

DECARBONIZATION AS A GLOBAL CHALLENGE FOR A CLEAN ENVIRONMENT

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Abstract

Decarbonization is a fundamental process aimed at reducing greenhouse gas emissions and mitigating climate change. According to the Intergovernmental Panel on Climate Change, global warming is directly linked to anthropogenic carbon dioxide emissions, which highlights the need for a systemic transformation of energy and economic models.

The European Union (EU) is positioning itself as a global leader in decarbonization through the implementation of the European Green Deal and the "Fit for 55" package. On the other hand, the Republic of North Macedonia (RNM), as a country aspiring to EU integration, is actively working to align with European policies for reducing emissions and developing a sustainable energy system. By reducing carbon dioxide emissions, developing renewable energy sources and improving energy efficiency, the country can contribute to the global fight against climate change. The challenges and opportunities for successfully implementing the energy transition, i.e. the transition from fossil fuels to renewable energy sources, are also discussed. It is further indicated that with the right strategy and international cooperation, the Republic of North Macedonia can successfully implement the energy transition and ensure a cleaner and more sustainable future.

The paper aims to analyze decarbonization as a global challenge, with a focus on policies, measures and challenges in the EU and the RNM. The results indicate that successful decarbonization requires an integrated approach, strong institutional support and significant investments in renewable energy sources.

Keywords: decarbonization, climate change, renewable energy sources, energy transition, sustainable development.

Introduction

Climate change is one of the greatest global challenges of the 21st century. The increase in the concentration of carbon dioxide (CO₂) and other greenhouse gases in the atmosphere is leading to global warming, changes in climate conditions and the occurrence of extreme weather events, which have serious consequences for ecosystems, the economy and human health (IPCC, 2023).

Decarbonisation is defined as the process of reducing the carbon intensity of the economy through a transition to renewable energy sources, increasing energy efficiency and developing innovative technologies. This process is key to achieving the goals of the Paris Agreement and limiting global warming to 1.5°C.

The European Union has set ambitious targets to reduce greenhouse gas emissions by at least 55% by 2030 and achieve climate neutrality by 2050. In this context, candidate countries, such as the RNM, are faced with the need to align their policies and economies with European standards. Hence, the RNM actively participates in these global efforts. The country has an obligation to reduce greenhouse gas emissions and modernize its energy system in order to ensure sustainable economic development and a better quality of life for its citizens (Ministry of Economy, 2020).

Climate change represents one of the most serious threats to modern society. The increase in the concentration of greenhouse gases in the atmosphere leads to an increase in global

temperature, extreme weather conditions and degradation of ecosystems. The main source of these emissions is the combustion of fossil fuels in the energy sector, industry and transport. In the context of the above, the paper is composed of two parts. In the first part, the decarbonization process and the activities undertaken for its successful implementation in the EU are analyzed. In the second part, we continue with a description of the measures and activities undertaken by the RNM to participate in the global efforts regarding decarbonization, as a candidate country towards EU integration. The paper continues with a comparative analysis of key indicators between the EU and the RNM, and then the paper discusses the challenges and recommendations. Finally, the paper ends with a conclusion.

Definition and meaning of decarbonization

Decarbonization is the process of reducing or completely eliminating carbon dioxide emissions from economic activities (International Energy Agency, 2022). This process is closely related to the energy transition, i.e. the transition from fossil fuels to renewable energy sources (IRENA, 2022).

The main objectives of decarbonization are (OECD, 2021).

1. reducing greenhouse gas emissions;
2. preventing climate change;
3. improving air quality;
4. developing a sustainable economy;
5. protecting the environment.

The decarbonization process covers multiple sectors such as energy, industry, transport, agriculture and households. Successful implementation of this process requires a combination of technological innovations, policy measures and economic investments.

Decarbonisation in the European Union

3.1 EU policies and objectives: The European Union has established a complex system of decarbonisation policies, the most significant of which are the European Green Deal and the “Fit for 55” package. The European Green Deal is a strategy for transforming the economy into a sustainable, low-emission model (European Commission, 2024). The “Fit for 55” package includes legislative measures to reduce emissions, increase the share of renewables and improve energy efficiency (European Environment Agency, 2025).

The aim is to reduce greenhouse gas emissions by 90% by 2040 and achieve climate neutrality by 2050 (Table 1).

In addition, the EU is investing significantly in research and innovation, with over €5.6 billion in the development of clean technologies, including green hydrogen and solar energy.

The table illustrates the evolution of the European Union’s climate targets in terms of reducing emissions and increasing the share of renewable energy sources.

Table 1. EU decarbonization targets

Year	Reducing emissions	Renewable sources (%)
2020	-20%	20
2030	-55%	40+
2050	Climate neutrality	80-90

Source: (European Commission, 2019); (IEA, 2022); (IRENA, 2022); (Rogelj et al., 2018)

In 2020, the European Union set a target to reduce emissions by 20%, representing an initial step toward the transition to a more sustainable energy system. At the same time, the share of renewable energy sources reached around 20%, indicating a gradual shift away from fossil fuels.

By 2030, the targets become significantly more stringent, with at least a 55% reduction in emissions and an increase in renewable energy sources to over 40%. This is part of the strategy to accelerate decarbonization and align with global climate goals.

The most ambitious target is set for 2050, when the European Union plans to achieve climate neutrality. This implies near-complete decarbonization of the energy sector, with a renewable energy share of 80–90%.

These goals position the European Union as a global leader in the fight against climate change and serve as a model for candidate countries, including RNM.

3.2 Energy transition and renewables: One of the key aspects of decarbonisation in the EU is the shift to renewable energy sources. In recent years, the share of wind and solar energy has increased significantly, with them surpassing electricity from fossil fuels for the first time in 2025.

The EU is actively investing in:

6. solar energy
7. wind energy
8. green hydrogen

The electricity sector plays a central role in decarbonisation, with over 80% of electricity expected to come from renewable sources by 2050 (Table 2).

Table 2. EU Energy Mix Trend

Source: (IEA, 2022)

Year	Coal	Renewable s	Gas
2000	30	10	20
2010	25	20	25
2020	15	35	20
2030	10	50	15
2050	5	80	10

The table presents the dynamics of changes in the structure of the energy mix during the period from 2000 to 2050, with a focus on three main energy sources: coal, renewable sources, and natural gas. The analysis of the data indicates a clear trend of transition from fossil fuels toward cleaner and more sustainable energy sources.

In 2000, the energy system was characterized by a relatively high dependence on coal (30%), while renewable sources had a minimal share of only 10%. Natural gas accounted for 20%, indicating its role as a supplementary energy source within the system. This structure is typical of traditional energy systems based on fossil fuels.

By 2010, a gradual decrease in the share of coal (25%) and a significant increase in renewable sources (20%) can be observed. At the same time, the share of natural gas rose to 25%, indicating its transitional role as a fossil fuel with lower emissions.

In 2020, the decarbonization trend became more pronounced. The share of coal decreased to 15%, while renewable sources reached 35%. This period was characterized by increased investments in solar and wind technologies, as well as the implementation of policies for emissions reduction.

Projections for 2030 show a significant reduction of coal to 10% and an increase in renewable sources to 50%, representing a turning point in the energy transition. Natural gas decreases to 15%, but remains important for maintaining the stability of the energy system.

The most significant changes are expected by 2050, when the share of coal will decline to only 5%, while renewable sources will dominate with 80%. This indicates a nearly complete decarbonization of the energy sector and the achievement of climate neutrality. Natural gas will have a minimal share of 10%, confirming its role as a transitional fuel.

Overall, the table shows a clear long-term trend of reducing dependence on fossil fuels and gradually increasing the share of renewable sources. This process is the result of technological progress, policy measures, and growing awareness of climate change.

3.3 Decarbonizing transport: The transport sector poses one of the biggest challenges, as it is the only sector with growing emissions. The EU has set a target to reduce transport emissions by 90% by 2050, and is promoting electromobility, the development of alternative fuels and the improvement of public transport (IEA, 2022).

Key measures include:

- electrification of vehicles
- development of sustainable fuels
- investment in rail infrastructure

The industrial sector, in turn, is being transformed through:

- digitalisation
- energy efficiency
- circular economy

3.4 Challenges and constraints: Despite progress, the EU faces numerous challenges:

- high investment costs
- resistance from industry and the agricultural sector
- dependence on energy imports

In addition, political and economic factors can slow down the decarbonization process. According to OECD (2023), a balanced policy is needed that integrates economic and environmental objectives.

Decarbonization in the Republic of North Macedonia

4.1 The Energy Sector in the Republic of North Macedonia: The energy sector in RNM has traditionally been based on fossil fuels, especially lignite, which is used to generate electricity (Energy Community, 2023). The main thermal power plants in the country are:

- MPC Bitola
- MPC Oslomej

These power plants play a significant role in the country's energy system, but they are also a major source of air pollution and carbon dioxide emissions (European Environment Agency, 2022).

Therefore, in recent years, measures have been taken to gradually reduce dependence on coal and develop alternative energy sources (World Bank, 2021).

The decarbonization process should mainly take place in the energy sector, in several sectors: buildings (residential, commercial and public), industry, electricity generation and transport. The main goal is to reduce energy needs by increasing energy efficiency and switching from fossil fuels to renewable energy sources (sun, wind and biomass), or so-called clean energy. This energy transition is not a simple matter and will last at least several decades, requiring large financial investments (Risto Tsicsonkov, 2023).

There are many reasons leading to a serious approach towards the initiation of this process within our society. By doing this, Macedonia would intensify its involvement in the worldwide process to 'save the planet from the influence of climate change' according to its possibilities. Despite the fact that our contribution to climate change is incomparably minor compared to highly industrialised countries, it is even more important to participate in the process coupled with the expected influence on a local level (K. Dimitrov & O. Dimitrov, 2016).

The Government of RNM has adopted energy transition strategies and plans that envisage increasing the share of renewable energy sources and improving energy efficiency.

Table 3 presents the structure of the energy mix according to the type of energy sources and their percentage share. The analysis shows that coal has a dominant role with 40%, indicating a significant dependence on fossil fuels. This dependence represents a serious challenge for the decarbonization process, as coal combustion is one of the main sources of carbon dioxide emissions and air pollution.

Table 3. Republic of North Macedonia Energy Mix

Source	Share (%)
Coal	40
Hydro	30
Solar	10
Wind	5
Other	15

Source: (IEA, 2022); (European Commission, 2019); (IRENA, 2022); (Energy Community Secretariat, 2023)

Hydropower ranks second with 30%, indicating a significant role of renewable sources in the energy system. This source provides relatively stable and clean electricity generation; however, its further development is limited due to natural and geographical factors.

Solar energy accounts for 10%, indicating a growing but still underutilized potential. Given the favorable climatic conditions, there is considerable opportunity to increase this share through investments in photovoltaic systems.

Wind energy has the smallest share at 5%, showing that this sector is still in an early stage of development. However, with appropriate investments and policies, wind energy can become an important part of the energy mix.

The category "other" sources, with 15%, includes various forms of energy such as biomass and other alternative sources, contributing to the diversification of the energy system.

Overall, the structure of the energy mix shows that RNM is still significantly dependent on coal, but there is a solid foundation for the development of renewable energy sources. For successful decarbonization, it is necessary to gradually reduce the share of coal and increase investments in solar and wind technologies, as well as improve energy efficiency.

4.2 Development of renewable energy sources: Renewable energy sources are a key element in the decarbonization process. They are energy sources that are naturally renewable and do not produce significant greenhouse gas emissions.

The trend of intensive investment in the construction of power plants using renewable energy sources, which began with the energy crisis in 2022, continued in both 2023 and 2024. The total number of renewable energy power plants as of 2024 amounts to 1,494, with a total installed capacity of 1,663 MW, representing nearly 56% of the total installed capacity within the country (Table 4). As in the previous two years, the majority of newly constructed power plants in 2024 are photovoltaic, namely 345 plants with a total installed capacity of 341.5 MW. The share of thermal power plants in the total installed capacity decreased from 49% in 2020 to 34.65% in 2024, as a result of the large number of new power plants utilizing renewable energy sources. The share of renewable sources in the total installed capacity was 37% in 2020, while in 2024 it reached 55.72% (Table 4).

The increased installed capacity from renewable energy sources has contributed to higher electricity production. The most notable growth is observed in production from photovoltaic plants. In 2023, 298 GWh of electricity were produced, while in 2024 production from this type of power plant reached 851 GWh (Table 4), representing an increase of 186% (ERC of the RNM, 2024).

Table 4. Number of Power Plants, Installed Capacity, and Electricity Generation from Renewable Energy Sources in 2024, by Technology

Type of power plants	Number of power plants	Installed power (MW)	Share (%)	Production (GWh)	Share (%)
Total	1.502	2.984	100%	6.129	100%
TPP	5	1.034	34,65%	2.355	38,43%
TE-TO (Th-H)	3	287	9,63%	1.259	20,54%
RES	1.494	1.663	55,72%	2.514	41,03%
HPP	10	587	19,67%	1.108	18,08%
WPP	3	82	2,76%	194	3,16%
Small HPP	125	133	4,46%	308	5,02%
PVPP	1.348	848	28,40%	851	13,91%

Biogas	7	12	0,40%	53	0,86%
Biomass	1	1	0,02%	0	0%

Source: (ERC of the RNM, 2024)

In North Macedonia, the most significant renewable sources are:

Solar energy: RNM has significant potential for the development of solar energy due to favorable climatic conditions and the large number of sunny days per year. In recent years, several solar power plants have been built, and the installation of photovoltaic panels on households and public buildings is encouraged.

Wind energy: The Bogdanci Wind Farm is the first and largest wind power project in the country and represents an important step in the energy transition process. This park contributes to reducing carbon dioxide emissions and increasing the production of clean energy.

Hydropower: Hydropower plants play a significant role in the electricity system and are one of the oldest renewable energy sources in the country. They use water resources to produce electricity and play a significant role in the stability of the energy system.

4.3 Energy Efficiency: Energy efficiency is an important aspect of decarbonization because it allows for a reduction in energy consumption without reducing economic productivity (OECD, 2021).

Measures to improve energy efficiency include:

- improving the insulation of buildings;
- using energy-efficient appliances;
- modernizing industrial processes;
- using smart energy management systems.

These measures reduce energy costs, increase energy security, and reduce pollution.

Improving the insulation of buildings, using energy-efficient technologies, and modernizing industrial processes are among the most important measures to improve energy efficiency (IEA, 2022).

4.4 Decarbonization of the transport sector: The transport sector is a significant source of greenhouse gas emissions globally (European Environment Agency, 2022). In North Macedonia, most of the transport is based on vehicles that use petrol and diesel.

The following measures are being taken to reduce emissions:

- encouraging the use of electric vehicles;
- improving public transport;
- developing cycling infrastructure;
- using alternative fuels.

These policies contribute to reducing air pollution and improving the quality of life in urban areas. The development of electric vehicles, improving public transport and developing cycling infrastructure are part of the strategies for reducing emissions in the transport sector.

4.5 The role of decarbonization policies and strategies: Successful decarbonization requires clear state policies, strategies and legal frameworks. In recent years, the RNM has adopted several documents defining the country's energy and climate policy.

One of the most important documents is the Energy Development Strategy, which sets the foundations for the long-term development of the energy sector. This strategy envisages a

gradual reduction in the use of coal and an increase in the share of renewable energy sources (Ministry of Economy, 2020).

In addition, the country is working on harmonization with the European Green Deal, which aims for Europe to become a climate-neutral continent by 2050 (European Commission, 2019). This means that RNM should also reduce greenhouse gas emissions and develop a sustainable energy system.

These policies envisage measures such as:

- stimulating investments in renewable energy sources;
- improving energy efficiency in public and private buildings;
- supporting the development of new technologies;
- promoting sustainable transport.

These policies aim to create an economy that is more resilient to climate change and ensures stable economic development.

4.6 Economic and social benefits of decarbonization: Decarbonization is not only an environmental necessity, but also an opportunity for economic development. The transition to clean energy can bring numerous economic and social benefits.

One of the most important benefits is the creation of new jobs. The development of solar power plants, wind farms and other green technologies requires a new workforce and skilled personnel. This can contribute to reducing unemployment and developing new industries.

In addition, decarbonization can lead to:

- reducing energy costs in the long term;
- improving the health of the population due to reduced pollution;
- increasing the energy independence of the country;
- attracting foreign investment.

Improving air quality is particularly important for cities in RNM, where air pollution is a serious problem. In addition, reducing air pollution can contribute to improving the health of the population (World Bank, 2021).

4.7 The role of international cooperation: The decarbonization process requires significant financial and technological resources. Therefore, international cooperation plays an important role in supporting countries undergoing energy transition.

North Macedonia cooperates with several international organizations and institutions such as:

- European Union
- World Bank
- European Bank for Reconstruction and Development
- United Nations

These institutions provide financial support, technical assistance and expertise for the development of projects in the field of renewable energy sources and energy efficiency (United Nations, 2020).

Through this cooperation, numerous projects are being implemented, such as the construction of new solar and wind power plants, modernization of the electricity grid and improvement of energy infrastructure.

4.8 Future Development Perspectives: In the future, the decarbonization process in RNM is expected to accelerate. Technological development, decreasing prices of renewable energy sources and increased awareness of environmental protection will contribute to a faster energy transition.

Some of the main directions for future development are:

- construction of new solar and wind power plants;
- gradual closure of coal-fired power plants;
- modernization of the electricity grid;
- development of smart energy systems;
- increasing energy efficiency in all sectors.

By implementing these measures, RNM can significantly reduce greenhouse gas emissions and contribute to the global fight against climate change.

In the future, an increase in investments in renewable energy sources and a gradual reduction in the use of fossil fuels is expected.

The development of smart energy systems and energy storage will play an important role in the modernization of the energy system.

Discussion

The decarbonization process in the RNM represents a complex transformation of the energy, economic and social system. Although the country has significant potential for the development of renewable energy sources, there are several factors that influence the dynamics of this transition.

One of the most important aspects is the dependence on existing coal-based energy capacities. Thermal power plants have long been the basis of the electricity system and their gradual replacement with renewable sources requires significant financial investments and infrastructure changes.

On the other hand, the development of new technologies such as solar and wind power plants opens up opportunities for diversification of energy sources and reduction of greenhouse gas emissions. However, the integration of these sources into the electricity grid requires modernization of the system and improvement of energy management.

In addition, an important aspect of decarbonization is the social dimension. The transition to a green economy may have an impact on workers in traditional energy sectors, especially in mining. Therefore, it is necessary to implement the concept of a just transition, which will provide new opportunities for employment and retraining of the workforce. In this context, it can be concluded that decarbonization is not only a technological process, but also a social and economic transformation that requires a coordinated approach between the state, the private sector and international institutions.

Comparative Analysis

Table 5 presents a comparative analysis of key decarbonization indicators between the European Union and the RNM.

Table 5. EU vs Republic of North Macedonia

Indicator	EU	RNM
Emissions Reduction Target	55	30
Renewables Share	40	20
Investments Index	90	40

Source: (European Commission, 2019); (IRENA, 2022); (World Bank, 2021)

The European Union has a significantly more ambitious target for reducing greenhouse gas emissions, with a goal of 55%, compared to 30% for the RNM. This difference reflects the EU's greater institutional readiness and financial capacity to implement climate policies.

Regarding the share of renewable energy sources, the EU has a target of 40%, while the RNM has a significantly lower share of 20%. This indicates the need for increased investments in solar and wind technologies within the national energy system.

The investment index further confirms this disparity, with the EU having a value of 90, while RNM has 40. This indicator points to limited access to financial resources and the need for increased international support.

Challenges in the decarbonization process

Despite the benefits, the decarbonization process faces significant challenges.

The most significant challenges are (Energy Community, 2023):

- high investment costs for new energy technologies;
- dependence on existing thermal power plants;
- the need to modernize the electricity grid;
- social consequences for mining workers.

Therefore, careful planning of the energy transition is necessary in order to ensure economic stability and social justice.

Recommendations

In order to successfully implement the decarbonization process in the RNM, it is necessary to take several specific measures and activities.

Firstly, it is necessary to increase investments in renewable energy sources, especially in solar and wind power plants. These technologies have great potential and can significantly contribute to reducing greenhouse gas emissions.

Secondly, it is necessary to improve energy efficiency in all sectors, including industry, transport and households. This can be achieved through the modernization of infrastructure, the use of energy-efficient technologies and increasing public awareness of the rational use of energy.

Thirdly, it is important to develop a modern and stable electricity grid that can integrate a greater share of renewable energy sources. This includes investments in smart grids, energy storage systems and the digitalization of the energy sector.

Fourthly, it is necessary to support education and training programs for the workforce in order to prepare personnel for new green industries. This will ensure a successful social transition and reduce the negative consequences of the closure of traditional energy capacities. Finally,

it is important to continue international cooperation and use the financial instruments and funds provided by international organizations. This will enable faster implementation of projects related to the energy transition and sustainable development.

Conclusion

Decarbonization is a complex and long-term process that requires an integrated approach at the global, regional and national levels. The European Union is a leader in this area, setting ambitious goals and policies, while RNM is making significant steps towards their alignment. Although there are numerous challenges, such as financial constraints and structural weaknesses, the trend of transition to clean energy is inevitable. With the right strategy and international cooperation, the RNM can successfully implement the energy transition and ensure a cleaner and more sustainable future.

With appropriate policies, investments and cooperation, decarbonization can contribute to sustainable development and improve the quality of the environment.

Nomenclature

EEA	European Environment Agency
EU	European Union
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
MPC	Mining Power Combine
OECD	Organisation for Economic Co-operation and Development
RNM	Republic of North Macedonia

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