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Review

The Progress and Framework of Ecological Welfare Performance Within the Context of the "Dual Carbon" Goal: A Comprehensive Literature Review

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Abstract: The "dual carbon" goal has become a major national strategy, an inherent requirement for high-quality economic development. As a crucial indicator of measuring sustainable development capabilities, ecological welfare performance has emerged as a core tool for enhancing human welfare, achieving sustainable development, advancing ecological civilization construction, and promoting green development. This study focuses on the "dual carbon" goal appeal, clarifies the concept connotation of ecological welfare performance, assesses the research progress of ecological welfare performance, deeply analyzes the internal relationship between the "dual carbon" goal and ecological welfare performance, builds a research framework for ecological welfare performance, and points out the marginal contribution, research prospects, and shortcomings of ecological welfare performance research under the "dual carbon" goal. The findings are as follows: (1) Research on ecological welfare performance has shifted from a single dimension to a multi-dimensional and multi-level comprehensive consideration, involving multiple disciplines. Literature research focuses on four aspects, namely, the connotation and representation of welfare, the interaction between ecosystems and welfare, ecological welfare performance research, and "dual carbon" target and ecological welfare performance research. (2) From the perspective of research hotspots and historical evolution, most scholars pay more and more attention to empirical research and application-oriented research, and it is still necessary to constantly explore new theoretical frameworks and methodologies in the future to better understand the changing rules and driving mechanisms of ecological welfare performance. (3) From the perspective of the ecological welfare performance research framework, an in-depth analysis of the relationship between natural ecological consumption, economic growth, and welfare is carried out. Based on the change in research paradigm, a two-stage ecological welfare performance evaluation framework is constructed to promote the realization of the "dual carbon" goal and the continuous optimization of ecological welfare performance, so as to provide a reference basis for the scientific assessment of sustainable development capacity.

Keywords: ecological welfare performance; "dual carbon" goal; research progress; enlightenment

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1. Introduction

The "dual carbon" goal has emerged as a major national strategic initiative, reflecting an inherent requirement for high-quality economic development. Addressing how to advance ecological civilization construction and green development to achieve the "dual carbon" goal is currently a prominent topic. With global climate change posing a significant

threat to human society, an increasing number of countries are elevating "carbon neutrality" to the status of a national strategic priority [1]. In 2020, driven by the intrinsic imperatives of promoting sustainable development and the responsibility of building a community with a shared future for humanity, China announced its vision of peaking carbon emissions and achieving carbon neutrality. General Secretary Xi Jinping emphasized the imperative of integrating the goals of peaking carbon emissions and achieving carbon neutrality into the overarching framework of ecological civilization construction. Looking forward, China will focus on constructing a higher-quality, more open, inclusive, and cohesive economic, political, and social system. The aim is to establish a sustainable development model characterized by greener, more efficient, and sustainable consumption and production practices, thereby collectively authoring a new chapter in ecological civilization. Currently, China is less than a decade away from achieving the carbon peak goal, with approximately 30 years remaining between the carbon peak and the realization of the carbon neutrality goal. In comparison to developed countries, China faces tighter timelines, greater magnitudes, and more challenges in achieving the "dual carbon" goal [2].

Ecological welfare performance, as a crucial tool for gauging the capacity for sustainable development, serves as a tangible representation of examining urban sustainable development capacity. It also serves as a measure of the effectiveness of urban ecological civilization construction and promotes the convergence of economic and welfare development. By incorporating human development indicators based on ecological efficiency, it connects the economic, social, and ecological systems, effectively addressing the limitations of ecological efficiency in the social dimension. With the maximization of human welfare and happiness indices as its pursuit, it reflects the economic quality and level of green transformation and development in current regional urban ecological civilization construction [3]. The fundamental objective of urban development is to seek welfare for residents, with continually improving welfare performance output being the ultimate goal of economic and social sustainable development [4]. Sustainable development economics posits that the economic system is a subsystem of the ecological system, with the consumption of the ecological system serving as the "source" of economic growth and welfare enhancement. While economic growth is merely an intermediary means and important tool for achieving welfare enhancement, it serves as a bridge linking ecological consumption and welfare levels. However, the expansion of the economic system is inevitably constrained and restricted by ecological boundaries, while strict reliance on the ecological system is observed at both the "source" and "sink" levels [5]. As industrialization and urbanization continue, the economic production model, which has long relied on high inputs and consumption of natural resources, has accumulated substantial artificial capital, rendering natural capital increasingly scarce. Cities are confronted with numerous issues such as ecological system degradation, resource scarcity, and environmental pollution, significantly constraining the sustainable and healthy development of economic and social systems. This phenomenon characterizes a "full world" scenario where the scarcity of natural capital increasingly limits the quality of economic development and the efficiency of social services, leading to a dilemma of "high economic growth, low welfare growth" [6]. In fact, within this "full world" context, resource constraints on economic growth become more pronounced, leading to the breaking of ecological system carrying capacity boundaries. Economic growth encounters an "ecological threshold", where the level of human welfare does not necessarily increase alongside economic growth, but instead experiences a decline or stagnation, encountering a "welfare threshold". This phenomenon has gradually attracted increasing attention from scholars [7–9]. Based on the research findings and framework construction of ecological welfare performance under the "dual carbon" goal, it is not only an important scientific issue for deepening the theoretical research of ecological welfare and urban wel-

fare, but also a significant direction for breaking through the "ecological threshold" and "welfare threshold" traps. Furthermore, it serves as an important theoretical foundation for promoting sustainable development, guiding policy formulation, optimizing resource allocation, enhancing enterprise competitiveness, promoting international exchanges and cooperation, and achieving low-carbon transition and development.

The "dual carbon" goal is not merely a significant measure to confront the challenge of global climate change but also a crucial way to enhance human well-being. Through the enforcement of the "dual carbon" goal, it can not only upgrade the environmental quality and raise the level of human well-being but also facilitate the transformation and upgrading of the economic development model, ultimately achieving a harmonious coexistence between humanity and nature. However, currently, research on the relationship between the "dual carbon" goal and ecological welfare performance is still in its nascent stage, and systematic theoretical and empirical research is urgently required to bridge this gap. In view of this, this study systematically analyzes the progress and framework of ecological welfare performance research from the perspective of "dual carbon" goal. The structure of this paper consists of six parts: the first part is the introduction, which introduces the research background and significance of this study. The second part is the definition of ecological welfare performance concept. The third part is the important progress of ecological welfare performance under the "two-carbon" goal. It systematically reviews the domestic and foreign research progress on welfare, the interaction between ecosystem and well-being, and focuses on the research progress on the relationship between carbon emission and welfare and ecological welfare performance. The fourth part constructs the theoretical research framework of ecological welfare performance on the basis of theory and determines the research paradigm based on the interaction between natural ecological consumption, economic growth and welfare, that is, the transformation from a weak sustainable model to a strong sustainable research model, so as to construct the ecological welfare performance evaluation framework. The fifth part is the discussion, which mainly focuses on the marginal contribution, research inspiration and shortcomings of this study. The sixth part is the conclusion of this paper. By systematically analyzing the relationship between "dual carbon" targets and ecological welfare performance, this study aims to fill the current research gap in this field, point out the direction for further exploration in the future, and provide a solid theoretical basis and practical guidance for relevant policy formulation.

2. Main Concepts

2.1. Ecological Welfare

Welfare represents both happiness and interests, constituting the objective enjoyment and subjective experience of the terminal outcomes of economic and social development by the people. Urban welfare denotes the objective enjoyment and subjective experience of the terminal outcomes and comprehensive functions of urban economic and social development, comprehensively manifested in the economic, social, and ecological dimensions. It encompasses residents' income, consumption, employment, education, social security, housing, healthcare, environment, and other material and non-material aspects, reflecting to a certain extent the realization status of urban economic and social development functions. Well-being signifies residents' favorable living conditions, focusing on the quality of life and psychological state. Compared to the concept of welfare, it is relatively narrow and difficult to reflect the overall capability and status of regional functional realization [10]. Furthermore, welfare level, as an objective category, covers the comprehensive effects of the economy, society, and ecology, with the three being interconnected, mutually promoting, and symbiotic.

Ecological welfare not only expands and complements social welfare but also constitutes an integral component of it. Within the connotation of ecological welfare, the natural environment provides not only material needs for humanity but also spiritual needs, such as aesthetic values, while also serving as the foundation for human safety and health [11]. The inclusion of ecological welfare has transformed traditional welfare concepts, shifting them from mere material wealth welfare towards the direction of harmonious prosperity among humans, nature, and society [12]. Ecosystem services are provided to humanity through various natural or artificial production methods, which can further form transmission mechanisms through allocation and consumption, ultimately translating into human welfare [13]. Ecological well-being refers to the products and services related to human welfare obtained from the natural environment, which can be realized and provided through the primary production and initial processing of ecosystems [14]. Within the framework of sustainable development, it is essential to comprehensively assess the contribution of urban ecosystems to human welfare and seek synergistic development paths between ecosystems, the economy, and society, thus providing scientific support and decision-making guidance for promoting the process of sustainable urbanization. Starting from the concepts of "ecology" and "welfare", ecological welfare can be understood as a new form of social public welfare provided by the government to residents, encompassing economic, social, and ecological aspects [15]. Therefore, in understanding ecological welfare, it is necessary to consider both the protection of the ecological environment and the sustainable development of the economy and society, thereby achieving the synergistic development of ecology and the economy and society. From the perspective of management, ecological welfare can be understood as a form of welfare provided by the government to all members of society free of charge or at low cost, supplying high-quality ecological environments, including efforts to establish national parks and restore the ecological environment, to meet people's demands and expectations for a favorable ecological environment [16]. Through a multidimensional perspective, it is essential to comprehensively evaluate the contribution of urban ecosystems to welfare and seek synergistic development paths between ecology, the economy, and society, thus exploring innovative paths to achieve sustainable development.

Ecological economics emphasizes that human welfare originates not only from economic development but also from the inseparable benefits provided by ecosystems. Therefore, the connotation of ecological welfare needs to be analyzed from both broad and narrow perspectives. Broadly speaking, ecological welfare is the satisfaction, utility, and enjoyment brought to humanity by ecosystem services through various processes such as the allocation, production, consumption, regulation, and management of natural capital. Ecosystem services are one of the main sources of human welfare, providing economic, social, and green welfare, and ecosystems are essential material foundations for human survival and development [17]. In this process, it is necessary to adjust the functions and content of ecosystem services according to corresponding ecological environmental policies to meet the needs and subjective well-being of different groups. The core idea is to minimize the negative effects of economic growth on the environment and achieve the optimization of natural capital and the sustainability of human welfare. From a narrow perspective, ecological welfare mainly refers to the unaltered natural landscapes provided by nature to humanity, including fresh air, unpolluted water sources, undisturbed green scenery, comfortable climatic environments, forest grassland resources, and other green benefits, focusing on the utility and subjective feelings brought by green living ecological environments. The economic system and the ecological system are inseparable; economic growth requires obtaining low-entropy materials and energy from the ecosystem and emitting high-entropy waste into the ecosystem [18]. Therefore, while achieving economic

growth, it is necessary to consider both the protection and sustainable utilization of the ecological environment and seek a synergistic development path between the two.

2.2. Ecological Welfare Performance

The concept of ecological welfare performance initially originated from Daly's research [19], which evaluates the sustainability of countries by calculating the improvement in welfare levels per unit of natural consumption. This evaluation is conducted by measuring the ratio of services to throughput, where "services" represent the benefits or utilities that humans obtain from ecosystems, and "throughput" represents the comprehensive low-entropy energy and materials obtained from ecosystems by humans and ultimately emitted back into the ecosystems as high-entropy waste. Based on this foundation, Zhu et al. proposed the concept of ecological welfare performance, which reflects the efficiency of natural consumption converted into welfare levels and can measure regional sustainable development capabilities and conditions [20]. Compared to traditional development models focused solely on GDP output, ecological welfare performance places greater emphasis on the development quality and intrinsic value of human society, advocating for maximizing welfare output with minimal natural resource consumption. Furthermore, ecological welfare performance considers not only ecological environmental factors but also social welfare and economic growth, enabling a comprehensive assessment of the development status of the three major systems. It represents the ratio of welfare value to the physical quantity of ecological resource consumption, reflecting both the degree of welfare improvement per unit of ecological resource input and the relative change trend between social welfare and ecological resource consumption. It also encompasses the economic, social, and ecological systems, serving as a quantifiable indicator of the relative health of economic growth considering social and ecological factors [21]. Furthermore, the concept of ecological welfare performance embodies two important dimensions highlighted by the green economy: the boundary of natural capital and social welfare with ecological "fairness" [22]. Through the application of social welfare indicators, ecological welfare performance can better reflect ecological fairness and the essence of the green economy, surpassing the limitations of traditional development models in pursuit of ecological economic efficiency. In practice, the concept of ecological welfare performance plays a crucial role in guiding regional economies to pay more attention to sustainable development and comprehensively promoting the coordinated development of the economy, society, and environment.

3. Research Progress on Ecological Welfare Under the "Dual Carbon" Goal

In recent years, significant progress has been made in the research on ecological welfare performance, both domestically and internationally, in terms of theoretical framework development, evaluation method innovation, factor analysis and empirical studies. At the international level, initiatives such as The Economics of Ecosystems and Biodiversity (TEEB) have garnered considerable attention for the valuation of ecosystem services [23]. This has led to the development of standardized classification systems, such as the Common International Classification of Ecosystem Services (CICES) [24]. These classification systems not only provide a foundation for the quantification of ecological welfare performance but also establish standards for comparative studies across different regions [25]. Moreover, the application of remote sensing technology, geographic information systems (GIS), and various economic models has significantly enhanced the scientific rigor and accuracy of ecological welfare performance assessments [26]. Global case studies and long-term trend analyses have revealed the patterns and driving factors of ecological welfare performance,

providing robust evidence for the formulation of effective environmental policies [27]. Chinese scholars have developed region-specific ecological welfare performance evaluation systems that align with the national context, emphasizing the principle that "clear waters and green mountains are invaluable assets", which underscores the complementary relationship between environmental protection and economic development. In view of the regional differences in China, especially the huge differences in economic level and natural conditions between the east and the west, scholars have conducted in-depth comparative studies [28–30]. At the same time, various environmental policies implemented at the national level, such as the establishment and development of carbon trading market and the implementation effect of the ecological protection red line system, have been evaluated in detail [31,32]. Interdisciplinary collaboration promotes the development of new research methodologies, such as combining ecology, economics and sociology, to better understand and solve complex ecological and environmental problems.

Ecological welfare performance is an important measure of the efficiency of a country or region in converting natural resource consumption into human welfare. It is concerned with how to maximize the output of social welfare while ensuring ecological sustainability. In recent years, with the increasing global attention to environmental protection and sustainable development, ecological welfare performance has become a topic of wide concern in academia, policy makers and all sectors of society. This study is based on Web of Science, Elsevier ScienceDirect, SpringerLink and other English databases. During the period 2000–2024, 108 valid papers were retrieved with "ecological welfare performance", "ecological well-being performance", and "ecological welfare" as the main topics. A total of 206 literature reviews were retrieved from the China National Knowledge Network (www.cnki.net, CNKI). In general, the research results on ecological welfare performance in the academic community showed a growing trend and went through three stages: "slow exploration period, rapid development period, and decline period". According to the number of published papers over the years, the research literature on ecological welfare performance has shown a relatively stable growth trend since 2010. Scholars have paid attention to four major fields, namely, ecological welfare and its element measurement, the relationship between ecosystem and welfare, the influencing factors of ecological welfare performance, and the correlation between carbon emission and welfare.

3.1. Advances in Welfare Representation Research

The level of welfare reflects a comprehensive assessment of quality of life, developmental potential, and happiness, serving as a direct manifestation of the overall socio-economic development status of urban areas. Scientifically evaluating welfare levels has long been a focal point for scholars. There exists a debate between subjective welfare and objective welfare evaluation. Subjective welfare measurement relies on individual perceptions and cognitive evaluations of residents' subjective feelings, susceptible to errors influenced by personal subjective consciousness [33,34]. With deepening understanding of happiness and welfare, scholars have continuously developed and improved welfare measurement indices. Objective welfare evaluation primarily consists of three categories: The first is economic welfare based on GDP and improved indicators, such as the Sustainable Economic Welfare Index [35] and Genuine Progress Indicator [36]. With socioeconomic development, the viewpoint of welfare economics advocating for measuring welfare levels solely based on monetary income has gradually been criticized. Scholars have recognized that happiness is not directly proportional to income, and material wealth cannot represent all aspects of happiness. Therefore, relying solely on GDP (GNP) measurements cannot accurately reflect economic welfare conditions. The second category is social welfare indicators based on life satisfaction. With the continuous improvement in social productivity, economic

development levels, and residents' quality of life, the connotation of welfare has gradually expanded from an economic dimension to a social dimension. Examples include the Material Quality of Life Index [37], Social Progress Index [38], and Happiness Index [39]. The third category is composite indicators based on the capability approach proposed by Sen, which bridges the link between utility and commodities, breaking the traditional economic methods linking welfare to utility and resources [40]. The United Nations Development Programme (UNDP) created the Human Development Index (HDI) based on the capability approach, evaluating the welfare and functional status of human development in various countries based on life expectancy, adult literacy rate, and per-capita GDP [41]. Due to the feasibility, authority, and intuitiveness of the Human Development Index [42], it has been widely utilized, alongside other indices such as the Strong and Weak Human Sustainable Development Indices [43] and Human Green Development Index [44]. However, there are still many shortcomings that make it difficult to comprehensively reflect welfare connotations.

As economic development and living standards continue to improve, the connotation of welfare is becoming increasingly diversified. With the deepening of societal and economic development and people's understanding of welfare, the connotation and measurement methods of welfare have evolved. They have expanded from the simple aggregation of economic welfare such as material possessions, income, and utility to a more comprehensive coverage of social welfare indicators that include non-economic factors. More and more scholars are attempting to construct multidimensional composite indicators representing welfare connotations, encompassing economic, social, environmental, and cultural dimensions [45,46]. Among these efforts, the capability approach theory proposed by Amartya Sen has had a significant impact. His multidimensional "function–capabilities" framework suggests that function represents existing welfare states, while capabilities refer to the substantive freedoms to achieve various combinations of function. However, Sen did not elaborate on the indicators constituting the assessment of function–capabilities welfare [47]. There is increasing research and application of the capability approach theory in academia, with some consensus and progress achieved in understanding its core concepts, evaluation dimensions, and methods. It is believed that capabilities can provide a clearer and more in-depth reflection of the true state and capabilities of various groups [48]. Wang Sheng yun and others have constructed a multidimensional welfare evaluation system based on the "function–capabilities" framework [40], covering elements such as income, health, consumption, education, social security, environment, and leisure. They explore the balanced model of functional welfare and capability welfare at the provincial level in China, offering a new perspective on welfare evaluation.

3.2. Research Progress on the Relationship Between Ecosystem Services and Welfare

Studying the relationship between ecosystems and human welfare is of great significance for managing ecosystem services, guiding and regulating human activities, and better coordinating the relationship between ecosystem service protection and socio-economic development to enhance human welfare [49]. The Millennium Ecosystem Assessment, jointly published by international organizations such as the United Nations Environment Programme, is the world's first study focusing on ecosystems and human welfare. It marks a new stage in ecological development, recognizing ecosystems as fundamental units of Earth's life support system. The assessment emphasizes that improving ecosystem services and sustainable utilization are essential guarantees for human welfare [50]. The relationship between ecosystems and their service functions and human welfare is the focus of ecosystem assessment [51]. The Millennium Ecosystem Assessment laid the theoretical foundation for research on the relationship between ecosystem services and human welfare.

Subsequently, researchers have conducted extensive theoretical and empirical analyses from various perspectives such as the conceptual framework of ecosystem services and human welfare relationships and the impact of changes in ecosystem service functions on human welfare.

Simultaneously, there exists a mutually interactive and constraining relationship between ecosystem services and human welfare [52,53]. Ecosystem service functions are categorized into welfare provisioning services, welfare maintenance services, and welfare enhancement services [54]; these functions directly impact the status of human welfare. Changes in welfare levels drive changes in the utilization methods and intensity of ecosystem services. For instance, core wetland ecosystem services such as regional biodiversity conservation and wetland tourism contribute significantly to the social welfare of local residents [55,56]. Higher ecosystem service values are associated with greater resident life satisfaction [57]. At the microscale, urban green spaces play a significant positive role in improving resident health and enhancing quality of life [58]. Conversely, external factors such as climate change, biodiversity loss, and localized forest logging have negative effects on resident welfare [59]. Furthermore, ecosystem services exhibit intergroup inequality, with ecosystem degradation posing a significant threat to the welfare of vulnerable groups, especially the poor, necessitating ecological compensation [60]. These observations underscore the role of ecosystem services as sources of human welfare, transforming through the consumption of natural capital into quantifiable values measurable in currency. They fulfill human needs and enjoyment and can be adjusted based on corresponding ecological environmental policies to meet the needs and subjective well-being of different groups. Continual scrutiny of ecosystem service systems and institutions is necessary based on human welfare conditions to better promote the enhancement of human welfare levels and facilitate the comprehensive release of ecosystem service functions and sustainable resource utilization.

3.3. Research Progress on Ecological Welfare Performance

Ecological welfare, as an important indicator for measuring the benefits derived from the consumption of ecological resources, originated from Daly's steady-state economics theory, defined as the ratio of services to throughput [61]. Chinese scholars, led by Zhu Dajian et al., first systematically defined the connotation of ecological welfare performance [20]. It has received widespread attention as a link closely associated with social policies. With the clarification and promotion of this concept, scholars have undertaken a series of studies on ecological welfare from different perspectives. They have employed various indicators, such as the ratio of the Human Development Index to ecological footprint [62], the ratio of happy life years to ecological footprint [63], the Happy Planet Index [64], and the welfare environmental efficiency index [65]; and the ratio of HDI to carbon emissions or energy consumption [66] to explore the trends in ecological welfare performance. However, some researchers have recognized the limitations of ratio-based methods and have advocated for the adoption of ecological efficiency thinking for measurement. Approaches such as the DEA model, SFA model, and multi-stage Super-SBM model have been proposed [2,31,67]. Studies indicate that achieving sustainable growth in ecological welfare can be pursued through two pathways: either reducing the consumption of ecological resources while maintaining current welfare levels or maximizing the efficiency of welfare output while considering human development as the ultimate goal, effectively decoupling resource and environmental consumption from human welfare.

Spatiality is a fundamental attribute of geography, and the expansion of ecological welfare in geographical space reflects the organic combination of functionality, effectiveness, and efficiency, covering both material space and relational space [68,69]. Scholars mainly

employ methods such as kernel density estimation, spatial autocorrelation functions, Theil index, coefficient of variation, convergence tests, and Markou chain analysis to conduct spatiotemporal heterogeneity analysis [70–72]. Research findings indicate that the overall level of ecological welfare is not high, with frequent fluctuations, exhibiting a spatially uneven and clustered pattern [73]. Significant spatial spillover effects are observed [74], and in some areas, the relationship between welfare and ecological consumption is predominantly characterized by absolute decoupling [75]. Furthermore, significant regional disparities in ecological welfare exist, with evidence of β-convergence effects, suggesting a "catch-up effect" of less developed regions on advanced regions [76], and the effect of spatial polarization is weakening [77].

The manifestation of ecological welfare performance is closely related to regional culture, technology, and skills, as well as the organizational patterns of factors and behaviors. Currently, in China, the realization of welfare benefits primarily relies on high inputs of natural consumption. Natural consumption factors serve as the "driving force" for the improvement of welfare levels, while service efficiency plays a continuously strengthening "inhibitory role" [30]. Economic growth, as an effective means to achieve urban benefits, exhibits an "inverted U-shaped" relationship with ecological welfare. Stable natural consumption production efficiency and economic growth service efficiency are important factors constraining the improvement of ecological welfare performance [20]. Moreover, factors such as economic growth mode, urban scale, consumption level, government policies, trade dependence, technological innovation, urbanization, industrial structure, energy intensity, environmental regulations, and energy structure all influence the enhancement and optimization of ecological welfare [2,72,74].

3.4. Research on the "Dual Carbon" Goal and Ecological Welfare Performance

Within research on welfare impacts from the perspective of carbon emissions, some scholars, through empirical analysis, argue that moderate increases and additions to carbon emissions can enhance human welfare levels. However, once surpassed, a "decoupling phenomenon" may occur. To achieve fair and equitable distribution, moderate increases in carbon emissions can enhance the welfare levels of developing countries. However, the high per-capita carbon emissions in developed countries have led to welfare decoupling, and measures should be taken to keep them below the global per-capita level [78–80]. Additionally, carbon emission transfer has negative spillover effects on social welfare, while carbon emission transfer-out, foreign capital scale, and industrial structure have positive spillover effects on social welfare [81]. The rational design of environmental regulation intensity and establishment of scientific and effective carbon emission trading systems can also improve social welfare levels [82]. Among G20 countries, the UK, France, Argentina, Brazil, and Germany exhibit higher carbon emission welfare performance, while China ranks lower with slower growth. A lack of static and dynamic advantages in low-carbon competitiveness can be observed. The urbanization rate, proportion of renewable energy in total energy consumption, export dependence, and proportion of value added in services to regional GDP have a positive impact on carbon emission welfare performance. However, the relationship between government size and carbon emission welfare performance follows an inverted "U" curve, suggesting the existence of governance thresholds [80]. The welfare performance of exported trade carbon emissions exhibits significant spatiotemporal heterogeneity. Regions such as Qinghai, Guizhou, Gansu, Beijing, and Jilin show increased welfare performance from exported trade carbon emissions, indicating some success in reducing carbon emissions through export trade efforts. Conversely, other provinces and regions experience varying degrees of decline in welfare performance from exported trade carbon emissions, possibly indicating ineffective control or even an increase in carbon

emissions in these regions [81]. However, some studies from a micro perspective suggest that there is no significant correlation between carbon emissions and residents' subjective welfare. High carbon emissions do not directly affect changes in residents' subjective welfare levels. For example, Frijters et al. found that although climate change (including climate change caused by carbon emissions) may have an impact on some aspects of life quality, no direct significant relationship between climate factors and subjective well-being has been found [83]. Based on the adaptation theory, Diener et al. believe that people will adapt to the new living environment, and environmental changes caused by carbon emissions may affect subjective welfare in the short term, but in the long run, this impact may be offset by the adaptation process [84]. Thus, while there exists a "U-shaped" trajectory in the relationship between carbon emissions and welfare level enhancement, the impact of increased carbon emissions on residents' subjective welfare is not significant at the micro level.

With the advocacy of green and low-carbon development and the introduction of the "dual carbon" goal strategy, some scholars have begun to explore the relationship between carbon emission reduction and ecological welfare performance. Successive studies have confirmed that ecological welfare performance can promote the release of carbon emission reduction effects, and carbon emission trading policies can effectively enhance ecological welfare performance. The economic and environmental effects of ecological welfare performance demonstrate phased characteristics. The enhancement of ecological welfare performance not only inhibits economic growth but also has significant carbon emission reduction effects. The effects on carbon emissions shift from increase to decrease, while the effects on carbon emission intensity reduction further strengthen. Policy formulation needs to balance the improvement of ecological welfare performance and the demand for economic growth, while also focusing on the effects of carbon emission reduction and environmental improvement [85]. The implementation of carbon emission trading policies can effectively enhance urban ecological welfare performance, but there is heterogeneity among different types of cities and geographical locations. The promotion of this policy is more significant in central cities and cities in the central region. The implementation of carbon emission trading policies can significantly promote industrial structure optimization and have a positive impact on urban ecological welfare performance, but it does not trigger the occurrence of regional Porter effects [86]. In fact, carbon trading policies have certain lag effects, and the economic benefits of carbon trading policies will not immediately manifest, requiring a period of accumulation and adaptation [87].

In summary, carbon emissions are one of the most significant causes of climate change and environmental pollution, while ecological welfare performance serves as an indicator for assessing urban ecological environmental quality and residents' welfare levels. A reduction in carbon emissions can lead to environmental improvement and ecological optimization effects, thereby enhancing ecological welfare performance. The implementation of carbon emission trading policies can incentivize enterprises to reduce carbon emissions through economic incentives and promote the optimization of industrial structure and the enhancement of environmental benefits. The implementation of carbon emission trading policies has a positive impact on the improvement of urban ecological welfare performance, providing an important reference basis for further exploring the relationship between carbon emissions and ecological welfare performance.

4. Theoretical Research Framework

4.1. Analysis of the Relationship Between Ecological Consumption and Welfare Factors

Ecological systems serve not only as the foundation for human survival but also as a crucial support for achieving economic, social, and green welfare. The economic

system, being a subsystem of the ecological system, relies on the provision of low-entropy materials and energy from the ecological system to sustain its operations while emitting high-entropy waste back into the ecological system [88]. The ecological system has its own boundaries, known as ecological carrying capacity, which imposes strict limitations on the operations and scale of the economic system. When the economic system exceeds these boundaries, economic growth needs to transition to economic development, which involves enhancing the qualitative level of human welfare starting from the existing stock of material wealth [89]. This process not only involves technological advancements but also necessitates fair and equitable distribution of wealth and income. Thus, from the perspective of both resources and sinks, the economic system is heavily reliant on the ecological system. In other words, while ecological systems provide critical resources for human survival and development, they also constrain the scale and manner of economic system development. It is imperative to fully understand and respect the boundaries of the ecological system to achieve sustainable development of economic, social, and green welfare while protecting the ecological environment [90].

In a scenario referred to as the "empty world", natural resources are relatively abundant, and economic development is in its early stages, with limited artificial capital and labor. In such circumstances, there are no apparent constraints on economic growth and improvements in human welfare. Economic growth can continue unabated, with the gradual accumulation of artificial capital and labor while natural resources are gradually depleted [90]. At this stage, the increase in artificial capital is believed to compensate for the decrease in natural resources, and the two are seen as interchangeable. This implies that economic growth has no clear boundaries and is not constrained by natural resources, and human welfare improves alongside economic growth, a concept known as "weak sustainability" [34]. However, as we transition into a scenario known as the "full world", the situation changes. At this stage, the economic system has significantly impacted the ecological system, and natural resources cannot meet the growing demands of economic production and consumption. Furthermore, the capacity to handle waste is challenged. Natural resources become increasingly scarce, and uncontrolled expansion of the economic system repeatedly surpasses the boundaries of the ecological system, becoming a key hindrance to economic growth and improvements in human welfare [91,92]. To achieve sustainable development, we must limit economic activities within the carrying capacity of the ecosystem, aligning with the current advocacy for ecological civilization and green development concepts. The concept of "strong sustainability" holds a different viewpoint, asserting that natural resources and artificial capital cannot be mutually substituted. It emphasizes that economic growth should not exceed the carrying capacity of the ecological system, and the consumption of resources and the environment forms the basis for economic growth and welfare improvement. In this model, the enhancement of human welfare is seen as the ultimate goal, with economic growth serving as a tool to achieve this objective, acting as a link between resource consumption and welfare improvement.

The operation of the economic system relies on obtaining low-entropy materials and energy from the ecosystem and releasing high-entropy waste back into it, leading to environmental pollution. These low-entropy materials and energy serve as the driving force behind economic growth. The improvement of the economy positively impacts human living conditions, healthcare, education levels, social security, and other basic livelihood needs, further enhancing people's happiness and satisfaction [93]. On the other hand, the ecosystem provides us with some natural or processed ecological products, such as fresh air, clean water sources, beautiful landscapes, comfortable climates, excellent environmental quality, and green facilities, all of which directly contribute to human experiences and well-being, known as green welfare. Therefore, this study considers natural capital as the

foundation of social and economic development, providing essential natural resources such as energy, land, and water for economic development. With rapid economic development, urban development and construction accumulate more artificial capital, thereby driving social progress. However, the boundaries of the ecosystem impose limitations on the material scale of social and economic development. In addition, environmental pollution, as a by-product of economic growth, poses threats and negative impacts on human health and development. Overall, the ecosystem, economic system, and social system interact and influence each other (Figure 1), necessitating consideration of the carrying capacity of the ecosystem and the impacts of environmental pollution while pursuing economic growth and social progress to achieve genuine sustainable development.

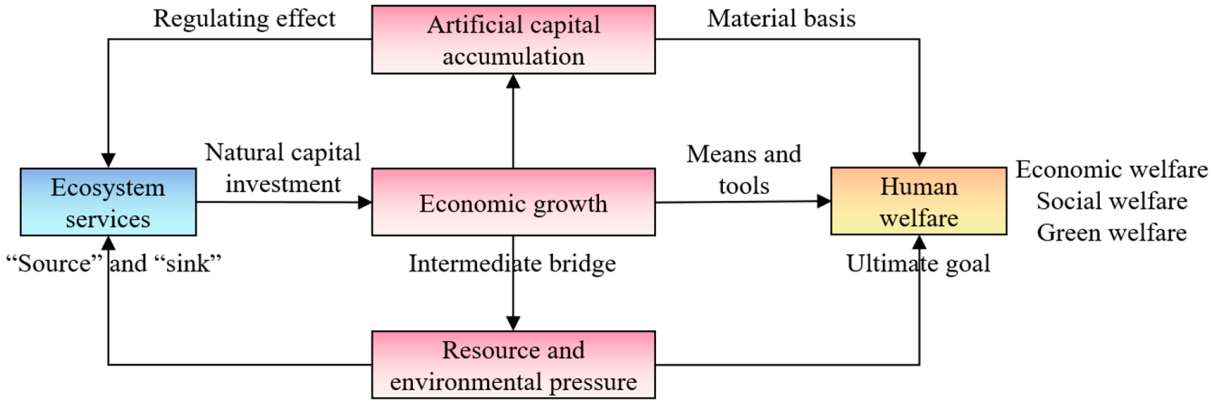

Figure 1. Relationship between ecological consumption, economic growth, and human welfare [4].

4.2. Research Paradigm: From Weak Sustainability to Strong Sustainability Paradigm

The ecosystem is not infinitely expandable; rather, it has certain boundaries known as ecological carrying capacity. When the extraction of natural capital exceeds the carrying capacity of the ecosystem, the scarcity of natural capital becomes a significant constraint on economic and social development. This necessitates that the economic system operates within these boundaries. Natural capital serves as a prerequisite for social and economic development, with the material scale of social and economic development constrained by the ecosystem. The social system serves as the carrier of the economic system, influencing the state of economic development, which, in turn, facilitates the accumulation of artificial capital for social development and progress. The interaction and feedback among the ecosystem, economic system, and social system are crucial [93]. Both ecological efficiency and ecological welfare performance serve as important tools for measuring sustainability capability and status. While scholars have traditionally explored sustainable development through ecological efficiency models, the increasing prominence of a people-centered scientific development concept highlights the need not only to ensure certain levels of economic development and ecological carrying capacity but also to ensure increasing happiness among the people. The concept of sustainable development has gradually evolved from the traditional two-dimensional development model based on economic development and the resource environment to a three-dimensional model incorporating economic growth, welfare level, and natural consumption. Ecological welfare performance, built upon ecological efficiency, incorporates indicators for human development evaluation, connecting the economic, social, and ecological systems. This fills the gap in the social dimension of ecological efficiency, shifting the focus to the social dimension and emphasizing a people-centered development concept. This aligns with the current demands of ecological civilization construction and the transformation of the primary social contradictions, making it known as an "upgraded version" of ecological efficiency (Figure 2).

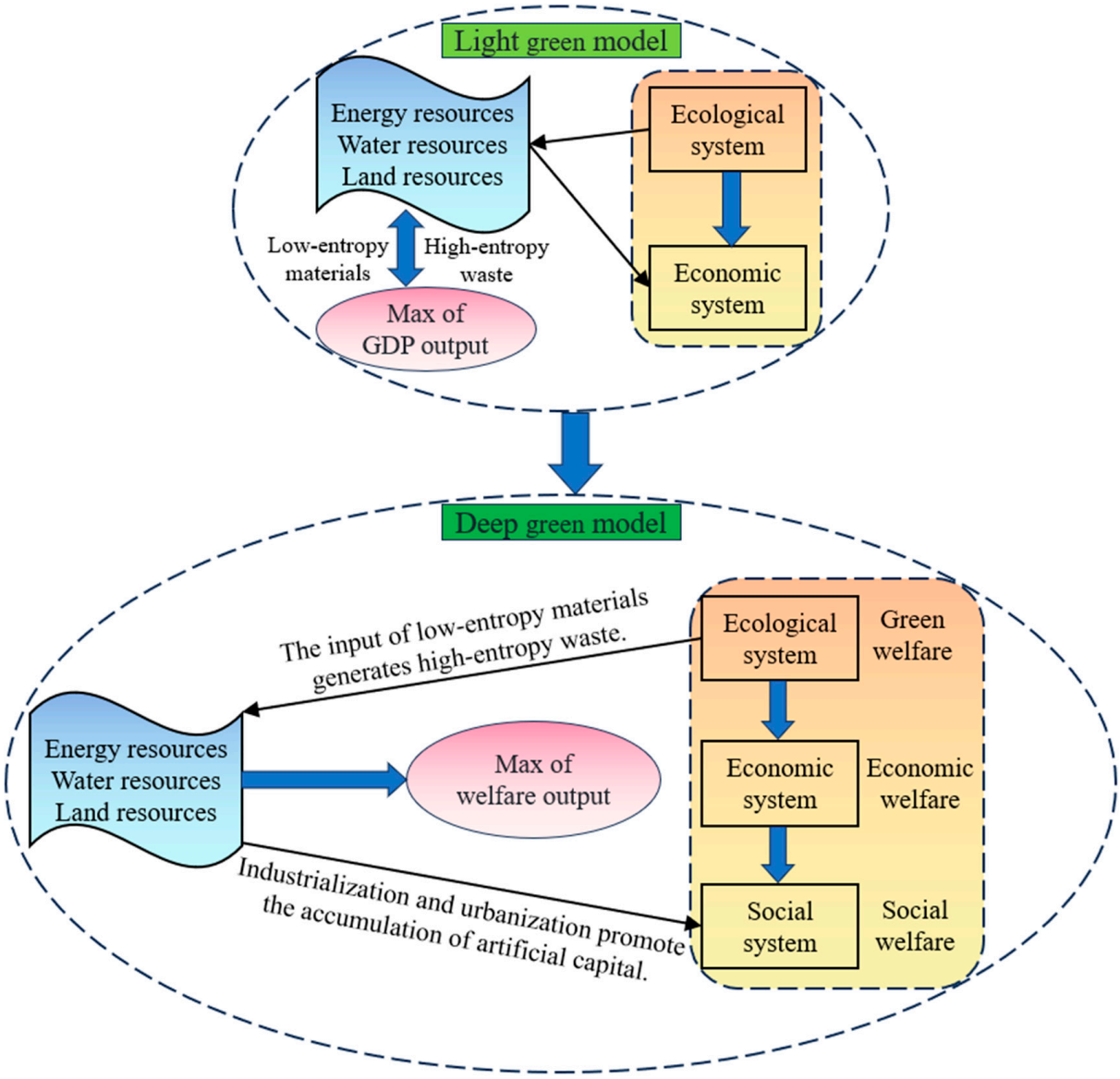

Figure 2. Process of research paradigm shift [5,21].

The transition from a two-dimensional to a three-dimensional sustainable development model primarily involves profound changes in development objectives and concepts. In terms of development objectives, the traditional sustainable development model primarily relied on ecological efficiency methods, aiming to maximize GDP output as the ultimate goal. In contrast, the ecological welfare performance has shifted away from the pursuit of GDP maximization, focusing instead on maximizing human welfare as the ultimate goal, with economic growth serving as an intermediary and communication tool, and accumulated material wealth being sufficient as long as it meets needs [94]. In terms of development concepts, there has been a gradual shift from the shallow green development concept to the deep green development trend. While ecological efficiency remains within the shallow green development trend, ecological welfare performance represents the advancement towards a deep green development model conducive to human society's sustainability [95]. From the perspective of research paradigms, there are generally two types: weak sustainability research paradigm and strong sustainability research paradigm. The weak sustainability research paradigm follows neoclassical economics, asserting that the economy can grow indefinitely without constraints from the ecosystem. It suggests that the accumulated human-made capital can replace the increasingly scarce natural capi-

tal. On the other hand, the strong sustainability research paradigm adheres to ecological economics and emphasizes that the economic system is a subsystem of the ecosystem, inevitably constrained by it. It argues that the economic scale should not exceed the boundary, and human-made capital cannot substitute for natural capital. Consequently, ecological efficiency characterizes the weak sustainability research paradigm, while ecological welfare performance extends into the realm of the strong sustainability research paradigm [96].

4.3. Construction of a Framework for Ecological Welfare Performance Evaluation

Ecological welfare performance refers to the efficiency of natural consumption converted into welfare levels. Achieving a higher level of welfare within the carrying capacity of the ecological environment is the goal of sustainable development. Under the premise of limited natural capital, if ecological welfare performance shows a gradually increasing trend, it indicates that the region has effectively improved comprehensive welfare with lower consumption of natural capital. This enhances the region's sustainable development capacity, gradually approaching the ultimate development goal of cities, which represents the correct trajectory and optimal ideal state of regional sustainable development. Conversely, if ecological welfare performance declines, it indicates that the region's economic and social development is gradually deviating from the sustainable development track, highlighting the current development pattern's irrationality [75]. Daly proposed the efficiency concept of sustainable development economics, decomposing development performance into production efficiency and service efficiency, known as two-stage efficiency. The first stage is the production stage, which requires balancing economic growth with resource and environmental pressures. Its objective is to achieve maximum economic value with minimal resource consumption and environmental pollution. The second stage is the service stage of economic growth, which provides essential material capital for social development. Its goal is to improve residents' quality of life and happiness index.

Due to the opaque nature of the single-stage DEA model calculation process, it is unable to clearly distinguish the ecological welfare performance transformation process and internal structure. This study constructs a network structure based on the ecological welfare transformation process (Figure 3), dividing ecological welfare performance into two stages: resource production efficiency and economic service efficiency. Resources such as water, energy, and land are included in the ecological input index system. Economic growth serves as both the expected output of the first stage and the input of the second stage, while environmental pollution emissions serve as the undesired outputs of both stages. Comprehensive welfare, determined based on the ultimate goal of socio-economic development, serves as the final output, forming the core of this study.

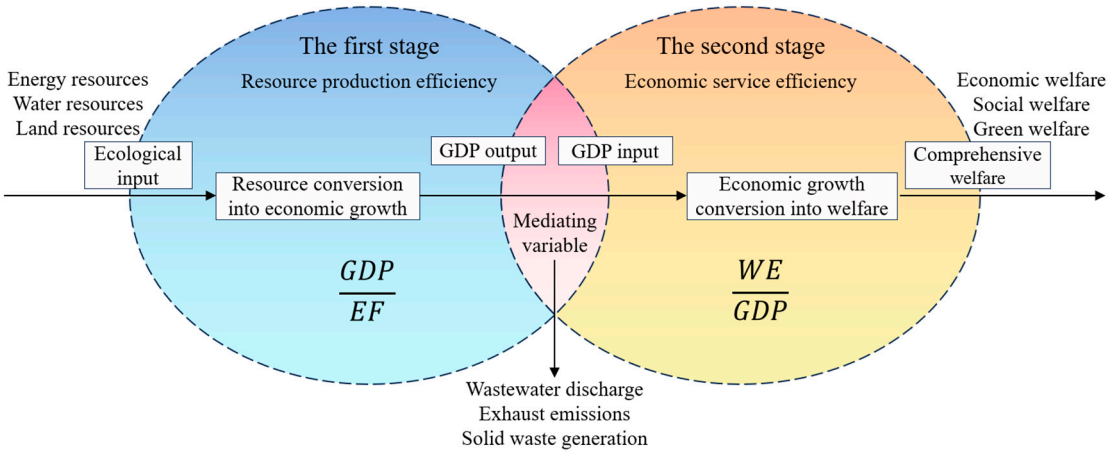

Figure 3. Ecological welfare performance transformation network structure [21,75].

Different from the previous ecological welfare performance assessment framework, the new framework adopts a two-stage analysis method to examine the efficiency of resource production (the first stage) and the efficiency of economic services (the second stage). This approach allows for a more detailed assessment of efficiency at different stages of development, whereas traditional assessment methods tend to consider these factors as a whole and fail to distinguish specific efficiency performance at each stage. More importantly, by introducing a network structure, the new framework makes the transformation process of ecological welfare performance more transparent and can track specific influencing factors. In contrast, the traditional single-stage DEA (Data Enveloping Analysis) model is regarded as a "black box" and its inner workings are not clear. Significantly, the new framework not only considers the traditional indicator of economic growth but also introduces environmental pollution emissions as the undesirable output, and comprehensive welfare as the final output, so that the sustainable development status of a region or city can be comprehensively evaluated. Traditional assessment methods may rely more on a single or small number of economic indicators, ignoring the importance of environmental and social dimensions. And finally, the new framework emphasizes the goal of achieving a high level of welfare within a limited stock of natural capital, which requires the consideration of resource consumption and environmental protection in the evaluation process, where traditional evaluation methods may not explicitly incorporate these constraints into performance evaluations. To sum up, the improved ecological welfare performance framework attempts to provide a more comprehensive and systematic method to measure regional sustainable development status, which makes up for the shortcomings of traditional assessment methods by refining assessment stages and increasing transparency, multi-dimensional consideration, and goal orientation.

5. Discussion

5.1. Marginal Contribution of Research

This study focuses on the proposition of the era of the "dual carbon" goal. By constructing a systematic ecological welfare performance evaluation framework, it not only deepens the understanding of the "dual carbon" goal in theory but also provides key guidance for policy formulation and implementation, with a significant marginal contribution. It is mainly reflected in the following two aspects:

(1) Theoretical research contributions: First of all, this study makes adjustments and innovations in the theoretical research framework of ecological welfare performance. This study proposes, for the first time, a two-stage assessment framework integrating the interaction between natural ecological consumption, economic growth, and social welfare. The framework emphasizes the transition from a weak sustainable development model to a strong sustainable development model [43,75], providing a new perspective for understanding and evaluating ecological welfare performance under the "dual carbon" target. Secondly, by combining the theories and methods of economics, environmental science, sociology, sustainable development economics, and other disciplines, this study systematically discusses the internal relationship between the "dual carbon" target and ecological welfare performance, which not only enriches and improves the research method system of ecological economics but also improves the research method system of ecological economics. It also fills a theoretical gap in the existing literature on how to integrate a "dual carbon" goal with improved human well-being.

(2) New research perspective: Previous studies were mostly carried out by means of quantitative analysis methods such as spatial analysis and mathematical statistics [48,61,66], such as the measurement of well-being level [37–40], the measurement of ecological

welfare performance [67,68], and the identification of temporal and spatial evolution characteristics and influencing factors [74]. Few studies theoretically explored deep-rooted topics such as conceptual connotation, theoretical research frameworks, and the internal mechanism of ecological welfare performance [47]. Moreover, there is little research that integrates into the "dual carbon" goal of the national major strategy, which will provide a new perspective for future scholars to study ecological welfare performance [73].

5.2. Research Implications

In general, a series of achievements have been made in the research on ecological welfare performance in the past two decades. Breakthroughs have been made in terms of conceptual connotation, theoretical deepening, measurement method improvement, empirical analysis, and policy guidance, and the internal correlations between ecological welfare performance and environmental regulation, carbon emission, green development, high-quality development and other factors have been deeply explored. A relatively mature and complete theoretical and methodological system has been formed, which provides theoretical and methodological reference for the in-depth study of ecological welfare. However, there are still some shortcomings in the current research:

First of all, no clear framework has been established in the quantitative evaluation of welfare, and studies linking "dual carbon" with welfare lack more empirical support. Previous studies mainly conducted comprehensive evaluation based on a single index such as GDP and its improvement index and human development index, and lacked a comprehensive consideration of multiple factors to form a welfare evaluation index system, indicating that the welfare evaluation model still needs to be improved. It is necessary to strengthen the research on the interaction between different factors and the weight allocation and build a more accurate and comprehensive welfare evaluation index system. In the future, it will be necessary to strengthen research efforts and provide more adequate empirical support to improve the theoretical framework and system in the field of "dual carbon" goal realization and welfare.

Secondly, existing research mainly focuses on the measurement of ecological welfare performance, spatial and temporal differences, convergence effect and influencing factors, etc., and has achieved fruitful results. However, there is still little research on the "dual carbon" target and ecological welfare performance, and there are still many shortcomings, a lack of systematic and comprehensive research, and a need to strengthen interdisciplinary exchanges and cooperation. To promote the smooth realization of the regional "dual carbon" goal and the effective improvement of ecological welfare performance. It is not difficult to find that the in-depth study of ecological welfare performance represents a new field to explore the coordinated and sustainable development model of economic development, human welfare, and the ecological environment system in the new era, and there is an urgent need to pay more attention to the theory, method, and technology system involved. With the deepening of such research, in order to scientifically understand the driving force and resistance of the urban happiness index, and correctly interpret the functional process and intrinsic nature of the "dual carbon" goal and ecological welfare performance, it is necessary to push the exploration of ecological welfare performance to a new height and depth, and provide more comprehensive and accurate guidance and value demands for regional high-quality development, ecological civilization and happy city construction. In the future, we should focus on the optimization mechanism and path of regional ecological welfare performance in the context of "dual carbon" goal realization, apply statistical methods or economic models (such as the input–output model and CGE model) to quantify the impact of carbon emission reduction measures on ecological welfare,

and design different policy scenarios, such as strengthening supervision, introducing carbon tax, or subsidizing green technology. To predict the potential effects of these policies on "dual carbon" targets and ecological welfare performance.

Ecological welfare performance is an interdisciplinary field of study that combines theories and methods from ecology, environmental science, economics, and sociology to assess the impact of economic activity on human well-being. The current academic research on ecological welfare performance has shifted from a single dimension to a multi-dimensional and multi-level comprehensive consideration, and more and more attention is paid to empirical research and application orientation, striving to provide strong support for practical problem solving. However, there are still many unsolved mysteries waiting for further exploration in this field; in particular, how to harness the benign interaction between economic development and ecological protection under the "dual carbon" goal will be an important direction of future research. Both the "dual carbon" goal and the ecological welfare performance focus on the mutual support and promotion of environmental protection, carbon reduction, sustainable development and social responsibility in energy transformation, green innovation and performance evaluation, and contribute to China's future modernization and sustainable development.

5.3. Limitations of This Article

Although this study accomplishes some achievements in discussing the theoretical progress of ecological welfare performance under the "dual carbon" goal, there are also some limitations, which need to be improved and perfected in future research. First of all, this study mainly relies on qualitative analysis methods to conduct a comprehensive review of the theories and research progress related to ecological welfare performance. However, it is still insufficient in quantitative analysis, especially in describing and visualizing the time distribution characteristics of the ecological welfare performance research literature. Future studies can introduce more quantitative analysis methods, such as using bibliometric analysis software such as CiteSpace to create knowledge maps, which will help describe the research trend and development context in this field more accurately, so as to make up for the lack of time series analysis in existing studies. Secondly, although this study theoretically discussed the effect of the promotion of the "dual carbon" goal on the improvement of ecological welfare performance, it failed to build a corresponding index system to conduct quantitative research. Future studies can quantify the correlation between carbon emissions and ecological welfare performance in specific regions or industries by establishing specific indicator systems, so as to provide more solid data support for policy making. In addition, although this study discusses in detail the impact of the "dual carbon" target on ecological welfare performance, there is a lack of discussion on how the optimization of ecological welfare performance will react to the "dual carbon" target. Future research should further clarify the two-way mechanism between the two, so as to improve the system mechanism of energy saving, pollution reduction and carbon reduction. A deeper understanding of this interaction can provide a more scientific basis for policy design and promote a positive interaction between the two to promote the achievement of the Sustainable Development Goals.

6. Conclusions

The realization of the "dual carbon" goal has an inseparable internal logical relationship with ecological welfare performance, and there is a clear logical connection between the two. This study systematically combs the existing research on ecological welfare performance from the perspective of conceptual connotation, theoretical basis, model expansion and research inspiration, and the main conclusions are as follows:

(1) In recent years, research on ecological welfare performance has undergone a significant paradigm shift, from a single-dimension discussion in the early days to a complex system with multi-disciplinary and multi-level comprehensive consideration. Current research focuses on the following aspects: First is the connotation and representation of welfare. Scholars have deeply explored the multidimensional nature of "well-being" in ecological welfare performance, which is not only limited to economic benefits at the material level but also emphasizes the importance of non-material factors such as social equity, cultural inheritance and personal happiness. The second is the interaction between the ecosystem and welfare. Through the establishment of more detailed models and empirical analysis, researchers have revealed the dynamic relationship between the service function of natural ecosystems and human social welfare. In particular, the issue of how to maximize social and economic benefits under the premise of ensuring ecological security has received wide attention. The third is ecological welfare performance evaluation. With the progress of research methodology, more and more studies have adopted the combination of quantitative and qualitative methods, such as the proportion method, DEA model, SFA model, multi-stage Super-SBM model, and other models, to measure the changing trend of ecological welfare performance. Fourth are the "two-carbon" goal and ecological welfare performance. Relevant studies pay special attention to the possible positive or negative impacts of carbon emissions, welfare, and low-carbon transition, and explore specific paths to achieve a win–win situation between green growth and environmental protection.

(2) From the perspective of historical evolution, the research in this field is gradually moving away from theoretical abstraction and toward a more pragmatic application orientation. Most scholars realize that in order to better serve the needs of decision making, empirical research must be strengthened, focusing on case analysis and interdisciplinary cooperation, while actively introducing cutting-edge technologies and innovative ideas. Future research will continue to focus on developing and refining new theoretical frameworks and methodologies for a more comprehensive understanding of the complex mechanisms underlying ecological welfare performance, including but not limited to its temporal evolution, spatial heterogeneity, and how drivers work.

(3) When constructing the ecological welfare performance evaluation framework, researchers prefer a two-stage methodology, which is divided into a production stage and service stage, and clearly identifies the transformation process and internal structure of ecological welfare performance, so as to deepen the understanding of the relationship between natural ecological consumption, economic growth and welfare. This method not only helps to scientifically assess the sustainable development capacity of a country or region but also provides a solid theoretical basis and technical support for formulating policy measures that meet the requirements of the "dual carbon" goal. It can be seen that ecological welfare performance research has entered a new stage of development, which is not only an important topic in the academic community but also a key link to solve the challenge of global climate change and promote the transformation of economic society to a green and low-carbon one. Through the continuous deepening of theoretical exploration and practical application, ecological welfare performance optimization and carbon emission reduction can promote each other, improve residents' well-being through reducing greenhouse gas emissions and improving the environment, and promote integrated management and international cooperation, which will help realize a low-carbon and high-welfare future and provide a scientific basis for policy formulation.

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