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Original scientific paper

ANALYSIS OF PRODUCTION CAPACITIES AND SUSTAINABILITY OF THE ENERGY SECTOR OF THE REPUBLIC OF NORTH MACEDONIA USING THE ENERGYPLAN SOFTWARE

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A b s t r a c t: The energy sector of the Republic of North Macedonia faces considerable challenges in achieving sustainable transition and reducing greenhouse gas emissions. Using the EnergyPLAN software, various scenarios were analyzed to evaluate the potential for a complete phase-out of coal and oil-fired thermal power plants, replaced by renewable sources and new natural gas cogeneration plants. The results indicate that increasing the share of renewables significantly enhances energy security and contributes to CO_2 emissions reduction, aligning with set climate targets. These findings highlight the need for a strategic approach to modernizing the energy sector, which would foster long-term sustainability, reduce dependence on energy imports, and enable greater energy independence for North Macedonia.

Key words: CO_2 emissions; EnergyPLAN; energy sector; renewable energy sources; sustainable development

АНАЛИЗА НА ПРОИЗВОДСТВЕНИТЕ КАПАЦИТЕТИ И ОДРЖЛИВОСТА НА ЕНЕРГЕТСКИОТ СЕКТОР НА РЕПУБЛИКА СЕВЕРНА МАКЕДОНИЈА СО ПРИМЕНА НА СОФТВЕРОТ ENERGYPLAN

А п с т р а к т: Енергетскиот сектор на Република Северна Македонија се соочува со значителни предизвици во насока на одржлива транзиција и намалување на стаклениčките гасови. Користејќи го софтверот EnergyPLAN, анализирани се различни сценарија за целосно исклучување на термоцентралите на јаглен и мазут со нивна замена со обновливи извори и нови когенеративни постројки на природен гас. Резултатите покажуваат дека зголемувањето на уделот на обновливите извори значително ја подобрува енергетската сигурност и води до намалување на емисиите на CO_2 за поставените климатски цели. Овие наоди нагласуваат потреба од стратегиски пристап кон модернизацијата на енергетскиот сектор, кој ќе ја поттикне долгорочната одржливост и ќе ја намали зависноста од увоз на енергија, овозможувајќи поголема енергетска независност за Македонија.

Клучни зборови: емисии на CO_2; EnergyPLAN; обновливи извори на енергија; одржлив развој; енергетски сектор

1. INTRODUCTION

The energy sector in North Macedonia faces significant challenges in its transition towards renewable energy sources, aiming to reduce greenhouse gas emissions and enhance energy independence [1]. Within the global context of sustainable development efforts, transforming national energy systems is essential, especially in countries highly dependent on fossil fuels [2]. North Macedonia strives to reduce emissions through a strategy focused on expanding the share of renewables, posing both technical and economic challenges for the country [3].

Previous studies on energy transition in North Macedonia focus on analyzing various scenarios and methods for integrating renewables using different simulation models.

Čosić, Krajačić, and Duić [4] analyze the potential for a 100% renewable energy system in North Macedonia by 2050, utilizing the EnergyPLAN model to simulate scenarios of 50% and 100% renewable sources. The results show that such a transition would require substantial investments in infrastructure and energy storage technologies yet would significantly reduce carbon emissions and increase energy independence.

A study published by the Macedonian Academy of Sciences and Arts [5] highlights how degraded and unused agricultural land could be repurposed for solar and wind installations, allowing for a significant increase in renewable energy production without altering natural resources. By fully utilizing these areas, North Macedonia could achieve high energy independence, reducing import dependency and enhancing system stability.

The paper "Assessment of Solar and Wind Energy Resources in Serbia" [6] evaluates the potential for solar and wind energy in Serbia by analyzing meteorological data and identifying optimal regions for renewable sources. The complementarity of these resources offers stability potential for energy systems relevant to similar systems such as North Macedonia's.

Lazova and Šešo [7] analyze North Macedonia's energy capacity, emphasizing the importance of developing infrastructure for renewable sources and introducing cogeneration plants. Their study evaluates scenarios for increasing the share of renewables, assessing impacts on system stability and the potential to reduce import dependency. The research suggests that proper planning and development of renewable energy infrastructure could significantly contribute to the country's energy independence and long-term system stability.

In their study, Mijakovski, Lutovska, and Mojsovski [8] examine the impact of the European energy crisis on North Macedonia, exploring measures to strengthen energy security through the integration of renewables. The findings indicate that expanding solar and wind capacities could substantially reduce import dependence and contribute to the stability of the energy sector.

This research aims to analyze the possibilities for the gradual phase-out of coal- and oil-fired power plants in North Macedonia by replacing them with renewable sources and new natural gas cogeneration plants. Using the EnergyPLAN software, detailed simulations of renewable integration scenarios are conducted to assess impacts on energy security, economic viability, and emissions reduction. Transitioning to renewable sources not only reduces imports but also contributes to economic stability by efficiently utilizing domestic and natural resources.

2. METHODOLOGY

The research employs a quantitative analysis method using EnergyPLAN software, designed to evaluate national energy systems and optimize energy resource distribution. EnergyPLAN facilitates the integration of renewable sources and assesses impacts on energy security, stability, and CO_2 emissions, providing iterative adjustments toward efficient, optimal solutions. This methodology is particularly suitable for modeling energy transitions in countries with systems similar to North Macedonia's.

Primary data sources include annual reports and databases from the Energy Regulatory Commission [9–13], AD ESM [14], and AD EVN [15], covering capacity, production, and energy imports-exports. The collected data span installed capacities (renewable and non-renewable), energy and fuel import-export figures (e.g., coal, natural gas, oil), fuel prices, electricity production, and consumption, as well as seasonal and daily demand variations. Additionally, information on consumption patterns across sectors enables an in-depth analysis of demand dynamics and resource allocation.

Data collection methods consist of reviewing reports from relevant institutions, accessing national and international databases, and analyzing official statistics, ensuring comprehensive and reliable data for simulations.

The analysis spans the years 2019 to 2023, capturing the impact of significant events on the energy sector, such as the COVID-19 pandemic and the Russia-Ukraine conflict, both of which have affected energy demand and supply. The pandemic led to reduced industrial and transport demand, accompanied by a rise in household energy use [16]. The conflict, on the other hand, has created global resource shortages and sharp price increases, underscoring the need for diversification and a transition to renewable sources [17].

Based on this analysis, two alternative scenarios are defined. Both involve constructing the Čebren pumped storage hydropower plant to balance the

electricity supply during high demand or low renewable generation. The scenarios differ regarding thermal power plant roles: in the first, one unit of the REK Bitola thermal plant remains operational as the sole active coal and oil-fired capacity; in the second, all thermal plants are retired, with coal fully replaced by renewables and new gas-based cogeneration.

Each scenario is examined from two perspectives: one prioritizes continuous operation to meet total energy demand, while the other focuses on economic viability, operating only when most cost-effective. The economic assessment considers the following costs: Čebren pumped storage – €1 billion, coal – €4/GJ, natural gas – €19/GJ, biomass – €9/GJ, €230 million for the new gas cogeneration plant, €790 million for new wind turbines, and €741 million for photovoltaic panels. A detailed descripttion of the scenarios is provided in Table 1.

T a b l e 1

Installed capacities of energy sources in N. Macedonia: actual capacities and two alternative scenarios

2023						
CHP	TPP	Dammed Hydro	HPP River Hydro	Pumped Back	Wind	PV
287.41	1034	557.4	162.4	0	72.8	310
Scenario 1:						
CHP	TPP	Dammed Hydro	HPP River Hydro	Pumped Back	Wind	PV
287.41	233	1015	162.4	458	600	1000
Scenario 2:						
CHP	TPP	Dammed Hydro	HPP River Hydro	Pumped Back	Wind	PV
487.41	0	1015	162.4	458	600	1000

3. RESULTS AND DISCUSSION

The analysis compares real data on North Macedonia's energy status, provided by the Energy Regulatory Commission, with theoretically possible scenarios simulated in EnergyPLAN. This comparison provides a detailed understanding of current opportunities for reducing imports by increasing domestic electricity production, as well as the potential for lowering CO_2 emissions. Through the additional two proposed alternative scenarios, the key role of renewable sources in the transition toward energy independence is also identified, contributing to the sector's long-term stability and sustainability.

The production of thermal energy from cogeneration plants and heating stations in Macedonia exhibits notable fluctuations throughout the analyzed period. These variations are attributed to several factors, including the growing demand for thermal energy, the condition of energy facilities, and the influence of policies aimed at promoting energy efficiency and the use of renewable sources. Simulations reveal that cogeneration plants possess significant potential to increase real production levels, with 2021 marking the highest recorded output compared to other years (Figure 1).

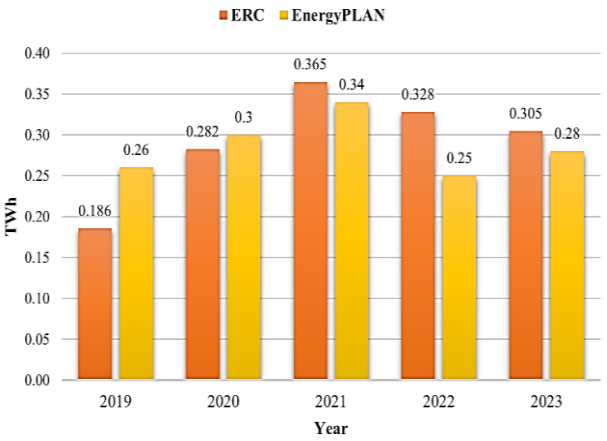


Fig. 1. Heat production from cogeneration plants during the analyzed period

This trend is crucial to the country's long-term energy strategy, as increased production from cogeneration sources may contribute to achieving energy independence and enhancing system stability. Additionally, heating stations, as traditional sources of thermal energy, continue to play a substantial role, although their contribution varies depending on market conditions and regulatory policies (Figure 2).

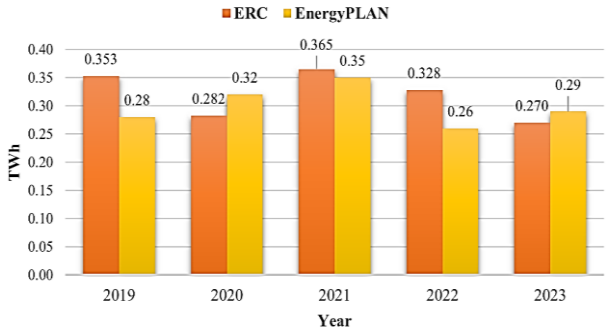
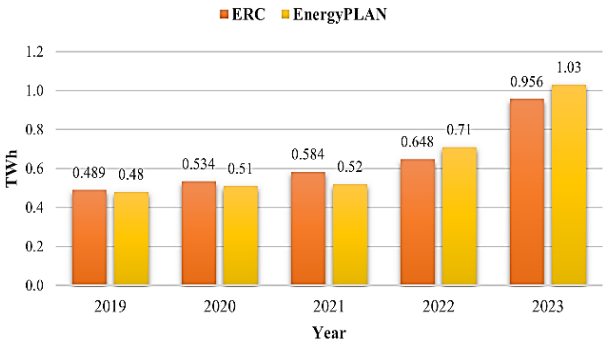
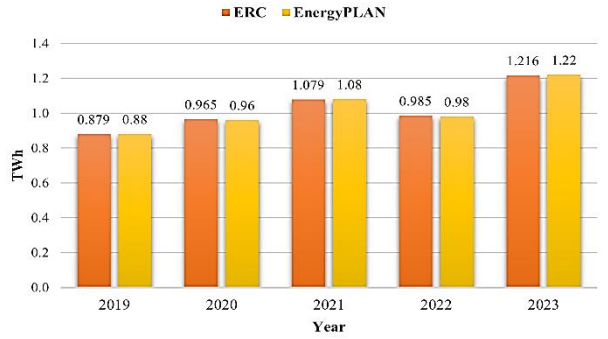


Fig. 2. Heat production from heating plants during the analyzed period

Electricity production from renewable sources and hydropower plants in Macedonia showed substantial growth over the analyzed period, particularly notable in 2023. This upward trend reflects ongoing investments and policy shifts favoring renewable technologies. Figure 3 illustrates this progress, highlighting increased energy generation from hydropower, wind, and solar sources. The 2023 peak production, the highest compared to previous years, underscores the effectiveness of strategies aimed at diversifying the energy mix. These results suggest Macedonia is gradually achieving its environmental goals, energy independence, and sustainable development, reducing reliance on fossil fuels and energy imports.



a) Electricity production from PV and wind



b) Electricity production from hydropower plants

Fig. 3. Electricity production from renewable sources during the analyzed period

According to data provided by the Energy Regulatory Commission, electricity production from thermal power plants and cogeneration facilities in North Macedonia has not demonstrated a clear trend of decline from 2019 to 2023. However, simulations conducted using the EnergyPLAN software indicate a potential decrease in production due to the gradual reduction in fossil fuel use and the shift toward more sustainable energy sources (Figure 4).

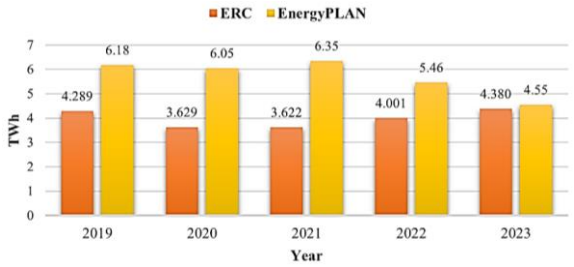


Fig. 4. Total electricity production from thermal power plants and cogeneration plants

These projections align with global and local decarbonization efforts in the energy sector, resulting in significant reductions in CO_2 emissions (Figure 5). This positive impact represents a critical step toward achieving the country's climate goals, supporting the global fight against climate change, and positioning

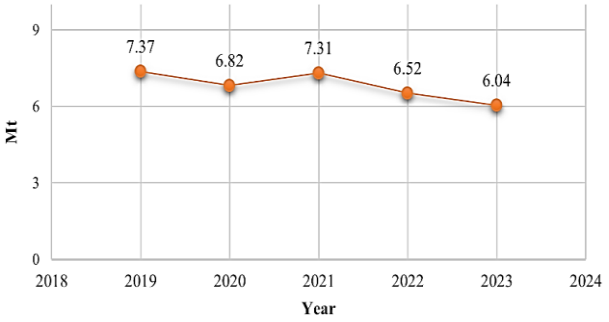


Fig. 5. CO_2 emissions from the energy sector in Macedonia during the analyzed period

North Macedonia is an active participant in global sustainability initiatives. Despite these projections, simulations suggest that thermal power plants and cogeneration facilities will continue to play an essential role in ensuring energy stability, particularly during periods of increased electricity demand or limited capacity from renewable sources.

Electricity imports, as depicted in Figure 6, have shown a steady decline, reaching their lowest point in 2023. Data indicate that electricity imports

dropped by 89.9% in 2023 compared to 2019, decreasing from 1.826 TWh in 2019 to just 0.185 TWh in 2023. This trend is particularly significant as it reflects North Macedonia's growing energy independence, achieved through increased domestic production and enhanced energy efficiency.

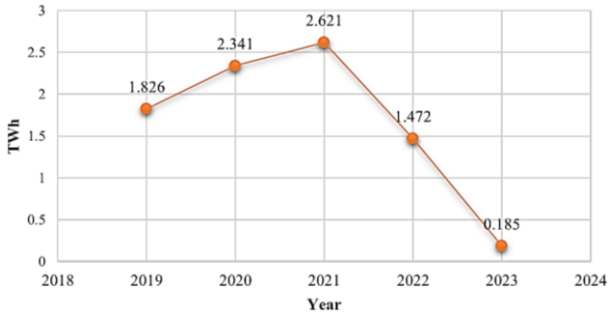


Fig. 6. Graphical representation of the trend in the reduction of electricity imports

The comparative graphs between the actual electricity generation from cogeneration plants and thermal power stations and the theoretically possible and necessary output, as shown in the software simulations, further highlight the system's reliance on electricity imports as a function of thermal power production. These graphs reveal that in years where the gap between actual production from cogeneration and thermal plants and the projected levels in the simulations is the greatest, a heightened need for electricity imports arises. This suggests that although cogeneration plants and thermal power stations have adequate capacity, various factors have prevented them from producing sufficient energy to fully meet the system's demands.

The two alternative scenarios for Macedonia's energy future reveal a strong potential for achieving full energy independence by increasing the use of renewable sources and optimizing existing capacities. Each scenario includes the installation of 600 MW of wind and 1000 MW of photovoltaic capacity, part of which is already underway. The first scenario involves the operation of a single unit from the REK Bitola plant (233 MW), providing a stable supply without imports and generating 0.66 TWh for export. The second scenario proposes the replacement of all coal capacities with a 200 MW gas cogeneration plant, allowing for 0.34 TWh in exports (Figure 7). Additionally, both scenarios anticipate the construction of the Čebren hydropower plant (458 MW), adding to supply and export potential.

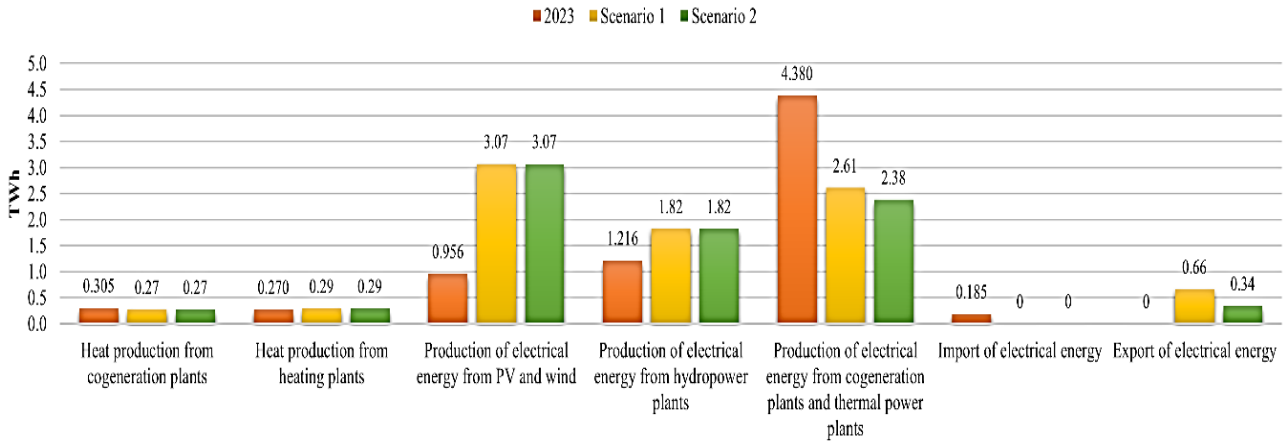


Fig. 7. Comparison of production capacities in the energy sector in Macedonia (2023 and Scenarios 1 and 2)

In the first scenario, CO_2 emissions would be reduced by 29%, while in the second, emissions would drop by 30.3% compared to 2023 levels (Figure 8), highlighting environmental and economic benefits, particularly concerning potential carbon taxes. These results indicate that Macedonia could make a significant contribution to the global fight against climate change while strengthening its energy stability and reducing costs associated with energy imports.

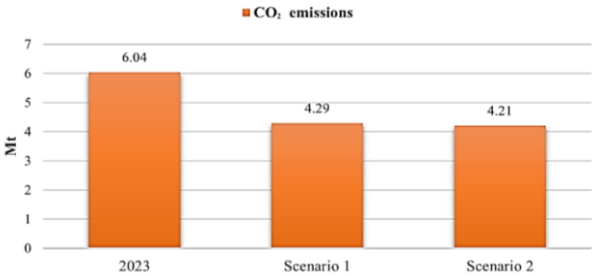


Fig. 8. Comparison of CO_2 emissions after the implementation of the two alternative scenarios

When analyzing the proposed scenarios from an investment perspective, where production capacities are activated only during the most economically viable periods, the results reveal significant challenges. The limited capacity of North Macedonia's existing distribution grid cannot adequately absorb and transmit energy from new installations, particularly renewable sources such as wind and solar. This infrastructure shortfall calls for substantial investment to upgrade and expand the transmission network.

The simulations also indicate that economically driven production increases the need for electricity imports, creating a greater dependency on external sources. To overcome these challenges, investments in the expansion and modernization of the electricity distribution network should be considered, enabling better integration of renewable sources. Such investments would entail increased costs for constructing new transmission lines, and transformer stations and improving systems for managing energy flows.

4. CONCLUSION

Based on analyses conducted for North Macedonia's energy sector from 2019 to 2023, this study reveals significant opportunities for advancing energy independence and reducing greenhouse gas emissions by increasing the use of renewable energy sources. These measures are crucial for achieving the country's climate goals and align with global trends toward decarbonization and sustainability of energy systems. The simulations indicate that North Macedonia has the potential to establish a stable electricity supply and enhance energy security through the achievement of energy independence.

The integration of new capacities, such as the Čebren pumped-storage hydropower plant, wind farms, and solar panels, plays a central role in this transition, yet presents a significant technological and economic challenge requiring substantial investment and support from the government and private sector. The findings also suggest that the addition of new cogeneration facilities could enhance energy stability and security while simultaneously reducing CO_2 emissions, which is essential for meeting national climate targets.

This research confirms the need to intensify efforts to modernize the energy sector and stimulate investments in renewable energy sources. Such measures will not only provide energy independence but will also contribute to the country's economic and environmental sustainability. Additionally, this approach will position North Macedonia as an exemplar of successful sustainable energy transition and increase its resilience to global and regional energy crises.

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