frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 18 December 2024
DOI 10.3389/fenvs.2024.1353107

OPEN ACCESS

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RECEIVED 09 December 2023
ACCEPTED 07 October 2024
PUBLISHED 18 December 2024

CITATION
Ionescu RV, Zlati ML, Antohi VM, Cristea DS, Petrea ȘM and Forțea C (2024) Modelling the economic and environmental impacts of water resources in the context of climate neutrality in the EUSDR member states.
Front. Environ. Sci. 12:1353107.
doi: 10.3389/fenvs.2024.1353107

Modelling the economic and environmental impacts of water resources in the context of climate neutrality in the EUSDR member states

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Introduction: This study explores the economic and environmental impacts of water resources in the context of achieving climate neutrality in the EU Strategy for the Danube Region (EUSDR). The research is focused on eight EUSDR member states: Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania, and Slovakia, with the aim of analyzing the dynamic relationship between water resources, economic growth, and environmental sustainability. Given the ambitious goals of the European Green Deal, this study examines how water management can support the transition towards climate neutrality.

Methods: A dynamic econometric model was developed using a consolidated database of relevant climate neutrality indicators from 2010 to 2021. The selected indicators included GDP per capita, water use in agriculture, gross water abstraction, sewage sludge production, and water productivity. The econometric model was validated using statistical tools such as the One-Sample Kolmogorov-Smirnov Test, and analysis was conducted using Gretl and IBM-SPSS 25 software.

Results: The findings reveal that water resources management significantly contributes to the achievement of climate neutrality targets. The model achieved over 86% significance in explaining the financial efforts needed to achieve the Green Deal's 2030 and 2050 goals. Moreover, water productivity and investments in water-related infrastructure were found to play critical roles in ensuring the success of these climate policies.

Discussion: The results highlight the importance of policy coordination across the EUSDR member states and the need for increased investment in sustainable water resource management. Achieving climate neutrality requires addressing economic disparities between states and enhancing regional cooperation.

Conclusion: The proposed dynamic model offers a valuable tool for monitoring progress towards climate neutrality, particularly in relation to water resource management. This research underlines the need for targeted policy interventions and investments to meet the Green Deal's goals while safeguarding the region's water resources.

KEYWORDS

blue economy, green deal, water supply, water productivity, energy crisis, circular economy, EUSDR

JEL Classification: C51, Q51, Q54, R11

1 Introduction

Europe has faced successive periods of health, economic and political crisis since 2019. These crises have overlapped with the strategic approaches being implemented and have slowed down, due to their effects (inflation, unemployment, social pressure, etc.) some policies which are significant strategic milestones for good European and global development. One such milestone is the European Green Pact, whose main goal is climate neutrality (European Commission, 2024). The new energy security challenges in the current context are a reason to prioritise the objective, and additional funding measures are needed on the basis of EU growth strategies and the Green Deal (International Renewable Energy Agency, 2023). On 17.09.2020, the European Commission proposed a plan for the progressive reduction of greenhouse gas emissions, which is projected for the medium horizon 2030 and a further horizon 2050. By 2030, the EU aims to reduce greenhouse gas emissions to 55% below 1990 levels across Europe (European Commission, 2020). Climate neutrality is targeted for the 2050-time horizon. At European level, a strategy on adaptation to the impacts of climate change is in place which aims to: improve knowledge of climate change impacts and uncertainty management; strengthen planning and risk assessment measures/actions; accelerate action to adapt to the impacts of climate change; increase overall resilience to the impacts of climate change. The means to achieve the objectives involve strengthening the international policy framework in the areas of climate change and biodiversity and ensuring coherence of European actions and policies with regional actions and policies. To this end, several macro-regions have been established in Europe, such as the EUSDR, the Alpine Region, the Lower Danube Region, the Baltic Region, etc.

The EU Strategy for the Danube Region (EUSDR) is a macro-regional strategy adopted by the European Commission in December 2010 (European Commission, 2010) and endorsed by the European Council in 2011. It aims to address common challenges faced by the countries in the Danube region, fostering cooperation and development across a diverse area spanning from Germany's Black Forest to the Black Sea. The EUSDR covers 14 EU and non-EU countries situated along the Danube River (see Figure 1). These countries collaborate to promote sustainable development, economic growth, and social cohesion in the region.

EUSDR objectives (EU Strategy for the EU Strategy for the Danube Region, 2024) are: enhance connectivity and infrastructure within the Danube area; Improve environmental protection and resource management; Strengthen economic and social development; Foster cultural exchange and cooperation. The strategy involves various stakeholders, including national

FIGURE 1
EUSDR states. *Source Authors contributions using* (Minas Giannekas, 2024)

governments, regional authorities, civil society, and international organizations. It focuses on specific priority areas such as transport, energy, environment, culture, and education. Within the study, we will focus in particular on the EUSDR region (European Commission, 2010) because within this region there is a marked polarisation of states, some of which are more able and prepared to achieve Green Deal compliance, while others have a lower economic status, which slows down the macro-region's contribution to Green Deal policy compliance.

The eighth Environment Action Programme (EAP), completed in January 2022, aims at common Green Deal objectives, namely,: reducing greenhouse gas emissions; adapting to climate change; a pattern of growth that gives more back to the planet than it takes; achieving zero pollution; protecting and restoring biodiversity; reducing the main environmental and climate pressures related to production and consumption. The eighth EAP is linked to the budget of the LIFE Programme 2021–2027 which aims to: contribute to the transition to a clean, circular, energy-efficient, low-carbon and climate-resilient economy, including through the transition to clean energy; protect and improve the quality of the environment; halt and reverse biodiversity loss, thus contributing to sustainable development.

The scope of this research includes water resources as a driver of economic welfare through the blue economy. The EUSDR region benefits from important water resources that need to be sustainably exploited to protect aquatic ecosystems. Water resources are strongly influenced by climate change and the industrial and agricultural structure of each country. Water resources analysis should be carried out in connection with wastewater generation and disposal. By volume, these indicators can express the level of water pollution in each EUSDR Member State and the need for action to reduce pollution and improve water quality.

An limit to the research was the lack of statistical reporting on wastewater generation and volume, such as in Germany and Hungary. The objectives of the research are based on the proposed goal of developing a dynamic model of the economic and ecological impact of water resources in the context of climate neutrality in the EUSDR Member States. Our approach takes into account concrete Green Deal objectives such as: Increasing the EU's Climate ambition for 2030 and 2050; Supplying clean, affordable and secure energy; A zero pollution ambition for a toxic-free environment; Preserving and restoring ecosystems and biodiversity; Financing the transition, and sets the following *specific research objectives*:

O1: Study of climate protection models presented in the current literature in line with the challenges induced by economic, health, political and energy crises.

O2: Establishment of a consolidated database at EUSDR Member State level with relevant indicators related to the concrete Green Deal objectives outlined above.

O3: Dynamic modelling of the economic and ecological impact of water resources in the context of climate neutrality.

O4: Model testing and validation.

O5: Dissemination of Green Deal compliant results and policies to be applied in the EUSDR macro-region.

The research continues with the presentation of the literature review, methodology, results and discussion, concluding with proposals and conclusions relevant to the purpose of the research.

2 Literature review

The literature takes a multi- and cross-disciplinary approach to the Green Deal, including economic activities within the blue economy.

The Web of Science database was searched for the following areas of interest: Blue economy; Green Deal; water supply; water productivity; energy crisis; Ukrainian war; and EUSDR.

The research revealed an increased interest in the blue economy domain, i.e., a number of 427 articles in the cluster connection, of which 18 were on blue economy, blue growth or blue economic zone. The reference period for the research is 2006–2022 and the number of citations for the studies considered exceeds the average of 18 citations per article (Figure 2).

In the case of the Green Deal, a total of 420 articles published between 2006 and 2021 were searched in the Web of Science database. The main branch highlighting European Green Deal, Green growth, green management, and green economy centralizes a number of 44 titles, the distribution of the clusters is shown in Figure 2.

2.1 Study of climate protection models presented in the current literature in line with the induced economic's challenges

Adelaide (Australia) represents an urban area with an impressive blue water footprint of urban green spaces as defined by Nouri et al. (Nouri et al., 2019). This creates a conflict between the need to create green cities and the consumption of limited water resources. The research makes an estimate of the blue water footprint (WF) of urban greenery, based on total water consumption per 10-ha parkland in Adelaide. The analysis makes comparisons between monthly water consumption and concludes that an integrated adaptive management strategy is needed.

Analysis of the efficiency of water companies is carried out by Walker et al. (Walker et al., 2019). The authors note that there are many exogenous factors that cannot be quantified in the evolution of these water companies. The research carries out a comparative analysis of the efficiency across a sample of water and sewage companies for 13 water and sewage companies in the UK and Ireland.

A study in Spain by Espinosa-Tasón et al. (Espinosa-Tasón et al., 2020) considers subsidies to water-saving infrastructure due to the economic crisis in connection with the development of irrigated agriculture. The authors find that water abstraction decreases while water consumption increases. Alongside this process, energy consumption for irrigation has also increased due to the use of alternative watering sources such as desalination. A similar approach is taken by Vargas and Paneque (Vargas and Paneque, 2019).

Environmental degradation entails costs for public administrations in the field of environmental protection including water resources. A study in this area covers 9 European economies over the period 1995 to 2014 and is conducted by Basoglu and Uzar (Basoglu and Uzar, 2019). The authors conclude that total public expenditures increase the ecological deficit while environmental expenditures decrease it.

The use of the Monte-Carlo method for weight allocation Water Quality Index is performed by Seifi et al. (Seifi et al., 2020) in order to assist management decision making in the field under uncertainty. This uncertainty is associated with establishment of probabilistic weight values for WQI. The authors develop four scenarios of water quality guidelines and the weights that recommended as the functions of proposed standards which cover Kerman aquifer region from Iran.

Sustainable development in the context of corporate social responsibility (CSR) and the strategies implemented by organizations to disseminate their business actions is approached by Murillo-Avalos et al. (Murillo-Avalos et al., 2021). The authors place great emphasis on transparency in the field of CSR and use a sample of 80 large companies and 67 multinational enterprises. The main conclusion of this analysis is that more than 50% of environmental indicators are not disclosed by large companies.

Rainwater, greywater, and groundwater considered as alternative water resources are studied by Burszta-Adamiak & Spychalski (Burszta-Adamiak and Spychalski, 2021). The analysis covers a period of 3 years, covers the field of sport and has as its main outcome the idea that environmental and financial benefits resulting from the exploitation of alternative water sources can be achieved. The carried out analysis is based on specific assumptions related to water consumption for athletes and alternative water sources (rainwater and groundwater).

An interesting connection between optimal scale of pollution, local initial endowment, economic investment capital and the marginal cost of environmental pollution caused by government's economic activities is proposed by Chou et al. (Chou et al., 2021). The authors note that a significant impact occurs on the decline in the scale of pollution when the government implements environmental protection and water price policy measures.

Cap-and-trade systems are market mechanisms that set a cap on total greenhouse gas (GHG) emissions and allow entities to buy and sell emission permits within that cap(Lessmann and Kramer, 2024). These systems are designed to provide maximum economic flexibility in achieving emission reduction targets while encouraging innovation and energy efficiency (Schmalensee and Stavins, 2017).

Carbon reduction models, such as cap-and-trade systems and carbon taxes, are recognised for their ability to address climate challenges through efficient economic mechanisms. These models are supported by an extensive literature exploring their effectiveness, economic impacts and policy and social implications.

Cap-and-trade systems set a cap on total greenhouse gas emissions and allow entities to buy and sell emissions permits within that cap. Studies show that cap-and-trade systems are effective in reducing emissions by creating a carbon price and encouraging technological innovation.

In a recent study the authors Cai & Jiang (Cai and Jiang, 2023) construct a low-carbon supply chain model consisting of a supplier and a producer under three power structures: supplier-led power structure, producer-led power structure, and competing Nash power structure. Based on differential game theory, the authors explore the optimal pricing and carbon abatement decisions of supply chain members, taking into account the impact of consumer preference for low-carbon products, cap-and-trade regulations, and the power

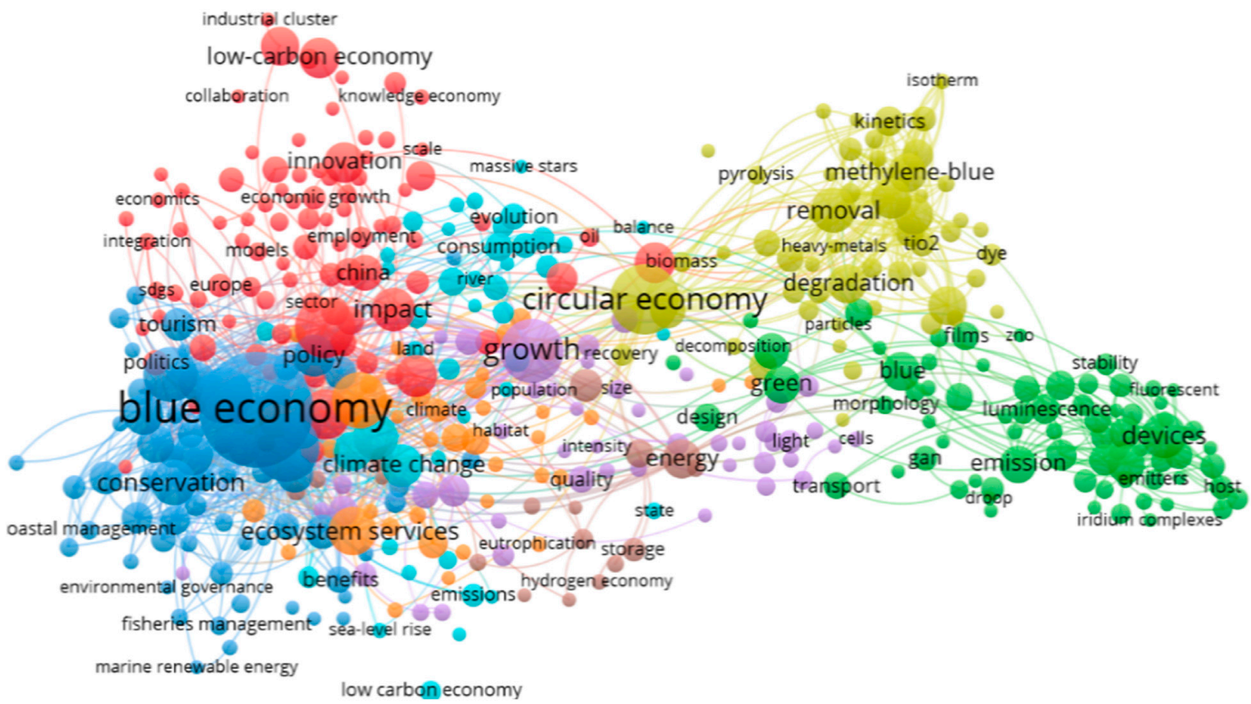

FIGURE 2
Cluster distributions of areas of interest for which scientific research relevant to the issue (Green Deal, blue economy). Source Authors contributions using Web of Science Database and VOSviewer Program.

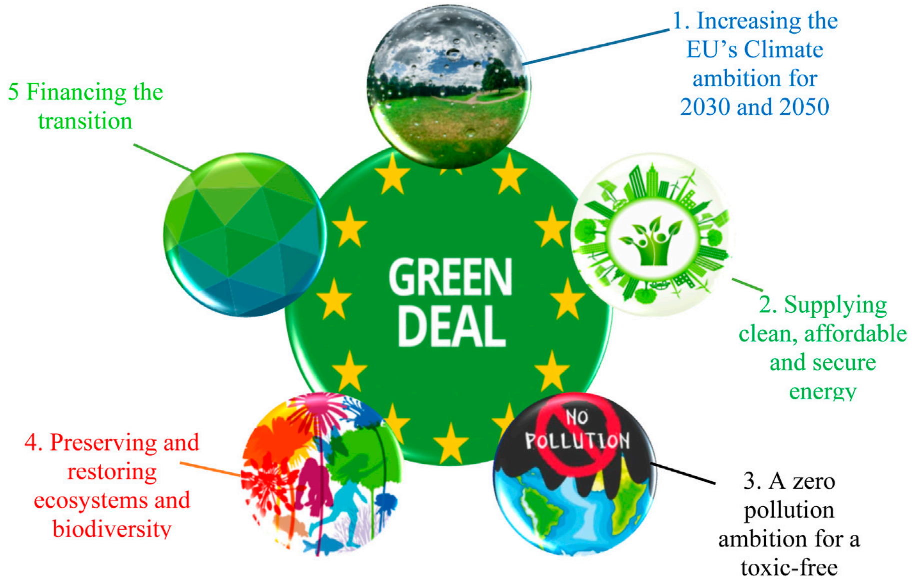

FIGURE 3
Green Deal climate neutrality targets. Source Authors contributions using 2030 climate targets (European Commission, 2023)

structure from a long-term perspective. The results indicate that consumer preference for low-carbon products is always beneficial for the environment and the performance of the low-carbon supply chain. However, whether cap-and-trade regulation can improve the environment and the performance of the low-carbon supply chain depends on the cap set and the price of carbon transactions.

Cap-and-trade regulation, as an efficient market-based mechanism, is adopted to motivate firms to invest in decarbonisation technologies to create sustainable supply chains. In practice, sustainable supply chains operate over the long term and decarbonisation investment decisions can evolve over time. In contrast to previous research, the study presented by the authors Kang & Tan (Kang and Tan, 2023) formulates an evolutionary game model to study the investment decisions of suppliers and producers under cap-and-trade regulation. First, the authors analyze the strategic stability of suppliers and producers and discuss the evolutionary stable strategies (ESS) of the game with related conditions. The "free-rider" problem can arise in the investment game and discourages those who would have invested to make efforts to reduce carbon emissions. As a result, the authors explored the impact of key parameters on ESSs for reducing free-rider behaviour. Numerical studies are conducted to simulate the evolution and stability of the game. The results show that coefficients related to income have a large impact on free-rider behaviours and parameters related to cap-and-trade regulation affect their willingness to invest in carbon reduction. Based on the findings and observations, some useful managerial implications for regulators to develop policy are provided.

In assessing the performance of infrastructure projects, techniques such as Earned Value Analysis (EVA) are essential for monitoring costs and progress, providing a clear picture of deviations from the initial planning. A recent study applied this method in the context of the construction of the Kotay Bridge in Afghanistan, revealing poor performance in the final months of the project, with significant cost overruns and delays. Similar to the need for careful resource monitoring in this project, the dynamic models proposed in our research emphasize the importance of strategic resource adjustment to ensure climate neutrality and achievement of environmental goals in EUSDR states (Ugural and Burgan, 2021).

The carbon tax sets a fixed price on carbon emissions, providing a clear and predictable signal for emission reductions. Studies indicate that carbon taxes are effective in reducing emissions and can be easier to administer than cap-and-trade systems. Sweden was one of the first countries to introduce a carbon tax in 1991. Using a unique dataset tracking CO2 emissions of Swedish manufacturing firms over a 26-year period for a recent research study, the authors Martinsson et al. (Martinsson et al., 2024) estimated the impact of carbon pricing on firm-level emissions intensities. A price elasticity of emissions was estimated to be about two, with substantial heterogeneity across subsectors and firms, where higher abatement costs and tighter financial constraints are associated with lower elasticities. A simple calibration suggests that Swedish manufacturing firms' 2015 CO2 emissions would have been about 30% higher without the carbon price.

Implementing a carbon tax has significant economic and social implications, including possible regressive effects on low-income households. Implementing a carbon tax has significant economic and social implications, including possible regressive effects on low-income households.

Given the challenges posed by climate change and increasingly ambitious global climate targets, the search for effective climate policy instruments is gaining momentum. Carbon pricing, for example, in the form of a carbon tax, and its effects are attracting increasing attention in academic and policy discussions. The authors Köppl & Schratzenstaller (Köppl and Schratzenstaller, 2023) conducted an analysis of the empirical effects of carbon taxes in relation to several impact dimensions commonly studied in the literature: environmental effectiveness, macroeconomic effects, competitiveness and innovation impacts, distributional implications and public acceptance. A growing number of empirical studies have shown that carbon taxes can effectively reduce carbon emissions, or at least temper their growth, without adversely affecting economic growth, employment and competitiveness. Existing empirical evidence suggests that the distributional impact of carbon taxes depends on the type of energy use and the indicators used to capture distributional effects, as well as household characteristics. Lump-sum transfers have been found to be more appropriate to mitigate regressive effects on lower incomes, while higher incomes benefit more from a reduction in labour taxes. Public acceptance of carbon taxes can be increased by providing public information, avoiding negative distributional effects, and directing part of the revenue to "environmental projects".

As nations strive for an equitable transition to net zero carbon emissions, the equitable distribution of carbon price impacts is of significant importance. Carbon pricing, recognized for its potentially regressive nature, tends to disproportionately burden lower-income households compared to wealthier ones. A current study (Shei et al., 2024) has examined how the choice of income or expenditure as metrics for assessing carbon burdens and classifying household economic status influences these distributional effects. Results showed that income-based valuations would amplify the regressive impact of carbon pricing. In contrast, using expenditure as the basis for carbon burden valuation showed considerably reduced regressive effects. The study also highlighted the role of employment structures in determining the fairness of classifying households by income or expenditure.

Comparative studies between cap-and-trade systems and carbon taxes provide valuable insights into the advantages and disadvantages of each model. Based on neoclassical assumptions, a model was developed in a study by the authors Yan et al. (Yan et al., 2022) to illustrate the effects of government use of carbon allowances to control carbon emissions. The authors found that the use of carbon allowances in the long run does not produce the same good results in the Decentralised Balance as in the Planning Problem. The authors believe that the price of carbon allowances is determined by the asset profiles of investors rather than externalities. In the steady state, consumption is determined by the rate of technological progress, the total amount of carbon dioxide at steady state, the technological level at which steady state is reached, and the total amount of remaining carbon allocations. Comparison with the optimal pathway reveals that the price of carbon allowances has risen too quickly, leading to excessive consumption of fossil fuels in the early stages.

Carbon abatement models, supported by a rich literature, offer valuable tools for addressing climate and economic challenges. Cap-and-trade schemes and carbon taxes each have distinct advantages and challenges, and their integration into coherent policies can maximise their benefits. The literature suggests that a combination of mechanisms, tailored to local economic and social conditions, can provide the most effective and equitable way to reduce greenhouse gas emissions and promote sustainable development.

2.2 Study of climate protection models presented in the current literature in line with the induced health`s challenges

In this context, water resources management and planning are strongly influenced by the quality of water bodies. The authors Mortazavi-Naeini et al. (Mortazavi-Naeini et al., 2019) start from the literature review studying the impacts of climate change on water resources. For this purpose, a model combining quantitative and qualitative aspects of water sources and a dynamic simulation of harmful algal blooms in storage reservoirs was built. The proposed model is implemented at the South of England level and succeeds in highlighting water resource vulnerabilities through the lens of Water quality constraints on public water supplies, Water shortages and System reliability measure.

The causes of industrial wastewater emissions are analysed by An et al. (An et al., 2019) in the context of national environmental regulation on industrial wastewater emissions. The main

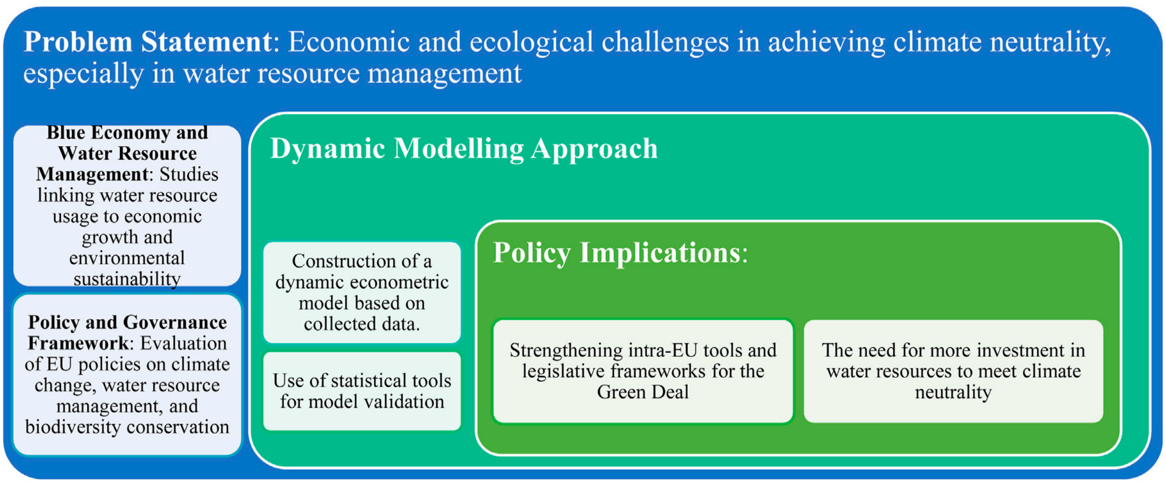

FIGURE 4
Flowchart of suggested methodology. Source Authors contributions.

conclusions of the study cover improving upon coal usage technology and shift towards clean energy sources, raising the investment in environmental treatment and embracing trade liberalization in the improvement of industrial wastewater management.

The analysis of the wastewater treatment in the context of strategies for water sustainability is carried out by López-Morales and Rodríguez-Tapia (López-Morales and Rodríguez-Tapia, 2019), who take over the connections between economic systems and water resources. The input-output approach allows the study of technological choice featuring resource endowments as production constraints and is applied in Mexico Valley Basin. Elements with significant positive impact in wastewater treatment are treatment technologies and conveyance infrastructure.

Groundwater suitability for drinking and agriculture from a qualitative point of view is analysed by Gharbi et al. (Gharbi et al., 2019) and is aimed at centrally Tunisia. The authors conduct a questionnaire which shows that groundwater contains high values of dissolved ions dominated by SO_4, Mg and Ca. Based on their observations, the authors define a Water Quality Index and compare it to the World Health Organization (Guidelines for drinking water quality, third edn, vol 1. Recommendations. The use of Water Quality Index is taken up by Tripathi & Singa (Tripathi and Singal, 2019) and covers the River Ganga region, India.

In the case of water resources, a particular problem is ageing infrastructure. The authors Alzahrani and Collins (Alzahrani and Collins, 2022) used a spatial quantile regression framework and covered the period 2012–2017. The study shows an inverse connection between boil water notices (BWNs) and residential properties.

Water securities threats viewed as a connection between natural capital with engineering-based (green-gray) is approached by Vörösmarty et al. (Vörösmarty et al., 2021). The authors note that public policy needs to combine green-gray approaches with a strategic commitment to preserve natural capital.

Interesting research covers public water infrastructure and water handling technologies on the water quality and water handling behaviour of households in Benin. The authors Gross et al. (Gross et al., 2022) make the connection between public water sources and disinfection efforts at home and conclude that the introduction of water decontamination technologies becomes essential.

Climate protection models are essential tools for mitigating the adverse effects of climate change. These models not only focus on reducing greenhouse gas emissions, but also address the health challenges induced by climate change.

Climate change affects both mental and physical health. In addition to limiting the extent and consequences of climate change, mitigation and adaptation measures can have additional and potentially unintended health impacts. In a recent review the authors Luyten et al. (Luyten et al., 2023) explore how the health effects of climate change mitigation and adaptation measures have been studied in the scientific literature. Articles related to adaptation and mitigation have most commonly investigated the environmental health determinants, air temperature and air pollution, respectively. Non-communicable diseases were predominantly studied, while other relevant categories of health outcomes, such as mental health, dietary and nutritional problems and communicable diseases, were rarely reported. The lack of studies focusing on social determinants of health and providing stratified health impacts among vulnerable groups suggests inadequate consideration of health equity issues. More efforts are needed to quantify health impacts more comprehensively and to identify underlying vulnerability factors among specific population groups.

Another study (Filho et al., 2022) presents some suggestions for optimising public health responses to health hazards associated with climate change, such as: incorporating climate-related components into public health policies, establishing monitoring systems to assess the extent to which specific climate events may pose a threat to health, establishing plans to address the health implications of heat waves, enhanced measures to protect vulnerable groups, and education and awareness-raising initiatives to reduce overall population vulnerability to climate-related health hazards.

Although the impact of climate change on nature and the global economy has been widely debated, some of the most pressing consequences of rising temperatures will affect human health and the global health system. In a current report, the World Economic Forum(Forum, 2024) aims to quantify the health consequences of climate change, looking at both direct health outcomes (mortality and loss of healthy life years) and the economic costs to the health system. Six major categories of climatic events have been identified and analysed as significant drivers of negative health impacts: floods, droughts, heat waves, tropical storms, vegetation fires and sea level rise. These climate events are assessed in the context of their effects on population health, highlighting both immediate risks and long-term implications for health infrastructure and the global economy.

2.3 Study of climate protection models presented in the current literature in line with the induced political challenges

In the case of water supply analysis for the population, the authors Fernandes et al. (Fernandes et al., 2020) consider alternatives such as the individual system for capturing and utilizing rainwater. Moreover, the study is intended as an alternative municipal policy and is based on a simulation model.

At the European level, public policies concerning water allocation need to be reviewed according to the authors Rey et al. (Rey et al., 2019). The authors analyse the reforms introduced in water allocation policy in the UK, France, Italy, Spain and the Netherlands and highlight the economic, social, legal, institutional and biophysical barriers to the implementation of effective public policies. The analysis considers issues such as: pressures on water resources, water charges, payment for ecosystem services, non-monetary voluntary agreements and subsidies. The impact of climate change on Europe through the lens of the Paris Agreement is analysed by Harrison et al. (Harrison et al., 2019). The authors focus their analysis on six sectors (agriculture, forestry, biodiversity, water, coasts and urban) and use an integrated assessment model. This model allows the assumption that the impact of climate change will be much greater in the 2050s and 2080s than today.

Policy challenges play a significant role in the implementation and success of climate protection models. These challenges include diverging interests, complex regulations and the need for international coordination. Adopting a green development strategy has become imperative for businesses to strengthen their resilience. The authors Wu & Tham (Wu and Tham, 2023) using questionnaires analysed the influence of environmental regulations, social and environmental governance performance and technological innovation on corporate resilience by constructing structural equations that include both external constraints and internal corporate management. The results showed that environmental regulations can stimulate technological innovation to promote sustainable development, thereby strengthening corporate resilience; by incorporating social and environmental governance principles into their operations, companies can cultivate environmental consciousness and encourage innovative solutions, enhancing their ability to adapt and recover quickly from crises; the practice of environmental regulations and the integration of social environmental and governance concepts act as a catalyst for technological innovation, promoting technological advancement and corporate resilience.

Cap-and-trade systems cap total greenhouse gas emissions and allow entities to buy and sell emissions permits. These systems encourage emission reductions where it makes the most economic sense. Striking a balance between free allocation and permit auctions can create political tensions. Industries heavily affected by additional costs may lobby for free allocation. Climate change is an existential threat. Theoretical and empirical research by the authors Blanchard et al. (Blanchard et al., 2023) suggests that carbon pricing and support for green research and development are the right tools, but their implementation can be improved. In the authors' view other policies, such as standards, bans and targeted subsidies, also have a role to play, but these have often been inconsistent and their implementation is complicated.

The carbon tax sets a fixed price on carbon emissions, giving a clear economic signal for reducing carbon footprints. The implementation of a carbon tax may face public opposition, especially if it is perceived as unfair or regressive. The ideal carbon tax policy should be internationally coordinated, fully inclusive of external costs, redistribute revenues to those affected and be politically accepted, providing clear and predictable market signals. In practice, however, these conditions are rarely fully met, leading to moral problems. Mintz-Woo (Mintz-Woo, 2024) examine works of moral philosophy that address some of these problems. First, they examine the moral factors that influence estimates of the social cost of carbon. Second, they explain how national interest can impede climate action and propose international policies, such as adjustments to carbon border taxes and carbon clubs, to address these issues. Third, it presents some of the social science literature on the political acceptability of carbon taxes and addresses some of the common public concerns about these taxes. Finally, it discusses four options for the use of carbon tax revenues, arguing that climate redistribution and offsetting measures are the most morally justified.

Policies that promote renewable energy and energy efficiency aim to replace fossil fuels with cleaner energy sources and improve the efficiency of energy use. In recent years, much research has been conducted to identify the determinants of eco-innovations. Zastempowski (Zastempowski, 2023) has shown that in most studies, eco-innovation has been analysed at a general level. From the perspective of climate change and the goal of achieving the Sustainable Development Goals and the objectives of the European Green Pact, the issue of innovations replacing fossil fuel energy with renewable energy sources in the European Union is particularly important. This article therefore has two purposes. The results show that six of the seven factors assessed positively influence the introduction of innovations that replace fossil fuel energy with renewable energy sources. These are (1) high cost of energy, water or materials, (2) expected future environmental regulations or taxes, (3) existing environmental taxes, fees or charges, (4) government grants, subsidies or other financial incentives for environmental innovations, (5) current or expected market demand for environmental innovations, and (6) voluntary actions or initiatives for good environmental practices within a sector.

Thus, traditional energy industries can resist the transition to renewable energy sources by influencing policies through lobbying. Effective implementation requires significant policy adjustments, including subsidies for renewable energy sources and strict regulations for energy use (Business & Human Rights Resource Centre, 2023).

The development of river basins, such as the Danube, has been significantly shaped by geopolitical dynamics, as highlighted by Lagendijk (Lagendijk, 2015) in his analysis of Cold War-era planning and water resource utilization. The competition between the American TVA (Tennessee Valley Authority) model and the Soviet approach via the CMEA (Council for Mutual Economic Assistance) influenced the structure of hydropower infrastructure projects, emphasizing the complex role of ideology in natural resource management. This historical perspective offers a valuable framework for understanding contemporary challenges related to sustainable development and efficient resource use within the political context of the EU Strategy for the Danube Region.

Climate change adaptation strategies focus on increasing resilience to climate impacts, including infrastructure improvements, disaster preparedness and sustainable water resource management. Implementing adaptation strategies requires cooperation between different levels of government and institutions, which can be complicated by political conflicts. While planning and policy instruments are important for adaptation to climate change, implementation of these measures is essential for success. In recent research authors Ray Biswas & Rahman (Ray Biswas and Rahman, 2023) studied different climate change adaptation strategies by analysing measures adopted by policymakers responsible for developing and implementing government policies to minimise the impacts of climate change in the tropical north Queensland region of Australia. Local government organisations have a responsibility to play a leading role in climate change adaptation. State and federal government agencies are primarily responsible for developing climate transition policies and guidelines, as well as providing limited financial assistance to support local government. The authors conducted interviews with local government practitioners identified from various local government authorities in the study region. While all government bodies have made some progress in developing better climate change adaptation policies, interview participants identified that much more is needed, particularly in terms of implementation, including the design and implementation of relevant action plans, economic assessments, and stakeholder participation and involvement.

Climate protection models offer valuable tools for addressing climate change, but political challenges remain a significant obstacle to their effective implementation. The success of climate policies depends on managing diverging interests, communicating benefits and creating a robust and adaptive policy framework. The literature suggests that an integrated and coordinated approach is essential to overcome these challenges and ensure the transition to a sustainable and climate-resilient economy.

2.4 Study of climate protection models presented in the current literature in line with the induced energy`s challenges

The sustainable urban water is the subject of research by Maurya et al. (Maurya et al., 2020), who consider the connection between rapid urbanization and the extraction of natural water resources. The analysis aims to achieve a positive water balance for sustainable development of an urban area, through the alternative use of Integrated Urban Water Management and pressure-state-response.

Sustainable development from the perspective of the water-energy-food nexus is addressed by Cansino-Loeza et al. (Cansino-Loeza et al., 2021). The authors believe that resource constraints can be mitigated through proper management to ensure access to basic social services and a healthy diet for all inhabitants of the areas under study.

The same food-energy-water approach leads in the view of Li et al. (S. Li et al., 2021) to define an integrated technology-environment-economics model (ITEEM) at a watershed scale. The model quantifies different variables and uses an input-output approach and aims to quantify the environmental and socioeconomic impacts of various management practices, technologies, and policy interventions.

Energy challenges are closely linked to climate protection efforts, given the global dependence on fossil fuels and the need to transition to more sustainable energy sources. The authors Yu et al. (Yu et al., 2023) investigate the relationship between clean energy technologies and climate change mitigation in top environmental pollution (TEP) economies over the period 1996–2020. The research considers factors such as energy efficiency, industrialisation and sustainable policies. The results show that clean energy technologies mitigate climate change, while energy efficiency reduces the environmental burden. However, industrialisation and economic growth are driving an upward shift in climate change, suggesting the need to move to service-intensive economies. The study found no significant evidence of a link between sustainable environmental policies and climate change and suggests that policymakers should implement holistic strategies to support innovation, technologies and energy efficiency improvements, while controlling for the negative effects of industrialisation and traditional growth patterns.

The relationship between economic growth, energy consumption and CO2 emissions is central to understanding the transition towards green and sustainable economies. The study by Litavcová and Chovancová (Litavcová and Chovancová, 2021) on the Danube region revealed a strong long-term correlation between these variables, emphasizing that economic growth and energy consumption have a significant impact on CO2 emissions in the countries of the region, particularly in Austria, the Czech Republic, Slovakia and Slovenia. These results provide a solid basis for the development of policies to promote energy efficiency and carbon reduction in infrastructure projects, contributing to the achievement of climate neutrality objectives.

The transition from fossil fuels to cleaner energy sources requires significant changes in energy infrastructure and may meet resistance from the traditional energy industry. A recent study (Chandra Voumik et al., 2023) examines the impact of GDP, population, renewable energy consumption, fossil fuels and FDI on carbon emissions in Kenya, using time series data from 1972 to 2021. Using the Autoregressive Distributed Lag (ARDL) method, based on the STIRPAT model, the authors show long-term cointegration between variables. GDP growth has a negative impact on CO2 emissions, while population growth positively affects emissions in the long term. The study also finds that fossil fuels have a positive but statistically insignificant impact on CO2 emissions. The findings suggest significant investment in renewable energy infrastructure for sustainable development.

Policies promoting renewable energy and energy efficiency aim to replace fossil fuels with cleaner energy sources and improve energy use efficiency (Jaiswal et al., 2022).

Renewable energy policies need to address the challenges of the intermittency of renewable energy sources, the need for energy storage and the modernisation of energy infrastructure (Gajdzik et al., 2023).

Climate change adaptation strategies focus on increasing resilience to climate impacts, including improved infrastructure, disaster preparedness and sustainable water resource management. Adapting to climate change requires significant investment in energy infrastructure to cope with extreme weather events and ensure energy security (Abbass et al., 2022).

Climate protection models provide valuable tools for addressing the energy challenges associated with climate change. The success of these models depends on effectively managing the transition to more sustainable energy sources, addressing energy infrastructure challenges and stimulating investment in clean technologies. The literature suggests that an integrated and coordinated approach is essential to overcome these challenges and ensure a transition to a sustainable and climate-resilient energy economy.

3 Methods

As part of the scientific approach, the authors aimed to develop a dynamic model of the economic and ecological impact of water resources in the context of climate neutrality in the EUSDR Member States. To achieve this goal, we started from the following Green Deal objectives (see Figure 3):

In Figure 3, the representation highlights the key climate neutrality objectives of the European Green Deal and their interrelations. The figure outlines five major objectives that form the cornerstone of the European Union's strategy towards achieving a sustainable, climate-neutral future. These objectives are interconnected, demonstrating the need for a comprehensive and integrative policy approach. With respect to these objectives, the authors investigated climate neutrality indicators collected at the EUSDR Member State level in direct connection with blue economy generating water resources, according the flowchart bellow (Figure 4.).

Figure 4 presents an integrated framework that addresses the dual economic and ecological challenges in achieving climate neutrality, with a specific focus on water resource management. The dynamic modelling approach outlined describes the construction of an econometric model, to analyze the complex interactions between economic and environmental variables. This model undergoes validation through the use of statistical tools, ensuring its accuracy in predicting outcomes related to water resource usage and climate neutrality. The flowchart encapsulates the multifaceted approach needed to address the intersection of economic growth, environmental sustainability, and water resource management in the context of achieving climate neutrality. From the multitude of indicators reported at Eurostat level, the following have been selected.

- Real GDP *per capita* (5RGDP): this indicator shows GDP per inhabitant expressed in euro and links to Green Deal Objective 5 Financing the transition in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania and Slovakia over the period 2010–2021 (Eurostat, 2022).
- Water use in agriculture, forestry and fishing (2WUAFF): the indicator is expressed in million cubic metres and relates to Green Deal Objective 2 Supplying clean, affordable and secure energy in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania and Slovakia over the period 2010–2021 (European Commission, 2022d).
- Total gross Water abstraction Fresh surface water (2TGWA): the indicator is expressed in million cubic metres and links to Green Deal Objective 2 Supplying clean, affordable and secure energy in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania and Slovakia over the period 2010–2021(European Commission, 2022b).
- Sewage sludge production and disposal from urban wastewater (3SSP): the indicator is expressed in thousand tonnes and links to Green Deal Objective 3 A zero pollution ambition for a toxic-free in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia,

Statistical Synthesis of Databases:	This stage involves collecting and aggregating data from various sources to create a coherent and comprehensive database.
Consolidation Procedures:	Consolidation procedures were applied to combine data from multiple sources into a single integrated database, ensuring data consistency and quality.
Dynamic Analysis:	Dynamic analysis involves evaluating data over a period of time to identify trends and variations within it. In this study, the analysis was carried out for the period 2010-2021.
Statistical Data Validation using the Kolmogorov-Smirnov Test:	The one-sample Kolmogorov-Smirnov test was used to validate the statistical distribution of the data. This test compares the distribution of a data series to a reference distribution to determine whether the two distributions are similar.
Pivoting Data into a Single Database:	The data were pivoted into a single database to facilitate their analysis and interpretation. Pivoting involves reorganizing data so that it is easier to manage and analyze.
Using Gretl Dedicated Statistical Software and IBM-SPSS 25:	Gretl and IBM-SPSS 25 were used for statistical data analysis. These programs provide a wide range of tools for econometric and statistical analysis, facilitating the modeling and interpretation of data.
Econometric Model Design:	The econometric model was designed to identify and analyze the relationships between the variables of interest. This model was grounded in economic theory and statistically validated.
Model Testing and Validation:	The econometric model was tested and validated to ensure the accuracy and reliability of the results. The validation tests included checking the model's assumptions and evaluating its performance.

FIGURE 5
The methodological approach of the study. Source Authors contributions.

Germany, Croatia, Hungary, Austria, Romania and Slovakia over the period 2010–2021(European Commission, 2022c).

- Water exploitation index, plus (4WEI): the indicator is expressed in % and links to Green Deal Objective four in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania and Slovakia over the period 2010–2021(European Commission, 2022d).
- Environmental protection government expenditure (1EPGEXP): The indicator is expressed as percentage of gross domestic product (GDP) and links to Green Deal Objective 1 Increasing the EU's Climate ambition for 2030 and 2050 in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania and Slovakia in the period 2010–2021(European Commission, 2022a).
- Water productivity (5WP): The indicator is expressed in Euro per cubic metre and links to Green Deal Objective 5 Financing the transition in Figure 3. The variable was collected for the EUSDR Member States Bulgaria, Czechia, Germany, Croatia, Hungary, Austria, Romania and Slovakia in the period 2010–2021(European Commission, 2022e).

The methods used in the research consisted of statistical synthesis of databases, consolidation procedures, dynamic analysis, validation of statistical data using the One-Sample Kolmogorov-Smirnov Test method, pivoting of data in a single database, use of dedicated statistical software Gretl and IBM-SPSS 25, design of the econometric model, its testing and validation. In Figure 5 is presented the methodological approach of the study.

Figure 5 outlines a comprehensive methodological framework used in the statistical synthesis and analysis of the economic and environmental impacts of water resources within the context of climate neutrality. The figure demonstrates the pivotal role of advanced statistical tools such as Gretl and IBM-SPSS 25 in conducting detailed econometric analyses. These tools support the design of the econometric model, which is grounded in economic theory and seeks to identify relationships between key variables influencing water resource management and climate neutrality efforts. The study was conducted dynamically over the period 2010–2021, closed reporting years at the time of the research.

To achieve the purpose of the research, we formulate the following *working hypotheses*.

H1. Achieving the 2030 and 2050 climate neutrality targets under the conditions of Community-generated transition financing is effective if and only if the aggregate targets are consistent with the macro-regional targets. The hypothesis is supported by the results of research carried out by some authors (Harrison et al., 2019; S; Li et al., 2021; López-Morales and Rodríguez-Tapia, 2019; Maurya et al., 2020; Rey et al., 2019; Seifi et al., 2020).

H2. The provision of clean, affordable and secure energy is possible in the context of the Green Deal by linking the correction of internal disruptive factors (level of economic development, regional disparities, target management and financial management) with effective measures to reduce the influence of external disruptive factors (economic crisis, geo-political climate, influence of climate change). The hypothesis is supported by the results of research conducted by (Cansino-Loeza et al., 2021; Gharbi et al., 2019; Maurya et al., 2020; Rey et al., 2019; Seifi et al., 2020).

H3. Achieving effective metrics on pollution reduction and climate neutrality requires at the time of the analysis only efforts to maintain the strategic directions already adopted, this objective being the best valued of the 5 Green Deal studied objectives. The hypothesis is supported by the results of research conducted by (Gharbi et al., 2019; Harrison et al., 2019; López-Morales and Rodríguez-Tapia, 2019; Maurya et al., 2020; Rey et al., 2019; Seifi et al., 2020).

H4. Preserving and restoring ecosystems and biodiversity can take place in the context of a better promotion and operationalization of the blue and circular economy. The hypothesis is supported by the results of research conducted by (Gharbi et al., 2019; López-Morales and Rodríguez-Tapia, 2019; Maurya et al., 2020; Nouri et al., 2019; Rey et al., 2019; Seifi et al., 2020).

The regression model performed using the multiple regression method allowed the representation of the annual equations according to the unstandardized β coefficients as follows:

TABLE 1 Model summary.

Model		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
R		0.98	0.999	0.931	0.999	0.999	0.865	0.994	0.954	0.995	0.987	0.966	0.949
R Square		0.960	0.998	0.867	0.998	0.997	0.748	0.988	0.910	0.989	0.974	0.933	0.901
Adjusted R Square		0.719	0.985	0.771	0.986	0.980	0.763	0.915	0.370	0.924	0.821	0.533	0.305
Std. Error of the Estimate		0.027	0.006	0.045	0.004	0.004	0.027	0.003	0.017	0.009	0.021	0.039	0.063
Change Statistics	R Square Change	0.960	0.998	0.867	0.998	0.997	0.748	0.988	0.910	0.989	0.974	0.933	0.901
	F Change	3.984	78.118	1.089	80.579	57.945	0.495	13.561	1.685	15.233	6.355	2.334	1.511
	df1	6	6	6	6	6	6	6	6	6	6	6	6
	df2	1	1	1	1	1	1	1	1	1	1	1	1
Durbin-Watson		1.552	1.691	2.123	1.081	1.834	1.741	1.399	2.545	1.680	1.886	1.456	1.168

Source Authors contributions using SPSS, 25v.

where: $5RGDP_i$ – dependent variable of the model projected for year i; i ϵ {2010; 2011; 2012; 2013; 2014; 2015; 2016; 2017; 2018; 2019; 2020; 2021}. $2WUAFF_i$; $2TGWA_i$; $3SSP_i$; $4WEI_i$; $1EPGEXP_i$; $5WP_i$ – regression variables (independent) projected for year i.

4 Results

The modelling results are more than 86% significant, indicating that at the macro-regional level the financing efforts of Objective 5 Financing the transition are relevantly represented relative to the independent regressors (Objectives 1–4). This means that the dynamics of the first four objectives explain 86% of the financing of the transition to climate neutrality for the macro-region studied (see Table 1).

According to Table 1, it can be seen that there is a differentiated evolution in the dynamics of climate neutrality financing, with disruptive factors being external, i.e., the onset of economic, geo-political or pandemic crises. Table 1 presents the statistical performance of the econometric model over the years 2010–2021, focusing on several key indicators that assess its reliability and accuracy. The adjusted R-squared values, which account for the number of predictors used, generally support the high explanatory power of the model, although there are fluctuations, especially in the years 2016 and 2017, where the adjusted R-squared values drop significantly, reaching as low as 0.370 in 2017. The standard error of the estimate, which measures the accuracy of predictions, remains low across the years, further indicating the model's precision, although it increases slightly in 2020 and 2021, signaling less accurate predictions during those periods. The Durbin-Watson statistic, which tests for autocorrelation, varies across the years but generally stays within acceptable ranges, suggesting that autocorrelation was not a significant issue for most years except in 2013 and 2017, where the values deviate from the norm. Overall, the table demonstrates a highly reliable model with minor deviations in performance during specific periods.

Using the ANOVA table, the homogeneity and accuracy of the errors were tested and validated, and the null hypothesis was rejected for all the years studied on the basis of the Sig. coefficient of the F function less than the chosen significance threshold of 0.05 (one-sided critical probability test). Thus, the prerequisites for admitting the alternative hypothesis and validating the model for the whole period analysed were established, which validates the way the general model was built and guarantees the representativeness of the proposal for the studied phenomenon, i.e., the creation of a dynamic model on the economic and ecological impact of water resources in the context of climate neutrality at the level of the EUSDR Member States (see Table 2).

Table 2 presents the sum of squares for both regression and residual values over the years 2010–2021. The sum of squares for regression indicates the variance in the dependent variable explained by the model, with values ranging from 0.017 in 2010 and 2019 to a higher 0.036 in 2021. This pattern shows that, particularly in later years, the model explained a larger proportion of the variance. The residual sum of squares, representing the unexplained variance, remains minimal across the period, demonstrating that the model consistently captured most of the variance in the data. The F-statistic, which tests the overall significance of the regression model, shows variability across the years. For instance, 2011 and 2013 have higher values of 78.118 and 80.579 respectively, reflecting strong model performance and significant explanatory power. In contrast, other years, such as 2015 and 2020, present lower F-statistics, indicating weaker explanatory power. However, the Sig. values for all years remain well below the 0.05 threshold, affirming that the model is statistically significant across the entire period. This indicates that the independent variables used in the regression model consistently contribute to explaining the variation in the dependent variable, despite minor fluctuations in model strength throughout the years.

The results of our analysis confirm that Green Deal financing policies are vulnerable to the external environment. This concept, while desirable, needs a more efficient approach to implementation strategies, including strengthening the legislative framework and creating intra-EU tools to monitor progress under the Green Deal.

The proposed model is a novel one, which allows the monitoring of climate neutrality implementations in a quantitatively valuable way, with a flexibility of policy adoption to current and projected needs and a clarifying structure based on reported realities, macro-regional dimension and dynamics.

Dynamic modelling for the year 2010 of the economic and environmental impacts of water resources in the context of climate neutrality on the protection and saving of water resources indicates an economic return of the O1 objective on increasing climate security with reference to the 2030 and 2050 horizons of 40%, under the condition of an increased

TABLE 2 ANOVA test.

Model		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Sum of Squares	Regression	0.017	0.018	0.013	0.010	0.006	0.002	0.001	0.003	0.007	0.017	0.022	0.036
	Residual	0.001	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.002	0.004
	Total	0.018	0.018	0.015	0.010	0.006	0.003	0.001	0.003	0.007	0.017	0.023	0.040
Mean Square	Regression	0.003	0.003	0.002	0.002	0.001	0.000	0.000	0.000	0.001	0.003	0.004	0.006
	Residual	3.984	78.118	1.089	80.579	57.945	0.495	13.561	1.685	15.233	6.355	2.334	1.511
F		0.366	0.086	0.625	0.085	0.1	0.795	0.205	0.53	0.194	0.295	0.463	0.553
Sig		0.001	0.000	0.002	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.002	0.004

Source Authors contributions using SPSS, 25v.

expenditure of one monetary unit for each protection action implemented.

For the O2 objective, the economic return was negative, i.e., measures to provide clean, affordable and secure energy impacted the budget of EUSDR Member States at an additional cost of 2.6% for each monetary unit invested.

The O3 objective registered a positive yield of 20%, allowing pollution to be better tackled in the context of common European policies in this field.

For objective O4, a low yield of 11.7% was recorded, which means that policies for preserving and restoring ecosystems and biodiversity have gone through a transitional phase while waiting for significant positive effects.

For objective O5, Financing the transition, the yield was maximum (of 41%) and demonstrated that during this period European policies had a guiding character, the legislative framework being shaped but without an extrinsic policy purpose.

In 2011, modelling showed that on objective O1, the yield decreased from the previous year to 28.5%, with difficulties in implementing climate security policies. This was in the context of uncertainty in 2011, when the global geopolitical context was uncertain and the main orientation at Member State level was to increase geo-political security and fight terrorism. These measures have influenced the transit of goods and people, favouring the conditions for the implementation of the O2 objective and the clean, affordable and secure supply for which the economic return has shown a strong upward trend, increasing to 33.7% the efficiency of the measures taken in this regard. In the case of objectives O3 and O4, a slight increase in efficiency of up to 5% was recorded, showing that the efforts undertaken in the previous year were sustainable. Objective O5 has seen a significant decline in efficiency, amid concerns about geo-security.

The year 2012 confirmed the unsustainable evolution of the O1 objective, with a negative return as in 2010. This yield is explained against the background of regional disparities and the increased need for funding to ensure an effective framework for implementing climate neutrality. The O2 objective generated a very good return of over 60%, confirming the sustainability of the measures to ensure a clean, affordable and secure supply. Objectives O3 and O4 did not generate significant positive results against the background of substantial allocations to the fight against terrorism and the exit from the crisis and the intensification of polluting economic activity. The O5 objective has been maximised, with increased EU interest in financing the transition and climate neutrality programmes and strategies launched.

The modelling presented in Equation 1 demonstrates that there have been several sustainability gaps in the dynamics of implementing climate neutrality in the economic and environmental context of water resource use. Thus, according to the model, the years of significant inflection were: 2012, 2015, 2017, registering until the end of the period after 2017 a normalization of the sustainable evolution marked by the

$$\begin{cases} \mathbf{5RGDP2010} = -0.026{*}2WUAFF2010 + 0.175{*}2TGWA2010 + 0.203{*}3SSP2010+ \\ 0.117{*}4WEI2010 + 0.4{*}1EPGEXP2010 + 0.41{*}5WP2010 - 0.319 \\ \mathbf{5RGDP2011} = 0.025{*}2WUAFF2011 + 0.337{*}2TGWA2011 + 0.256{*}3SSP2011+ \\ 0.129{*}4WEI2011 + 0.285{*}1EPGEXP2011 - 0.064{*}5WP2011 - 0.113 \\ \mathbf{5RGDP2012} = -0.209{*}2WUAFF2012 + 0.602{*}2TGWA2012 - 0.104{*}3SSP2012- \\ 0.257{*}4WEI2012 - 0.217{*}1EPGEXP2012 + 0.98{*}5WP2012 + 0.219 \\ \mathbf{5RGDP2013} = 0.117{*}2WUAFF2013 - 0.15{*}2TGWA2013 + 0.223{*}3SSP2013+ \\ 0.213{*}4WEI2013 - 0.368{*}1EPGEXP2013 - 0.117{*}5WP2013 + 1.109 \\ \mathbf{5RGDP2014} = -0.004{*}2WUAFF2014 + 0.809{*}2TGWA2014 + 0.44{*}3SSP2014- \\ 0.012{*}4WEI2014 + 0.065{*}1EPGEXP2014 + 1.254{*}5WP2014 - 1.529 \\ \mathbf{5RGDP2015} = 0.065{*}2WUAFF2015 - 0.142{*}2TGWA2015 + 0.068{*}3SSP2015- \\ 0.013{*}4WEI2015 - 0.002{*}1EPGEXP2015 + 0.072{*}5WP2015 + 0.933 \\ \mathbf{5RGDP2016} = 0.027{*}2WUAFF2016 + 0.173{*}2TGWA2016 - 0.023{*}3SSP2016+ \\ 0.026{*}4WEI2016 + 0.013{*}1EPGEXP2016 + 0.472{*}5WP2016 + 0.319 \\ \mathbf{5RGDP2017} = -0.331{*}2WUAFF2017 - 5.193{*}2TGWA2017 + 0.345{*}3SSP2017+ \\ 0.524{*}4WEI2017 - 0.211{*}1EPGEXP2017 + 0.5{*}5WP2017 + 5.257 \\ \mathbf{5RGDP2018} = -0.071{*}2WUAFF2018 + 0.479{*}2TGWA2018 + 0.113{*}3SSP2018+ \\ 0.018{*}4WEI2018 - 0.014{*}1EPGEXP2018 + 0.264{*}5WP2018 + 0.283 \\ \mathbf{5RGDP2019} = -0.074{*}2WUAFF2019 + 0.554{*}2TGWA2019 + 0.306{*}3SSP2019- \\ 0.039{*}4WEI2019 - 0.067{*}1EPGEXP2019 + 0.629{*}5WP2019 - 0.251 \\ \mathbf{5RGDP2020} = -0.067{*}2\mathrm{WUAFF}2020 + 0.91{*}2\mathrm{TGWA}2020 - 0.005{*}3\mathrm{SSP}2020- \\ 0.066{*}4WEI2020 + 0.004{*}1EPGEXP2020 + 1.186{*}5WP2020 - 1 \\ \mathbf{5RGDP2021} = -0.198{*}2WUAFF2021 + 1.6{*}2TGWA2021 - 0.089{*}3SSP2021- \\ 0.062{*}4WEI2021 + 0.686{*}1EPGEXP2021 + 3.209{*}5WP2021 - 4.413 \end{cases} \tag{1}$$

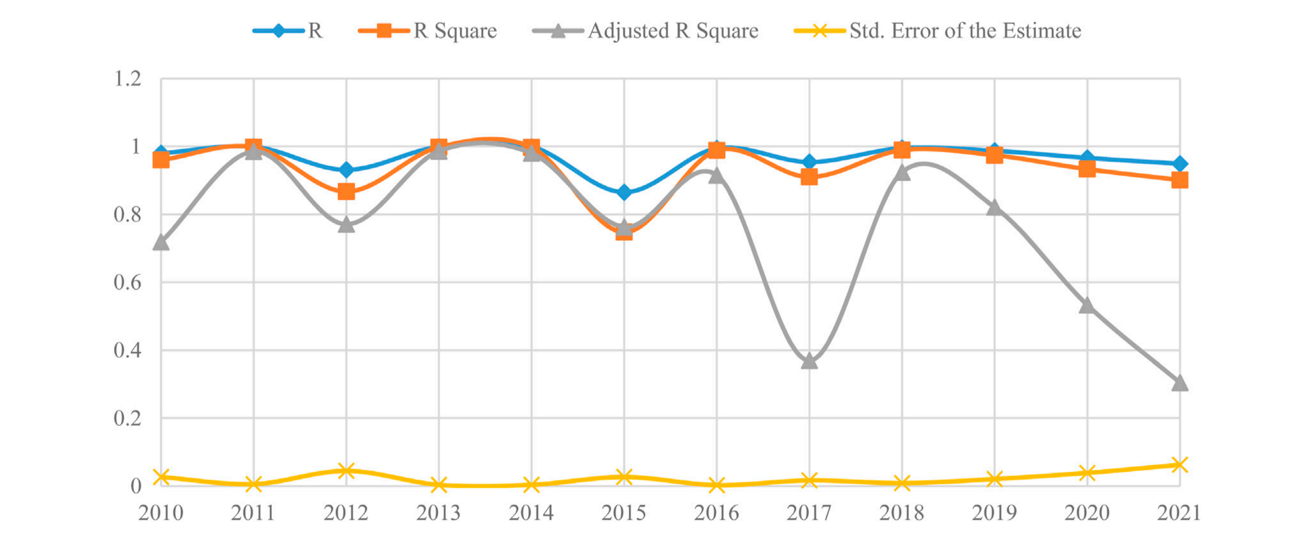

FIGURE 6
Dynamic diagram of climate neutrality policy implementation in econometric model perspective. Source Authors contributions.

flattening of the trend curves of the model coefficients according to Figure 6.

Over the years analyzed, Figure 6 highlights fluctuations in these statistical indicators, demonstrating how the model's performance evolved in response to various external and internal factors impacting water resource management and climate neutrality goals. The trend suggests periods of higher accuracy and reliability, reflected in the peaks of R and adjusted R-squared values, alongside intervals where external disruptions such as economic crises or environmental events may have affected model performance. These fluctuations emphasize the importance of continuous model validation and adjustment to account for changing real-world conditions, ensuring that the econometric model remains a reliable tool for guiding policy decisions related to water resource governance and the broader objectives of the European Green Deal.

For the year 2020, a year marked by the uncertainties of the onset of the global pandemic, the evolution of climate neutrality in the economic and environmental context of water resource use has generated the following status of the effectiveness of the implementation of the Green Deal objectives. Objective O1 remains in unsustainable parameters, registering a negative return, i.e., the implementation of neutrality policies at the level of EUSDR Member States fails to ensure convergence with European policies. As far as the O2 objective is concerned, it is valued at the level of the 2TGWA2020 indicator, with a return of 90%, while for the 2WUAFF2020 indicator the return remains negative and not very significant in terms of the results of the dependent variable, real GDP/capita growth. Objectives O3 and O4 are in unsustainable parameters and not in line with real GDP *per capita*. Objective O5 is maximised so that there is a significant regional allocation effort for transition, but insufficiently implemented in terms of the results observed for the other objectives.

In 2021, based on the normalisation of the coefficients' trends, there are no significantly different developments compared to 2020. Thus, it is target O1 that benefits from additional efficiency gains, but target O2 accentuates its negative trend for 2WUAFF2021 and positive trend for 2TGWA 2021, resulting in a slight improvement in the implementation of clean, affordable and secure energy policies. Objectives O3 and O4 mark a slight progress in implementation performance, benefiting from the general context of the pandemic, where following prevention and control measures, human transit and economic activity were significantly reduced. Objective O5 reaches new peaks of representation in relation to the dependent variable, indicating that as we approach the 2030 horizon, efforts by the EU and in line with the EUSDR region are intensifying and it is likely that in the coming years we will see a strengthening of the EU legislative framework to facilitate the transition to climate neutrality.

5 Discussion

Appendix A1 provides detailed descriptive statistics for key variables across the EU Danube Region countries (Austria, Bulgaria, Croatia, Czechia, Germany, Hungary, Romania, and Slovakia) for the period 2010–2021. The dataset includes water use in agriculture and forestry (2WUAFF), total gross water abstraction (2TGWA), sewage sludge production (3SSP), water exploitation index (4WEI), environmental protection government expenditure (1EPGEXP), real GDP *per capita* (5RGDP), and water productivity (5WP). Each country demonstrates distinct statistical characteristics across these indicators, highlighting the diverse environmental and economic contexts within the region. For instance, Austria and Germany present high values for water abstraction and real GDP *per capita*, with Austria recording a median 5RGDP of €36,345 and Germany showing a maximum of €35,980. These figures underscore the significant economic outputs of these countries, likely tied to more advanced infrastructure and water resource management systems. In contrast, countries such as Bulgaria and Romania display lower GDP *per capita* values, with medians of €5,805 and €7,480, respectively, indicating more modest economic performance relative to their water use. Bulgaria also exhibits lower water productivity (5WP), with a median of €7.40, which may reflect inefficiencies in converting water usage into economic output. Sewage sludge production (3SSP) varies significantly across countries, with Germany recording the highest values due to its large-scale industrial activity, while countries like Croatia and Slovakia show much smaller figures (Figure 7).

The variance and skewness in several indicators (Appendix A1), such as 2WUAFF and 5RGDP, indicate asymmetrical distributions and the potential presence of outliers, particularly in water resource usage. Kurtosis values also highlight the degree of peakedness in the data, with certain countries showing either highly peaked or flat distributions, suggesting varying levels of consistency in environmental and economic practices across the region. Overall, the dataset provides a robust foundation for analyzing the complex relationships between water resource management and economic performance within the framework of achieving climate neutrality in the EU Danube Region.

Figure 7 presents boxplot diagrams that illustrate the temporal distribution characteristics of several key indicators for each member state of the EU Strategy for the Danube Region (EUSDR). The analyzed indicators include water use in agriculture, forestry, and fishing (2WUAFF), total gross water abstraction from fresh surface water (2TGWA), water exploitation index (4WEI), environmental protection government expenditure (1EPGEXP), sewage sludge production (3SSP), real GDP *per capita* (5RGDP), and water productivity (5WP). Each boxplot provides a visual summary of the data distribution over time, highlighting the median, interquartile range, and potential outliers for each country. In the case of 2WUAFF and 2TGWA, the boxplots reveal significant variation in water usage across countries, with countries like Germany and Austria showing higher levels of water abstraction compared to Bulgaria and Romania, which exhibit lower usage. The boxplot for 5RGDP, representing real GDP *per capita*, demonstrates the economic disparities within the region, where wealthier countries like Austria and Germany have higher median GDP values, while countries like Bulgaria and Romania are positioned lower. The 1EPGEXP and 3SSP boxplots also show variability in environmental protection expenditures and sewage management practices, indicating differing levels of investment in sustainable practices and infrastructure across the EUSDR member states.

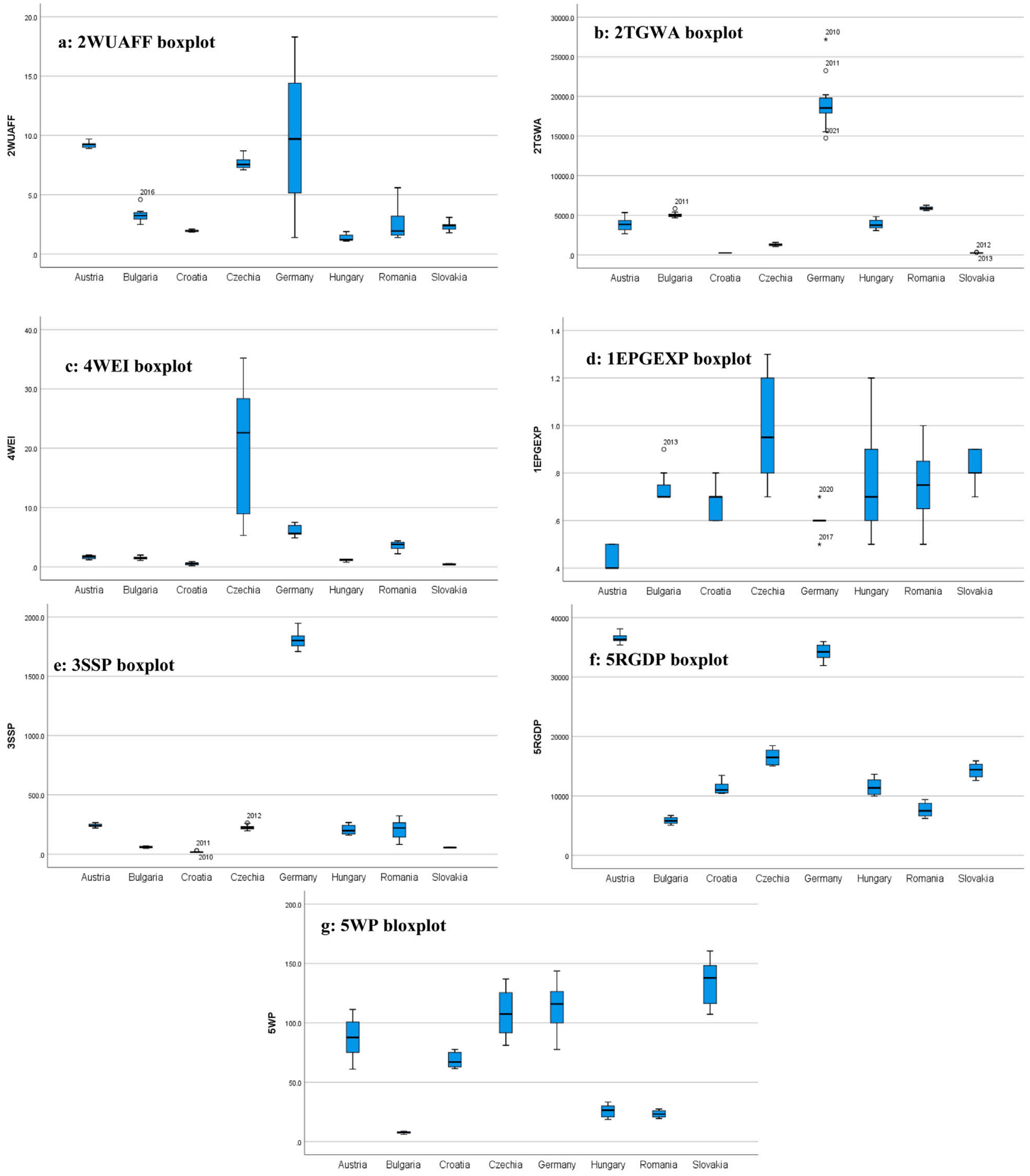

FIGURE 7
Boxplot diagrams and temporal distribution characteristics of the analyzed indicators for each EUSDR member state **(A)**: 2WUAFF boxplot (Water use in agriculture, forestry and fishing); **(B)** 2TGWA boxplot (Total gross Water abstraction Fresh surface water); **(C)** 4WEI boxplot (Water exploitation index, plus); **(D)** 1EPGEXP boxplot (Environmental protection government expenditure); **(E)** 3SSP boxplot (Sewage sludge production and disposal from urban wastewater); **(F)** 5RGDP boxplot (Real GDP per capita); **(G)** 5WP boxplot (Water productivity). Source Authors contributions.

With respect to the proposed model, the calculation of the Pearson correlation coefficients projected in dynamics in the period 2010–2021 reflects the following aspects of the integration of climate neutrality objectives (see Table 3).

Table 3 presents the Pearson correlation coefficients between real GDP *per capita* (5RGDP) across the years 2010–2021 and several independent variables related to water resource management and environmental factors. The correlations vary

TABLE 3 Table of Pearson coefficients attached to the dynamic model.

Pearson correlation	5RGDP 2010	5RGDP 2011	5RGDP 2012	5RGDP 2013	5RGDP 2014	5RGDP 2015	5RGDP 2016	5RGDP 2017	5RGDP 2018	5RGDP 2019	5RGDP 2020	5RGDP 2021
2WUAFF2010	−0.494	−0.657	−0.656	0.169	−0.457	0.572	0.345	−0.558	−0.550	−0.651	−0.624	−0.653
2TGWA2010	0.647	0.469	0.341	0.190	−0.082	−0.586	−0.118	0.488	0.677	0.657	0.769	0.804
3SSP2010	0.774	0.673	0.765	0.470	0.490	0.332	−0.328	0.567	0.708	0.836	0.836	0.571
4WEI2010	0.061	−0.153	−0.232	0.014	0.082	−0.177	0.448	0.311	0.226	0.193	0.042	0.094
1EPGEXP2010	−0.257	−0.033	0.220	−0.646	0.082	−0.431	−0.156	−0.659	−0.373	−0.321	−0.297	−0.058
5WP2010	−0.399	0.014	−0.133	0.124	0.181	0.621	0.402	−0.088	0.512	−0.265	−0.329	−0.533

Source Authors contributions using SPSS, 25v.

significantly over the years, highlighting both positive and negative relationships between the independent variables and GDP growth. For instance, 2WUAFF shows predominantly negative correlations with GDP across most years, with particularly strong negative relationships in 2011, 2012, and 2021. This suggests that higher water use in agriculture and forestry is associated with lower GDP *per capita*, potentially reflecting inefficient water usage or environmental degradation that hinders economic performance. Conversely, 2TGWA (total gross water abstraction) demonstrates positive correlations with GDP in most years, especially in 2020 and 2021, with coefficients reaching 0.769 and 0.804, respectively. This indicates that higher water abstraction is positively associated with economic growth, likely due to more productive water usage in economic activities. Sewage sludge production (3SSP) also shows strong positive correlations, particularly in 2019 and 2020, suggesting that more efficient waste management practices could support economic growth. Meanwhile, environmental protection expenditure (1EPGEXP) exhibits predominantly negative correlations with GDP, especially in 2013 and 2017, implying that while such expenditures are important for long-term sustainability, they may impose short-term economic costs. The varied correlations across different years and variables reflect the complex interactions between environmental policies, water resource management, and economic outcomes within the studied period.

In the case of Objective 1: Increasing the EU's Climate ambition for 2030 and 2050, there is an inverse correlation with the efficiency of financing the transition to climate neutrality, which we believe is favoured by the fragmentation of implementation methodologies, regional disparities and inefficiency of structural instruments in relation to the proposed objective. We believe that a stricter legislative framework, the development of operational structural instruments and the congruence of regional objectives in relation to Community objectives could be factors favouring improved implementation results. This aspect demonstrates hypothesis H1: Achieving the 2030 and 2050 climate neutrality targets under the conditions of a Community-generated transition financing is effective if and only if there is congruence between the aggregate targets and the macro-regional targets. The literature supports the hypothesis that achieving climate neutrality targets for 2030 and 2050 is only effective under community-generated transitional financing if there is congruence between aggregate and macro-regional targets. Coordination between national and regional targets is essential for the successful implementation of climate policies and the achievement of climate neutrality targets. This coordination can ensure efficient use of resources, avoid policy conflicts and maximise the impact of adopted measures. The literature provides numerous examples and case studies highlighting the importance of this alignment by avoiding duplication of effort and policy conflicts (Kyriakopoulos and Sebos, 2023), maximising resource efficiency (Huovila et al., 2022), the creation of a coherent legislative framework (Salvador and Sancho, 2021).

Effective coordination between national and regional targets is fundamental to the success of climate policies and the achievement of climate neutrality goals. Case studies and examples from different countries show that close alignment between national and regional strategies can lead to efficient use of resources, avoidance of policy conflicts and effective implementation of energy transition measures. The use of appropriate tools and mechanisms can facilitate this coordination, ensuring that climate objectives are achieved in a coherent and integrated way.

Consistency of objectives between different levels of government and economic sectors is essential to achieve an efficient and equitable energy transition. Coherence ensures that efforts and resources are allocated coherently, avoiding duplication of effort and maximising the positive impact of policies. The literature highlights many issues that highlight the importance of this alignment, such as resource efficiency and avoiding duplication of effort and maximising economic efficiency (World Economic Forum, 2024).

Financing the energy transition is a significant issue for achieving climate and sustainability goals. The role of communities in this process is essential, as they can contribute both through local initiatives and by participating in wider funding schemes. The literature explores various financing models and underlines the importance of community involvement in the transition to renewable energy and carbon reduction (Bhattacharyya, 2021; Pillan et al., 2023; Sovacool et al., 2023; Ulpiani et al., 2023).

Implementing climate neutrality objectives is a complex process that requires effective coordination, strategic planning, and integration of various public policy measures. The literature provides multiple perspectives and case studies highlighting the challenges and effective solutions to achieve these goals through strategic planning and governance, technologies and innovation, stakeholder participation and involvement, monitoring and evaluation tools (Kilkis et al., 2024; Kyriakopoulos and Sebos, 2023; Shtjefni et al., 2024).

The level of correlation of efforts in the area of Objective two reflected by the indicator Water use in agriculture, forestry and fishing is inversely proportional to the financing of the transition to climate neutrality in an almost constant way over the period analysed, which means that achieving climate neutrality targets in the area of Water use in agriculture, forestry and fishing is a costly process, influenced by climate change, pollution levels, desertification and economic crisis. Policies in this area are currently aimed at financing environmentally friendly alternatives in line with socio-economic and geo-political dynamics. As disadvantaged factors in the process of transition to climate neutrality we mention for the EUSDR land fragmentation, poor organisation of agricultural associations, forestry and aquaculture entities, which dilute macro-regional and EU efforts to implement Objective 2: Supplying clean, affordable and secure energy. Another indicator that relates to Objective two is Total gross water abstraction Fresh surface water. According to the model, the Pearson correlation with the efficiency of climate neutrality implementation for this indicator reveals that EU concerns were better valued at the beginning of the period (2010–2011) and at the end of the period (2019–2021). It seems that the pandemic has been an enabling factor for the implementation of Green Deal policies in the protection of water and biodiversity, i.e., the cessation of economic activity against the backdrop of measures to combat the disease and the reduction of trade have allowed the restoration of water balance and ecosystems. This approach demonstrates the validity of hypothesis H2. The provision of clean, affordable and secure energy is possible in the context of the Green Deal by linking the correction of internal disruptive factors (level of economic development, regional disparities, target management and financial management) with effective measures to reduce the influence of external disruptive factors (economic crisis, geo-political climate, influence of climate change).

The hypothesis that the provision of clean, affordable and secure energy is possible in the context of the Green Deal by linking the correction of internal disruptors with effective measures to reduce the influence of external disruptors is supported by several studies in the literature. These studies highlight the interaction between internal and external factors and the effectiveness of integrated strategies in achieving energy goals (Anser et al., 2020; M; Li et al., 2023; Strielkowski et al., 2021). Studies highlight that regional disparities in economic development can influence the effectiveness of energy policies. For example, the EU Green Deal aims to address these disparities through targeted investment and support for less developed regions to ensure an equitable transition to clean energy (European Commission, 2021; Sasse and Trutnevyte, 2023). Other studies show that effective targeting and financial management is essential for the successful implementation of energy policies. Setting clear targets, transparent monitoring and adequate financing are essential to drive progress and ensure accountability (Agrawal et al., 2023; Lu et al., 2020). Economic crises can disrupt energy markets and hamper investment in clean energy. However, strategic policy responses can mitigate these impacts and even turn crises into opportunities for green investments (Caetano et al., 2023; European Investment Bank Group, 2024). Geopolitical factors, including international relations and trade dynamics, can significantly influence energy security and the transition to clean energy (Q. Wang et al., 2024). Effective diplomacy and international cooperation are essential to navigate these challenges. Climate change itself is a disruptive factor impacting energy systems (Jasiūnas et al., 2021). Adaptation measures and resilient infrastructure are needed to ensure energy security in the face of climate disruption. Delivering clean, affordable and secure energy under the Green Deal is feasible by correcting internal disruptors and mitigating the influence of external disruptors. The literature supports the hypothesis that integrated approaches that combine internal governance with strategic external measures can achieve energy goals and address broader economic and political challenges.

In the field of Objective 3: A zero pollution ambition for a toxic-free environment, the analysed indicator Sewage sludge production and disposal from urban wastewater demonstrated through modelling a good correlation and adherence to the macro-regional and EU implementation effort, however, an oscillating evolution was observed with peaks in 2010–2012 and 2019–2020. In 2021, the level of correlation dropped again dramatically, from 83% to 57% Pearson correlation with financing the transition to climate neutrality. With this approach, the hypothesis H3: Achieving effective parameters on pollution reduction and climate neutrality requires at the time of the analysis only efforts to maintain the strategic directions already adopted, this objective being the best valued of the 5 Green Deal objectives studied is validated.

The hypothesis that achieving effective pollution reduction and climate neutrality metrics only requires efforts to maintain the policy directions already adopted, this objective being the highest rated of the five Green Deal objectives studied, is supported by several studies in the literature. These studies underline the importance of maintaining and strengthening existing policies to achieve the ambitious climate targets (Bäckstrand, 2022).

The studies show that maintaining the continuity of previously adopted climate policies is important to achieving the pollution reduction and climate neutrality targets (F. Wang et al., 2021). Policy stability allows economic and social actors to adapt and invest in sustainable technologies and practices. Constantly evaluating current policies and adjusting them based on new data and analysis is essential to maintain the right policy direction. Some studies show that well-assessed and adjusted policies contribute significantly to reducing emissions and achieving climate neutrality (Chipangamate and Nwaila, 2024; Sánchez-García et al., 2024). Climate neutrality is an essential and achievable goal that can be reached by maintaining current policies and stepping up efforts in critical areas. Climate neutrality is often considered the most important of the Green Deal targets. Reducing pollution, including greenhouse gas emissions, is a essential intermediate target for achieving climate neutrality. Maintaining pollution reduction policies contributes directly to improving air quality and public health (Lin et al., 2023; Milner et al., 2020).

Maintaining and strengthening the policy directions already adopted is essential to achieve effective pollution reduction and climate neutrality. The literature supports the hypothesis that stability and continuity of climate policies are fundamental to achieving the ambitious goals of the Green Deal. Constant evaluation and adjustment of policies on the basis of up-to-date data ensures continuous progress and achievement of the targets set.

Regarding Objective 4: Preserving and restoring ecosystems and biodiversity, we found an oscillating, slightly destabilized correlation of the objective through the Water exploitation index, which means that the level of financial allocation related to protection, biodiversity and water has so far failed to generate the achievement of the proposed targets in the 2030 and 2050 horizons. In our opinion, the unfavourable factors are of an external nature (economic crises, environmental protection dysfunctions in terms of watershed pollution, climate change). The internal unfavourable factors are the irrational exploitation of water, the increase in consumption, the energy crisis which transfers pressure on the hydropower system. European policies on the protection and restoration of ecosystems and biodiversity should favour a more accelerated development of the blue economy and the circular economy as factors for normalising tensions between resource allocation and economic output in the context of a desirable climate neutrality. These developments validate hypothesis H4: Preserving and restoring ecosystems and biodiversity can take place in the context of a better promotion and operationalization of the blue and circular economy.

The validation of the hypothesis that conservation and restoration of ecosystems and biodiversity can take place in the context of better promotion and operationalization of the blue and circular economy is supported by several studies in the literature. These studies highlight the importance of integrating the principles of the blue and circular economy into environmental policies to support biodiversity conservation and ecosystem health (Alhawari et al., 2021; Elegbede et al., 2023; Schröder et al., 2018).

The blue economy promotes the sustainable use of ocean and water resources for economic growth, improved livelihoods and jobs, while maintaining the health of marine and freshwater ecosystems (Appiah et al., 2022; Elegbede et al., 2023). The circular economy focuses on waste reduction, recycling and reuse, thus helping to reduce pressure on natural resources and ecosystems (Obaideen et al., 2022).

Public policies that support the transition to the blue and circular economy are essential to facilitate the conservation and restoration of ecosystems. The involvement of local communities and the private sector in promoting the blue and circular economy is fundamental to the success of these initiatives (Calisto Friant, 2022; Kirchherr et al., 2023).

Conservation and restoration of ecosystems and biodiversity can take place effectively in the context of better promotion and operationalization of the blue and circular economy. The literature supports the hypothesis that integrating the principles of these economies into environmental policies and involving communities and the private sector are key to protecting natural resources and biodiversity. Adoption and implementation of these strategies can lead to significant results in preserving the environment and ecosystem health.

- Objective 5: Financing the transition is deficient both in terms of the balance of financial allocations, regional disparities and differences in national or regional economic capacity to implement climate neutrality measures. Thus, the Pearson correlation of the Water productivity indicator in relation to the dependent variable Real GDP *per capita* is predominantly inverse proportional and asymptotic, the best results being achieved in 2015–2016 (see Figure 8).

Figure 8 provides a graphical representation of the relationships between selected independent variables—such as 2WUAFF (water use in agriculture, forestry, and fishing), 3SSP (sewage sludge production and disposal), and 1EPGEXP (environmental protection government expenditure)—and their corresponding impacts on the dependent variable, represented by real GDP *per capita*. The graph reveals varying impacts of these variables, with some demonstrating a stronger positive correlation (e.g., 1EPGEXP), while others, such as 2WUAFF, exhibit negative correlations. This visualization suggests that environmental protection expenditure is positively associated with GDP growth, supporting the notion that government investments in environmental sustainability can yield economic benefits. In contrast, water use in sectors like agriculture and forestry seems to negatively affect economic outcomes, likely due to inefficient resource utilization or environmental degradation. The graph serves as a valuable tool for policymakers, highlighting the areas where targeted interventions, such as increasing environmental protection investments or optimizing water resource use, can drive both ecological and economic improvements within the framework of the Green Deal.

The research also has a prospective character by extending the variance curves of the implementation of climate neutrality policies in the econometric model perspective, the authors projecting the prospective dimension starting from the forecast intervals determined from the residual statistics of the proposed

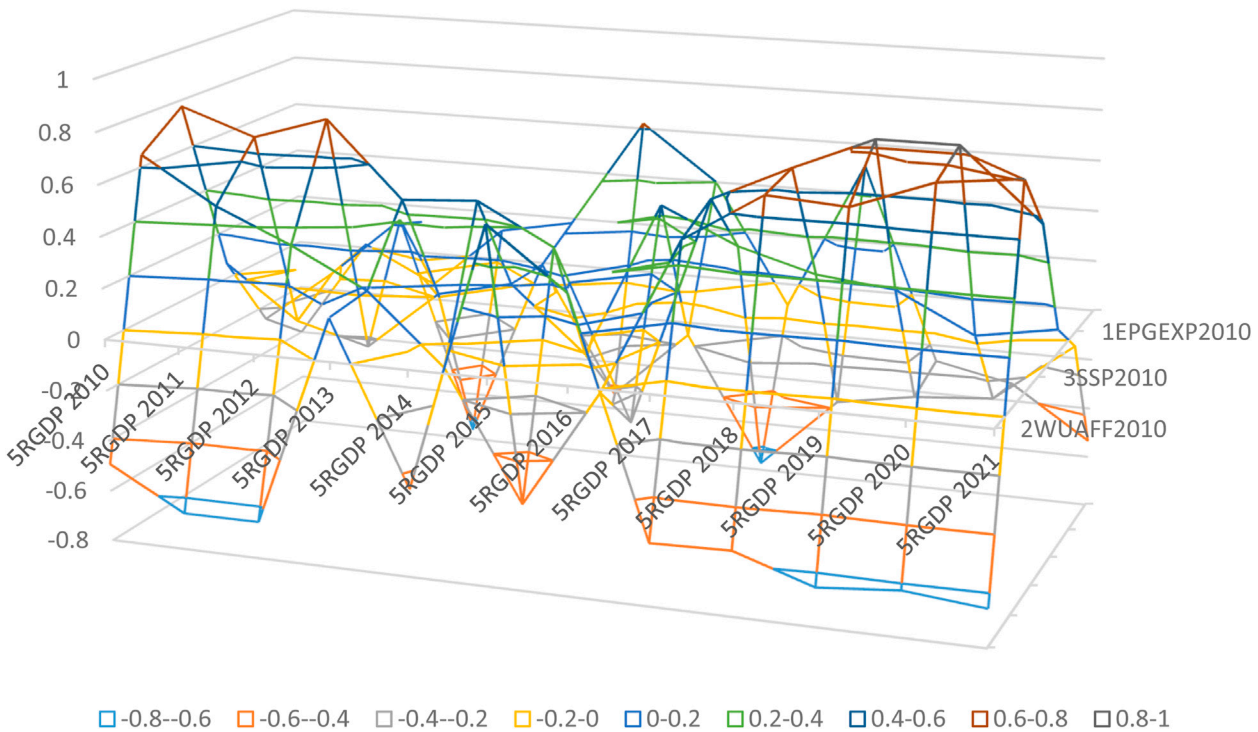

FIGURE 8
Histogram of the dynamics of the Pearson correlation level of the dependent variable of the model in relation to the regressors for determining the effectiveness of the implementation of climate neutrality targets. Source Authors contributions.

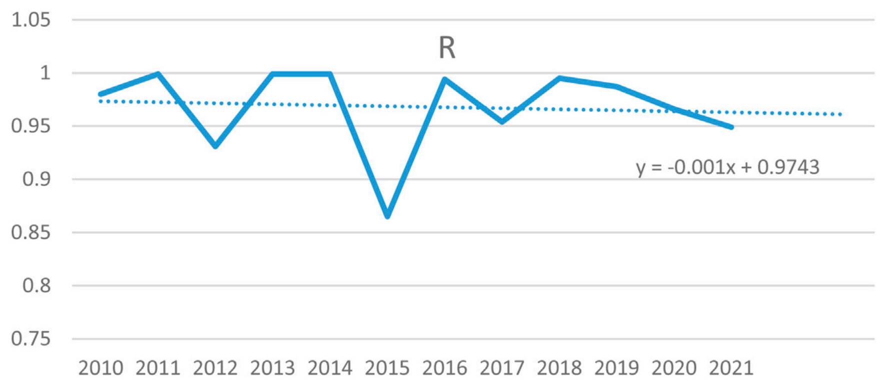

FIGURE 9
Pearson correlation trend prediction of the dynamic model. Source Authors contributions.

econometric model. The trend curve for the Pearson correlation coefficient is defined by the polynomial equation:

according to Figure 9.

$$y = -0.001x + 0.9743, \quad (2)$$

Figure 9 illustrates the trend of the R-value (correlation coefficient) over the period from 2010 to 2021, with the equation of the regression line (please see Equation 2) indicating a very slight negative slope. The R-value consistently hovers around 1, demonstrating a high level of correlation between the predicted and actual values in the econometric model. This near-perfect correlation suggests that the model was highly effective in capturing the relationship between the key variables analyzed, particularly in terms of water resource management and climate neutrality in the European context. The linear regression line shows minimal variation over the years, implying the model's robustness and stability in explaining the data across different time periods. The slight downward trend in the R-value, while still close to 1, may indicate that as new variables or external factors were introduced into the model (such as economic crises or environmental changes), they slightly affected the model's predictive strength. Nonetheless, the figure confirms that the model remains highly reliable, with minimal deviation from perfect correlation, underscoring its value in policymaking related to sustainable water use and economic outcomes under the European Green Deal framework.

We believe that the proposals formulated in the Discussions section would be able to improve the prospects of achieving climate normality objectives, the authors being more optimistic about achieving them by 2050, because the current geo-political context, energy crisis, pandemic crisis still active induce vulnerabilities at least for the 2030 horizon.

The study highlighted the potential vulnerabilities of the EUSDR (EU Strategy for the Danube Region) member states in achieving the Green Deal objectives for the 2030 and 2050 horizons. These vulnerabilities include issues related to water resource management, economic and ecological impact, and the ability to adapt to climate change. The blue economy, which encompasses economic activities related to oceans, seas and inland waters, has a significant role in achieving climate neutrality goals. The study analyzed the contribution of these activities to reducing carbon emissions and protecting water resources. Through the use of dynamic models, the economic and ecological impact of water resources was assessed, the study providing a long-term perspective on how environmental protection policies and initiatives can influence economic sustainability and development. The study contributes to the existing literature by integrating the economic and ecological dimensions in water resource impact analysis. This holistic approach is essential for developing effective policies that support both economic growth and environmental protection. By testing and validating existing theoretical models, the research provides empirical evidence supporting the need for sustainable water management. This process helps to refine theories and develop new models that are more applicable in the current context. Building and analyzing a database of relevant indicators is an important contribution to existing knowledge, providing a robust dataset for future research and public policy development. The study emphasizes the importance of sustainable management of water resources in the context of climate neutrality objectives. By highlighting the ecological and economic impact of these resources, research promotes sustainable practices that can reduce carbon footprints and protect aquatic ecosystems. The results of the study can provide support for the development of public policies to support the transition to a green economy. These policies may include measures to protect water resources, stimulate the blue economy and reduce greenhouse gas emissions. By identifying vulnerabilities and offering solutions for their management, the study contributes to improving the adaptation capacity of EUSDR member states to climate change. This is essential to ensure long-term sustainability and to achieve climate neutrality goals. In conclusion, this study makes a significant contribution to understanding the economic and ecological impact of water resources in the context of the EU's climate neutrality objectives, providing empirical evidence and solutions for promoting sustainability.

6 Conclusion

The research achieved its objectives by critically analysing the Green Deal issue from the perspective of wise use of aquatic resources, and the authors show that there are significant threats that could create impediments to achieving climate neutrality in the EUSDR area by 2030.

The most significant impediments identified are the significant regional disparities affecting the region's compliance with EU policies, as well as some impediments to the organisation and exploitation of the resources of the countries in the region in terms of both national organisation and efficient and sustainable community organisation in the exploitation of these resources.

The main productive activities that impact irrational consumption of resources come from the agricultural area, and here the main shortcomings are land segmentation, poor organization of associative forms in some countries and poor infrastructure. From the industry's point of view, there are threats from excessive pollution generated by the chemical and steel processing industry, which in the authors' opinion must benefit from public financial support and government regulatory input to improve sustainability and environmental parameters, a useful but still insufficiently used tool being the GRI (Global Reporting Initiative) reports and the unitary interpretation that could strengthen a national and regional vulnerability monitoring framework as a basis for the implementation of corrective regional policies.

The novelty of our paper, lies in its comprehensive approach to dynamically modeling both economic and ecological impacts of water resources specifically in the EUSDR region in the context of achieving the EU's Green Deal targets for climate neutrality. While there have been numerous studies on the Green Deal and climate neutrality, few focus specifically on the EUSDR (EU Strategy for the Danube Region), a macro-region with significant economic and environmental disparities. This paper uniquely examines how the blue economy - particularly water resources - plays an important role in achieving climate neutrality in this region. Previous studies have focused on individual countries or broad EU regions, often addressing climate policies or environmental impacts in isolation. This study integrates both economic and environmental modeling specifically for the EUSDR, a region with distinct characteristics such as water resource distribution, industrial structures, and agricultural patterns. Our paper introduces a dynamic econometric model that integrates key variables such as water use in agriculture, GDP *per capita*, sewage sludge production, and water exploitation index to project the impacts on climate neutrality over time. This model is unique in that it offers a comprehensive, data-driven approach to evaluating both short-term and long-term impacts. While earlier research has utilized econometric modeling to assess climate or environmental impacts, few have done so with such a dynamic perspective focused on water resources. Most models are static or linear, whereas this paper's model allows for a longitudinal assessment of water's role in economic growth and ecological sustainability in the context of climate goals. Our study is one of the few that directly aligns the Green Deal's climate neutrality goals with the blue economy framework, particularly focusing on water resources. The circular economy and blue economy are frequently discussed in isolation, but this paper integrates them into a cohesive model, demonstrating how the management of water resources is pivotal for both economic growth and environmental conservation in the EUSDR. Prior studies have largely separated climate policy from water resource management, treating them as parallel but disconnected areas. This paper bridges that gap by showing the interdependence of water resources and economic growth in achieving climate neutrality, especially in a region like the EUSDR with abundant but vulnerable water resources.

The novelty of the present research lies in demonstrating the problem addressed in a critical, applied manner, the results of which confirm the vulnerable status of climate neutrality in the absence of effective corrective measures targeted at regional non-conformities whose causes lie in deviation from EU recommendations or insufficient financing capacity for change.

We appreciate that the blue economy dimension used in a novel way in which the integrative potential of this new approach is exploited can bring a significant added value to the region, bringing the climate neutrality objectives closer to the European goal.

The limitations of the study lie in its reference to a region with heterogeneous particularities and cluster distributions of economic development, but also in the relatively limited number of indicators analysed, the authors proposing, on the occasion of a future research, to extend the research to the entire European space, estimating the wastewater generation information for Germany thought the inventory of wastewater treatments plants listed by the European Commission (WISE-Freshwater, 2024) and the HydroWASTE database (HydroSHEDS, 2024) to extend the number of indicators and the observation period in order to generalize the model and validate it.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the [patients/ participants OR patients/participants legal guardian/next of kin] was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

RI: Conceptualization, Methodology, Supervision, Writing–original draft. MZ: Conceptualization, Investigation, Methodology, Supervision, Writing–original draft. VA: Conceptualization, Investigation, Methodology, Project administration, Writing–original draft. DC: Data curation, Resources, Software, Validation, Visualization, Writing–review and editing. SP: Data curation, Formal Analysis, Resources, Validation, Visualization, Writing–review and editing. CF: Formal Analysis, Investigation, Project administration, Validation, Visualization, Writing–review and editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This work was supported by the project “DINAMIC”, financed by the Romanian Ministry of Research and Innovation, Contract no. 12PFE/2021 and Internal grant Dunarea de Jos University of Galati 2024: Sustainable development of the European economy from the perspective of the transition to climate neutrality, Contract no. 2464/31.05.2024. The present research was carried out in the framework of the project An Integrated System for the Complex Environmental Research and Monitoring in the Danube River Area, REXDAN, SMIS code 127065, project co-financed by the European Regional Development Fund through the Competittiveness Operational Programme 2014-2020, contract no. 309/10.07.2020.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher’s note

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Appendix A1: Descriptive statistics by country in analysed period (2010–2021).

Country	Statistics	2WUAFF	2TGWA	3SSP	4WEI	1EPGEXP	5RGDP	5WP
Austria	Median	9.25	3,848.15	238.10	1.75	0.40	36,345.00	87.65
	Maximum	9.70	5,340.70	266.30	2.00	0.50	38,110.00	111.20
	Variance	0.05	632,591.15	228.53	0.07	0.00	671,315.15	249.64
	Kurtosis	0.15	−0.39	−0.58	−1.29	−1.65	0.18	−1.03
	Skewness	0.64	0.37	0.64	−0.49	0.81	0.64	−0.17
Bulgaria	Median	3.25	4,990.50	59.80	1.50	0.70	5,805.00	7.40
	Maximum	4.60	5,840.40	68.60	2.00	0.90	6,690.00	8.80
	Variance	0.30	104,490.81	41.28	0.07	0.00	305,638.64	0.74
	Kurtosis	2.35	2.48	−1.43	−0.11	3.17	−1.47	−0.83
	Skewness	1.01	1.44	−0.19	0.23	1.93	0.20	−0.08
Croatia	Median	1.95	254.00	17.75	0.60	0.70	11,005.00	67.00
	Maximum	2.10	292.10	31.00	0.90	0.80	13,460.00	77.60
	Variance	0.01	308.66	29.65	0.04	0.01	1,026,369.70	40.49
	Kurtosis	0.45	−1.32	1.51	−0.60	−0.87	−0.13	−1.84
	Skewness	0.61	0.48	1.59	0.05	0.48	0.92	0.27
Czechia	Median	7.55	1,266.90	223.10	22.60	0.95	16,480.00	107.40
	Maximum	8.70	1,573.40	263.30	35.20	1.30	18,460.00	136.90
	Variance	0.23	25,556.24	394.06	114.83	0.05	1,640,063.64	364.75
	Kurtosis	0.56	−0.37	0.33	−1.55	−1.40	−1.74	−1.27
	Skewness	1.04	0.53	0.77	−0.19	0.23	0.16	0.12
Germany	Median	9.70	18,534.00	1,801.55	5.65	0.60	34,220.00	115.95
	Maximum	18.30	27,195.00	1,946.30	7.50	0.70	35,980.00	143.60
	Variance	32.02	10,897,960.50	4,715.06	0.82	0.00	1,452,311.36	405.58
	Kurtosis	−1.19	2.54	0.21	−1.04	5.50	−0.47	−0.47
	Skewness	−0.02	1.33	0.59	0.73	0.00	−0.29	−0.40
Hungary	Median	1.20	3,754.00	197.85	1.20	0.70	11,360.00	26.50
	Maximum	1.90	4,834.80	266.80	1.30	1.20	13,660.00	33.30
	Variance	0.08	340,239.32	1,711.49	0.02	0.06	1,707,275.00	24.73
	Kurtosis	−0.88	−0.99	−1.79	1.07	−0.14	−1.41	−1.24
	Skewness	0.84	0.41	0.30	−1.21	0.84	0.32	−0.16
Romania	Median	1.95	5,876.00	220.55	3.80	0.75	7,480.00	23.10
	Maximum	5.60	6,264.00	323.10	4.40	1.00	9,380.00	27.40
	Variance	1.52	40,081.70	6,552.55	0.50	0.02	1,309,551.52	7.84
	Kurtosis	3.04	−0.68	−0.95	−0.34	−0.47	−1.61	−1.41
	Skewness	1.70	0.25	−0.33	−0.78	0.00	0.18	0.12

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Country	Statistics	2WUAFF	2TGWA	3SSP	4WEI	1EPGEXP	5RGDP	5WP
Slovakia	Median	2.40	243.30	55.35	0.40	0.80	14,425.00	137.85
	Maximum	3.10	326.40	58.70	0.60	0.90	15,890.00	160.50
	Variance	0.18	1,036.05	3.38	0.01	0.00	1,314,062.88	320.59
	Kurtosis	−0.04	1.76	−0.93	−0.91	−0.09	−1.60	−1.30
	Skewness	0.40	1.58	0.42	1.05	−0.17	−0.07	−0.21
Total	Median	3.05	3,780.75	201.50	1.50	0.70	13,215.00	75.10
	Maximum	18.30	27,195.00	1,946.30	35.20	1.30	38,110.00	160.50
	Variance	14.76	34,697,546.01	313,403.67	52.48	0.04	122,046,218.55	2,165.08
	Kurtosis	1.36	3.27	3.13	7.91	1.03	−0.81	−1.32
	Skewness	1.30	1.95	2.20	2.89	0.81	0.89	0.09