship example is the conversion of Stara Zagora Airport into a logistics-industrial park, functionally linked to the Radnevo and Galabovo areas, where energy infrastructure is concentrated.

Alongside energy and infrastructure interventions, the plan emphasises the research and innovation built on local capacity. Trakia University, located in Stara Zagora, the

Institute for Sustainable Transition and Development, and other local institutions are conceived as hubs for deploying clean technologies and innovations to accelerate structural transformation and enhance regional competitiveness.

The socio-economic measures aim to support labour transition through reskilling programmes and pathways for workers from mining and TPPs into new sectoral niches. Investments are envisaged in digitalisation, the circular economy (reuse, recycling), and social and technical infrastructure. The development of e-government services, investor incentives, and local competitive advantages is supported as well.

In summary, the Stara Zagora transition combines the controlled decommissioning of coal capacity, land reclamation and repurposing for RES and industry; development of industrial parks and logistics zones; investments in education, research and innovation; and social guarantees for workers and communities—aimed at a smooth and predictable transformation that minimises social costs and maximises long-term regional sustainability.

4.6. Hydrogen as a Strategic Direction for Maritsa-Iztok

Hydrogen technologies are positioned as a strategic vector in the TJTP, with particular significance for the Stara Zagora Region. Within decarbonisation and diversification of the energy mix, green hydrogen is seen as a key energy carrier that can both reduce emissions in industry and transport and preserve the region's energy role after the coal phase-out.

Planned interventions include hydrogen capacity and infrastructure for production, storage and end-use of green hydrogen produced via electrolysis powered by renewables (primarily solar). Technologies target both electricity generation and hard-to-abate industrial processes where alternative solutions are limited. Reclaimed mining lands are expected to be repurposed for such installations, enabling functional reindustrialisation of freed areas.

Hydrogen-economy development is framed as an opportunity for high-tech employment and investment attraction, supported by training programmes and partnerships with Trakia University and the Institute for Sustainable Transition and Development. The goal is to build local capabilities and a sustainable talent pipeline to speed the transformation of an economy strongly dependent on mining and TPPs.

Overall, however, the concept of replacing coal with hydrogen has some drawbacks. As is well known, hydrogen does not exist on its own; on Earth, it is found bound in molecules, most commonly in water and various organic compounds. To extract hydrogen, which can then be used as a combustible gas, energy must be invested in processes to separate the molecules.

One of the prospects outlined for the energy sector is the use of the hydrogen cycle as part of a renewable energy storage system: when there is a surplus of renewable energy, it can be used to separate hydrogen and oxygen from water molecules. The next time there are no suitable conditions for RES operation, the load obtained from burning the accumulated hydrogen is connected to the grid.

Commercial technologies for splitting water molecules are already available, but not on a scale that meets the needs of base loads in an electricity system. The cost of these facilities and operating expenses at the current stage of technological development would not allow for competitive electricity production.

The second part of the concept of hydrogen energy as a substitute for coal is related to the storage, transportation, and combustion of hydrogen. Although the processes were described experimentally more than a century ago, there are currently no technological solutions available for their implementation. There is also no legislation regulating the use of hydrogen for energy purposes. A significant challenge in integrating the hydrogen energy concept is defining specific, measurable criteria for the safe storage, transport, and combustion of hydrogen in quantities sufficient to meet the base and peak loads of the electricity system.

In the Bulgarian context, hydrogen-based technologies could also be linked to the potential transformation of the Maritsa-Iztok energy complex, where existing energy infrastructure and industrial capacity may provide opportunities for future hydrogen-related projects supported by national policy initiatives. In the context of capital-intensive investments such as hydrogen infrastructure, state-owned enterprises represent the most strategic investors due to their robust governance frameworks and superior credit ratings. To date, the RRP of the Republic of Bulgaria, supported by the EC, has allocated approximately €69.9 million (BGN 136.9 million) toward strategic pilot projects and research initiatives. These efforts are specifically directed at enhancing hydrogen production and its technical utilisation within the national energy sector [39].

4.7. Obtaining Energy from Biomass

Biomass is commonly viewed as a near-zero-emission energy source because, although its combustion releases carbon dioxide at levels comparable to fossil fuels, this carbon can be reabsorbed within a generation through the growth of new biomass; however, this balance depends critically on the time lag between immediate emissions and subsequent carbon uptake, often referred to as a carbon debt [45]. In the context of the transformation of the Maritsa-Iztok 2 complex, replacing the coal infrastructure with one designed to utilise wood chips would be economically feasible, as part of the existing infrastructure could be used [15,46]. However, it is necessary to make an additional assessment of the available areas for growing wood and whether there is potential to provide the entire necessary capacity [47]. If a local energy source cannot be secured, the costs and environmental impacts of transporting raw materials will significantly reduce the applicability of this approach [48]. Furthermore, in the long term, the combustion of wood and its derivatives may no longer be considered zero-emission energy production. Secondary wood products obtained as waste from other technologies (furniture production, etc.) alone may not be sufficient to meet large loads [47,49].

The authors of the article "Coal Share Reduction Options for Power Generation during the Energy Transition: A Bulgarian Perspective" elaborate on this possible solution as a pragmatic short-/medium-term option to convert typical units in Maritsa-Iztok (300 MW and 210 MW) to 100% solid biomass—wood chips from fast-growing species, e.g., Paulownia, which would require an area of about 0.22% of Bulgaria's territory [50].

4.8. Flexible, Safer, and More Affordable Low-Carbon Nuclear Power Reactors

The SMRs, although an innovative concept, generate energy based on well-known and proven technological solutions for implementing nuclear fission reactions [51]. Nuclear safety and radiation protection systems have been refined over the years of operation of nuclear reactors of different capacities and operating on different physical principles (pressurised water reactors, gas-cooled reactors, boiling water reactors, breeder reactors, etc.). Bulgaria has a 50-year tradition in nuclear energy and a regulatory framework that would allow for the relatively rapid implementation of small modular reactors in the country. It is important to note that the existing regulatory framework could not be directly applied for licencing of SMRs, but it is a legislative basis for future updates if the national plans drive in this direction [52]. In the context of the transformation of our coal-based energy sector, SMRs could offer a solution for complete decarbonisation by 2040, including the integration of other aspects of sustainable development, for example, through the use of existing infrastructure [53]. There are three main challenges to the idea of replacing coal-fired power plants with small modular reactors: the high initial capital investment, the lack of complete public confidence in their safety, and different radioactive waste management issues [54].

TPP and traditional nuclear reactors need many workers and offer stable jobs, but they are expensive to operate because of the large staff required. SMRs, on the other hand, use modern automation and modular designs, so they need fewer people on site and can run more efficiently. This does not remove the need for workers—it simply changes what skills are needed. Table 2 compares the number of staff needed for coal, nuclear and SMR power plants.

Table 2. Workers for coal, nuclear, SMR. Own work based on SMR 300 Product Data [55], 265 Obshtini [44] and International Atomic Energy Agency (IAEA) [56].

Plant/Type	Capacity (MW)	Employees	Workers Per MW
Maritsa-Iztok 2	1620	~2400 (TPP only)	1.48
Kozloduy NPP	2000	~3706	1.85
SMR (i.e., Holtec twin 2 × 300 MW)	600	~270	0.45

Moving to SMRs means training people in new areas like digital systems, remote monitoring, and modern nuclear technologies, so special reskilling and training programmes will be important for a smooth transition [57]. This also outlines challenges in front of SMRs implementation due to social factors like unwillingness to retrain and involvement in qualification courses of the affected employees [58].

4.9. RES and BESS

The renewables and the battery energy storage systems are another potential scenario to replace the TPPs with a system of renewable energy sources, particularly photovoltaic installations, for energy generation and battery installations for energy storage and to compensate for the lack of production at night.

This concept has several serious drawbacks:

1. A very high share of variable renewable generation may create challenges for frequency stability and system balancing if not supported by sufficient storage capacity, grid flexibility, or backup generation [59].
2. Although energy storage technologies such as battery systems and pumped hydro storage are already deployed, their large-scale implementation remains limited by high investment costs and system integration challenges [60].
3. There are limited practices in place for managing the waste generated by these technologies, which also have a significantly shorter operational life (20–30 years, compared to 60+ for nuclear reactors) [61].
4. Renewable energy systems generally require fewer workers during the operational phase than traditional power plants. However, employment effects may vary across the value chain, including manufacturing, installation, and maintenance activities [62].

4.10. Suggestions for the Alternative Direction of the Region's Strategic Development

The advent of technological progress has made feasible the transformation of this greenhouse gas into high-value products, a process that simultaneously reduces emissions and creates new markets [63].

In this context, two primary approaches can be distinguished, based on different technologies:

Carbon capture and utilisation (CCU)—the process of capturing CO_2 and subsequently utilising it as a raw material for the production of chemical compounds, energy carriers, or synthetic fuels.

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Carbon Capture and Storage (CCS) is a process that involves the transportation and storage of liquefied carbon dioxide (CO_2) in geological formations. The primary objective of CCS is to isolate CO_2 from the atmosphere permanently.

Divergent philosophies characterise the two technologies. CCS is oriented towards the long-term underground storage of carbon, while CCU aims to close the industrial carbon cycle through repeated utilisation. CCU can be regarded as a strategic alternative for the Maritsa-Iztok complex, as it successfully combines environmental and economic benefits [64].

On a global scale, a significant number of countries are currently engaged in the development of programmes within this field. Germany, for instance, funds 33 joint projects with a budget in excess of EUR 100 million [65] within which pilot and demonstration plants are already in operation. The production of polyols for construction foams is undertaken in Dormagen, while synthetic fuels are manufactured in Werlte, Stuttgart and Dresden. Furthermore, the direct utilisation of carbon dioxide (CO_2) is already well-established in several industrial contexts, including the production of carbonated beverages, fire extinguishers, and dry ice. However, these applications represent a relatively minor proportion of the overall industrial output. The range of CO_2 utilisation applications is summarised in Table 3.

Table 3. Summary diagram of technologies for utilising CO_2 generated by industrial facilities. Own work.

Application Area	Examples
Food and Beverage Industry	Carbonated drinks
Biological Conversion	Algae; Greenhouse gases
Plastics Production	Polycarbonates; Polymers
Minerals Production	Carbonates
Fire Protection Equipment	Fire extinguishers
Enhanced Oil Recovery	Oil; Natural gas
Extraction Agent	Flavour enhancers; Aromatizers; Decaffeinators
Coolant	Refrigerants; Dry ice
Chemical Industry	Methanol; Urea; CO; Methane; Liquid fuels; Fertilisers; Secondary chemicals
Inert Agent	Inert gas in the textile industry; Protection of carbon coatings; Welding in protective atmosphere
Other Applications	Injection in metal castings; Additive to medical O_2 as a respiratory stimulant; Filling vials under pressure; Dry ice pellets as abrasive material

The International Energy Agency reported that CO_2 emissions from energy-producing enterprises reached 32.5 Gt in 2017, an increase of 1.4% from the previous year. Concurrently, the utilisation of this material is limited to 0.15 Gt globally [63]. This underscores the strategic significance of on-site local CCU technologies in power plants (thermal, combined heat-and-power, and condensation), as they obviate the costs of transporting and storing substantial volumes of gas.

The most promising technologies, with minimal socio-economic side effects for the Maritsa-Iztok region, are those for the chemical transformation of CO_2 into reagents (such as urea), liquid and gaseous fuels, as well as polymers and polycarbonates. Such processes have been shown to reduce carbon emissions and to offer sustainable market solutions that combine ecological and economic benefits [66]. A notable example is the Steelanol project of ArcelorMittal in Ghent, Belgium, where captured industrial carbon emissions are converted into ethanol and chemical products [67].

5. Policy Implications

The findings of this study have several implications for policymakers managing the transition of coal-dependent electricity systems. First, the transformation of coal-based regions requires coordinated regional development strategies that combine energy policy with labour-market and social policies. In regions such as Stara Zagora, where local economies are strongly dependent on coal mining and thermal power plants, targeted workforce reskilling programmes and economic diversification initiatives will be essential in order to mitigate potential social disruptions.

Second, long-term investment planning will play a critical role in enabling the transition to low-carbon electricity generation. The feasibility of different technological pathways—including renewable energy systems with storage, hydrogen technologies, biomass conversion, small modular reactors, and carbon capture solutions—depends not only on technological readiness but also on access to financial resources, regulatory stability, and coordination between national and European policy frameworks.

Third, the transition process requires transparent governance and effective stakeholder engagement. Public trust and community participation are particularly important in regions where energy infrastructure has historically been a major source of employment and regional identity. Policies that integrate social dialogue, local participation, and clear communication strategies are therefore essential for ensuring that the transition remains socially acceptable.

6. Conclusions

The transition of Bulgaria's electricity sector presents complex economic, environmental, and social challenges that reflect the broader difficulties faced by coal-dependent energy systems across Europe. This study analysed the sustainability of the Bulgarian electricity sector through an integrated framework based on the three pillars of sustainable development—economic performance, environmental impact, and social implications—focusing particularly on the role of state-owned energy companies.

The analysis shows that coal-based thermal power plants face increasing structural pressures resulting from the tightening regulatory framework associated with European climate policies and the rising costs of carbon emissions under the EU Emissions Trading System. These factors significantly affect the long-term economic viability of lignite-based electricity generation. At the same time, coal-based power plants remain deeply embedded in regional labour markets and local economies, particularly in the Maritsa-Iztok region, where energy production continues to play a central socio-economic role.

In contrast, nuclear power generation demonstrates relatively stable economic performance and low operational emissions, making it an important component of Bulgaria's current electricity mix. However, future investment decisions in nuclear technologies, including small modular reactors, involve significant financial, technological, and regulatory considerations that require careful evaluation.

The study also examined several possible technological pathways for the transformation of carbon-intensive electricity production. These include renewable energy systems combined with energy storage, hydrogen-based technologies, biomass conversion, carbon capture solutions, and advanced nuclear technologies such as small modular reactors. Each of these options presents specific advantages and limitations in terms of technological maturity, investment requirements, environmental performance, and potential social implications. No single technological pathway can independently address the transition challenge. Consequently, the transition of Bulgaria's electricity sector is unlikely to rely on a single technological solution but will instead require a diversified and flexible energy strategy.

From a policy perspective, the results highlight the importance of coordinated strategies that combine energy policy with regional development and labour-market policies. The transition process will require targeted workforce reskilling programmes, economic diversification initiatives in coal-dependent regions, and long-term investment planning in low-carbon energy infrastructure. In this context, state-owned energy companies will play a particularly important role, as their strategic investment decisions will strongly influence the direction and pace of the national energy transition.

The findings of this study may also be relevant for other countries in Central and Eastern Europe where coal-based electricity generation and state ownership remain important features of national energy systems. The Bulgarian case illustrates that successful energy transitions require not only technological transformation but also institutional capacity, regional development policies, and inclusive governance mechanisms capable of addressing the social dimensions of structural economic change.

Ultimately, the transition of Bulgaria's electricity sector should not be understood solely as a technological substitution of carbon-intensive generation but rather as a broader structural transformation involving regional economies, labour markets, and institutional governance. Ensuring that this transformation remains economically viable, environmentally sustainable, and socially acceptable will be one of the key policy challenges facing the Bulgarian energy sector in the coming decades.

These findings may also provide useful insights for other coal-dependent energy systems in Central and Eastern Europe undergoing similar transition processes.

Future research could expand the analysis through scenario modelling and stakeholder-based empirical studies in order to evaluate alternative transition strategies under different technological and policy assumptions. Such approaches would further contribute to understanding how coal-dependent energy systems in Central and Eastern Europe can achieve a socially balanced and economically viable decarbonisation pathway.

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Abbreviations

The following abbreviations are used in this manuscript:

BEH	Bulgarian Energy Holding
BESS	Battery Energy Storage Systems
CCU	Carbon Capture and Utilisation
CCS	Carbon Capture and Storage

CO_2	Carbon Dioxide
ETS	Emissions Trading System
EU	European Union
EUA	European Union Allowance
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IBEX	Independent Bulgarian Energy Exchange
MW	Megawatt
MWh	Megawatt-hour
NSI	National Statistical Institute
NPP	Nuclear Power Plant
PV	Photovoltaic
RES	Renewable Energy Sources
RRP	Recovery and Resilience Plan
SD	Sustainable Development
SMR	Small Modular Reactor
SOECs	State-Owned Energy Companies
TPP	Thermal Power Plant
TJTP	Territorial Just Transition Plan
VVER	Water-Water Energetic Reactor

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