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A Review of Technological Innovation and Renewable Energy on Ecological Footprint in G20 Countries

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Abstract
The main purpose of this study is to examine the visions of the literature on technological innovation, energy consumption and institutional quality toward ecological footprint in the perspective of G-20 countries. This review inspects and produces prevailing empirical and theoretical literature on said problem. It firstly stimuluses the summary of technological innovation, energy consumption and institutional quality toward ecological footprint in G-20 countries. Secondly, it recognizes the literature based on the theoretical empirical and theoretical visions from the existing literature. Moreover, this article put light on theoretical approaches that defines how/ why these approaches work. Thirdly, this article suggests four productive dimensions for further policy development. This research also adds to the area of institutional quality, technological innovation, renewable energy concerning ecological footprint by critically investigating and synthesizing prevailing theory and research on ecological footprint, renewable energy, technological innovation and institutional quality.
Keywords: Ecological Footprint, Technological Innovation, G-20 Countries

1. Introduction

Today's most urgent global challenges are ecological shifts and environmental deterioration. Thus, promoting sustainable ecological policies has become imperative for both developed and emerging economies (Rahman & Bakar, 2018; Apergis and Garćıa 2019). Emerging economies have grown astronomically during the last ten years, taking the lead in the world economy. Economic growth promotes the construction of necessary infrastructure, the reduction of poverty, and an improvement in people's quality of life. But there are unavoidable side effects to developmental processes; this is especially true when nations repeatedly prioritize artificial luxury over protecting the environment. Population expansion, energy demand, industrialization, urbanization, and economic development are some of the elements causing climate change (Rahman & Bakar2019; Rahman**,** Bakar, & Idrees, 2019; Ahmed et al. 2022a). Energy is acknowledged as a vital component of economic growth and as a means of accomplishing sustainable development objectives (Fakher et al., 2023). From 43,248 TWh in 1965 to 162,194 TWh in 2019, the amount of energy used worldwide has increased dramatically (BP 2016; Qayyum et al. 2021).
The majority of industrialized countries primarily use conventional energy sources including coal, oil, and gas for energy production, which is primarily responsible for global pollution (Behera and Mishra 2020). From the start of the industrial revolution, carbon dioxide (CO2) emissions have increased to previously unheard-of levels—possibly by as much as 50% (IEA 2021a). This study focuses on the G20 countries, which produce around 84% of the world's economic activity, 77% of the world's renewable energy generation, and 82% of the world's CO2 emissions (Warren 2020; Younas et al. 2021; Shafique et al. 2021) (Figs. 1 and 2). Excessive energy use has two effects: it increases CO2 emissions and creates electrical insecurity (Ahmed et al., 2022b).
The issue of energy instability that developing economies face arises from their reliance on extensive use of fossil fuels. Consequently, policymakers encounter considerable challenges in assessing the ecological consequences of energy policy formulation. Using renewable energy may be a useful strategy for achieving energy diversification. The energy market will be more resilient to shocks if it depends less on fossil fuels (Eren et al. 2019; Sarwar et al.2021; Rahman et al. 2021; Zhu, Fang, Rahman, & Khan 2021). Analyzing energy use and ecological footprint requires technological innovation. According to (Ahmed et al. 2022a; Hassan, Sheikh, & Rahman, (2022); Khan, Afridi, Shad, Rahman, (2022); Rahman, Ali, Idrees, Ali, & Zulfiqar, (2022); Li, Bai, Yu, Meo, Anees, &. Rahman, (2022) technological advancements increase energy efficiency, lower energy consumption, and lessen the negative environmental effects of energy use. Furthermore, new technology can encourage the development of renewable energy sources like hydroelectric, solar, and wind power, which can lessen greenhouse gas emissions and the need for non-renewable energy sources. However, institutional quality, particularly the laws and rules controlling energy consumption, has a significant impact on how well technological innovation and renewable energy reduce ecological footprints (Uzar, (2021); Khoula, Rahman, Idress, (2022); Zulfiqar, Ansar, Ali, Hassan, Bilal, & Rahman, (2022). Reducing barriers to entrance and fostering research and development, high-quality institutions can foster technological innovation (Ahmad et al. 2021). Furthermore, by encouraging the use of renewable energy sources and lowering reliance on non-renewable ones, efficient laws and regulations can encourage their adoption. Numerous studies have demonstrated a positive correlation between technological innovation and a reduction in ecological footprint (Chunling et al. 2021; Destek and Manga 2021a; Chu 2022; Jahanger et al. 2022; Sahoo and Sethi 2022). Zeraibi et al. (2021) underscored the significance of technological innovation in the alternative energy sources of ASEAN-5 countries as a means of mitigating ecological imprint. In a similar vein, (Sherif et al. 2022; Hafiza, Manzoor, Fatima, Sheikh, Rahman, Qureshi, 202; Shahid, Muhammed, Abbasi, Gurmani, & Rahman 2022; Qureshi, Zaman, Rahman, Shahzadi, 2022).contended that technical innovation may aid in improving

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energy use efficiency, cutting emissions, and making efficient use of energy resources. Additionally, Ahmed et al. (2022b) demonstrated how integrating technical innovation with renewable energy can significantly improve sustainability and lessen negative environmental effects. The efficiency of technical innovation and renewable energy in lowering ecological footprint is significantly aided by institutional quality (Christoforidis and Katrakilidis 2021; Uzar 2021; Ahmad et al. 2022; Amegavi et al. 2022; Mehmood 2022). Xue et al. (2021), for example, emphasized that strong institutional quality encourages the use of renewable energy and lessens reliance on non-renewable energy sources. Similarly, it has been demonstrated that the moderating effect of institutional quality on foreign direct investment has a detrimental impact on the ecological footprint of the growing economies of Brazil, Russia, India, China, and South Africa (BRICS) (Chaudhry et al. 2022). Given this background, the goal of this review paper is to investigate how institutional quality affects the relationship between technological innovation and the ecological footprint of G20 countries from the perspective of renewable energy.

The main objective of the study is to review the literature on the relationship between energy consumption, economic growth, and ecological effect while highlighting the importance of institutional quality in promoting sustainable development. Interestingly, a moderating function for institutional quality is included in the analysis of the effects of technological innovation and renewable energy on the ecological footprint in a panel of G20 countries from 2000 to 2022. A distinctive and valuable perspective on the relationship between economic growth, energy consumption, and environmental degradation is provided by the study's focus on the G20 countries, which account for a significant portion of global economic output, renewable energy consumption, and carbon emissions (Habib et al. 2021b, 2022; Ilyas, Awan, Kanwal, Banaras, Rahman, Ali, 2023; Awan, Rahman, Ali, & Zafar, 2023; Fatima, Jamshed, Tariq, & Rahman,2023; Shahzadi, Ali, Ghafoor, & Rahman, 2023). It is expected that this study will provide insight into the extent to which technical innovation and high-quality institutions have contributed to sustainable development in emerging and developed countries. Studies investigating the connection between institutional quality and environmental degradation have been conducted as a result of the growing interest in institutions as a research topic over the years (Abd Razak et al. 2021; Islam et al. 2021; Chaudhry et al. 2022). To improve the interaction between the aforementioned variables, it is imperative that robust governance mechanisms and high-quality institutions be taken into consideration. Five sections comprise the remainder of the study. The first segment included a review of the literature. The theoretical underpinnings are presented in the second section, while the data and technique are covered in the third. The conclusion is covered in part four, and policymakers' future recommendations are covered in section five.

2. Literature Review

Researchers' curiosity has been piqued by the severe worry that has emerged over environmental sustainability. The field's empirical investigations have become more diverse as a result of this increasing emphasis. The ecological footprint (EF), which acts as a stand-in for evaluating environmental quality, has received a lot of attention. Several recent studies have looked at the factors that affect how large or small ecological footprints get. These include the following: the use of renewable energy sources; urbanization; economic growth; exploitation of natural resources; Koengkan and Fuinhas 2020; Gani 2021; Muhammad and Long 2021; Sayed et al. 2021; Sharif et al. 2021; Habib et al. 2021a; Kihombo et al. 2021; Jahanger et al. 2022). The pertinent literature on the study variables is succinctly reviewed in the sections that follow.

2.1. Technological Innovation and Ecological Footprint

It is often acknowledged that environmental sustainability and pollution reduction are significantly influenced by technological innovation. It is anticipated that technological developments would lower pollution levels and enhance environmental quality in host nations when combined with strong environmental laws. Numerous studies have examined the role that technological innovation plays in advancing environmental sustainability. Using the CS-ARDL method, Ahmad et al. (2020) looked into how technological progress affected EF between 1984 and 2016. Their research indicates that technological advancement has an adverse effect on EF. In a similar vein, (Kihombo et al. (2021); Zhao, Rahman, Afshan, Ali, Ashfaq, & Idrees, (2023); Qadri, Shi, Rahman, Anees, Ali, Brancu, & Nayel, (2023). investigated how technological innovation affected carbon emissions reduction in West Asian and Middle Eastern countries between 1990 and 2017 using the STIRPAT paradigm. According to their research, cutting-edge technologies can improve the quality of the environment. Additionally, Yang et al. (2021) looked into how technological innovation affected the prevention of environmental damage. The second-generation advanced estimator was used to examine data from the BRICS nations (Brazil, India, China, and South Africa). Their results confirmed that BRICS countries' EFs have decreased as a result of technological advancement. (Chunling et al. 2021; Zainab, Qaisra, Hassan, Haris, Rahman, & Ali, 2023; Mukhtar, Mukhtar, Mukhtar, Shahid, Razzaq, Rahman, 2023; Nawaz, Rahman, Zafar, & Ghaffar, 2023) found an unfavorable relationship when they looked into the relationship between Pakistan's tourism sector and ecological footprint. According to their research, as the tourism industry grew in developing countries, less environmentally friendly imported equipment was used, which had a greater negative impact on the environment.

2.2. Renewable Energy and Ecological Footprint

Research on the relationship between energy use and the environment has grown significantly in the last few years. Numerous aspects of this connection have been explored by researchers in different nations and situations

(Koengkan and Fuinhas 2020). Usman et al. (2020b) conducted research from 1985 to 2014 to look at the effects of trade policy on environmental degradation in the US and the relationship between economic growth, biomass capacity, and the consumption of renewable energy. Maji and Adamu (2021) investigated the potential environmental impact of employing renewable energy sources in Nigeria while taking government. Khan et al. (2016) looked at Pakistan's energy use, water availability, and carbon dioxide emissions. Usman et al. (2020a) examined how globalization and renewable energy affected the ecological footprint while taking real output and economic development outcomes into account.

(Shahzad et al. 2021; Zahra, Nasir, Rahman, & Idress, 2023; Ullah, Rehman, Raman, 2023; Hafiza, Rahman, Sadiq, Manzoor, Shoukat, & Ali, (2023; Chaudhary, Nasir, Rahman, & Sheikh, (2023); Khan, Rahman, Fiaz, 2023) employed a number of statistical tests to evaluate the relationship between the ecological footprint, fossil fuel energy, and the complexity of the US economy. Sayed et al. assessed the environmental effects of small and medium-sized wind, hydropower, biomass, and geothermal power generating systems (2021). Umar et al. (2021) examined the effects of changes in the energy use of biomass, the energy use of fossil fuels, and the growth of the US transportation sector's economy on CO2 emissions using a range of econometric techniques. (Gani (2021); Huang, Rahman, Meo, Ali, & Khan, (2024); Song, Anees, Rahman, & Ali, (2024).

looked into the effects of fossil fuel power generation on environmental quality from a supply-side perspective. By utilizing quantile-on-quantile regression to concentrate on the top ten solar energy-consuming nations, (Sharif et al. 2021; Shahzadi, Sheikh, Sadiq, & Rahman, 2023; Dawood, Rahman, Majeed, Umair, & Idrees, 2023). examined the dynamic impact of solar energy consumption on the ecological footprint. These studies provide insight into the factors and processes that influence sustainability and environmental degradation, assisting us in understanding the complex relationship between energy usage and the environment.

2.3. Institutional Quality and Ecological Footprint

Recent years have seen an increase in interest in the relationship between institutional quality and environmental quality. In numerous nations and country groups, a great deal of research has been done to examine how different institutional components affect environmental outcomes. In 24 transition nations, institutions play a part in lowering CO2 emissions, according to Tamazian et al. (2010). In a similar vein, Ibrahim et al. (2016) found that in 40 Sub-Saharan African nations, institutional quality, as determined by a range of metrics, reduces CO2 emissions. According to Abid (2016), political stability and democracy reduce CO2 emissions in Sub-Saharan African nations.

According to Bhattacharya et al. (2017), there is a correlation between lower CO2 emissions and economic freedom indices in 85 different nations. According to Sarkodie & Adams (2018), political institutions in South Africa have a detrimental impact on CO2 emissions. According to Salman et al. (2019), three Asian nations with robust legal systems had significant reductions in CO2 emissions. On the other hand, corruption raises CO2 emissions in countries in South Asia, as per Zakaria & Bibi (2019). On the other hand, Ali and colleagues (2019) shown that in 47 developing nations, institutional quality—which encompasses measures to reduce corruption, the legal system, and bureaucratic quality indices—reduces carbon dioxide emissions. According to (Muhammad & Long, 2021), the rule of law, stable governments, and reduced corruption are crucial catalysts for the reduction of CO2 in 65 countries. Additionally, according to Godil et al. (2021), India's institutional excellence helps with environmental issues by using less traditional energy. There is evidence, though, indicating the contrary. Pakistan's CO2 emissions are increased by institutional quality, claim (Hassan et al. 2020; Tabassum, Rahman, Zafar, & Ghaffar, (2023); Idrees, Awan, Arslan, Hussain, Razzaq, Haris, & Rahman, (2023). Similarly, (Le & Ozturk 2020; Usman, Rahman, Shafique, Sadiq, & Idrees, (2023); Shahid, Gurmani, Rahman, & Saif, (2023); Ilyas, Banaras, Javaid, & Rahman, (2023).

Found that when economic activity rises, rising government spending and institutional quality in emerging market nations lead to an increase in CO2 emissions. Through their demonstration of the varied effects discovered in various contexts, these studies aid in the understanding of the complicated link between environmental outcomes and institutional quality.

3. Methodology

The author of this study gathered and critically examined the pertinent literature by following the systematic literature review process as outlined by Jesson, Matheson, and Lacey (2011). The focus of the paper, bibliographic details, theory used (where applicable), research philosophy (Zikmund, Babin, Carr, & Griffin, 2013), key findings, methodology, definition of technological innovation, institutional quality, renewable energy and ecological footprint, research context, geographical location of the study, theoretical and practical review, further conclusion, and reported limitations are all included in the critical review form that the author developed for a thorough and critical analysis of the prior studies.

From November 2020 to April 2023, the author explored the literature for the critical review of this work. In order to find the most pertinent ecological footprint papers, the researcher first identified the papers and then carried out a thorough search by assessing the pertinent papers downloaded from (1) Economics journals listed in the Master Journal List 2022 and the Journal Citation Report 2019 in Clarivate Analytics; and (2) Comprehensive databases (Business Source Premier by Ebsco and Scopus). (3) Google Scholar; (4) a comprehensive bibliography spanning

many disciplines that includes numerous references on the topics of technical innovation, institutional quality, ecological footprint, and renewable energy published in various periodicals.
For example, papers that do not address renewable energy, institutional quality, technological innovation, or ecological footprint, as well as those that are not empirical or conceptual, such as books, commentaries, summaries of conference summaries, abstracts and keywords, executive abstracts, editorials, literature reviews, and newspaper/magazine articles, were excluded from consideration for this literature review. After eliminating duplicates, the author found nearly 700 items in total. When necessary, the author looked at the abstract, title, and methodology of each paper to establish its applicability.

4. Conclusion

The World Health Organization (WHO) claims that the primary cause of the global warming's increasing rate is carbon dioxide emissions brought on by human activity. Numerous studies have discussed ways to reduce greenhouse gas emissions from industrialization while criticizing international environmental protection (Wang et al. 2020). The current study looks at how the use of renewable energy, institutional quality, and technology advancements have impacted the ecological footprint in G20 nations. using G20 country data from 1990 to 2022. Following a thorough analysis of the literature, it is determined that institutional quality, renewable energy sources, and technical advancements have both good and negative effects on ecological footprint. The fact that each of the two findings fills a vacuum in the literature on its own is really intriguing. Thus, the impact of technological advancement, institutional quality, and renewable energy on ecological footprint is still up for debate, and numerous research have been done to determine how these factors affect greenhouse gas emissions. While some studies have looked at considerable negative effects on ecological footprint, others have shown significant positive effects. As a result, it is crucial to discuss the main causes in detail and create strategies to solve this grave issue. Since ecological footprints are the primary source of greenhouse gases, the relationship between them and advancements in technology, renewable energy, and institutional quality has dominated discussions about global warming. Furthermore, this review does not develop the analysis of the variables. Thus, the primary goal of the study is to present a clear and thorough overview of previous research on institutional quality, ecological footprint, technology advancement, renewable energy, and ecological footprint—including contextual approaches and practices.

4.1. Future Recommendations for Policy Makers

Consequently, there is a clear need for the national energy policies of the G20 to be changed in order to facilitate the substitution of green energy sources for fossil fuels and give priority to the consumption of renewable energy. One possible way to achieve this would be to create incentives for affordable and easily available renewable energy. These incentives can take many different forms, such as tax breaks, interest rate subsidies, green certifications for "green enterprises," and financial aid for families using renewable energy sources. A minimal ecological footprint can result from the effective and efficient use of technology, which can have a significant impact on resource efficiency. To ensure that natural resources are managed responsibly and to deter the use of natural fossil fuels like coal, governments should levy taxes on these materials. Two further strategies to support long-term economic growth include taxing carbon emissions and promoting environmentally friendly technology. Furthermore, it is anticipated that the system will be fully operational in around a year with policies aimed at promoting economic development and advancing technology.

4.2. limitations for Future Research

This study has certain limitations and research proposal ideas for the future. First of all, it restricts its analysis to twenty economies by concentrating only on the G20 nations. Second, future research can expand the time period covered by the data used in this study, which spans the years 1990 to 2021. Thirdly, future research can think about including an interactive term that compares the rent of natural resources with technological advancement. Lastly, future studies can investigate the function of human capital in G20 nations as well as other nations.

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