GREEN TECHNOLOGICAL ATTRIBUTES IN CLEAN ENERGY PRODUCTION AT ZERO EMISSION: A REVIEW ON MITIGATING CLIMATE CHANGE

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ABSTRACT: *This review investigates the growing adoption of green technologies in the energy sector and their potential to achieve zero-carbon emissions while fostering economic and environmental sustainability. A comprehensive analysis of the literature was conducted, focusing on published research that evaluates the implications of green technologies for clean energy production and environmentally sustainable economic activities. Statistical methods were applied to clean energy production data, revealing a significant increase (p-value < 0.05) in the use of green technologies ($R^2 = 0.86$), contributing to a marked reduction in carbon emissions. The data also demonstrated a strong correlation between the passage of time and the growth of clean energy production ($r = 0.92$). Furthermore, the widespread integration of green technologies across various economies underscores a positive relationship between carbon emission reduction, economic growth, and climate change mitigation. These findings offer valuable insights for policymakers and researchers, providing a foundation for the development of frameworks that encourage the further adoption of green technologies in clean energy production. This study serves as a reference point for future research aimed at leveraging green technologies to combat climate change and emphasizes their critical role in sustainable energy generation. The originality of this review lies in its dual focus: first, on the potential of green technologies for clean energy production, and second, on the relationship between these technologies, climate change mitigation, and the growth of a green economy. While the review does not introduce entirely new concepts, it presents a fresh perspective on the interconnectedness of green technologies, clean energy, and climate action. However, the study highlights the need for further research to assess the long-term impact of these technologies on mitigating climate change.*

Keywords: Green Technology, Clean Energy, Zero Emission, Climate Change, Carbon Emission, Economic Sustainability, Environmental Sustainability.

1.0 BACKGROUND OF STUDY

Climate change is one of the most pressing challenges facing the world today, primarily driven by the excessive release of greenhouse gases, especially carbon dioxide. Clean energy technologies offer a promising solution by enabling power generation without contributing to atmospheric pollution. This paper focuses on presenting methods of producing clean energy from natural resources with zero carbon emissions. Clean energy is generated from renewable energy (RE) sources, which are naturally replenished. Green technology is employed to process RE for clean energy production, which is then converted into electricity and heat [1]. Green technology, often described as an umbrella term, integrates science and technology to develop products, services, and energy solutions with zero carbon emissions[2–4]. This paper aims to review published studies on the interconnection between green technology, clean energy, and carbon emissions.

The intricate relationship between energy consumption, economic activities, and carbon emissions is crucial for addressing climate change. This review examines how the increasing adoption of green technologies can mitigate this issue. Rising carbon emissions and climate change, largely due to the reliance on fossil fuels for electricity, heating, and economic activities, pose significant challenges to global economic growth and environmental sustainability [5–10]. This raises a critical question: how can carbon emissions be effectively controlled? This review seeks to identify gaps in our understanding and explore potential solutions through green technologies.

Reports from the Intergovernmental Panel on Climate Change (IPCC) [11],), the International Energy Agency (IEA) [12], the United Nations Environment Programme (UNEP), [13] and the Organisation for Economic Co-operation and Development (OECD, [6], indicate that the burning of fossil fuels for electricity and heat production is a major contributor to carbon emissions and climate change. Addressing this issue involves the adoption of green technologies and renewable energy (RE) for producing clean energy in economic activities, which have been identified as sustainable solutions [14]. Climate change will continue to worsen if economies remain dependent on fossil fuels. The link between climate change and carbon emissions indicates that the traditional fossil fuel-based economic model could seriously hinder progress towards achieving the Sustainable Development Goals (SDGs) [15, 16]. The perspectives of UN water, [17], UNEP, [18], IPCC, [19] suggest that green technology provides a viable and sustainable approach to combating climate change. Consequently, implementing strategies for zero-carbon emissions is essential.

The review of this section provides a solid overview of the relationship between climate change, carbon emissions, and energy production, referencing credible global organizations. Emphasis on green technology's role in processing renewable energy is well-explained, but further details on specific green technologies (e.g., solar, wind) could enhance the understanding of their practical applications. The review draws attention to the need for policy shifts toward zero-carbon strategies and renewable energy adoption to meet global climate goals, which is a crucial takeaway for decision-makers. The integration of economics, technology, and environmental studies makes the review interdisciplinary. However, adding case studies or examples of successful green technology implementations could make the theoretical discussion more tangible. The connection to Sustainable Development Goals is essential, but it could further explore how specific SDGs (e.g., affordable and clean energy, climate

action) are being impacted or progressed through green technology.

Building on this context, this review aims to consolidate information on various green technology options, particularly their use in harnessing renewable energy (RE) to produce clean energy and converting it into heat and electricity to support economic activities with zero carbon emissions [20,, 21].To achieve this objective, the study is structured into four sections. The first section explores the concept of green technology concerning renewable energy harvesting. The second section reviews current trends in clean energy production from RE to reduce carbon emissions. The third section investigates how

green technology can facilitate the transition to a green economy. The fourth section analyses the relationship between green technology, renewable energy, and the green economy in reducing carbon emissions to achieve environmental sustainability. The methodology used to achieve the study's objectives is outlined in section 1.2.

1.2 Research Methodology

The primary methodology employed in this study is a comprehensive literature review. A total of 103 published journal articles, spanning from 2010 to 2024, were reviewed to gather information on the implementation of green technology in renewable energy production and to address the research question.

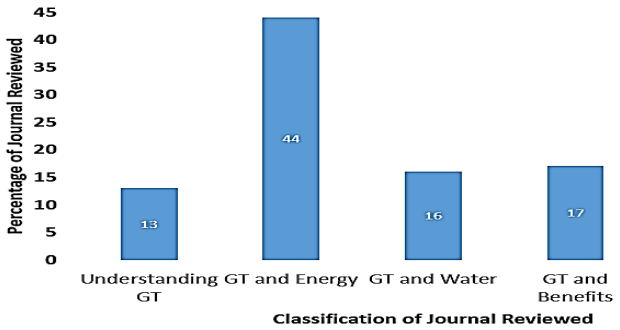

Figure 1.0: Classification of Journals Reviewed

The statistical data analysis of the histogram shows the following results: Mean = 0.056, Median = 0.025, Standard Deviation = 0.115, and Mode = 0. The histogram indicates that most of the data is concentrated around lower values, as reflected by the low mean and median. The standard deviation of 0.115 suggests moderate variability around the mean, while the mode of 0 signifies that this value occurs most frequently in the normalized dataset. The selection of published journals effectively represents the objectives of this research.

2.0 Understanding the Green Technology in the Aspect of Clean Energy Production

Green technology is defined in various ways within the literature, but the most widely accepted definition describes it as the application of science and technology to create environmentally friendly products and services. It is closely linked to cleaner production processes, which enhance operational efficiency, increase energy efficiency, reduce waste, and lower carbon emissions.

In the context of mitigating climate change, Dong *et al*. [2] , Wang *et al.* [22] and Isabella *et al.* [4] have highlighted that green technology helps replace carbon-emitting fuels with renewable energy sources, such as solar and wind power, and hydroelectricity, which produce electricity and heat with zero emissions. To address this issue, Li *et al*.[2] and Zhoushan *et al.*, [23] emphasize that green technology is instrumental in promoting a green economy and achieving environmental sustainability.

Experts believe that the primary aim of green technology is to reduce dependence on fossil fuels for electricity generation, thereby lowering carbon emissions (CO_2eq) [24, 25]. According to Khan *et al.* [26] and Su and Gao [27], green technology also enhances energy efficiency, contributing to the growth of the green economy. Additionally, renewable energy and environmental experts have highlighted that solar, wind, hydroelectric power, and green hydrogen are central components of green technology and represent potential solutions for achieving net-zero emissions and combating climate change [28, 29].

The reports published by Neoh *et al*. [30] and Qinhua et al. [31] demonstrate that the latest innovations in green technology aim to produce clean energy, store it, and supply it for various economic activities without carbon emissions. Examples include advancements in solar energy harvesting, efficient battery storage systems, smart grids, and hydrogen.

Although green technology is still relatively young in the energy sector, its growth is promising. A projection of clean energy production and its impact on carbon emissions, as presented in Figure 2.0, shows that green technology has a positive effect on reducing CO_2eq [32]. A projection of the effect of using green technology on carbon is presented in Figure 2.0.

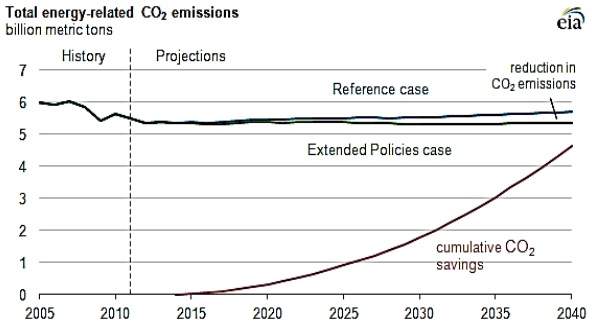

Figure 2.0: Green Technology Use and Expected CO_2eq Reduction [33, 34]

The document provides an overview of green technology, which is defined as the application of science and technology to create environmentally friendly products and services. It emphasizes that green technology enhances energy efficiency, reduces waste, and lowers carbon emissions by replacing fossil fuels with renewable energy sources like solar, wind, and hydroelectric power. The goal is to reduce reliance on fossil fuels, achieve environmental sustainability, and promote a green economy. Green hydrogen, smart grids, and efficient battery storage systems are cited as key innovations. Although green technology is still developing, its potential for reducing carbon emissions and supporting clean energy production is promising

3.0 Green Technology in Clean Energy Production for Mitigating Carbon Emission

Experts in clean energy and environmental fields assert that green technology plays a crucial role in producing clean energy from natural sources and converting it into electricity and heat with zero carbon emissions ($CO_2eq = 0$) [4, 35]. The use of clean energy is essential in combating the ongoing global climate crisis. This section of the review paper explores the potential of green technology in producing clean energy to mitigate climate change. Ian Tiseo [36] and Hanna and Max [37] reported that the energy sector contributes approximately 25% of total global carbon emissions (CO_2eq), significantly exacerbating global warming. To address this, Yong-Gu and Kangmin [38] advocate for producing clean energy from natural sources to support various economic activities, such as water treatment and the production of goods and services. According to Fan *et al.* [39] and Murad *et al* [40], incorporating clean energy into economic activities can significantly reduce carbon emissions, contributing to slowing climate change. Moreover, Raihan *et al.* [41] and Shao *et al.* [42] have identified clean energy as an environmentally sustainable solution for mitigating climate change. Although research and innovation linking green technology, clean energy, and economic development are still in their early stages, some studies on renewable energy (RE) technologies, such as solar power, wind turbines, hydroelectric systems, and green hydrogen, have emerged [43, 44]. The World Energy Outlook [34] has provided data on total clean energy production from renewable energy and use, as shown in Table 1.0

Table 1.0 Renewable Energy Production Growth [45]

Sources of RE	2000	2010	2020	2022
Solar (TWh)	3	59	2244	2772
Wind (TWh)	93	773	4186	4852
Hydro (TWh)	7826	9066	11448	11222

Table 1.0 demonstrates the trend of clean energy use in economic activities. The World Energy Outlook 2023*[34]* provides information on the growth of clean energy production in major global economies.. Table 2.0 presents the growth trends of green energy production.

Table 2.0: Clean Energy Production Growth of Major Economies [34]

Year of Operation	China (GW)	EU (GW)	USA (GW)	Total GW
2000	0	12	3	15
2005	1	41	10	62
2010	31	110	43	84
2015	175	215	97	487
2020	536	316	165	1017
2022	759	405	254	1418

Table 2.0 presents the growth trends of green energy production, showing positive developments in the USA, European Union (EU), and China. According to Xiao and Zhang [46], Zhang et al., [47], and Henryk [48], solar, wind, and hydro energy are key contributors to the global energy mix, helping to reduce carbon emissions and mitigate climate change. This energy mix plays a vital role in curbing emissions. The current trends of the global energy mix are detailed in Table 3.0 [49].

Table 3.0 Data on Global Energy Mix

Year	Contribution in %
2000	2.88
2005	4.85
2010	10.55
2015	19.91
2020	34.87
2022	45.18

Data listed in Table 3.0 shows a growth trend in the global energy mix, which demonstrates a change in economic operations with clean energy instead of fossil fuel. Reports on fossil fuel-driven economies stated that a primary source of carbon emissions is fossil fuel and the traditional economy is a significant driver of climate change[50, 51]. The EPA [52] and IPCC [19] have warned that the continued reliance on fossil fuels will lead to severe environmental degradation. Khan et al. [53] and Wang et al. [22] argue that fossil fuel-based economies are neither environmentally sustainable nor climate-friendly. To address this, researchers have recommended the transition to clean energy to replace fossil fuels.

Khan *et al.* [54] and Shabaz *et al.* [55] assert that transitioning away from fossil fuels is critical for achieving zero carbon emissions. Brunnermeier and Cohen [56], as well as Wang [22], have called for increased research to enhance the efficiency of converting clean energy into electricity and heat, thereby boosting the share of clean energy in the global energy mix. On this issue, EIA [57] has published a report to describe the expected effect of using clean energy on global temperature and climate change, which is presented in Figure 3.0

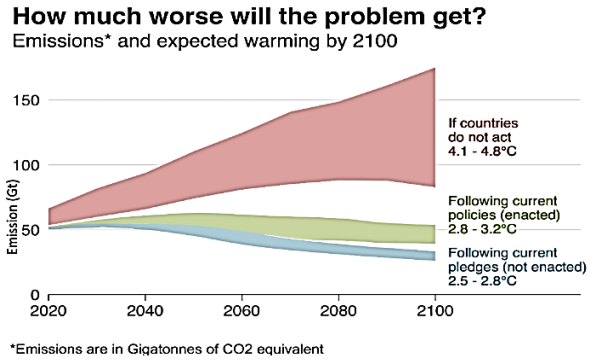

Figure 3.0: Expected Global Warming by 2100 [58]

Figure 3.0 presents strategies for integrating renewable energy into the economy. The data suggests that by 2100, total carbon emissions could drop below 50.0 Gt if clean energy is widely adopted. Conversely, failure to act may result in a temperature rise of 4.5°C [58, 59]. Experts recommend increasing the share of clean energy in the energy mix to address the rising global temperatures [35, 60]. In this regard, renewable energy from various natural sources including waste biomass and biofluid can be considered. According to Eugen et al., [61], Shahidul et al. [62], and

Janke, [63] energy derived from waste biomass is an important component of green technology. Their studies reveal that biofluids (a byproduct of waste biomass) are a potential source of methane emissions, which significantly contribute to global warming.

Various green technologies have been developed to capture methane emitted from biofluids and convert it into electricity and heat. According to Fauzianto, [64] green technology contributes to reducing carbon emissions while increasing clean energy supply. green technology contributes to reducing carbon emissions while increasing the clean energy supply. Similar findings have been published by other researchers [61, 65 .66]. A process model of clean energy and electricity production from biofluid is presented in Figure 4.0

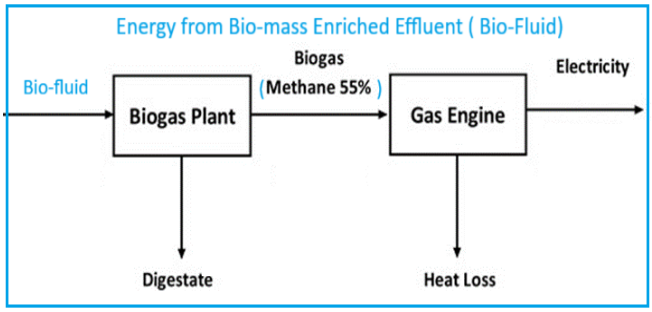

Figure 4.0: Electricity production from carbon emission potential fluid (POME) [67]

Figure 4.0 illustrates the process of electricity generation from biofluid. In this regard, Shahidul [35] highlighted that palm oil mill effluent is a methane gas-emitting biofluid from which hydrogen can be produced. Some reports advocate for the adoption of Waste-to-Energy (WtE) models to generate energy from the emitting methane [68–70]. The European Environmental Agency [71] and the European Commission [72], Shahidul [44] have also emphasized the importance of converting methane-producing waste biomass into energy as part of efforts to combat climate change.

The nexus among green technology, clean energy, and energy recovery from waste could reduce dependence on fossil fuels and provide a proven path to reducing carbon emissions [46, 47]. It has also been reported that increasing clean energy consumption in economic activities is associated with a reduction in carbon emissions [48, 73], making this process a sustainable route for mitigating climate change [2], [56]. The evidence presented in this section underscores the potential of green technology in producing clean energy from renewable sources to reduce dependence on fossil fuels, thereby lowering carbon emissions and mitigating climate change.

4.0 Green Technology in Clean Energy Production in Achieving Green Economic Growth

Since the Industrial Revolution, the global economy has predominantly relied on fossil fuels, which have negatively impacted environmental quality and contributed to climate change. The current critical issue is the rise in global temperatures and significant climate variability resulting from the extensive use of fossil fuels [74, 75].

To address these challenges, clean energy production driven by green technology is increasingly prioritized for sustaining economic activities [76]. In this regard, Sohag *et al*. [77] and Lin and Zhou [78] highlighted that the primary benefit of employing green technology in electricity generation is the reduction of dependency on carbon-intensive fossil fuels. According to Shahidul *et al*.[79], the use of green technology in the energy sector not only enhances electricity production efficiency but also leads to a lower carbon emission rate per kilowatt-hour (CO_2eq/kWh)..

Similarly, Alper and Ogu, [80] and Sharif *et al.*, [81], stated that the implementation of green technology in electricity production reduces fossil fuel consumption through improved thermal efficiency, thereby decreasing greenhouse gas emissions per unit of electricity generated [CO_2eq/kW].

Green technology has been contributing to grow the green economy in various ways. In this regard, Wang et al., [82] and Ahmed *et al.*, [83] point out that a green technology-driven circular economy, which produces clean energy from waste biomass, has been identified as an effective method for replacing fossil fuels. This approach has the potential to reduce carbon emissions and mitigate climate change.

The influence of green technology and clean energy on economic growth was examined by Sharif *et al*.[84], who reported that a 1% increase in the use of clean energy in economic activities leads to a 3% increase in green economic growth. Bhattacharya et al., [55] reported similar finds.

Several researchers have investigated the combined impact of green technology and clean energy on green economic growth and climate change. According to Raihan [85] and Wurlod and Noailly [86], the nexus of green technology, clean energy, and environmental sustainability benefits society by enabling economic activities with zero carbon emissions.

Omri [33], also found a positive relationship between the adoption of clean energy consumption, economic growth, and environmental sustainability. Shahbaz et al., [87], and Kias and Anis, [88] further confirmed a positive association between green technology, clean r energy, and green economic growth.

Green technology has become a critical tool in clean energy production, addressing the environmental and economic challenges posed by the widespread use of fossil fuels. Researchers highlight the reduction in dependency on carbon-intensive energy sources and the enhancement of energy efficiency as key benefits of green technology. For instance, the adoption of green technologies has significantly decreased carbon emissions per kilowatt-hour and improved thermal efficiency, resulting in less fossil fuel consumption. Additionally, the circular economy, driven by green technology, offers innovative solutions like converting waste biomass into clean energy, further reducing carbon footprints.

Studies have demonstrated the positive impact of clean energy on economic growth, with findings indicating that even a 1% increase in clean energy use can lead to a 3% boost in green economic growth. Furthermore, the integration of green technology with clean energy has shown significant potential to enhance both environmental sustainability and economic activities, contributing to a greener, more sustainable global economy. The findings discussed in this section suggest that the integration of green technology and clean energy within the green economy framework is beneficial for society, as it enables economic activities to operate with zero emissions.

5.0 Scenario Analysis of Findings

This review evaluates the growth rate of clean energy production from renewable energy (RE) and its impact on green economic growth, aiming to reduce carbon emissions. Clean energy production growth data were analyzed to develop models for characterizing the growth patterns of clean energy and to assess the significance of clean energy growth at a 95% confidence level.

5.1 Analysis of Green Energy Production's Strength

The published data presented in Table 2.0 were analyzed using statistical tools such as a simple regression model and ANOVA to determine the R^2, 'r,' and 'F'-statistics [89, 90]

The analytical values of 'R^2'and 'r' statistics are presented in Figure 5.0.

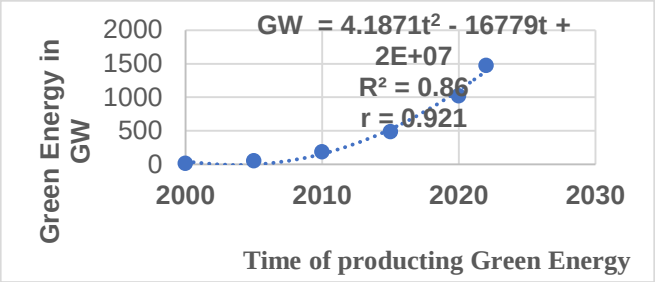

Figure 5.0: Regression Analysis of Historical data on Green Energy Production growth

Figure 5.0 shows an Analysis of the R^2 Statistic on Clean Energy Growth over Time. The R^2 statistic is an indicator of the strength of the relationship between the dependent variable (energy growth) and the independent variable (time). Figure 5.0 shows an R^2 value of 0.86, derived from a one-way ANOVA analysis. This R^2 value at a 95% confidence level indicates an 86% probability that the growth in clean energy production could replace fossil fuels, thereby reducing carbon emissions.

5.1(a) Findings Correlation Coefficient Between Variable (r)

Figure 5.0 indicates that the correlation coefficient (r) is 0.921, suggesting a near-perfect positive linear correlation (upward slope) between the variables. An r-value of 0.921 at a 95% confidence level implies that clean energy production is expected to continue growing and has the potential to replace fossil fuels.

5.1(b) F-Statistic on Green Energy Production Growth

The F-test conducted yielded a calculated F-statistic of 5, 10, 05, and the ANOVA test result showed an F-value of 24.87 at a 95% confidence level. The critical value (Fc) for F was determined to be 6.6 from the F-table at F (5, 10,05).

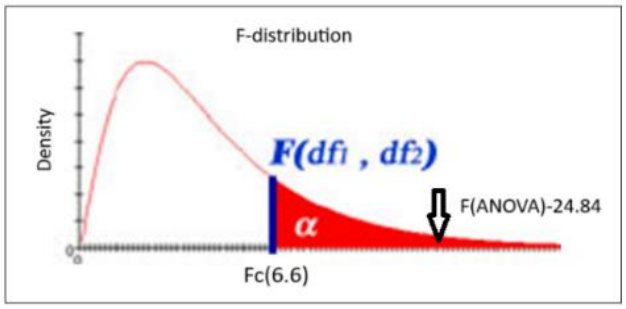

Figure 6.0: F-statistic of green energy production from 2000 to 2022

As shown in Figure 6.0, the estimated F-value exceeds the critical value at a 95% confidence level Fc>Fest), resulting in a P-value of <0.05. This indicates that the growth rate of clean energy production over time is significant at the 95% confidence level, implying that clean energy production will continue to grow and is likely to replace fossil fuels.

5.1(c) Determine Clean Energy Production Growth Rate

The clean energy production growth rate for supporting economic activities has also been estimated with growth rate model. The data listed in Table 2.0 has been used to estimate the growth rate of green energy production from 2000 (15 GW) to 2022 (1418 GW) by the standard growth rate formula [90]. The estimated value is presented by Equation (1).

$$\text{Growth Rate} = \left[\frac{GW_{2022}}{GW_{2000}}\right] 1^{\frac{1}{22}} - 1 = 23\% \qquad \text{Eq.(1)}$$

The significance level of green energy production was also estimated using ANOVA. The F-statistic was estimated at a 95% confidence level.

6.0 Review Findings

The review findings are organized into several sections. The statements are presented under the research objectives outlined in section 1.1.

6.1 Concept of Green Technology for Water and Energy

(a) Green technology involves the application of science and technology to develop models for clean energy production with zero carbon emissions, aiming to mitigate climate change [2–4, 30, 31, 91, 38, 43, 91]

(b) Green technology serves as a means to reduce carbon emissions, thereby mitigating climate change, protecting environmental quality, and fostering economic growth [41, 50, 92].

6.2. Green Technological Innovation in Energy Industry

(a). Green technological innovations contribute to increased energy efficiency and reduced energy consumption [37, 40, 39, 46],

(b) These innovations also facilitate the replacement of fossil fuels by generating energy from renewable sources with zero emissions [42, 56, 87].

(c). The carbon emission rate for electricity production (measured as CO_2eq per kWh) is significantly lower compared to traditional methods [34, 47, 93].

(d). Generating $1.0 million in revenue from water and energy production using fossil fuels results in approximately 2634 metric tons of CO_2eq per kWh, which can be mitigated by using green energy [24, 77, 94].

(e). A positive growth trend has been observed in major global economies [48, 73,[84].

63.0 Green Technological for Environmental Quality

(a). Green technology enables the production of energy with zero carbon emissions, thereby improving environmental quality and contributing to climate change mitigation[23, 75].

(b). It also supports the production of clean water with zero carbon emissions, which enhances environmental quality and helps slow down climate change [95, 96].

(c). Green technological innovations increase energy efficiency by recycling waste energy, thereby reducing the carbon emission rate per kWh [CO^2eq $(kW)^{-1}$].[76, 82].

6.4 Benefits of Green Technology and Clean Energy in the Economy

(a). Green technology contributes to the development of a green economy by providing green energy [78, 82].
(b). It facilitates the recycling of waste materials in energy production, thus enhancing economic performance and mitigating climate change[68, 97].
(c). A circular economy driven by green technology supports the recycling of natural waste resources (primary materials), thereby reducing carbon emissions and improving economic performance [76, 83].
(d). The synergy between green technology and clean energy is a potential avenue for slowing global warming [33, 73].

7.0 CONCLUSION AND RECOMMENDATIONS

This comprehensive review provides an in-depth analysis of the current landscape of green technology adoption in energy for green energy. A significant growth trend is evident, showcasing the increasing utilization of green technology for generating clean energy, which has resulted in a measurable reduction in carbon emissions [CO_2eq(kW)-1]. Furthermore, the review highlights the widespread adoption of green technology across various economic sectors, yielding substantial benefits for both society and the environment.

The study concludes that to effectively combat climate change and reduce carbon emissions, a global transition away from fossil fuel independence is essential. This ambitious objective can be achieved through accelerated innovation in green technology and the expansion of renewable energy sources. The study also offers novel insights into the complex relationship between green energy and economic growth emphasizing their interdependence in addressing climate change. This enhanced understanding of the "green technological nexus" enriches the existing literature and provides valuable guidance for future sustainable development strategies. The review not only reaffirms the growing importance of green technology in energy and water production but also underscores the urgent need for accelerated innovation and widespread adoption to tackle the pressing challenge of climate change.

7.1 Recommendations

Governments worldwide should implement green technologies tailored to their local capabilities to address energy scarcity and enhance environmental quality. Policymakers are encouraged to prioritize investments in green technology, particularly in promoting green energy as a strategy to combat climate change. Incentive programs such as tax benefits, investment subsidies, and green certifications should be considered to motivate businesses to adopt green technologies. Further research is recommended to identify and address barriers to green technology adoption in developing economies, ultimately contributing to global climate change mitigation efforts.

8.0 ACKNOWLEDGMENT

The authors would like to acknowledge Universiti Malaysia Sarawak for their support of this project under the Ministry of International Trade and Investment of Sarawak, Malaysia, the grant number is MINTRED/MM/13(20)2.

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