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How Do Industrial Ecology, Energy Efficiency, and Waste Recycling Technology (Circular Economy) Fit into China's Plan to Protect the Environment? Up to Speed

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Abstract: The challenges of environmental protection are especially prevalent in South and Southeast Asian nations, which adversely affects their sustainable developmental goals. During the last two decades, increased industrialization and urbanization have caused massive air pollution, particularly in the most industrialized and densely populated countries. Due to China's fast economic expansion and development, the demand for natural resources has increased, resulting in climate change, biodiversity loss, soil degradation, and environmental risks. China's ecological footprint has been the subject of little investigation on the premises of a circular economy. This study used a literature review methodology on the critical key factors that hinder or facilitate the transition of a linear economy towards a circular economy. Further, based on the literature review, this study used industrial ecology, energy efficiency, and waste recycling technology factors to analyze the role of the circular economy on the country's environmental sustainability agenda for the period of 1975–2020. The results show that in the short run, the link between ecological footprints and per capita income is monotonically decreasing; however, in the long run, the relationship is U-shaped. In both the short and long run, waste recycling technology and cleaner manufacturing significantly decrease ecological footprints. Renewable energy consumption increases ecological footprints in the short run but decreases them in the long run. The management of natural resources reduces ecological footprints to support the 'resource blessing' hypothesis. The Granger causality corroborated the unidirectional relationship between ecological footprints, oil rents, and urbanization and ecological footprints. In addition, economic growth Granger causes industrialization and waste recycling technology while green energy Granger causes economic growth, industrialization, and recycling technology. The two-way link between economic development and urbanization exists within a nation. The variance decomposition analysis (VDA) predicts that in the future, China's natural resources, green energy demand, and technological spillover will limit its ecological footprint through material and technology efficiency.

Keywords: circular economy; ecological footprints; renewable energy; waste recycling technology; urbanization; natural resources; industrialization; China

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1. Introduction

The notion of a circular economy (CE) promotes environmental sustainability. It addresses issues of system stability, economization, process efficiency, operational procedures, and reduced resource extraction while maintaining economic development at the same level [1]. The development of CE requires the use ofclean, ecological, and helpful sources for the environment, integrating CE and environmental protection goals, with the understanding that governance and monitoring are essential [2]. The circular economy is a regenerative double-loop system that maximizes eco-efficiency, and its initiatives encourage environmentally friendly goods and resource efficiency. The circular economy has economic and commercial advantages, which emphasizes the need to consider the field's description to analyze and improve its complexity and diversity [3]. The use and recycling of resources and the reduction of input resources, effluent fluxes, and greenhouse gas emissions create a closed-loop cycle [4].

Today, the world confronts two significant global challenges: achieving economic growth (EG) and preserving the planet's ecology. The concentration of greenhouse gases (GHGs) in the atmosphere has elevated environmental degradation to the forefront of contemporary issues for all nations [5]. Over the last two centuries, rapid industrialization has significantly increased energy consumption (EC), primarily dependent on nonrenewable fossil fuels [6]. Consequently, decision makers find it very difficult to strike a balance between economic development and environmental protection. Minerals and energy sources are crucial inputs for producing goods and services and are thus necessary for economic progress. Following the industrial revolution, the global production of greenhouse gases increased due to the exploitation of these resources [7]. In recent years, the ecological footprints (EFPRINTS) assessment has received significant attention worldwide due to its importance in drafting legislation to battle increasing temperatures and air pollution. This issue reveals that more natural resources are used than can be replenished by nature. Globalization has resulted in economic expansion across nations and has profoundly affected human existence's social, environmental, and sociopolitical aspects [8]. Globalization expands a country's interdependence through commerce, exchange of goods and services, money flows, capital movement, technology acquisition, and knowledge diffusion. Globalization often results in the rise of polluting companies in poorer countries where climate policies are weak [9].

South and Southeast Asian countries have a more widespread commitment to ecological sustainability. So, examining the states' economic growth patterns is crucial to see how they affect environmental sustainability and what can be done about it [10]. Examination of the ecological effect of the economic development pattern requires consideration of the EG drivers. Due to their rapid growth, South and Southeast Asian nations have a high EC powered mainly by fossil fuels. Because of the gravity of environmental problems worldwide, people have started debating whether environmental laws can improve environmental governance. So, many environmental and ecological problems, such as air pollution, global warming, and sandstorms, have worsened, putting the health of people in emerging nations in grave danger. In total, 1.6 billion people worldwide are affected by urban air pollution, caused mainly by power plants and cars burning fossil fuels [11]. EFPRINTS, suggested by Rees [12] and Wackernagel et al. [13], is a valuable environmental measuring method for analyzing the influence and potential of the ecological environment in the processing of human activities. Green energy plays a crucial role in achieving the decarbonization plan [14,15]. It can quantify and accurately assess the consumption extent of human activities on the ecological environment through the biologically productive land area, indicating the pressure that social and economic activities place on the ecological environment [16]. In recent years, EFPRINTS has increasingly surpassed CO2 emissions as the subject of study attention. The literature has judged itto be a more comprehensive and reliable indicator of environmental strain [17]. A country's or region's EFPRINTS is described as a method for assessing the effect of human activities on the environment, demonstrating how much land and water are necessary to produce commodities for people and absorb pollutants caused by those activities [18].

China, which has a population of 1.402 billion people, has experienced incredible EG. The Asian giant advances its vast industrialization agenda, which typically requires a large-scale energy demand, making the country the world's largest energy consumer [19].

As the biocapacity steadily drops over time, the nation now occupies the top position among worldwide GHG emitters with an increasing EFPRINTS [20]. China's urban development has made tremendous strides in recent years. However, the urbanization trend has resulted in substantial air pollution. Seven Chinese cities were among the world's ten most polluted cities. In addition, less than 1% of China's cities fulfilled WHO's air quality requirements. China's cities use 20% of the world's energy, increasing pollution emissions [21]. China's rapid economic expansion has made it the world's leading source of anthropogenic PM2.5 pollution, and it has a substantial obligation to reduce its emissions [22]. Severe weather is an early warning prediction for PM2.5 occurrences. It may potentially contribute to a decrease in human health in many regions of China, particularly in industrialized and heavily inhabited areas. It may have various negative repercussions, including decreased air quality and climate change [23].

Globally, climate change impacts not just the environment and ecosystems but also every area of society and the economy [24]. Significantly higher than the rate of population expansion in wealthy nations, EFPRINTS and resource use are the leading sources of environmental degradation [25]. The EFPRINTS divides human demand and environmental strain into several areas: farmland, grazing, fisheries, forest products, development and infrastructure, and anthropogenic pollution absorption [26]. This single environmental indicator offers a plethora of data to anticipate the global resource consumption limit and its long-term sustainability. Consequently, EFPRINTS analysis is a more holistic and complete environmental approach that is a more accurate and successful policy instrument among sustainability analysis variables and techniques [27]. According to a social–ecological perspective, human society is rooted in the natural environment and integrated into the complex and synthetic social–ecological system [28]. People in low-, middle-, and high-income nations are impacted by air pollution, a sensitive and crucial environmental health issue [29]. Automobiles, the burning of agricultural waste, and industrial sectors are the most significant contributors to air pollution. In addition, human activity significantly influences air quality via fossil fuels, heating, and traditional cooking techniques [30]. Poor air quality harms the global ecosystem and ecology. Air pollution increases water acidity, which has disastrous effects on the forest reserve and soil health [31]. Air pollution hurts the environment and has direct and indirect economic consequences, such as decreased agricultural production, increased healthcare costs, and reduced workplace productivity [32].

Rapid urbanization in China has contributed to the country's recent EG. However, it has also worsened environmental problems such as PM2.5-dominated air pollution, which has a detrimental impact on public health, human development, and global warming [33]. Urbanization is the migration of people from rural to urban regions in a quest for better living circumstances, and it is closely related to pollution. The greater population density in cities results from greater industrial activity in metropolitan areas, which draws more people seeking employment [34]. The ecology and air quality of urban populations are impacted by the increased demand for energy, groundwater, and land caused by urban agglomeration in various places. Population growth in urban areas may deplete natural resources and negatively impact the environment by reducing the carrying capacity [35]. In recent years, environmental threats and risks have grown due to the rising EC-fueled economic expansion and development. Consequently, the most effective use of finite resources and energy is a priority for many nations' environmental objectives and increasing energy efficiency is one of the three primary goals of the European Climate Commission. Improving energy efficiency may help countries achieve sustainable economic development [36]. EC is a prerequisite for economic development; reducing EC reduces EG. Consequently, increasing energy efficiency and reducing energy waste is a primary objective for most nations, especially those with rising economies, to support economic development while safeguarding the environment [37]. Natural resources are the most significant contributor to a nation's economic and social growth. Economic activity mainly depends on natural resources and disregards their environmental repercussions in the early phases of EG.

As the economy develops, the conservation of natural resources becomes more crucial. Natural resources and EG are two critical variables for enhancing environmental quality. On the other side, it has been shown that natural resources serve as an emission sink in the ecosystem, helping to recycle human activity's emissions and wastes [38].

1.1. Research Question(s) and Novelty of This Study

Research questions specific to China have emerged from the discussion, such as whether the EKC hypothesis can be applied to the Chinese EFPRINTS. Understanding whether China needs to investigate the driving causes behind EFPRINTS to achieve the goal of urban environmental sustainability necessitates research into the limiting and influencing components that impact the establishment of green energy infrastructure. This suggests that when economic development advances, ecological damage increases initially but then declines. China's economic and geopolitical context makes it even more important to investigate the evolving nature of the country's impact on the environment. Increases in population, affluence, and automation all increase competition in the free market, increasing negative environmental externalities. The second question is do natural resources and waste recycling technology advances contribute to decrease EFPRINTS in China? In order to reduce their reliance on human resources, developed countries are laying the groundwork for expanding their use of natural resources. So, the adaption of natural systems to human needs contributes to environmental degradation. Because limited farmland and dwindling supplies are stifling productivity growth, natural stress needs to be reduced and resource efficiency boosted if China is to enjoy economically sustainable expansion. Thirdly, does the energy efficiency in developing countries increase within the circular economy? Because they value economic growth more than environmental quality, emerging economies negatively affect ecological quality. China would do well to accommodate emergency backup and interim markets, which feature practices such as cheap energy hoarding and variable fuel pricing. These elements may help reduce electricity bills and stimulate economic growth. Some of China's proposed methods for increasing efficiency and decreasing waste can be used to boost productivity and save money. A more diverse energy usage system, the increased generation and consumption of cleaner fuels, and the expanded planning and development of additional power capacity are necessary to reduce environmental issues and achieve sustainable results. Finally, do higher levels of urbanization and population density boost EFPRINTS? Air pollution increases in countries with rapid population expansion and increased reliance on urban infrastructure. At the same time, an increase in product and service demand drives urbanization and industrialization. The resource extraction, regeneration, and absorption rate have grown to keep up with rising demand, but this has led to unsustainable outcomes such as soil degradation, deforestation, and increased carbon emissions [39]. China's major urban environmental issues have been brought to the forefront by the country's rapid urban development. In order to ensure China's ecological sustainability, a comprehensive and impartial assessment of the increasing pressures brought on by the interaction of nature, community, and business is required. The current study considered a case study of China to identify whether an inverted U-shaped curve for EFPRINTS holds for a country.

1.2. Research Objectives

This research has specific goals to bridge the gap between current literature:

(i) To examine the presence of the EKC hypothesis for EFPRINTS as a significant measure of human strain on the natural environment in the premises of a circular economic system in China;
(ii) To analyze the effect of REC in lowering a country's EFPRINTS; and
(iii) To investigate the relationship between China's current levels of EG, including urbanization, industrialization, and oil resources, and the state of EFPRINTS.

The present literature considers EFPRINTS, an all-inclusive metric for measuring the impact of human activities on nature [40,41]. This research investigates China's ecological impact from a specific perspective. It also aims to explore the influence of EG, EC, urbanization, population density, natural resources, and recycling technology on EFPRINTS. This research examines the impact of technology developments on China's environment. Finally, modern econometric methodologies are used to provide dependable and robust findings, which will aid policymakers in formulating successful strategies for China's economy.

This research paper is divided into the following sections: Following the introductory material offered in Section 1, a comprehensive literature review is presented in Section 2. The materials and methods are presented in Section 3. Section 4 deals with the findings. This research is concluded in the last section.

2. Literature Review

The literature review is divided into two main sub-sections. First, its shows the causation between the circular economy and environmental sustainability while the latter part discusses the different factors affecting ecological footprints worldwide. Finally, both the sub-sections were merged and some conclusive remarks provided.

2.1. Circular Economy and Environmental Considerations

The circular economy aims to reduce waste and limit the use of environmental resources by repairing, adapting, and composting methods. The closed-loop system is associated with ecological sustainability and greenhouse gas emission reduction [42]. Building a business model that maximizes resource efficiency is challenging, and few understand how substance regeneration enterprises in scientific areas create and capture value [43]. The rise of digitalization has resulted in hasty and contradictory assumptions about the resource efficiency and distribution system [44]. Thus, technological innovation should align with the circular economic system to convert into cleaner production technologies [45]. As a reaction to the impending climate disaster, many metropolitan areas are switching to a circular economy. It is one of the critical choices that may assist governments achieve the goal of the Paris Agreement, which is to limit the increase in temperature caused by climate change to 1.5 degrees Celsius above its pre-industrial levels. Vanhuyse et al.'s [46] study looked at the social effects of a shift toward recycling and reuse in urban areas. In analyses of circular cities, social ramifications are seldom investigated, and even when they are, the attention is often focused on business practices and the effects of industries on organizational effectiveness. Kyriakopoulos [47] investigated the transition from the linear paradigm toward emphasizing pricing over the environment. This study was centered on the procedural requirements, European industrial emission regulations, and social planning for linear economies. This demonstration discussed the guidelines and methods, related research, liberal attitudes, and working norms that help move towards a circular economy. In their investigation of the relevant scientific literature, Calzolari et al. [48] investigated the instruments for supporting choices and related aspects used to assess the circular distribution networks' efficacy. The application of qualitative methods and pattern recognition occurred together. Both academic study and business operations emphasize the financial and ecological repercussions of their actions more than they do the moral and logical standards they must adhere to. Regarding scientific papers, the financial side takes precedence; nevertheless, stakeholders more often investigate and explain the consequences of actions related to the circular economy. Pizzi et al. [49] investigate the role that Fintech plays in the transition SMEs make to more environmentally friendly business models using the green business strategy. One component of Industry 4.0, Fintech, may facilitate the growth of SMEs toward a business model that is more environmentally responsible. The research results were used to construct a road map for a long-term business model that integrates Fintech into the concept of a sustainable society.

D'Amato [50] concluded that CE concepts had to be transformed into short- and medium-term plans that assist in evaluating the causal relationships between individual nations and regional areas, which are essential for sustainable development. Co-evolution and the unification of different discourses should have the goals of lowering dependency on resources such ascoal and natural gas, reversing the decline in species and the ecological collapse, and increasing the quality of life. Van Fan et al. developed an enhanced pinch analysis-based targeted strategy [51] to decrease carbon effects in urban waste reduction. Material trading for reclamation results in lower overall net GHG emissions when the amount of trash that has to be transported by truck is more than 5 tons, and the distance to the combustion plant is between less than 500 and more than 940 km. Costs at landfills need to increase to remain economically viable. In total, 240 Chinese firms participated in a study by Jinru et al. [52] to investigate green financing and logistics' role in adopting sustainable manufacturing and the circular economy. The circular economy and sustainable manufacturing benefit from implementing sustainable financing and logistics. The supply chain strengthens the value chain. It has become clear that sustainable management plays a significant role in the crucial differential effect played by these components. Babbitt et al. [53] concluded that CE offers a new approach for addressing the requirement of using metal via design and material, replacement components, and composting. Items containing vital chemicals are seldom meant to be modified, reused, or destroyed at last. Meglin et al. [54] noted that to construct a value chain, governments worldwide are now working to adopt new legislation. The construction industry is responsible for almost half of the world's annual use of resources and the production of garbage. Because stakeholders are responsible for enforcing CE regulations, both the policy and the result need to understand the regional context of this transition. Based on the literature, thisstudy formsits first hypothesis, i.e.,

Hypothesis 1 (H1): *Circular economy improves green production to decrease ecological footprints.*

Improvements in environmental quality and lessening the human impact on arable land are two results of CE's implementation in China's business sector. This is why governments must adopt policies that promote the integration of cutting-edge technologies into their production processes. It is the best way to ensure sustainable outcomes are realized.

2.2. Literature Review on Industrial Ecology, Energy Efficiency, Technology Innovation, and Ecological Footprints

Numerous studies have examined EFPRINTS, air quality, and other vital factors. The impact of urbanization, renewable resources, power consumption, scientific advancement, and capital formation on EFPRINTS is primarily framed through a single lens. Few studies on the same topic have been conducted combining REC, urbanization (URB), EG, and EC. Using panel data from 1998 to 2012 for 30 provinces, Chen et al. [55] analyzed the extent of environmental regulation's impact on environmental quality and the variables that determine the effects of environmental law on pollution. The generalized method of moments accounts for possible endogeneity and integrates dynamic effects. The results indicate that strict environmental regulation and the size of the shadow economy appear to be positively and significantly related to China's environmental pollution. However, more stringent environmental controls would aid in reducing pollution at a given size of the shadow economy. Hao et al. [56] utilized city-level panel data from 2013 to 2015 to examine the potential effect of a population increase on environmental pollution. The impacts of PM2.5 concentrations on per capita income werecomputed using a method based on correctly constructed simultaneous equations. In addition, many temporal and area dummies were added to adjust for fixed effects. The findings indicate that haze pollution significantly negatively impacts EG. As of 2015, a 5 mg/m^3 increase in pollutant concentrations may cause a decline in EG of around 2500 yuan.

The objective of Zhao et al. [57]'s study was to examine the temporal and spatial variations in air pollution and the impacts of macro-influencers on four pollutants in five Chinese hotspots. From 2011 to 2014, regional and temporal variations in the air pollutants PM10, sulphur dioxide, and nitrogen oxide and their ratios were examined. The findings indicate that PM outperformed national standards nationwide. After 2013, most toxins decreased, and air pollution in southern China decreased. In addition, macro-influencing variables had diverse impacts on various hotspot pollutants. PM2.5 levels were affected by the gross domestic product, private autos, and energy usage. Li et al. [58] examined the regional spillover effects of significant pollutant emissions and analyzed emissions concerning industrialization and urbanization. Based on the geographical weight matrix, the spatial Durbin model examined industrialization and urbanization factors' direct and spatial spillover influences on 7 pollutant emissions in 53 Chinese cities from 2009 to 2014. According to the results, CO is the most abundant pollution component in 53 cities, followed by SO_2 and NOx. The direct effects of per capita GDP, non-agricultural industries, and urbanites' per capita consumption on pollution emissions are the most substantial. GDP per capita's direct effect on air emissions is usually wholly negative, although the indirect impact for non-agricultural businesses is typically positive. Three characteristics have the highest geographical spillover effect on pollution emissions: non-agricultural industries have a positive spatial spillover effect, whereas per capita GDP has a negative spatial spillover effect. Using environmental Kuznets and environmental sustainability curve theories, Sarkodie et al. [59] analyzed the variables leading to harmful greenhouse gas emissions and the economic consequences of their growth for Australia, China, Ghana, and the United States from 1971 to 2013. The paradigm changes and structural transition from energy-intensive and carbon-heavy sectors to service- and information-intensive businesses have reduced carbon dioxide emissions in developed nations. The economy drives agriculture, transportation, and services and blames increased carbon dioxide emissions in developing and emerging countries. Environmental laws and regulations in emerging and least developed nations are weaker than in industrialized nations, enabling energy- and carbon-intensive enterprises to flourish. In developed nations, a rise in environmental sustainability knowledge, technological innovation, and strong environmental regulations and laws lead to decreased energy intensity and carbon dioxide emissions. Du et al. [60] examined the relationship between haze pollution and economic development in China and its turning points in various locations. China's relationship between air quality and EG is not a unique inverted U-shaped EKC, according to panel data from 27 Chinese capital cities and municipalities from 2011 to 2012. The results show that changing the industrial structure and boosting the energy efficiency effectively minimizes haze pollution. The center area had a U-shaped correlation, but the eastern, northeastern, and western regions had inverted N-shaped correlations.

Miao et al. [61] utilized the Luenberger productivity index to analyze the performance of air pollution emissions for 30 provinces and autonomous areas from 2006 to 2015. Both SO_2 emissions from industrial pollution and NOx emissions from vehicle exhaust are substantial contributors to environmental inefficiency in regional atmospheres, but the former seems more relevant. Comparatively, the southeastern coastal provinces have lower levels of inefficiency than the northwest interior. Liu and Lin. [62] evaluated the primary influencing elements of environmental pollution using a comprehensive ecological pollution index that includes sulphur dioxide, dust and smoke, wastewater, and solid waste emissions to quantify pollution in each province using data from 2000 to 2015. The results indicate that environmental contamination in various regions has a significant geographical correlation. There is an inverted N relationship between environmental pollution and economic progress, and most provinces have not yet reached the second inflection point of the inverted N-shaped curve. Industry and R&D significantly affect pollution levels, but FDI has a minor effect. Liang et al. [63] utilized the analytic hierarchy process, entropy method, and the principle of essential information randomness to obtain the qualitative, objective, and total weights of the evaluation indexes, and the effects of urbanization aspects and sub-systems on environmental pollution from 2000 to 2015 utilizing a spatially and temporally weighted regression model. As measured by the results, the urbanization index rose rapidly from 0.157 in 2000 to 0.438 in 2015. National policies affect the environmental protection of urban agglomerations. Due to factors such as the service sector, fiscal revenue, local income, education level, and Internet use, environmental degradation has decreased.

The pace of urbanization, population concentration, sustainable growth, industrialization, urban development, and transportation building aggravated environmental degradation. The consequences of urbanization on pollution vary regularly, according to the five-year plan of China.

Using the STIRPAT model and panel data for 277 regional capital cities in China from 2003 to 2015, Xu et al. [64] examined the EKC link between urbanization and pollutant emissions. Manufacturing waste and domestic sewage climbed 83% and 43.50%, respectively, whereas wastewater discharge and SO_2 emissions fell 7.4% and 10.5%, respectively. Urban sprawl and particulate emissions have a reversed U-shaped connection, supporting EKC. Hao et al. [65] examined the relationships between urbanization and different industrial pollutants for 29 Chinese provinces using data from 1998–2015. The results provide evidence of a complicated connection between urbanization, industrial structure, and environmental pollution levels. Urbanization has contributed to a rise in environmental pollution. In addition, as the percentage of secondary industries increases, urbanization contributes more to environmental degradation. Shahbaz et al. [66] studied the relevance of technological advancements in China's carbon emissions function and developed the link between them from 1984 to 2018. The empirical data indicate that public–private partnership energy investments harm the environment and increase carbon emissions. On the other side, technological developments have a detrimental effect on carbon emissions. The EKC theory states that EG and carbon emissions are inverted-U shaped. Exports are inversely proportional to carbon emissions. The increase in CO_2 emissions caused by FDI is detrimental to the environment. Kazemzadeh et al. [67] examined the impact of resource and energy efficiency, exporting quality, and other characteristics on EFPRINT of 16 rising nations from 1990 to 2014. Resources, energy efficiency, and trade liberalization all reduce the environmental impact. Gross domestic product, fossil fuel use, and population contribute to a deteriorating environmental footprint. The environmental footprint deepens between the tenth and twenty-fifth quantiles of export quality, and for urban people, all quantiles except the tenth worsen EFPRINTS. Ansari et al. [68] investigated EKC development in G20 countries between 1991 and 2016. There has been an inverted N-shaped association between environmental degradation and economic development in nations. Furthermore, globalization, REC, and urbanization enhance the ecological quality in G20 nations, but nonrenewable energy (NRE) use worsens the environmental quality. Hence, the need for greenfield energy investment is pivotal for sustained growth. Table 1 shows the recent literature on the different determinants of EFPRINTS worldwide.

Table 1. Ecological footprints literature worldwide.

Authors	Country	Time Period	Results
Irfan et al. [69]	Pakistan	1975–2020	Air pollution strains EFPRINTS over the long term and potentially harms ecosystems.
Kazemzadeh et al. [70]	25 Countries	1970–2016	Economic complexity index, gross domestic product, fuel consumption, and population increase positively affect EFPRINTS. Economic openness has had a detrimental impact on EFPRINTS.
Pata et al. [71]	China	1980–2016	Human capital has a long-term beneficial effect on the environment, but globalization, trade openness, and income contribute to environmental harm. REC had no effect.

Table 1. *Cont.*

Authors	Country	Time Period	Results
Ahmed et al. [17]	G7 countries	1985–2017	The economy's complexity lowers EFPRINTS and is strengthened by democratic responsibility, followed by a U-shaped relationship. REC and continue EG have been shown to alleviate EFPRINTS.
Murshed et al. [72]	South Asian countries	1990–2014	Environmental regulations are essential in reducing South Asia's EFPRINTS directly and indirectly. NRE rises as REC declines.
Yao et al. [73]	China	2000–2019	Economic, demographic, and urban land use concerns are responsible for propagating EFPRINTS.
Usman et al. [74]	China	2000–2018	The agricultural added value, NRE, and financial growth raise the ecological impact. At the same time, the decrease in the environmental footprint may be attributed to an increase in forestry and the usage of RE sources.
Liu &Nie [75]	China	2000–2018	Strong geographical spillover effects are associated with EFPRINTS. China's provincial per capita has a geographical agglomeration effect and a positive spatial dependency link.
Chu [76]	OECD economies	1990–2015	By reducing EFPRINTS, increased trade integration may aid the environment.
Salman et al. [77]	ASEAN-4	1980–2017	Urbanization and EFPRINTS do not exhibit an inverted U-shaped curve over the short and long term. Population, economic development, and NRE significantly increase EFPRINTS while REC has a rebound effect.

The following study hypotheses are proposed based on the cited literature:

Hypothesis 2 (H2): *Waste recycling technology reduces EFPRINTS on the premises of renewable energy consumption;*

Hypothesis 3 (H3): *Industry value addition is expected to increase EFPRINTS due to overexploitation of natural resources; and*

Hypothesis 4 (H4): *Continued economic expansion will aid in reducing EFPRINTS in a country through sustainable development projects.*

This research has far-reaching implications. First, an innovation-based country would reduce EFPRINTS using cleaner manufacturing processes. This is measured by the number of environmental technology patents filed by residents and non-residents. Greenfield FDI [78], waste recycling [79], ICT [80], and digital technologies [81] all help to improve environmental quality, but they do not do enough to address the challenges of reducing EFPRINTS. Second, REC was the primary factor in this study's success in reaching the zero-carbon goal and reducing the human footprint on agricultural land. Several studies [82–84] have examined REC's efficiency in reducing carbon emissions. However, its impact on EFPRINTS has generally been disregarded. Because of this, the positive benefits of this study's inquiry into the viability of green energy sources may last for quite some time. Thirdly, more EFPRINTS was a direct outcome of the heavy industrial use of natural resources. Therefore, it is essential to use cleaner production techniques [85–87]. At last, the U-shaped association was inverted by employing EG as a control variable in an EFPRINTS model. Many studies have investigated the EKC hypothesis in the context of carbon emissions and EG. Contrarily, EFPRINTS modeling was less likely to be investigated [88,89].

3. Materials and Methods

This study used a mixed-method approach to make an appropriate circular economy model that helps reduce environmental problems. By Google searching, the following key phrases in the article titles are available for ready reference:

(i) 'Sustainable circular economy';
(ii) 'Circular economy and environment'; and
(iii) 'Circular economy and technology.'

These phrases showed 1380, 168, and 116 search results, respectively. Further, the following phrases were also searched for, maintaining the database:

(iv) 'Circular economy and economic model';
(v) 'Circular economy and environmental model'; and
(vi) 'Circular economy and innovation.

The given phrases search results were 17, 14, and 246, respectively. Based on the given phrases, thisstudy searched for different socio-economic and environmental factors that help to make a statistical model for estimation. Industrial ecology, energy efficiency, and technology innovation factors were used to analyze CE's impact on the country's EFPRINTS. The number of Google search results determined the majority of the selection criteria for variables. There is a chance that essential regressors may have been unidentified, resulting in the prospect of a new research path in the future.

Table 2 shows the list of variables used in this study.

Table 2. List of variables.

Variables	Symbol	Measurement	Expected Signs	Theoretical Support
Ecological Footprint	EFPRINT	Arable land (Hectares)		—
Independent Variables				
GDP Per Capita	GDPPC	Constant 2015 US$	Positive	Ali et al. [90], Jiang et al. [91], and Yousaf et al. [92].
Renewable Energy Consumption	REC	% of total EC	Negative	Murshed et al. [93] and Usman et al. [74].
Urbanization	URB	% of total population	Positive	Salman et al. [77], Ahmad et al. [94], and Khan et al. [95].
Industrialization Value Added	IND	% of GDP	Positive	Usman et al. [96], Sahoo &Sethi [32], and Opoku et al. [97].

Table 2. *Cont.*

Variables	Symbol	Measurement	Expected Signs	Theoretical Support
Independent Variables				
Waste Recycling Technology	WRTECH	Total number of patent applications served as a proxy for waste recycling technology	Negative	Wang et al. [98], Jahanger et al. [99], and Shahzad et al. [100].
Natural Resource Rents	ORENTS	Oil Rents (% of GDP)	Positive	Alfalih & Hadj [101], Adekoya et al. [102], and Afshan & Yaqoob [103].

The data was collected from the World Bank database. Arable land in hectares was used as a substitute for ecological footprints. The data for Chinese economic growth was represented with the country's per capita income in constant 2015 US$. Green energy supply data was captured from renewable energy data, which is available in % of the total energy supply. The percentage share of the urban population in the total population, industry value added relative to the country's per capita income, and share of oil rents relative to GDP were also collected from the stated database. The total number of patent applications was used as a recycling technology indicator, helping to decrease ecological factors in China.

Companies are paying close attention to China since it has one of Asia's fastest-growing economies. China has a human development index (HDI) of 0.752, placing it 86th worldwide. China's net exports are worth the equivalent of 41.2% of GDP. China's overall population is 1409.5 million. MPI for China is 0.07% while the country's per capita GNI is15,270 USD [104,105]. China is the leading CO_2 producer, accounting for 27.52 percent of world emissions. China leads the globe by producing the most power, producing the most crude oil, and consuming the most electricity [91]. As part of its strategy to ensure its economic future and safeguard the Earth, China is increasing its use of renewable energy sources and greener industrial processes [71]. The sustainability of China's energy plans is being questioned from an ecological perspective. Energy and environmental concerns are intertwined, and this causes major ecological challenges. Electricity is produced by burning fossil fuels, which are rapidly becoming depleted. Accordingly, this is a significant contributor to poor air quality. Primary sources of these emissions come from nonrenewable energy sources as well. The Chinese government encourages research and development of RE sources to combat air and water pollution and reduce economic and environmental risks. The Chinese government has placed a premium on RE [106] to reduce air pollution.

3.1. Theoretical Framework

This study followed a diverse range of multifaceted theories that helped to build an econometric framework for this study.

3.1.1. Theory of Sustainable Circular Economy

Measuring environmental quality based purely on greenhouse gas emissions into the atmosphere does not adequately represent the complexity of environmental issues. A circular economy is vital for limiting carbon footprints using energy efficiency, material effectiveness, and industrial ecology. Wackernagel and Rees [107] created EFPRINTS, a more thorough evaluation of environmental quality. EFs serve as a framework for comparing human needs for ecological resources with the natural environmental capacity to satisfy these demands while also absorbing waste created in the process. Economic development and environmental quality are often related [108]. This research relies on the theoretical foundations of EFPRINTS and air pollution, also known as the theory of sustainable CE, even though multiple environmental modeling techniques depict the mechanisms by which various macroeconomic variables affect the environment's health [109].

3.1.2. Theory of Green Energy

This research used the green energy demand approach to determine the efficiency of energy source utilization and environmental deterioration. Green energy initiatives are essential for sustained economic development [110]. For instance, industries that invest in green energy incur high initial costs, and due to this circumstance, businesses are cautious about investing in this region. Green energy investments are complex and costly [111]. This project uses the analytic hierarchy approach to evaluate energy choices and build a systematic strategy and decision support system to aid municipalities in picking the most practical solutions.

3.1.3. Theory of Innovation

Countries throughout the globe diversify their investments in various energy sources to meet the expanding energy demand in several places. In addition to the immediate damage they cause, such as fine dust emissions from oil combustion and mercury emissions from coal combustion, oil and natural gas are not sustainable energy sources and cause significant and irreversible environmental damage over the long term. Alternatives to fossil fuels, such as solar and wind, are easily accessible and might be utilized to provide a portion of the demand [112]. This research is also based on the theoretical work of technology-induced emissions and the theory of innovation, both of which rely on product innovation, which is essential for market expansion and affects innovation capabilities, contributing to the enhancement of the capacity to function in the contemporary period [113]. This study is in line with the theory of sustainable production and consumption, which links urbanization and industrialization [114,115] and helps to move toward sustainable economic outcomes.

3.2. Econometric Framework

Based on the theoretical linkages, this study developed the following equation:

$$lnEFPRINT_t = \propto_0 + \propto_1 lnGDPPC_t + \propto_2 lnGDPPC2_t + \propto_3 lnREC_t + \propto_4 lnURB_t + \propto_5 lnIND_t + \propto_6 lnWRTECH_t + \propto_7 lnNR_t + \mu_t \quad (1)$$

This study expected the following relationship between the variables:

$\frac{\partial \ln(EFPRINT)}{\partial \ln(GDPPC)} > 0$ The higher the per capita growth rate, the higher the country's ecological footprints;

$\frac{\partial \ln(EFPRINT)}{\partial \ln(REC)} < 0$ The higher the REC, the lower the country's ecological footprints;

$\frac{\partial \ln(EFPRINT)}{\partial \ln(URB)} > 0$ The higher the urbanization rate, the higher the country's ecological footprints;

$\frac{\partial \ln(EFPRINT)}{\partial \ln(IND)} > 0$ The higher the industry value added, the higher the country's ecological footprints;

$\frac{\partial \ln(EFPRINT)}{\partial \ln(WRTECH)} < 0$ The higher the environmental and technological innovations, the lowerthe country's ecological footprints; and

$\frac{\partial \ln(EFPRINT)}{\partial \ln(NR)} > 0$ The greater the overexploitation of natural resources, the higher the country's ecological footprints.

The following sequential methods were used for empirical testing.

(i) Unit Root Tests

Dickey and Fuller [116] were the first to present unit root tests in the literature. Perron and Qu [117] brought a shift in the testing idea in general. Enders and Granger [118] showed that the usual tests for unit root and cointegration have decreased power in the context of miss-specified dynamics. In recent years, there have been considerable advancements in nonlinear unit root testing, and numerous significant tests utilizing various types of models have been produced [119–122]. The null hypothesis is that the lagged level's parameter is zero if the dependent variable is the first difference. The null hypothesis is that the time-series variable has a unit root, whereas the alternative hypothesis is that the series is stationary [123]. Of course, the test outcome is contingent on the right-hand side's remaining specifications. In addition, delays of the variable's first difference may be provided to allow for any autocorrelation in the error term [124]. Diebold and Rudebusch [125] further demonstrated that the test has minimal power when compared to the fractionally integrated series option.

The augmented Dicky–Fuller [112] test was used to check for the presence of a unit root. The ADF test produces a parametric adjustment for higher-order correlation as follows:

$$\Delta Y_t = c + \propto y_{t-1} + \sum_{j=1}^{k} d_j \Delta y_{t-1} + \varepsilon_t \quad (2)$$

$$\Delta Y_t = c + \alpha y_{t-1} + \beta t + \sum_{i=1}^{k} d_j \Delta y_{t-1} + \varepsilon_t \quad (3)$$

Equation (2) compares the null of a unit root to a mean-stationary while Equation (3) is a trend-stationary alternative and is used to compare the null of a unit root [126–128].

(ii) ARDL Bounds testing approach

The ARDL model, introduced by Pesaran and Shin [129] and improved by Pesaran et al. [130], primarily involves single cointegration. Cointegration entails measuring the ARDL model's conditional error correction version [131]:

$$\Delta y_t = \lambda_0 + \sum_{i=1}^{p} \lambda 1 \Delta y_{t-i} \sum_{i=0}^{p} \lambda 2 \Delta i_{t-i} + \delta_1 y_{t-1} + \delta_2 i_{t-1} + \cdots \mu_t \quad (4)$$

The ARDL approach has the advantage of not requiring all variables to be I(1), as the Johansen framework does, and it can still be used if our set contains both I(0) and I(1) variables. The Wald test is the foundation of the ARDL bound test (F-statistic). Under the null hypothesis of no cointegration among the variables, the Wald test asymptotic distribution is non-standard. The ARDL equation is as follows:

$$\begin{gathered}\Delta \mathrm{lnEFPRINT_t} = \mathrm{c_0} + \delta_1\, \mathrm{lnGDPPC_{t-1}} + \delta_2\, \mathrm{lnREC_{t-1}} + \delta_3\, \mathrm{lnURB_{t-1}} + \delta_4\, \mathrm{lnIND_{t-1}} + \delta_5\, \mathrm{lnWRTECHt_{t-1}} + \\ \delta_6 \mathrm{lnNR_{t-1}} + \sum_{i=1}^{p} \varphi_\mathrm{i} \Delta \mathrm{lnGDPPC_{t-i}} + \Delta_{j=1}^{q1} \varphi_\mathrm{j} \Delta \mathrm{lnREC_{t-j}} + \sum_{k=1}^{q2} \varphi_\mathrm{k} \Delta \ln URB_{\mathrm{t-k}} + \sum_{l=1}^{q3} \varphi_\mathrm{l} \Delta \mathrm{lnIND_{t-1}} + \\ \sum_{m=1}^{q4} \varphi_\mathrm{m} \Delta\, \mathrm{lnWRTECH_{t-m}} + \sum_{n=1}^{q5} \varphi_\mathrm{n} \Delta \mathrm{lnNR_{t-n}} + \varepsilon \mathrm{t}\end{gathered} \quad (5)$$

(iii) Granger Causality

This study employed the Toda–Yamamoto causality test created by Hacker and Hatemi-J [132] and the time-varying version of the same test. The asymmetric Toda–Yamamoto causality test produced by Hatemi-J andUddin [133] was used to evaluate the causality between the variables. To use the Toda–Yamamoto [134] causality test, the series may have a different order of integration, which could be used for causal estimates. As a result, this method requires a large number of pre-tests and the simultaneous realization of numerous conditions.

After obtaining short- and long-run estimates, the Granger causality test inferences the different postulates:

Postulate I: Unidirectional causality running from EFPRINTS to their regressors;

Postulate II: Reverse causality running from GDPPC, REC, URB, IND, WRTECHINOV, and ORENTS to EFPRINTS;

Postulate III: There exists bidirectional causality between the variables; and

Postulate IV: No causality running between the variables.

Equation (4) is simplified using VAR(2) model testing:

$$
\begin{aligned}
&EFPRINT_t = c_1 + \sum_{i=1}^{2} \beta_1 EFPRINT_{t-i} + \sum_{i=1}^{2} \beta_2 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_3 REC_{t-i} + \sum_{i=1}^{2} \beta_4 URB_{t-i} + \sum_{i=1}^{2} \beta_5 IND_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 WRTECH + \sum_{i=1}^{2} \beta_7 NR_{t-i} + \varepsilon_{EFPRINT,t} \\
&GDPPC_t = c_2 + \sum_{i=1}^{2} \beta_1 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_2 EFPRINT_{t-i} + \sum_{i=1}^{2} \beta_3 REC_{t-i} + \sum_{i=1}^{2} \beta_4 URB_{t-i} + \sum_{i=1}^{2} \beta_5 IND_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 WRTECH + \sum_{i=1}^{2} \beta_7 NR_{t-i} + \varepsilon_{GDPPC,t} \\
&REC_t = c_2 + \sum_{i=1}^{2} \beta_1 REC_{t-i} + \sum_{i=1}^{2} \beta_2 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_3 EFPRINT_{t-i} + \sum_{i=1}^{2} \beta_4 URB_{t-i} + \sum_{i=1}^{2} \beta_5 IND_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 WRTECH + \sum_{i=1}^{2} \beta_7 NR_{t-i} + \varepsilon_{REC,t} \\
&URB_t = c_2 + \sum_{i=1}^{2} \beta_1 URB_{t-i} + \sum_{i=1}^{2} \beta_2 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_3 REC_{t-i} + \sum_{i=1}^{2} \beta_4 EFPRINT_{t-i} + \sum_{i=1}^{2} \beta_5 IND_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 WRTECH + \sum_{i=1}^{2} \beta_7 NR_{t-i} + \varepsilon_{URD.t} \\
&IND_t = c_2 + \sum_{i=1}^{2} \beta_1 IND_{t-i} + \sum_{i=1}^{2} \beta_2 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_3 REC_{t-i} + \sum_{i=1}^{2} \beta_4 URB_{t-i} + \sum_{i=1}^{2} \beta_5 EFPRINT_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 WRTECH + \sum_{i=1}^{2} \beta_7 NR_{t-i} + \varepsilon_{IND.t} \\
&WRTECH_t = c_2 + \sum_{i=1}^{2} \beta_1 TINOV_{t-i} + \sum_{i=1}^{2} \beta_2 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_3 REC_{t-i} + \sum_{i=1}^{2} \beta_4 URB_{t-i} + \sum_{i=1}^{2} \beta_5 IND_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 EFPRINT + \sum_{i=1}^{2} \beta_7 NR_{t-i} + \varepsilon_{WRTECH.t} \\
&NR_t = c_2 + \sum_{i=1}^{2} \beta_1 NR_{t-i} + \sum_{i=1}^{2} \beta_2 GDPPC_{t-i} + \sum_{i=1}^{2} \beta_3 REC_{t-i} + \sum_{i=1}^{2} \beta_4 URB_{t-i} + \sum_{i=1}^{2} \beta_5 IND_{t-i} \\
&+ \sum_{i=1}^{2} \beta_6 WRTECH + \sum_{i=1}^{2} \beta_7 EFPRINT_{t-i} + \varepsilon_{NR.t}
\end{aligned} \tag{6}
$$

(iv) Innovation Accounting Matrix

This study employed the impulse response function to infer the dynamic impact to a system of shocks. This study also adopted the variance decomposition techniques for forecasting. In strategic management and economics, variance decomposition analysis is commonly used to analyze the relative variance explained by time, industry, firm, or business characteristics [135].

Equation (6) is further transformed into different VDA equations from Equation (7) to Equation (12):

$$
\begin{aligned}
Var(\sigma EFPRINT, GDPPC) = Var(E[\sigma \perp GDPPC]) + E[Var(\sigma \perp GDPPC)] \\
\Rightarrow Var(E[\sigma \perp GDPPC]) \leq Var[\sigma(EFPRINT, GDPPC)]
\end{aligned} \tag{7}
$$

$$
\begin{aligned}
Var(\sigma EFPRINT, REC) = Var(E[\sigma \perp REC]) + E[Var(\sigma \perp REC)] \\
\Rightarrow Var(E[\sigma \perp REC]) \leq Var[\sigma(EFPRINT, REC)]
\end{aligned} \tag{8}
$$

$$
\begin{aligned}
Var(\sigma EFPRINT, URB) = Var(E[\sigma \perp URB]) + E[Var(\sigma \perp URB)] \\
\Rightarrow Var(E[\sigma \perp URB]) \leq Var[\sigma(EFPRINT, URB)]
\end{aligned} \tag{9}
$$

$$
\begin{aligned}
Var(\sigma EFPRINT, IND) = Var(E[\sigma \perp IND]) + E[Var(\sigma \perp IND)] \\
\Rightarrow Var(E[\sigma \perp IND]) \leq Var[\sigma(EFPRINT, IND)]
\end{aligned} \tag{10}
$$

$$
\begin{aligned}
Var(\sigma EFPRINT, WRTECH) = Var(E[\sigma \perp WRTECH]) + E[Var(\sigma \perp WRTECH)] \\
\Rightarrow Var(E[\sigma \perp WRTECH]) \leq Var[\sigma(EFPRINT, WRTECH)]
\end{aligned} \tag{11}
$$

$$
\begin{aligned}
Var(\sigma EFPRINT, NR) = Var(E[\sigma \perp NR]) + E[Var(\sigma \perp NR)] \\
\Rightarrow Var(E[\sigma \perp NR]) \leq Var[\sigma(EFPRINT, NR)]
\end{aligned} \tag{12}
$$

4. Results

In this section, the determinants of EFPRINTS and air pollution are evaluated for China using the data from 1975 to 2020. This study's primary goal was to examine the status of the environmental footprint with the ongoing level of development in China. Table 3 shows the results of the descriptive statistics.

Table 3. Descriptive statistics.

Methods	EFPRINT	WRTECH	REC	ORENTS	GDPPC	IND	URB
Mean	1.166068	233,419.7	26.25654	2.902339	2734.934	44.65823	33.93226
Maximum	1.266068	1,542,002	34.08361	11.79766	9619.192	48.05769	59.15200
Minimum	96,949,000	8009	11.33820	0.082889	295.3796	39.58062	17.18400
Std. Dev.	9,590,862	409,659.8	9.175358	2.691226	2756.061	2.288441	13.30026
Skewness	−1.210178	1.993800	−0.658364	1.696357	1.119079	−0.646872	0.398951
Kurtosis	2.675074	5.799941	1.650482	5.732401	2.980519	2.472628	1.859522

The descriptive statistics show that WRTECH has a mean value of 233,419.7 with a maximum weight of 1,542,002 and a minimum of 8009. EFPRINTS has a mean value of 1.16608 with a negatively skewed distribution, and REC and IND also show a negatively skewed distribution. The mean values of REC and IND are 26.256% and 44.658%, respectively. The average per capita income, ORENTS, and URB are US$2734.934, 2.902%, and 33.932%, respectively. The trend analysis shows that the country used a substantial share of green and conventional energy sources to minimize the risk of exacerbated EFPRINTS. Table 4 shows the correlation matrix.

Table 4. Correlation matrix.

Variables	EFPRINT	WRTECH	REC	ORENTS	GDPPC	IND	URB
EFPRINT	1						
WRTECH	(0.086) 0.255	1					
REC	−0.443 (0.002)	−0.787 (0.000)	1				
ORENTS	−0.548 (0.000)	−0.431 (0.002)	0.538 (0.000)	1			
GDPPC	0.431 (0.002)	0.941 (0.000)	−0.938 (0.000)	−0.544 (0.000)	1		
IND	−0.207 (0.166)	−0.517 (0.000)	0.072 (0.631)	0.268 (0.071)	−0.322 (0.029)	1	
URB	0.610 (0.000)	0.821 (0.000)	−0.951 (0.000)	−0.614 (0.000)	0.958 (0.000)	−0.193 (0.197)	1

Note: Small bracket shows the probability value.

The correlation matrix shows that REC, ORENTS, and IND are negatively correlated with EFPRINTS. Hence, this validates the theory of green energy, the resource blessing hypothesis, and the cleaner production approach in a country [136,137]. The greater level of WRTECH, continued EG, and URB are positively correlated with EFPRINTS, which implies that these factors cause human strain on arable land and are subsequently responsible for increasing EFPRINTS in a country. The positive correlation between GDPPC and WRTECH infers that continued EG supports more innovation capabilities to move forward toward sustainable outcomes. Before estimating the regression analysis, the pre-requisite test must be completed to pick the proper statistical procedures for parameter estimations. Table 5 displays the unit root estimates for ready reference.

Table 5. ADF unit root test estimates.

Variables	Level [I(0) Values]		First Difference [I(1) Values]		Decision
	Intercept	Trend and Intercept	Intercept	Trend and Intercept	
EFPRINT	−3.509 (0.012)	−3.156 (0.107)	−2.426 (0.140)	−2.594 (0.284)	I(0)
WRTECH [a]	−5.285 [a] (<0.01)	−7.257 [a] (<0.01)	−7.674 [a] (<0.01)	−10.447 [a] (<0.01)	I(0)
REC	−0.513 (0.878)	−2.498 (0.327)	−3.003 (0.042)	−2.965 (0.153)	I(1)
ORENTS	−2.123 (0.236)	−4.060 (0.013)	−5.754 (0.000)	−5.803 (0.000)	I(0)
GDPPC [a]	0.142 [a] (>0.99)	0.025 [a] (>0.99)	−2.671 [a] (0.841)	5.400 [a] (<0.01)	I(1)
IND	−1.934 (0.314)	−1.998 (0.585)	−4.791 (0.000)	−4.956 (0.001)	I(1)
URB [b]	5.151 [b] (1.000)	−3.620 [b] (0.039)	−3.284 [b] (0.021)	−2.610 [b] (0.277)	I(0)

Note: [a] shows the breakpoint unit root test estimates. [b] shows the Phillips–Perron unit root estimates.

The variables, i.e., FPRINTS, WRTECH, ORENTS, and URB, are stationary at the level and show the zero order of integration, i.e., I(0) variables. On the other hand, IND, GDPPC, and REC are first differenced stationary variables, which have an order of integration, i.e., I(1) variables. This conclusion suggests that EFPRINTS, WRTECH, ORENTS, and URB constantly move through a specific period. In contrast, IND, GDPPC, and REC have a broader dispersion in their respective series at different time dimensions. The mixture of I(0) and I(1) in the variables series allows for the selection of an ARDL-bound testing technique, which is suitable for managing various orders of integration in the short run, which helps to estimate the long run.

The VAR lag order selection is desirable for applying lags in the regression estimator before using the ARDL bound testing approach. Table 6 demonstrates that three of the six alternative lag length criteria verified that the third lag order is adequate for parameter estimations. Hence, this study continued to use the third lag order in the model estimations.

Table 6. VAR lag length selection criteria.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	−1999.793	NA	8.12×10^{31}	93.33920	93.62591	93.44493
1	−1460.563	877.8167	1.05×10^{22}	70.53780	72.83145 *	71.38362 *
2	−1406.972	69.79232	1.02×10^{22}	70.32428	74.62489	71.91021
3	−1333.611	71.65518 *	5.57×10^{21} *	69.19120 *	75.49875	71.51723

* criteria for choosing thelag order.

The results of Table 7 are about the ARDL short- and long-run estimates. The key benefit of using this technique is that it eliminates the requirement to categorize variables into I(1) and I(0). Furthermore, unlike typical cointegration, no unit root pre-testing is required [138,139]. The ARDL cointegration test assumes that the dependent and explanatory variables have just one long-run relationship. The VAR lag order selection is desirable for applying lags in the regression estimator before using the ARDL bound testing approach. Table 6 demonstrates that three of the six alternative lag length criteria verified that the third lag order is adequate for parameter estimations. Hence, this study continued to use the third lag order in the model estimations.

Table 7. ARDL short- and long-term estimates.

Dependent Variable: EFPRINT				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
D(EFPRINT(-1))	−0.121	0.075	−1.607	0.183
D(EFPRINT(-2))	0.045	0.050	0.900	0.419
D(GDPPC)	−16,315.438	5418.223	−3.011	0.040
D(GDPPC(-1))	25,151.742	9563.619	2.630	0.058
D(GDPPC(-2))	13,571.794	8358.486	1.624	0.180
D(GDPPC(-3))	36,691.699	6892.930	5.323	0.006
D(SQGDPPC)	0.956	0.594	1.610	0.183
D(SQGDPPC(-1))	−4.083	1.103	−3.703	0.021
D(SQGDPPC(-2))	−1.097	1.128	−0.972	0.386
D(SQGDPPC(-3))	−6.373	1.060	−6.012	0.004
D(WRTECH)	−23.317	2.818	−8.274	0.001
D(WRTECH(-1))	52.987	5.295	10.008	0.001
D(WRTECH(-2))	28.602	5.352	5.344	0.006
D(WRTECH(-3))	31.916	6.103	5.230	0.006
D(REC)	423,355.417	119,328.837	3.548	0.024
D(REC(-1))	1,068,096.017	106,808.050	10.000	0.001
D(REC(-2))	984,287.921	177,619.515	5.542	0.005
D(REC(-3))	−244,287.921	93,610.888	−2.610	0.059
D(ORENTS)	4386.590	57,170.272	0.077	0.943
D(ORENTS(-1))	435,647.430	72,287.025	6.027	0.004
D(ORENTS(-2))	300,351.150	74,377.224	4.038	0.016
D(ORENTS(-3))	−141,043.427	57,435.860	−2.456	0.070
D(IND)	−1,046,168.798	124,836.408	−8.380	0.001
D(IND(-1))	332,956.051	97,503.776	3.415	0.027
D(IND(-2))	104,706.178	113,734.214	0.921	0.409
D(URB)	5,338,842.909	2,051,455.933	0.000	0.000
D(URB(-1))	1,944,407.638	2,431,329.323	0.000	0.000
D(URB(-2))	−9,748,534.633	1,700,152.022	0.000	0.000
D(URB(-3))	7,482,632.278	1,130,506.443	0.000	0.000
CointEq(-1)	−0.869	0.064	−13.526	0.000
Long Run Coefficients				
Variables	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
GDPPC	−42,578.575	3039.301	−14.009	0.000
SQGDPPC	7.474	0.443	16.886	0.000
WRTECH	−191.567	10.060	−19.043	0.000
REC	−1,835,620.527	164,051.540	−11.189	0.000
ORENTS	−695,065.950	305,377.792	−2.276	0.085
IND	−3,421,460.648	82,856.278	−41.294	0.000
URB	2,461,788.421	451,649.964	5.451	0.006
C	289,524,022.832	11,189,842.784	25.874	0.000

The ARDL short-run estimates reveal that GDPPC has a negative relationship with EFPRINTS. It implies that continued EG supports a decrease inthe strain of human pressure from arable land and economic activities are likely to follow the sustainable development policies. These results are consistent with earlier studies [140–142]. There is a positive relationship between REC and EFPRINTS, which does not validate the theory of green energy sources. Although the Chinese economy used substantially more than one-quarter of the green energy sources in production, the concern of an increase in EFPRINTS has not culminated. The economy should follow the COP26 policies and use more eco-friendly technologies in the production process that efficiently use green energy to make their production at sustainable nodes. These results align with earlier studies [143,144].

WRTECH negatively affect EFPRINTS, implying that cleaner production technologies help reduce EFPRINTS in a country. These results align with earlier studies [145,146]. IND negatively impacts the environmental footprint, meaning that it promotes environmental sustainability. Environmental rules push the economy toward a cleaner transformation, allowing resources to be exploited more effectively and avoiding short-term EG losses, assuming a successful transition to higher-value-added and cleaner industrial processes [147,148].

There is a positive relationship between EFPRINTS and URB, which implies that URB increases the strain on the environment to degrade. This demonstrates that during the early stages of growth, the environment's quality deteriorates due to inefficient industrial methods and rapid URB, significantly impacting the environmental quality while reducing the ecological rate by using the ecosystem. Similarly, rising energy use and URB decrease the environmental quality by increasing EFPRINTS. These results align with earlier studies [149–151].

Similarly, the ARDL method gives an error correction term, which explains how short-term policies can lead to long-term goals. The rate at which the dynamic model's equilibrium is restored is referred to as the error correction term (ECM). The ECM coefficient, which should be statistically significant and negative, reflects how quickly or slowly the connection returns to its equilibrium path [152]. The cointegrating equation with a considerable probability value verified the long-term convergence of the provided parameters to equilibrium, with an adjustment coefficient speed of -0.869% ($p< 0.000$).

5. Discussion

In the long run, the U-shaped EKC relationship between EFPRINTS and GDPPC implies that the countries initially followed stringent environmental regulations to limit EFPRINTS. However, in the later stages, when the URB pressure increases, EFPRINTS is exacerbated and compromises the environmental quality. Thus, it follows the theory of ecological degradation [45]. There is a negative relationship between WRTECH, ORENTS, REC, and IND with EFPRINTS, which implies that environmental technologies and industrial added value are eco-friendly. Hence, it follows the theory of sustainable production and consumption. Moreover, green energy sources and efficient use of natural resources are helpful to limit EFPRINTS and validate the idea of green energy sources and the resource blessing hypothesis in a country. These results align with earlier studies [153–155].

Both aims of economic expansion and the protection of the environment are in direct opposition with one another around the world. Even if the fast growth of technology has opened up new prospects for attracting investment, it also presents a significant obstacle to human attempts to maintain the ecological integrity of the environment. It is envisaged that environmentally friendly inventions would help in the quest for economic prosperity and ecological balance [156]. Regulatory compliance that encourages the development and broad use of environmentally sound technology may be one way to help offset the effects of biological insufficiency [76]. They might also consider lowering taxes on R&D for environmentally friendly technologies and sponsoring such initiatives via public–private partnerships [157]. The development of a market for buying and selling patents on environmentally friendly technologies is another factor essential to its success. Alternative power production plays a significant part in propelling the economic expansion and satisfying fundamental human requirements. Even though it is used in such a broad range of settings, the energy demand has been on an upward trend for the better part of the previous several decades [158]. The vast growth in the use of fossil fuels is almost entirely related to the expansion of metropolitan areas [159]. When businesses and consumers embrace environmentally friendly practices, it boosts the economy and adds to overall environmental expenditures. This will lead to a decrease in China's carbon impact [160].

The computed value of the F statistics is 78.844, which exceeds the upper bound critical values. Hence, the model is long-run co-integrated and useful for coefficient estimations. The next step is determining the causation between variables after determining the long-run and short-run coefficients. As a result, the Granger causality test was used in this study to assess the causality direction, as shown in Table 8.

Table 8. VAR Granger causality estimates.

Variables	$\sum$EFPRINT	$\sum$GDPPC	$\sum$IND	$\sum$ORENTS	$\sum$URB	$\sum$REC	$\sum$WRTECH
$\sum EFPRINT$	—	$\neq$	$\neq$	$\rightarrow$	$\neq$	$\neq$	$\neq$
$\sum GDPPC$	$\neq$	—	$\rightarrow$	$\neq$	$\leftrightarrow$	$\neq$	$\rightarrow$
$\sum IND$	$\neq$	$\neq$	—	$\neq$	$\neq$	$\neq$	$\neq$
$\sum ORENTS$	$\neq$	$\neq$	$\neq$	—	$\neq$	$\neq$	$\neq$
$\sum URB$	$\rightarrow$	$\leftrightarrow$	$\neq$	$\rightarrow$	—	$\rightarrow$	$\rightarrow$
$\sum REC$	$\neq$	$\rightarrow$	$\rightarrow$	$\neq$	$\neq$	—	$\rightarrow$
$\sum WRTECH$	$\neq$	$\neq$	$\rightarrow$	$\neq$	$\neq$	$\neq$	—

Note: $\neq$ shows no causality, $\rightarrow$ shows unidirectional causality, and $\leftrightarrow$ shows bidirectional causality.

The causal results show that EFPRINTS Granger causes ORENTS, implying that volatility in the oil prices leads to EFPRINTS in a country. A feedback relationship was found between GDPPC and URB, as both move in the same direction over time. There is unidirectional causality running from GDPPC to IND, confirming the growth-led industrialization hypothesis. Further, the waste recycling technology Granger causes industrial added value, confirming the green innovation hypothesis in a country. There is a unidirectional causality running from URB to EFPRINTS, ORENTS, REC, and WRTECH. On the other hand, REC Granger causes GDPPC, IND, and WRTECH. Finally, the REC-led industrialization hypothesis is confirmed in a given country's context.

The variance decomposition technique was used to see how the outcome variable (EFPRINTS) reacts to the independent factors' shocks. Table 9 shows the VDA estimates for ready reference.

Table 9. VDA estimates of the ecological footprints.

Period	S.E.	EFPRINT	GDPPC	SQGDPPC	WRTECH	REC	ORENTS	IND	URB
2022	1,195,472	100	0	0	0	0	0	0	0
2023	2,308,263	99.08579	0.005092	0.191304	0.010138	0.011390	0.003007	0.587133	0.106147
2024	3,215,532	96.33529	0.011255	1.304857	1.116794	0.026326	0.223904	0.500705	0.480873
2025	3,896,612	90.77090	0.218892	2.880151	2.914998	0.104166	1.356172	0.362502	1.392214
2026	4,366,532	84.32223	0.625406	4.022843	4.235238	0.244720	3.340541	0.290782	2.918239
2027	4,658,794	78.63048	1.080200	4.392098	4.812456	0.400126	5.771730	0.282552	4.630358
2028	4,837,053	74.01080	1.488858	4.310789	4.974657	0.466557	8.318755	0.324043	6.105536
2029	4,958,580	70.46698	1.821934	4.142205	4.999288	0.447196	10.53684	0.411920	7.173636
2030	5,053,487	67.97548	2.081744	4.001700	5.012354	0.495455	12.05213	0.553479	7.827658
2031	5,135,661	66.26590	2.288601	3.912087	5.075377	0.769769	12.79805	0.758940	8.131269

The results suggest that EFPRINTS will mainly influence the volatility of oil prices, with variance error shocks of 12.798% till 2031. The stated variable will increase for the year 2026, with3.340% error shocks that will become four times higher in the next 5 years. Further, URB and WRTECH will likely influence EFPRINTS, with a variance of 81.31% and 5.075%, respectively, for the next 10 years. The least effective will be IND and REC as both followed the cleaner production instruments, having less of an influence on EFPRINTS over time.

6. Conclusions

The production of commodities and the use of scarce resources are two distinct stages in a circular economy. It is ecologically sound, socially beneficent, and business friendly. CE is committed to finding effective responses to many global problems, such as rising temperatures, the destruction of natural habitats, pollution, and waste. To keep the average world temperature below 1.5 degrees Celsius, the COP26 agenda seems to be an open-door policy for all nations to enhance environmental quality and minimize EFPRINTS. The Chinese economy is making concerted efforts to conform to the COP26 guidelines. By bolstering technical innovation, which paves the path to environmental sustainability, it significantly raises the proportion of green energy sources in their conventional electricity systems. Several vital contributors to a country's EFPRINTS were investigated here, such as ORENTS, URB, and sustained EG. The long-term connection between EFPRINTS and GDPPC was a U-shaped EKC relationship, whereas the short-term relationship decreased monotonically. In order to achieve a green developmental goal, WRTECH needs cleaner manufacturing methods and green energy sources (-191.567, $p < 0.000$). The causal inferences confirmed the EFPRINTS-led ORENTS, EG-led IND and WRTECH, REC-led EG and WRTECH, and innovation-led IND hypothesis. The forecast estimates suggest that ORENTS, URB, and WRTECH will likely influence EFPRINTS for the next ten years.

Despite modernization and growing populations, precious resources are overused. Climate change, contamination, and biodiversity loss generate global challenges. The contemporary eco-environmental catastrophe affects human and regional sustainability. Technology offsets the impact of firms via scientific advances and is a fundamental means of minimizing the carbon footprint. This study's findings support claims that urbanization, resource overexploitation, and industrialization negatively impact the environment and leave behind larger ecological footprints in the short and long term. China should concentrate on the technological quality to support environmental product advances and establish sustainable policies to support and steer the growth of technology-led R&D activities, which will likely optimize performance, decrease fuel reliance, and streamline infrastructure. Technological innovations can generate a ripple effect to help developing nations limit emissions and save energy. Financial operations heavily rely on supply chains and conventional alternative fuels to produce and move products and services. Therefore, it should import environmentally friendly machinery and equipment for longer. In addition, carbon pollution and EFPRINTS policies and procedures must be coordinated with environmental issues to achieve broad benefits. Asia's emerging nations significantly rely on fossil fuel-based energy to meet demand. Cross-border energy exchanges allow for sustained expansion. These countries have seen unprecedented economic development. This technique increases environmental costs, making the planet warmer. The optimized solution is to use green energy sources in the conventional grids to adjust the global temperature to less than 1.5 degrees Celsius. Regulators should push renewable technology to replace fossil fuels in sectors. They must also decrease inefficiency and establish institutions to support environmental and energy regulations that restrict damaging foreign activities. More effective use of natural assets and more intelligent systems boost the likelihood of reaching ecological sustainability initiatives.

The Chinese economy requires more efforts to preserve assets for future generations by pursuing energy-efficient products, sustainable power sources, and carbon sequestration management. Formal and customary safety regulations may help to minimize China's

EFPRINTS. An emissions trading scheme may provide another policy tool for the utilization of natural resources. Alternative energy is vital for long-term economic development and decarbonization; therefore, climate financial assistance and environmental conservation have been crucial for the Chinese economy in advancing toward some eco-friendly development policies. The adoption of eco-friendly standards protects natural habitats and helps move toward globally shared prosperity.

This study was limited to the Chinese economy, although a diverse panel of Asian countries can be used in the given modeling framework to generalize sustainable policies. Environmental regulations, waste recycling techniques, and financial indicators can be further added to the given modeling framework to assess the institutional capabilities and financial deepening that help lower EFPRINTS. Further, the Perron and Yabu procedure should be used to check for the presence of structural change due to the outbreak of COVID-19. Hence, these limitations open new doors for researchers to work on the stated theme to propose sound policy implications at the regional level. This study recommends the best model to implement in other countries.

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Abbreviations

CE	Circular Economy
EG	Economic Growth
EC	Energy Consumption
EFPRINTS	Ecological Footprints
PM2.5	Particulate Matters 2.5
REC	Renewable Energy Consumption
URB	Urbanization
NRE	Non Renewable Energy
GDPPC	GDP Per Capita
IND	Industrialization
WRTECH	Waste Recycling Technology
NR	Natural Resources
ARDL	Autoregressive Distributed Lag
ORENTS	Oil Rents
R&D	Research and Development

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