

Literature Review on the Relation of Energy, Economy and Environment (3E) System

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Abstract: The progression of industrialization and the social economy has resulted in an escalating demand for resources, culminating in several ecological difficulties, including climate change, water pollution, and biodiversity loss, posing severe challenges to human survival and development. The coordinated development of resources, environment, and social economy has garnered global attention to address these issues. Academic research on this problem has developed over the years. Currently, research on the energy-economy-environment (3E) system predominantly concentrate on the interconnections among the three elements. Based on a systematic review of the existing literature, this paper summarizes the representative research results in the field of 3E systems, analyzing the advantages and disadvantages of different research methods and perspectives. This work seeks to offer a significant reference for future relevant studies through a thorough analysis of these investigations, thereby fostering the integrated advancement of resource management, environmental protection and economic development. This study aims to encourage additional investigation and cooperation between academia and policymakers to attain sustainable development objectives.

Keywords: energy-economy-environment system, 3E, sustainability, relationship model.

1. Introduction

Energy is the material basis of social development, and the environment is the carrier of energy. However, with the acceleration of the industrialization process and the rapid development of the economy, the unreasonable exploitation and use of natural resources and the arbitrary discharge of pollutants without regard to the consequences have made the world face the severe challenges of resource depletion and degradation, the deterioration of the ecological environment, and the imbalance of social and economic development. Seeking the coordinated development of energy, economy and environment subsystems is not only the most essential requirement of sustainable development theory, but also an effective way to achieve sustained, steady and rapid development of the national economy. The government and academia face a significant challenge in resolving the issue of coordinating the relationship between the three and deeply exploring the law of change. Numerous countries have conducted extensive analysis and research on this topic, yielding significant results. These combined studies on the concept, mechanism, strategic conception and realization path of sustainable development, which are widely concerned by the international community, have important guiding significance for building a perfect policy and legal system.

This paper mainly uses the method of literature review to sort out and analyze the literature in the field of energy-economy-environment (3E) system research at home and abroad. The review of existing research results identifies the main viewpoints of different scholars in the 3E system. The specific methods include literature review, comparative study and case study. This paper first studies the theoretical framework of the 3E system, discusses the internal relationship between energy, economy and environment, and analyzes their interaction mechanism. Then it introduces the current status of empirical research, summarizes the important empirical research in the field of 3E system in recent years, and evaluates its impact on policymaking.

2. The development of 3E system

For a long period of time after the industrial revolution, people simply pursued the growth of material wealth, took obtaining economic benefits as the primary goal, and took gross domestic product as the gold standard to measure development. Scholars did not fully recognize the role of energy scarcity in economic growth at that time. When analyzing the impact of energy on economic growth, most neoclassical economists generally regard energy as an intermediate variable produced by major production factors such as capital, labor, and land, and take Cobb-Douglas' bivariate production function of capital and labor as its expression form.

The outbreak of the Oil Crisis in the 1970s made the scarcity of energy increasingly apparent due to the rapid development of the machinery industry. As the global demand for energy continues to rise, the ecological damage and environmental pollution resulting from the production and consumption of mineral energy have become a serious threat to human survival, prompting a reevaluation of past development models. Only then have economists paid full attention to the important role of energy and environment in economic growth. Researchers in various countries began to study energy problems and environmental problems, respectively by using economic theories and methods, and gradually formed a theoretical system with energy and economy, and environment and economy dual system as the research object.

After the 1980s, with the continuous improvement of the sustainable development concept and the deepening of human understanding of energy, environment and economy, people gradually realized that only by incorporating energy, environment and economy into a whole study can they have a more comprehensive, in-depth and systematic understanding of the mechanism of action between them. As a result, many international energy research and environmental protection institutions began to cooperate with economists to build an energy-economy-environment system research framework system to analyze the development laws and internal links between the three, and to carry out research on the comprehensive balance and coordinated development of the 3E system.

3. Research on the relationship between energy, environment and economic growth

With the deepening of human understanding of economy, energy and environment, a series of comprehensive studies on balanced 3E systems have been carried out internationally. Some countries have incorporated the research results into their national long-term development plans to analyze the operation laws of energy, economy and environment as well as the relationship between them. The theoretical system of the 3E system, which aims to achieve the coordinated and sustainable development of the economy and society, has gradually taken shape.

3.1. The relationship between energy and economic growth

The research on the relationship between energy and economic growth mainly adopts the Granger causality test or co-integration theory to analyze the causality between them. For the first time, J.raft and A.Raft conducted causal tests on the data of the United States from 1947 to 1974 and found that

there was only a one-way causal relationship between gross national product and energy consumption, while the reverse was not true, pointing out that energy protection policies would not affect the growth of GNP. However, the relationship between energy consumption and economic growth has different conclusions in different countries or regions. The empirical studies of Bhartendu, Wankeun, Mehrara and others support the research conclusions of J. Raft and A. Raft. Erdal et al. investigated the causal relationship between energy consumption and GNP in Turkey from 1970 to 2006 and found a two-way causal relationship [1]. Asafu-Adjaye uses a co-integration test and error correction model to study the relationship between energy consumption and income in India, Indonesia, the Philippines and Thailand and finds that there is a one-way causal relationship from energy consumption to income in India and Indonesia in the short term [2]. There is a two-way causal relationship between energy consumption and income in Thailand and the Philippines. Lee Chien-Chiang selected 18 developing countries as research objects and studied the relationship between energy consumption and GDP from 1975 to 2001 by using the unit root test, panel cointegration analysis and error correction model [3]. In both the long and short term, the study found a one-way causal relationship between energy consumption and GDP. Papapetrou applied Var model to investigate the relationship between oil prices, stock market returns, interest rates, real economic activities and employment, and the research showed that oil price changes would have an impact on real economic activities and employment [4]. It can be seen that due to the differences in the observation period of sample data and data processing methods, scholars have not reached a consensus on the relationship between energy and economic growth in different countries.

3.2. Relationship between environment and economic growth

There are many studies on the relationship between environment and economic growth, most of which focus on the environmental Kuznets curve (EKC). Some scholars attempt to conduct an empirical analysis of the environmental Kuznets curve, utilizing cross-sectional and panel data from various countries, to determine if the degree of environmental deterioration correlates with an inverted U-shaped curve that rises and then declines with economic development. Selden and Galeotti confirmed the existence of inverted U-shaped curves, and some studies also questioned the understanding of inverted U-shaped EKC. Stern argues that EKC has a weak statistical basis. Dinda pointed out that only part of air pollutants were consistent with the EKC curve by combining previous literature, and no consensus was reached on the inflection point of the EKC curve. Bertinelli and Trovati used semi-parametric regression analysis to retest the existence of an environmental Kuznets curve and found that there was no inverted U-shaped curve between environmental degradation and national affluence [5].

After the environmental Kuznets curve was proposed, some scholars analyzed the formation of EKC from the perspectives of production scale, economic structure, scientific and technological level, trade, and so on. Generally speaking, with the increase of per capita income level, the economic scale will increase, which will first lead to the increase of pollution and the deterioration of environmental conditions. With the further improvement of economic level, energy-intensive industries will gradually be replaced by technology- and service-intensive industries, resulting in the improvement of environmental quality. Scientific and technological progress has contributed to the improvement of environmental quality mainly from two aspects: one is to effectively improve the efficiency of resource use; the other is to continuously develop clean technologies to replace traditional technologies [6]. From the perspective of trade, pollution will be transferred from rich countries to low-income countries through international trade, which will improve the environmental quality of developed countries and further deteriorate the environmental quality of developing countries. Grainger also found through analysis that the emergence of EKC decline was due to the correct formulation and effective implementation of government policies [7].

In order to further analyze the factors driving energy conservation and emission reduction in industrialized countries in the process of economic growth, some scholars adopted a more detailed decomposition analysis method to study the characteristics of contributing factors to pollution change and the comparison of emission reduction effects of these factors. Liu Lan-Cui et al. used the LMDI method to decompose and analyze the driving factors of carbon emissions in the end energy consumption of 36 industrial sectors in China from 1998 to 2005, and the results showed that the change of industrial structure had a great impact on carbon emissions [8]. Based on the data of 13 industries in different provinces, He Jie analyzed the driving factors of China's industrial SO₂ emissions, and the results showed that economic scale and technological progress had the greatest impact on energy consumption and emissions, but the two effects were opposite [9]. Freitas and Aneko decomposed and analyzed the driving factors of CO₂ emissions generated by energy consumption in Brazil, and found that economic activities and population pressure were the main driving factors of pollution emissions, and reducing carbon emission intensity and developing energy structure toward clean energy had a greater effect on emission reduction[10].

3.3. Relationship system of energy, environment and economic growth

One of the goals of sustainable development is to establish a stable state of coordinated development among various subsystems. Therefore, the coordination degree evaluation of the 3E system has become the main content of the research on energy, environment and economic growth, and different scholars have carried out a lot of related work from their own professional perspectives. Lenzen and Dey selected energy consumption, greenhouse gas emissions and a series of economic parameters to analyze the relationship between Australia's energy-environment-economy system, and the results showed that the reduction of energy consumption and greenhouse gas emissions should be coordinated with the broad social and economic benefits such as increasing employment and income and reducing imports [11].

Carter used the dynamic input-output model to analyze the impact of environmental pollution emission reduction and new energy technologies on the economic growth rate and the relative importance of different economic sectors in the United States in the next 10-15 years. Oliveira and Antunes established a multi-objective linear programming model to analyze the sustainability of energy policy, social welfare, economic growth, and environmental friendliness, and to provide policy approaches for environmental and economic development. Based on the multi-objective optimization model, Lazzaretto and Toffolo used system analysis and thermodynamic methods to analyze the 3E system, and estimated the environmental treatment cost of industrial waste gas emitted in the process of energy consumption [12].

On the basis of those logics, many scholars have built models in various industries for more specific research and analysis. Hanley et al. used the CGE model to study the impact of the improvement of energy efficiency on the economy and environment in the UK [13]. The conclusion shows that higher energy efficiency will promote the increase of energy consumption and production, and then lead to the reduction of environmental quality. The authors point out that policies to improve energy efficiency do not lead to improved environmental quality, and that governments should rely more on cleaner alternatives to limit the increase in primary energy use. Barker et al. studied the relationship between low greenhouse effect and high fossil fuels in Mexico [14]. The results show that investments in low-carbon industries, such as electric vehicles and geothermal power plants, can create jobs, reduce environmental pollution, and sustain economic growth, while also reducing the risk of future declines in oil revenues. Ang studied the relationship between economic growth, energy consumption and environmental pollution in Malaysia [15]. The results show that there is a causal relationship between economy and energy, and there is a causal relationship between energy and environment in the long run. Lenzen et al. studied the relationship between the elements of Australia's

3E system [11]. By analyzing the relationship between the country's economic indicators, energy consumption and greenhouse gases such as carbon dioxide, they showed that the reduction of energy consumption and greenhouse gas emissions in Australia's 3E system had a coordinated relationship with the employment and output of the economy.

4. Research review and future direction

From the analysis of the existing literature, it can be seen that econometrics software and supporting systems are widely used in the study of the sustainable development of 3E systems. However, due to the varying data processing and evaluation methods used by different researchers, there are still significant differences in the conclusions drawn from these studies. The current research still has some shortcomings, necessitating future enhancements in certain areas. At present, different scholars have built many models for the analysis of energy and environment. However, these analysis methods and evaluation systems are based on the historical background of a specific country or region, and the setting of parameters and various assumptions of baseline scenarios are usually different from the actual situation, which affects the credibility of their application. With the different research problems, the government should strengthen the modification and testing of model parameters, and start to compare different models in order to adapt to the research needs of new fields and new problems.

3E system research has high data requirements, and the analysis cannot be separated from a large number of continuous data. However, the construction of statistical systems and environmental protection work in most developing countries started late, making it difficult to obtain some long-term continuous energy, environment and economic data, and the comparability of different regions is poor due to differences in statistical caliber. Future research should first analyze and process data differences to minimize the constraints imposed by regional or national differences. Different regions have different natural condition endowments and different stages of economic development, industrial structure and economic growth mode, which may weaken the significance of statistical analysis conclusions. Therefore, the actual situation of different regions and different levels of needs should be studied according to the level of economic development, in order to better explain the actual situation of the local energy environment.

The establishment of evaluation index systems is frequently discussed in the context of the coordinated evaluation of the 3E system—comprising energy, environment, and economy. However, the index systems that have been developed often remain within the confines of traditional sustainable development frameworks. These systems frequently fall short of offering a comprehensive and scientifically robust environmental index that accurately reflects the full spectrum of environmental degradation and resource depletion. To address these limitations, it is crucial to enhance both the certainty and the systematization of the index system development process. This involves a more thorough and integrative research focus on evaluating renewable resources and ecological damage. Such improvements are essential for refining sustainable development strategies within the 3E system, ensuring that these strategies are well-informed and capable of addressing the intricate challenges of balancing energy use, environmental preservation, and economic growth. Strengthening the methodological rigor and comprehensiveness of the evaluation indices will provide a more accurate representation of the overall state of sustainability, thereby supporting more effective policy-making and strategic planning.

5. Conclusion

Based on a comprehensive review and description of the existing relevant literature, the relationship between 3E and its variation in different countries and regions are classified and summarized. It can be seen that, on the one hand, both theoretical discussion and the application of empirical methods

have formed a mature research paradigm for the integration of the three relations, and it is further evolving; At the same time, this analysis paradigm will provide more detailed and scientific research objectives and conclusions for sustainable development theory. On the other hand, the increasing maturity of theoretical and empirical analysis will provide a positive reference for the future innovation of relevant government policies. With energy and environment playing an increasingly important role in people's daily production and life, the balanced and sustainable development of energy, environment and economy has attracted widespread attention worldwide. From the analysis of the existing literature, it can be seen that econometrics software and computer-aided decision support systems are widely used in the study of the sustainable development of 3E systems. However, due to the varying methods of data processing and evaluation used by different researchers, there are still significant disparities in the research conclusions. Generally, the current research still exhibits certain limitations, necessitating future enhancements in areas like model research, data processing and analysis, and a comparative examination of regional disparities.

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