


Review

Progress in the Research of Environmental Macroeconomics

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Abstract: This review systematically introduces the current main research directions of environmental macroeconomics. Environmental macroeconomics research aims to study the relationship between economic development and the ecological environment and ultimately achieve green outcomes. At the same time, maintaining a moderate economic scale within the environmental setting is vital to get rid of excessive dependence on economic growth. This review draws on the traditional macroeconomics framework, focusing on economic growth, the economics of climate, economic policy, work, consumption, technological progress, industrial structure, and other topics. Although most studies have highlighted the importance of environmental issues, few empirical analyses combine environmental policy with economic policy, production, consumption, climate change, etc., and theories such as ecological, technological progress, business cycle, and environmental policy lack the necessary practical support. It is, therefore, difficult to put forward appropriate and measurable policy recommendations. Environmental macroeconomics is still a relatively new field of research, the theoretical system has flaws, and innovations in models still need to be improved. We suggest that environmental policy formulation be placed in a dynamic general equilibrium framework.

Keywords: environmental macroeconomics; environment and economic growth; economic policies; environmental Kuznets curve



Citation: Niu, M.; Zhang, S.; Zhang, N.; Wen, Z.; Xu, M.; Yang, Y. Progress in the Research of Environmental Macroeconomics. *Sustainability* **2022**, *14*, 1190. <https://doi.org/10.3390/su14031190>

Academic Editors: Jan Parobek, Andreja Pirc Barčič, Hubert Paluš and Branko Glavonjic

Received: 16 December 2021

Accepted: 20 January 2022

Published: 21 January 2022

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1. Introduction

In the past 40 years, more than half of the vertebrates on the planet have become extinct (international). The global average temperature has risen by 0.9 °C, and the global population has increased by more than 90%. At present, human impact on the ecosystem is increasing and more extensive than ever before. International economic activities have destroyed the ecological foundation of biodiversity and have produced many greenhouse gases and pollutants; the ecosystem on which human well-being depends is constantly deteriorating. According to relevant predictions, the global average temperature may rise by 4 °C by 2100 [1,2], which will lead to unimaginable catastrophic consequences [3].

For this reason, a large number of scholars have called on governments of all countries to immediately formulate effective policies to mitigate the adverse effects of the ecological crisis on human welfare and economic growth [2,4,5]. Countries have signed a series of documents (the 1972 Stockholm Declaration, the 1987 Montreal Protocol, the 1992 Rio Declaration on Environment and Development, the 1997 Kyoto Protocol, the 2002 Johannesburg Declaration, and the 2009 Copenhagen Agreement Document) to improve the protection and management of the ecosystem and jointly respond to environmental problems. However, to compete for the right to development, countries have significant differences on critical issues such as allocating carbon emission rights. Their willingness to implement the documents is not strong. Therefore, although the global environmental

problem is severe, the supply of public products such as capital and technology required for environmental management is seriously insufficient. Environmental governance is difficult to achieve, and the ecological environment is still deteriorating. In response to climate change, in 2021, the two sessions of China proposed the “carbon peak” and “carbon neutral”—“two carbon” goals. They promised that carbon dioxide emissions would reach their peak by 2030 and strive to achieve afforestation, energy conservation, and reduction by 2060. Emissions, etc., offset their carbon dioxide or greenhouse gas emissions, achieve positive and negative offsets, and relatively “zero emissions”.

In this context, environmental macroeconomists put forward the enormous development contradictions that current society is facing: On the one hand, under the current energy-intensive growth model, high-speed economic growth is bound to approach the limit of environmental carrying capacity, and irrational change may lead to ecological disasters and cause severe and irreversible consequences. On the other hand, the current economic system and mainstream economic theories are too dependent on economic growth. Suppose the environment’s constraints on economic growth are recognized, and low or even zero economic development is implemented. In that case, it will intensify internal social conflicts such as unemployment, polarization between the rich and the poor, and lack of welfare, causing social unrest. Therefore, it is necessary to develop new macroeconomic tools to coordinate the relationship between the environment and economic growth, analyze the situation of low-speed economic growth, and free the financial system from dependence on economic growth. Environmental macroeconomics has emerged as the times require.

As an emerging interdisciplinary field, environmental macroeconomics (also known as ecological macroeconomics) mainly integrates the relevant theories of ecological economics and post-Keynesian macroeconomics. Macroeconomics is regarded as a part of the ecosystem [6] that aims to analyze the complex relationship between economic activities and the ecological environment, calculate the upper limit of the economic scale, and develop macroeconomic models and modeling tools that are different from traditional economics. The advocacy concepts of environmental macroeconomics such as green development, new energy, and carbon neutrality are no longer imaginary but represent the direction of human development and have begun to become a social consensus. For example, at the end of 2020, the market value of new energy electric vehicle Tesla surpassed the sum of the nine traditional car companies. The market value of the Ningde era, which focuses on lithium batteries, exceeded PetroChina. Today, environmental macroeconomics has attracted more and more attention. It is a critical way forward and has broad development prospects [7].

The literature in the field of environmental macroeconomics is rapidly increasing. But so far, there has not been a systematic review and commentary on the theoretical basis, model methods, main viewpoints, and research frontiers of environmental macroeconomics. Stemming from research frontiers of environmental macroeconomics, this paper systematically combs the new research progress in environmental macroeconomics.

Traditional macroeconomics ignores the link between macroeconomics and the environment. The limitations of conventional macroeconomics are becoming more and more apparent when explaining today’s world economic phenomena. The background of environmental macroeconomics is that resources and the environment increasingly restrict human economic behavior, and macroeconomic activities must consider the impact of the ecological environment. Mainstream economic theories and literature are too dependent on economic growth. After incorporating environmental factors into macroeconomics, growth should be limited to a sustainable economic scale, making it possible to innovate in environmental macroeconomics theories. Environmental macroeconomics is still a relatively new field of research, the theoretical system has flaws, and innovations in models still need to be improved. Discussing it facilitates its further integration into mainstream economic research fields and paradigms. Moreover, environmental macroeconomics has solid practical significance, and it is associated with almost all sustainable development goals (SDGs) (see Figure 1).

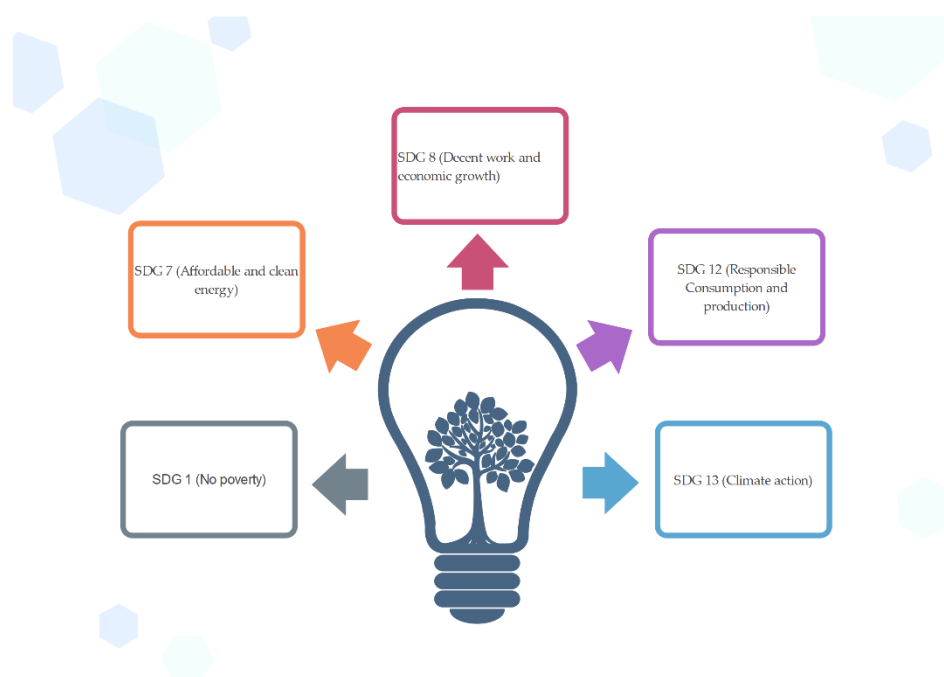


Figure 1. Environmental macroeconomics and the SDGs.

2. The Rise of Environmental Macroeconomics

As we comb through the research, the formation and development of environmental macroeconomics have roughly gone through three periods [8–10]:

First, in the period of feudalism and the outbreak of World War II was the embryonic period of environmental macroeconomics. It was subdivided into three stages: (1) The feudalism stage before the 17th century: Most of the economics only paid attention to land resources and lacked the awareness of other environmental resources such as climate, air, and biodiversity. The mainstream physiocrats believed that only agriculture creates wealth, and land production was the sole or primary source of income and wealth in various countries. (2) The 17th century, the stage of capitalism development in the early 20th century: As Adam Smith criticized the one-sided view of the physiocrats' "land-only theory" in "The Wealth of Nations" and believed that all material production sectors could create wealth, classical economics gradually replaced the physiocrats as the mainstream economy at that time. Environmental resources in economic theory were no longer limited to a single land resource. Early classical economic theories included Adam Smith's "absolute cost theory", David Ricardo's "comparative advantage theory," John Muller's "mutual demand principle," and Thomas Malthus's "population theory", etc.; all had discussions about economic growth being restricted by environmental conditions. (3) The beginning of the 20th century-the stage of monopoly capitalism that broke out in World War II: Along with theoretical innovations such as marginal revolutions, neoclassical economics has gradually become the mainstream, and schools of thought have also emphasized the importance of the environment. The representative Alfred Marshall wrote in "Principles of Economics" that, "To some extent, there are only two products, namely nature, and human beings. Human beings are largely controlled by their circumstances, among which Nature plays an important role". Marshall believed that all the components of economic activity originated from nature, and for the first time, included the environment as capital into the analysis framework of macroeconomics. Pigou discussed the impact of the environment on welfare in "Welfare Economics". Fisher also regarded natural endowments such as lakes and rivers as capital when making various definitions of capital.

Second, from the end of World War II to the 1970s was a transitional period for environmental macroeconomics. After World War II, Western countries experienced rapid economic growth and materialistic values became the mainstream values of society [11].

The government and the public generally believe that economic growth has a higher priority than environmental protection. During this period, neoclassical economics almost solely emphasized the problem of economic growth. Economic growth analysis models such as the Harold-Domar and the Solow models usually only used labor and capital as output factors and the natural environment as exogenous variables; they were excluded from the production function. Neoclassical economists at this time generally rejected the concept of “growth limit”. Although it was recognized that environmental problems such as land desertification and species extinction will harm economic activities, it was not believed that ecological problems would pose a severe threat to the continued global economic growth. The main reasons were for two reasons: On the one hand, the “external theory” believed that as long as the external effects generated by economic activities were correctly priced, external costs such as pollution could be internalized, and economic growth could be decoupled from adverse environmental impacts. On the other hand, neoclassical economics regarded economic growth as a prerequisite for technological change, and technological change would eventually free economic growth from the constraints of the ecological environment.

Third, the development period of environmental macroeconomics is from the 1970s to the present can be subdivided into three stages: (1) The stagflation stage from the late 1960s to the early 1980s: At this time, economic growth in Western countries generally slowed down, and the mainstream social values gradually shifted from materialist to post-materialist values [11]. Economic growth models began to pay attention to the scarcity of natural resources again [12]. At the same time, the concept of “sustainable development” was first put forward in the “Outline for the Protection of Natural Resources of the World” promulgated in 1980. Sustainable development research has also emerged, and environmental macroeconomics occurred. (2) The stage of economic globalization after the 1980s: Daly first proposed the specific concept of “environmental macroeconomics” in 1991. He believed that macroeconomics is a subsystem of the natural ecosystem and forms a dependency relationship with it. There is a low-entropy energy input and high-entropy energy between the two. The output, the cross-border material exchange between systems and subsystems, is the subject of environmental macroeconomics. (3) After the outbreak of the global financial crisis in 2008, the expectation of rapid economic growth was shattered. The academic circle began to think about the constraints of economic growth, and at the same time, some environmentalists began to pour into the field of environmental macroeconomics. In 2018, climate economist Nordhaus won the Nobel Prize in Economics, and environmental macroeconomics research was officially recognized by mainstream economics. These representative events continue to increase the heat of ecological macroeconomics. The combination of environmental macroeconomics with sustainable development, post-Keynesianism, ecology, social psychology, and other theoretical methods has developed rapidly [13].

3. Research Direction of Environmental Macroeconomics

This article draws on the traditional macroeconomic framework and systematically combs the main research directions of environmental macroeconomics from economic growth, economic policies, employment, consumption, technological progress, and industrial structure.

3.1. Environment and Economic Growth

There is a complex and contradictory relationship between the environment and economic growth: On the one hand, economic growth is an essential prerequisite for social stability and development and is the top priority of governments of all countries. No government will actively abandon economic growth for the sake of the environment. On the other hand, as the scale of the economy continues to expand, the ecological environment will restrict economic growth from climate, energy, land, and other aspects in the foreseeable

future. Irrational growth may lead to irreversible environmental disasters. In traditional economics, the vision of continued growth may be shattered.

There is no mature theory to solve the contradiction between economic growth and the environment. Although the “green growth” theory is beautiful, it is challenging to be self-consistent. There is almost no evidence that there is a substantial decoupling between GDP and large-scale carbon-intensive energy use, “economic growth” and “ecological environment” are still contradictory at present [14].

Simon Kuznets has significantly contributed to studying national income accounts while allowing us to better understand the general economic development [15]. One of his observations about income inequality is that in the early stages of development, increases in per capita income increase inequality, while later in effect, as incomes increase, inequality decreases. By plotting the curve of inequality level to per capita income or time change, we can find that the curve first rises and then falls, which is an inverted U-shaped curve. As for pollution or environmental degradation, economists have found that the relationship between it and per capita income or economic development stage is an inverted U-shaped curve that first rises and then falls. This relationship is known as the environmental Kuznets curve (EKC) (See Figure 2); Grossman and Kruger [16] initially developed this theory. Andreoni and Levison [17] further improved the corresponding theoretical model.

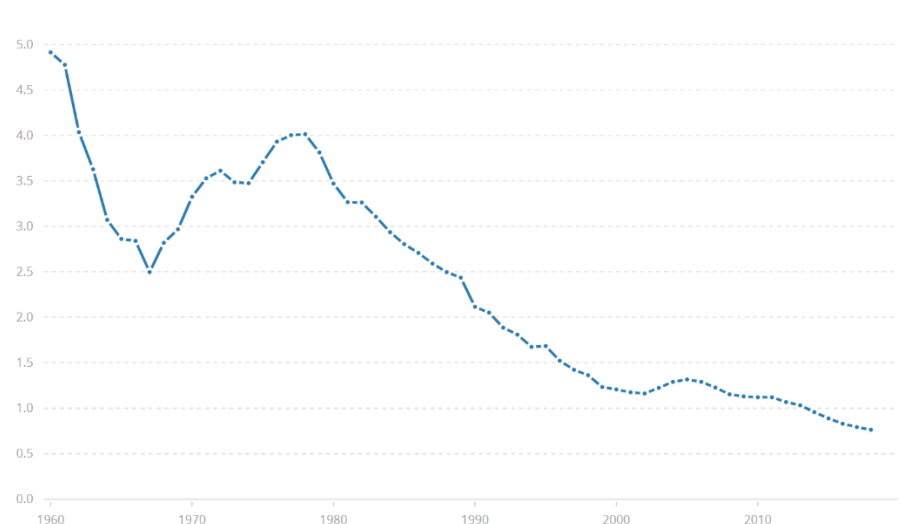


Figure 2. CO₂ emissions (kg per 2015 US\$ of GDP)—China 1960–2018. (World Bank Open Data, data.worldbank.org/).

There is a lot of controversy over whether there is an environmental Kuznets curve in academia [18–23]. The environmental Kuznets curve holds that in economic development, with real GDP per capita growth, the emission of pollutants per capita first rises and then falls. An estimate embodied in the following formula [24]:

$$Y_{it} = \alpha_i + \beta x_{it} + \gamma x_{it}^2 + u_{it} \quad (1)$$

Here Y_{it} is the natural logarithm of per capita pollutant emissions in country i in year t ; x_{it} is the natural logarithm of real GDP per capita in country i in year t ; u_{it} is a random disturbance term, there may be heteroscedasticity, serial correlation, and the corresponding relationship between countries value is also related. We wish to test the null hypothesis for the given data: model coefficients = 0, as opposed to the alternative hypothesis that the coefficients are negative.

Furthermore, as a practical policy analysis tool in economics, the computable general equilibrium model (CGE model) can reasonably simulate the impact of the implementation of policies and management measures on the behavior of various economic agents. By adding natural resources or environmental policy variables into the CGE model (that is,

building an environmental, economical general equilibrium model, referred to as “environmental CGE model”), through the quantitative description of the complex relationship between the environment and the economic system, it is possible to achieve an environmental general equilibrium [25–28].

The environmental CGE model tries to find a balance point between the environment and the economic system to realize the coordinated development of the environment and the economy. The model assumes a mutually restrictive relationship between the environment and the economic system. On the one hand, the environment provides resources for economic development, and on the other hand, the quantity, quality, type, and composition of environmental resources also restrict economic growth. Similarly, on the one hand, economic development plays a positive role in improving the environment. Conversely, unreasonable mode, structure, and scale of economic growth will destroy natural resources, pollute the environment, and even threaten the balance of the entire environmental system. Nordhaus has published the new DICE/RICE Models on his official website [29].

The dynamic stochastic general equilibrium model (DSGE) has gradually become a dazzling star in economic analysis tools in the past three decades, one of the most widely used mainstream research methods and analysis platforms. The DSGE model studies the general equilibrium of the economy in an uncertain environment. It is strictly based on the general equilibrium theory. It uses dynamic optimization methods to describe the behavioral decisions of various economic entities (residents, manufacturers, government, etc.) in an uncertain environment. The optimal behavior equation of the subject under the conditions of resource constraints, technical constraints, and information constraints, coupled with market-clearing conditions, and considering the aggregation method, finally derive the equation that the overall economy satisfies in an uncertain environment.

The DSGE model not only absorbs the revolutionary development achievements of modern economics such as rational expectation, dynamic optimization, and general equilibrium analysis but also attempts to analyze macroeconomic phenomena such as economic growth, economic fluctuations, monetary and fiscal policies based on microeconomic behavior. On this basis, macroeconomics and microeconomics are closely linked. The DSGE model attaches great importance to its theoretical basis and the characterization of the mechanism from micro to macro. The increase of economic subjects is not arbitrary but needs the support of the microeconomic theory. Under the framework of general equilibrium, the DSGE model adopts the method of dynamic optimization to examine the decision-making of actors in the economic system from the bottom up. At present, the central banks, financial departments, and other economic departments of many countries, as well as international organizations such as the European Central Bank, the International Monetary Fund, the World Bank, and the OECD, have developed and are developing DSGE models of different degrees of complexity. Many related fields such as cycles, monetary and fiscal policies, international trade, energy, and the environment are also affected. Scholars have also been trying to introduce environmental factors into the DSGE model, but there is no unified method. Taking the environment as a production factor and internalizing it to incorporate it into the production function as an independent factor is still worthy of further investigation [30–34].

Currently, environmental macroeconomics mainly focuses on three aspects when studying economic growth issues:

(1) Economics of climate

At the European Commission’s Luxembourg meeting in 1996, the governments of various countries proposed the “2 °C targets” [35] based on the prediction results of the climate model: that is, based on the pre-industrial level, the global average temperature increase should be controlled at 2 °C. At the 2015 Paris Climate Change Conference, countries reaffirmed this commitment and proposed the “1.5 °C targets”.

Economics of climate mainly focuses on the relationship between economic growth and greenhouse gas emissions and discusses the government’s environmental regulatory

policies. Whether existing environmental policies can achieve the joint development of the economy and environment, that is, to achieve “green development”, depends on whether labor productivity can eventually increase. The “Porter hypothesis” believes that the local government’s environmental regulations can help achieve “green development”, and the “pollution paradise hypothesis” believes that relaxed ecological rules can promote local economic development. Both theories have confirmed cases.

The selection of environmental regulation indicators is the main difficulty of current research. The existing ecological indicators are relatively single, and it is not easy to describe the overall picture of government environmental governance. Starting with the DICE (Climate and Economic Dynamics Model) and RICE (Integrated Regional Climate and Economic Model) developed by Nobel Prize winner Nordhaus in 2018 [29], the current research mainly focuses on model analysis and numerical simulation. “Structural” research paradigm. Among them, the comprehensive, coordinated development model of energy, economy, and environment is a modular large-scale CGE model developed by professional institutions, such as the GREEN model created by the OECD, the NEMS model of the United States, the GEM-E3 model of the European Union, the ORANI-E model of Australia, The MACRO model of Austria and the 3Es-Model model of Japan, etc. Most models include macroeconomic modules, energy modules, supply modules, demand modules, conversion modules, etc. They are mainly used to test policy effects and predict short-term economic trends. China’s large-scale environmental macro-CGE models include the dynamic recursive China Environmental-Economic CGE model co-developed by the Research Center of the State Council and the OECD, and the PRCGEM model co-developed by the Chinese Academy of Social Sciences and Australia.

(2) Explore the negative feedback effect of the environment on economic growth

Most mainstream opinions remain optimistic about whether green development can be achieved in the end. But at the same time, some scholars have discussed the restrictive path of the environment on economic growth from a realistic point of view.

First, climate change. Some scholars have combined economics and ecology to more accurately predict the extent of global warming and possible ecological disasters to develop a new macroeconomic model that endogenizes economic activities and environmental conditions. For example, the forecast results of Roos [8] show that the global average temperature in 2100 will increase by 1.77 °C and 4.8 °C, respectively, from 1995 in optimistic and pessimistic situations. Economic conditions, environmental technology investment, etc., will all have a more significant impact on the forecast result. Experience has shown that the financial system is path-dependent on energy, and it often takes decades to switch energy types. Decarbonizing the economy means rising energy prices and falling supply. At present, the “2 °C targets” have become the basic consensus of the academic community and climate conference negotiators. To achieve the “2 °C goals”, developed countries need to maintain an average annual decarbonization rate of 8–10% in the coming decades [36]. The economy cannot support GDP growth while reducing energy consumption so significantly. Stern [37] pointed out that even a long-term emission reduction of 1% will cause an economic recession, while the actual emission reduction target of 8% is incompatible with sustained economic growth. For this reason, in the next few decades, either abandoning the “2 °C goals” will cause humanity to face a worse living environment, or even an ecological disaster; or by achieving the “2 °C goals”, humankind must sacrifice economic growth, endure economic recession, and adapt to the lack of development system. Kallis [38] proposed that perhaps it is time to transform the energy-intensive growth model of the traditional industrial economy and adopt a planned economic system to achieve economic “low growth” or even “zero growth”, and to achieve emission reduction targets.

Second, the supply of non-renewable resources has declined. Take oil as an example. Due to geological, economic, or geopolitical reasons, oil production in any region cannot grow. The maximum oil production that can be reached is the “peak oil”. After oil production reaches its peak, it will inevitably begin to decline. In 2005, oil production deviated from the historical growth path and fluctuated at high levels. Oil producers had

to extract unconventional oil such as shale oil with a low return on investment to meet the increasing oil demand [39]. The irreversible decline in the supply of non-renewable resources may seriously impact economic growth.

Third, the supply of renewable energy is insufficient. Some literature believes that renewable energy seems to be challenging to maintain an economic growth-oriented industrial civilization composed of 7 billion (or more) energy-intensive consumers [40,41]. Intermittency, storage difficulties, scarcity of resources, and other issues will greatly increase the price of renewable energy. Although renewable energy can bear 100% of the electricity supply from a technical point of view, electricity only accounts for 20% of the world's final energy consumption [42].

(3) Explore the feasibility of “decoupling” economic growth from the environment

Some scholars believe that sustainable economic growth needs to address the restrictive effect of the environment on the financial system, that is, to achieve the “decoupling” between GDP and the environment [43]. Whether the decoupling is feasible is one of the core issues of whether the economy can grow. Since the 1970s, the feasibility of decoupling has been one of the research directions of environmental macroeconomics. The existing literature mainly discusses the feasibility of decoupling from two perspectives:

First, quantitatively analyze the historical data of various countries to study whether there is a correlation between economic growth, environment, welfare, employment, and other factors. Many empirical results show [44–46] that, so far, GDP and environmental indicators are generally negatively correlated, and economic growth has not been decoupled from the environment [47]. GDP is probably the most important environmental impact factor [48].

Second, qualitatively study the feasibility of decoupling economic growth from the environment. Decoupling mainly faces two obstacles: first, the technology is immature. Antal [43] pointed out that decoupling needs to solve three fundamental problems: energy use (including greenhouse gas emissions), material use, and land use. The relevant research is still immature. Second, forced decoupling will generate high social, political, and economic costs.

3.2. Environment and Other Economic Fields

When it is necessary to limit the economic scale to the range that the ecological environment can bear, the financial system must eliminate its dependence on economic growth. For this reason, many current economic policies may be adjusted. Fiscal policy implements zero government debt, grants essential income guarantee subsidies, optimizes taxation plans and property rights systems, etc., to reduce government burdens, reduce the gap between the rich and the poor, and ensure the welfare of the bottom of the society [49]. In addition, some scholars have proposed related policies such as stipulating the upper limit of resource extraction [50], reducing working hours, and realizing work-sharing [51].

In terms of employment, the core issue of the research is how to ensure the employment rate in low-growth economies. Major environmental problems such as climate change, energy shortages, and land shortages need to be quickly alleviated. Otherwise, the unemployment rate in most market economies may rise sharply, harming society. Some scholars qualitatively proposed plans to reduce labor costs, increase high wage flexibility, public employment, self-sufficient non-wage employment, and reduce working hours through tax reforms [43]. However, the current labor market, unemployment rate, the relationship between wage differences, green jobs, green skills, different labor intensity, and other employment factors and the environment still needs further research [52].

In terms of consumption, there are many studies on green consumption, and the concept originated in Europe in the 1940s. In 1963, starting from the relationship between consumption and the environment, the International Consumers Union put forward the idea of “ecological consumption” for the first time, pointing out that consumers should have the obligation of “environmental protection”. In 2001, the China Consumers Association launched a nationwide “Green Consumption Year” theme activity and interpreted “green

consumption” from three aspects: First, it encouraged consumers to choose unpolluted or conducive to public health products when they consumed. Green products; the second was to pay attention to the recycling of consumer goods and the generated garbage during the consumption process, so as not to cause pollution to the environment; the third was to guide consumers to change their consumption concepts, advocate the pursuit of healthy and natural consumption, and pay attention to environmental protection, resource conservation, and efficient use of energy to realize the sustainability of consumption.

In 2016, ten departments, including the National Development and Reform Commission, issued the “Guiding Opinions on Promoting Green Consumption”, which defined “green consumption” as a consumption behavior characterized by resource conservation and environmental protection. It can be said that consumers’ ecological consumption behavior determines the greenness and sustainability of the entire ecological economy, and consumers’ ecological consumption concepts and ecological consumption responsibilities will entirely determine the trend of global climate warming [53].

In terms of technological progress, although the mainstream view believes that advanced technology is the ultimate solution to environmental problems, the abuse of advanced technology is also an essential factor leading to the deterioration of the global environment. The existing literature mainly discusses the relationship between the environment and technological progress from two aspects: on the one hand, most of the literature maintains technological optimism and believes that technological progress can help solve environmental problems. The positive impact of technological progress on the environment mainly includes three points: (1) element-saving environmental, technological innovation can improve the efficiency of capital and energy production. (2) Increase the added value of the final product, promote the greening and dematerialization of the secondary industry, and reduce the energy consumption intensity so that consumers can consume fewer materials while obtaining the same utility. (3) Promote the replacement of fossil energy by renewable energy; on the other hand, some documents maintain technological pessimism, believing that technological progress can be divided into progressive technological reforms and more radical technological revolutions. The former can improve production efficiency and is beneficial to the environment. At the same time, the latter will change consumer behavior and industrial structure, prompting large-scale structural changes in the economic system. Still, the impact of these changes on the environment is unknown. The abuse of radical production techniques may lead to further deterioration of the ecological environment. For example, the controversy of biofuels, the rebound effect [54], etc. The technological revolution requires the linear accumulation of time and capital, but the output is uncertain and non-linear. When climate change or energy shortages make energy-intensive lifestyles unsustainable, “low-tech” lifestyles and production methods may be the only option to maintain basic needs. For example, Cuba has not chosen to research and develop more advanced agricultural production technology when it is subject to US sanctions and a severe shortage of domestic agricultural production materials such as chemical fertilizers and tractors; food self-sufficiency has been achieved under the premise of the large-scale use of chemical fertilizers [55].

The industrial structure mainly affects the environment from two aspects: First, the emission intensity and emission reduction costs of different industrial sectors are extra. Changes in the industrial structure, the emergence of emerging industries, and green sectors will change the input and output of the economic system. The coefficient (I/O coefficient) affects the ecological environment. Second, some companies will outsource production, and the transportation link will generate a lot of greenhouse gases. Therefore, the market concentration and geographic clusters of industries will also affect the environment. At present, the research on the elements of industrial structure is still immature, mainly focussing on the environmental impact assessment model, the carbon emission decomposition model, the environmental Kuznets curve model, and other index models.

4. Discussion

This article systematically introduces the development context, fundamental theories, policy propositions, and current main research directions of environmental macroeconomics. With the continuous development of this field, environmental macroeconomics will play an essential role in solving pollution problems, achieving green development goals, and fulfilling the “two carbon” goals. Although the field has developed rapidly in recent years, there are still many research difficulties that need to be further resolved:

First, when describing the interaction between the economy and the environment, the existing models are still not perfect: (1) the numerical model is too simple to explain the environmental impact, and it is necessary to demonstrate further whether the existing model can provide a comprehensive description of the environmental impact. (2) The negative feedback of the environment on the economy is too simple. The environment can restrict economic development from many aspects such as climate, energy, and resources. Existing numerical models often choose only one of the two negative feedbacks of climate change and peak oil. Few pieces of literature integrate multiple negative feedbacks into the numerical model. Even fewer models discuss environmental constraints from the perspective of resource scarcity. (3) The environmental damage function is not only challenging to incorporate into the demand-driven model, but the existing environmental damage function is also too simple to reflect the complexity of negative environmental feedback.

Second, the factors of income inequality are not included. Most input–output models and system dynamics models do not have the elements of income inequality. The integrated and coordinated development model of energy, economy, and environment, such as Japan’s 3Es-Model model, contains the income distribution estimation module, but it is not straightforward. In contrast, the stock-flow consistency model can easily subdivide the household sector into capitalists, wage earners, and unemployed [56,57], and performs best when dealing with income inequality factors. The fundamental obstacle to incorporating the elements of income inequality into the environmental macroeconomic model lies in the lack of understanding of the mechanism of income inequality. Most numerical models cannot properly distribute the increased output to different household sectors.

Third, it is not included in the financial sector—because monetary elements are not included, input–output analysis models and some system dynamics models are often missing the financial industry. Almost all stock-flow consistency models include the banking sector to provide necessary loans to companies. Although some stock-flow consistency models [58,59] and agency evolution models have begun to try to incorporate credit constraint coefficients into the model, the description of the financial system is still too simplistic, and the development of the model is still at an early stage.

Fourth, green industries and green consumption have not been separated [60,61]. To reflect green industry and green consumption in the numerical model, one of the current ideas is to divide the industry according to different environmental intensities and clarify the proportion of household green consumption. Compared with other numerical models, the input-output model can process a large amount of sub-industry data in detail and may have advantages in representing green industries and green consumption.

Fifth, it fails to show different corporate behaviors. Due to the lack of understanding of green business models and corporate behaviors, most numerical models rely on the same behavior equation, and only some documents describe different corporate behaviors. For example, Dafermos et al. [62–64] decompose capital into traditional and green money. The two types of capital stock are affected by conventional and green investments, respectively. The composition of capital stock depends on the environmental parameters in the model. Environmental deterioration will stimulate green investment and increase the Percentage of green capital.

Sixth, some data, especially international data, are missing. Due to the lack of data such as global capital flows, most literature only discusses the domestic situation, and few models incorporate elements such as import and export; due to the lack of relevant social surveys, most models use objective economic environment data instead of subjective

questionnaire data to express people's happiness. At the same time, the lack of government data on the environment makes it difficult for environmental macroeconomic models to describe the government behavior in the model accurately.

5. Conclusions and Policy Recommendation

Given the above shortcomings, this article believes that the following aspects may be worth further study: (1) simplify the overly complex system dynamics model and integrate different numerical models such as input-output models and inventory flow consistency and develop modular aggregation models. (2) To further understand the economic logic of core issues in environmental constraints, environmental policies, unequal distribution, and incomplete employment, and incorporate the issues into numerical models. In particular, the current research on the "two carbons" target mostly stays at the qualitative level. It is urgent to construct a numerical model to plan the realization path quantitatively. (3) The model further simulates the policy effects of economic policies under low-growth situations such as green investment, green consumption, zero interest rate, zero debt, and work sharing. (4) The system that environmental macroeconomists are trying to understand is highly complex. The introduction of diversified economic models such as evolutionary economics, ecological, economic physics, and complex economics is conducive to the further development of this field.

The government should strengthen the regulation of the environment. There is an environmental market failure in the absence of government intervention, and the macroeconomy cannot spontaneously adjust to the environmental equilibrium curve. Therefore, the government must implement environmental policy intervention to correct the failure of the environmental market to ensure that the utilization of resources and the environment reaches the optimum scale. At the same time, environmental policy formulation should be placed in a dynamic general equilibrium framework.

Author Contributions: Conceptualization, M.N., S.Z., and Y.Y.; methodology, Y.Y., S.Z., N.Z., and Z.W.; formal analysis, Y.Y. and M.N.; writing—original draft preparation, M.N. and Y.Y.; writing—review and editing, S.Z.; supervision, S.Z., Y.Y., M.X., N.Z., and Z.W. collected and analyzed data, contributing equally as the second authors. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data are included in the paper or could be openly achieved.

Acknowledgments: The authors would like to thank the constructive comments and engagement with the paper for our reviewer's significance to the world and choice of variables.

Conflicts of Interest: The authors declare no conflict of interest.

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