PERFORMANCE ANALYSIS OF GREEN TECHNOLOGY NEXUS FOR CLEAN ENERGY AND FRESH WATER PRODUCTION TOWARDS ZERO EMISSION GOAL

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ABSTRACT: *This study examines the increasing adoption of green technologies in the energy and water sectors, emphasizing their potential to achieve net-zero carbon emissions while promoting economic and environmental sustainability. A comprehensive literature review was conducted, focusing on published data concerning green technologies for clean energy and water production in the context of zero-carbon emissions. Statistical analyses, including ANOVA, were employed to evaluate clean energy and water production data, revealing a significant increase (p-value < 0.05) in the utilization of green technologies, which has contributed to a reduction in carbon emissions. The findings also demonstrated a strong positive correlation (r = 0.92) between the passage of time and the growth in clean energy harvesting (23%) for economic activities, including water production. Furthermore, the widespread integration of green technologies across various economies highlights a positive relationship between carbon emission reduction, economic growth, and climate change mitigation. These insights provide valuable guidance for policymakers and researchers, laying the groundwork for frameworks that encourage the further adoption of green technologies in clean energy and water production. This study serves as a reference for future research aimed at leveraging green technologies to combat climate change, underscoring their critical role in sustainable energy generation. Its originality lies in its dual focus: first, on the potential of green technologies for clean energy and water production, and second, on the relationship between green technologies, climate change mitigation, and the growth of a green economy. While the study does not introduce entirely new concepts, it presents a fresh perspective on the interconnectedness of green technologies, clean energy for water production, and climate action. Nonetheless, the study emphasizes the need for further research to assessing the long-term impact of these technologies on climate change mitigation.*

Keywords: Green Technology, Technological Nexus, 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 study examines increasing adoption of green technology in clean energy production for economic activities including fresh water production at zero 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 solution [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 study 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 broad objective, the study is structured into four specific objectives, which are:

(1) **Explore** the concept of green technology in relation to renewable energy harvesting and **model** its impact on carbon emissions.

(2) **Identify** current trends in clean energy production growth and their contribution to climate change mitigation.

(3) **Investigate** the role of green technology in fresh water production from various sources.

(4) **Establish** the relationship between green technology, renewable energy, and the green economy in terms of carbon emissions and 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 was a comprehensive literature review to collect relevant data on the growth of green energy harvesting and its application in economic activities. A total of 108 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.

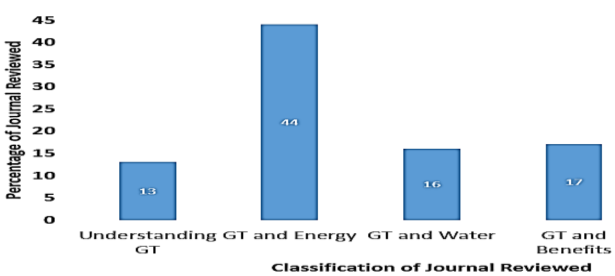

Figure 1.0: Classification of Journals Reviewed

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 Explore renewable energy harvesting and model its impact on carbon emission

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 replacing 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] demonstrates that the innovations in green technology aims to produce clean energy, store it, and supply it for economic activities without carbon emissions. Examples include advancements in solar energy harvesting, efficient battery storage systems, smart grids, and hydrogen.

2.1 Modelling Green Energy Growth and its impact on carbon Emission

Varius report stated that primary source of carbon emissions is fossil fuel driven economy. and the traditional economy is a significant driver of climate change[32, 33]. The EPA [34] and IPCC [19] have warned that the continued reliance on fossil fuels will lead to severe environmental degradation. Khan et al. [35] 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.* [36] and Shabaz *et al*. [37] assert that transitioning away from fossil fuels is critical for achieving zero carbon emissions.

During this transition period every efforts should be made to make existing processes (based on fossil fuel) energy efficient by optimising design and operation [38–40]

Brunnermeier and Cohen [41] , 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 [42] has published a report to describe the expected effect of using clean energy on global temperature and climate change, which is presented in Figure 2.0

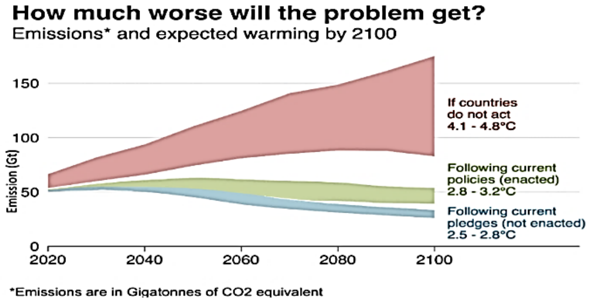

Figure 2.0: Expected Global Warming by 2100 [43]

Figure 2.0 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 [43, 44]. Experts recommend to increasing the share of clean energy in the energy mix to address rising of global temperatures [35, 60]. In this regards, renewable energy from various natural sources including waste biomass and biofluid can be considered. According to Eugen et al. [47], and Janke [48] , 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.

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 [49]. A projection of effect of using green technology on carbon is presented in Figure 3.0.

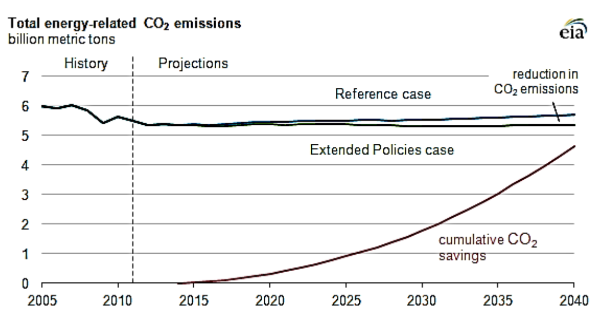

Figure 3.0: Green Technology Use and Expected CO_2eq Reduction [50 51]

Figure 3.0 presents Green Energy Production Growth Over Time with its impact on carbon emission. **Historical Data** showing the production levels of green energy sources such as solar, wind, hydro, and geothermal over recent decades. This growth is typically measured in terms of the installed capacity (in megawatts or gigawatts) or energy output (in megawatt-hours or gigawatt-hours). The theoretical presentation of the graph developed by IEA is exponential model where green energy production E(t) increases over time (t): Assuming exponential growth:

$$E(t) = E_0 . e^{kt} \qquad \textbf{Eq.(1)}$$

Where E_0 is the initial energy production and kt is the growth rate. **Impact on Carbon Emissions C(t)**: A reduction model for carbon emissions can be introduced based on the energy mix:

$$\boldsymbol{C(t) = Co.\{1 - \delta(E)(t)\}} \qquad \textbf{Eq.(2)}$$

where C_0 is the baseline carbon emission, and $\{1 - \delta(E)(t)\}$ represents the percentage of the Fossil Fuel energy replaced by renewables; which effect on reducing carbon emission. Thus, research question is answered.

The models presented in equations (1) and (2) illustrate that green technology significantly enhances energy efficiency and reduces carbon emissions. By substituting fossil fuels with renewable sources like solar, wind, and hydroelectric power, these technologies offer a promising solution for addressing climate change. While green technology is still evolving, its potential for supporting clean energy production and mitigating greenhouse gas emissions is substantial. Therefore, this study successfully achieves its first objective and provides a strong foundation for understanding the role of green technology in building a sustainable future.

3.0 Clean Energy Production Growth

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 (CO2eq = 0) [4, 46]. 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 [52] and Hanna and Max [53] 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 advocate for producing clean energy from natural sources to [54] support various economic activities, such as water treatment and the production of goods and services. Al-Obaidi et al. [55] examined the potential use of renewable energy sources in several water desalination technologies (thermal and membrane). The performance and economic viability of these technologies in conjunction with renewable energy sources—solar energy, wind energy, and geothermal energy, were systematically examined in this study. According to Fan *et al.* [56] and Murad *et al* [57], incorporating clean energy into economic activities can significantly reduce carbon emissions, contributing to slowing climate change. Moreover, Raihan *et al.* [58] and Shao *et al.* [59] 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 [32].

3.1 Clean Energy Production from Varius Energy Sources

Various green technologies have been developed to capture methane emits from biofluids and convert it into electricity and heat. According to Fauzianto, [60] green technology contribute to reduce 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, 62]. Biofluid Methane Production Anaerobic Digestion: Methane is produced from biofluids (organic waste, sewage, or agricultural by-products) through anaerobic digestion. Microorganisms break down organic matter in the absence of oxygen, producing biogas, which consists of methane (CH_4) and carbon dioxide (CO_2). A process model of clean energy and electricity production from biofluid is present by Figure 4.0

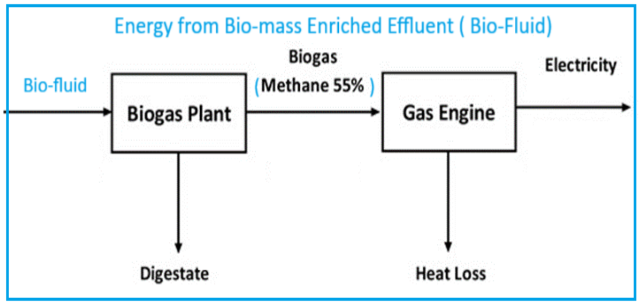

Figure 4.0: Electricity production from carbon emission potential fluid (POME) [61]

Figure 4.0 illustrates the process of electricity generation from biofluid. Were, Q_0 biofluid (POME) feed to the anaerobic digester. E_0 methane gas produce from digester. E(e) electrical energy produce by gas turbine from methane (Eo).

Figure 4.0 illustrates the process of electricity generation from biofluid. The relationship between biofluids, methane gas production, and electrical energy generation demonstrates a promising path towards sustainable energy solutions. Methane capture from biofluids not only reduces harmful methane emissions but also provides a renewable energy source that can help mitigate climate change. While there are challenges, the environmental benefits, including GHG reduction, waste management, and resource recovery, offer significant long-term potential for green energy production.

In this regard, Shahidul [46] 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 [65] the European Commission [66], Bentsen [67], Shahidul [68] 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], making this process a sustainable route for mitigating climate change [2, 41]. 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.

3.2 Modelling the Green Energy Growth

The World Energy Outlook [50] has provided data on total clean energy production from the renewable energy and use, as shown in Table 1.0

Table 1.0 Renewable Energy Production Growth [73]

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
Total (TWh)	7922	9898	17,878	18846

Table 1.0 demonstrates the trend of clean energy use in economic activities. The average green energy growth listed in Table from 2000 to 2022 can be determined by estimating equation 3.0 [108] .

$$\textbf{Growth Rate} = \left[\frac{GW_{2022}}{GW_{2000}}\right]t^{-1} - 1, \qquad \textbf{Eq.(3)}$$

Where TWh $_{2022}$ = 18846 TWh. TWh_{2000} = 7922. t=22 year

The estimated average growth rate is:

$$\textbf{Growth rate} = \left[\frac{G18846_{2022}}{G7922_{2000}}\right]22^{-1} - 1 = 42.3 \qquad \textbf{Eq.(4)}$$

The estimated average green energy growth over 22 years is 42.3%, which looks like quite acceptable.

3.3 Clean Energy Production Growth in Major Global Economies

The World Energy Outlook 2023[50] 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 [50]

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. The data listed in Table 2.0 can be used to estimate green energy production growth rate by using model presented in equation (2).

$$\textbf{Growth Rate} = \left[\frac{GW_{2022}}{GW_{2000}}\right]t^{-1} - 1$$

Where GW_{2022} = 1418. GW_{2000} = 15. t=22 year

$$\text{Growth Rate} = \left[\frac{GW_{2022}}{GW_{2000}}\right]t^{-1}\text{-}1$$

$$\approx \textbf{1.23-1 = 23\%} \qquad \textbf{Eq.(5)}$$

The estimated growth rate of green energy from 2000 to 2022 is about 23%.

3.3(a) 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 [75].The analytical values of 'R^2'and 'r' statistics are presented in Figure 5.0.

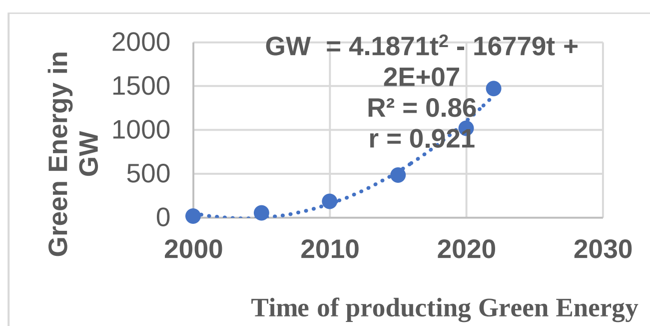

Figure 5.0: Regression Analysis of Historical data on Green Energy Production growth

Figure 5.0 shows 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.

3.3(b) 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.

3.3(c) F-Statistic on Green Energy Production Growth

The F-test was conducted to calculated F-statistic at 5, 10, 05. The ANOVA test result showed an F-value of 24.87 at a 95% confidence level. The critical value (Fc) for F was determined from F-table at F (5, 10,05). The findings is presented in Figure 6.0.

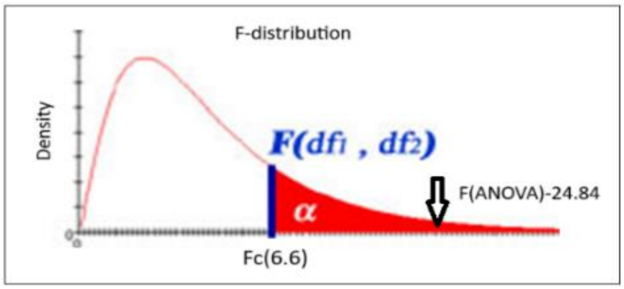

Figure 6.0: F-statistic of green energy production from 2000 to 2022

As shown in Figure 6.0, the estimated F-value exceeds the critical value at a 95% confidence level (Fc>Fest), resulting in the P-value is <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.

3.4 Global Energy Mix Growth Rate

According to Xiao and Zhang [69], Zhang *et al.*, [70] , and Henryk[76] , 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 global energy mix is detailed in Table 3.0 [77].

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 trends of global energy mix, which demonstrates a positive in replacing Fossil Fuel by clean energy. The data listed in Table 3.0 can be used to estimate energy mix growth rate by using growth model presented in equation (1).

$$\textbf{Growth Rate} = \left[\frac{EM_{2022}}{EM_{2000}}\right]t^{-1} - 1$$

Where EM_{2022} = 45.8%. EM_{2000} = 2.88%. t=22 year

$$\text{Growth Rate} = \left[\frac{45.8\%_{2022}}{2.88\%_{2000}}\right]22^{-1}\text{-}1$$

≈ 1.133-1 = 13.3% Eq. (6).

The estimated energy mix growth rate from 2000 to 2022 is about 13.3%. The estimated global clean energy growth from 2000 to 2022 was found to be 42.3%. The growth rate of clean energy use in the economies of major countries worldwide was 23.3%, while the global growth in energy mix was 13.3%. These data demonstrate that the growth rate of clean energy is positive and significant (P-value<0.05) and contributing to reducing carbon emissions and mitigating climate change. These findings are the answers of the equation relating to the objective two of this study.

4.0 Green Technological Nexus among Water, Energy and Climate Change

This section explores the intersection of green energy, clean water production, and carbon emissions. It presents a literature review investigating the trend of utilizing green technology in clean water production. Experts emphasize the critical role of clean energy in freshwater production, as well as their significant contributions to carbon emissions. The implementation of green technologies within the water industry has demonstrated its effectiveness in mitigating climate change by reducing carbon emissions .[1, 78, 79].

Water and energy are indispensable utilities and key drivers of economic growth. However, they also represent significant sources of potential carbon emissions. Statistical data on electricity and water production and supply reveal that the combined carbon emissions from these sectors are approximately 2,634 Mt of CO2eq per $1.0 million in revenue generated [14, 16]. Reports indicate that the carbon footprint of clean water production ranges from 0.18 to 0.79 kg CO_2eq per cubic meter of water [7, 18, 19]. Wastewater treatment falls between 0.51 and 1.14 kg CO_2eq per cubic meter [16, 17]. These data on carbon emission figures underscore the substantial emission potential of traditional water treatment methods powered by fossil fuels. Researchers like Shahidul *et al.* [46] and Young-Gu *et al* [54] have addressed this issue by exploring the potential of green energy. Reports demonstrated that traditional water treatment powered by fossil fuels is a process with significant emission potential.

4.1 Green Technology for Clean Water Production

Green technology for clean water production is a science-based approach that operates with zero carbon emissions. This technology encompasses nanotechnology, biotechnology, and separation technology, all powered by renewable energy sources [70], [81]. Studies by Núñez et al. [82] and Yadav et al. [83] . support the potential of these technologies to achieve zero carbon emissions.

The OECD [14] and Emelko and Stone [84] define green technology, driven by green energy, as a viable replacement for traditional technologies and fossil fuels in water production. Optimizing the water production process can further reduce carbon emissions, as highlighted by Tahereh *et al.* [85].

Green technology has the potential to transform the water industry into an energy-efficient, low-carbon domain [10], [86]. Bekhet [87], Ahmad [88] and Zhang *et al.* [89], advocate for developing clean water production processes using green technology to meet the "fit-for-purpose" standard for protecting public health and the environment.

4.2 Green Technology in Water Reclamation

Green technology enables the production of clean water from wastewater, which traditionally has high carbon emissions. While treating wastewater to produce environmentally friendly effluents is associated with higher carbon emissions [1.14 kg CO2eq per cubic meter due to increased energy consumption [57, 90] the combination of biotechnology, green energy, and nanotechnology can produce clean water with nearly zero carbon emissions [91, 92] .

Van and Zydney [93] Safa *et al*. [94], Yadav [95] and Bart [96] have published experimental findings demonstrating the successful use of biotechnology, nanotechnology, green energy, and microfiltration systems to produce environmentally friendly effluents from palm oil mill wastewater without using fossil fuels, achieving zero carbon emissions.

Ajith *et al*. [97], Mary *et al*. [98] , Neoh *et al*. [30] , Bart [99], Basu *et al.* [92], Zhang *et al*. [100] and Yadav [95] have reported on the successful use of green technology and green energy in producing clean water from industrial and municipal wastewater. Their studies have shown that energy consumption is significantly reduced, leading to lower carbon emissions and improved effluent quality compared to traditional methods.

The findings in this section conclude that a significant reduction in carbon emissions can be achieved in clean water production by designing, building, and operating filtration plants using green technology and green energy. This approach contributes Eto mitigating climate change. On the other hand, Traditional water treatment methods powered by fossil fuels contribute substantially to carbon emission and accelerate climate change. Thus, nexus of green technology, clean energy for fresh water production towards zero carbon emission can be achieved. Hence, objective three (3) of this study active and relevant question is answered.

5.0 Green Technology 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 [102]. n this regard, Sohag *et al*. [103] and Lin and Zhou [104] highlighted that the primary benefit of employing green technology in electricity generation is the reduction dependency on carbon-intensive fossil fuels. According to Shahidul *et al*. [105], 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_2eqkWh^{-1})].

Similar, Alper and Ogu, [106] and Sharif *et al.*, [107] , who 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.*, [108] and Ahmed *at al.* [109] 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.*[110], 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., [37] reported a similar finds .

Several researchers have investigated the combined impact of green technology and clean energy on green economic growth and climate change. According to [58] and Wurlod and Noailly [111], the nexus among green technology, clean energy, and environmental sustainability benefits society by enabling economic activities with zero carbon emissions.

Omri, [51] also found a positive relationship between the adoption of clean energy consumption, economic growth, and environmental sustainability. Shahbaz et al., [112] , Kias and Anis, [78] further confirmed a positive association among 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 Economy. 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 demonstrated the positive impact of clean energy on economic growth, which 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 and economic sustainability. 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. Thus, objective four of this study has achieved and relevant questions has answered.

6.0 Scenario Analysis on 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.

6.1 Concept of Green Technology for water and Energy

(a) Green technology employs scientific and technological advancements to create models for clean energy production that generate zero carbon emissions. This approach aims to mitigate climate change [2–4, 30, 31, 91, 38, 43, 91]

(b) Green technology acts as a catalyst for reducing carbon emissions, thereby mitigating climate change, safeguarding environmental quality, and promoting green 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].

6.3 Benefits of Green Technology and Clean Energy in Economy

(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 $(kW)^{-1}$].[82].
(d). Green technology contributes to the development of a green economy by providing green energy [78, 82].
(e). It facilitates the recycling of waste materials in energy production, thus enhancing economic performance and mitigating climate change[68, 97].
(f). 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].
(g). 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 study presents an in-depth analysis of the current adoption of green technology within the energy sector. From 2000 to 2022, the global energy landscape witnessed a significant growth rate of 42.3%, while the energy mix grew by 13.3% during the same period. These findings highlight the increasing reliance on green technologies for clean energy generation, which has led to a measurable reduction in carbon emissions [CO_2eq(kW)-1].

Furthermore, this study underscores the widespread adoption of green technology across various economic sectors, delivering substantial societal and environmental benefits. It concludes that to effectively reduce carbon emissions and mitigate climate change, a global transition from fossil fuel dependence is crucial. Achieving this ambitious goal will require accelerated innovation in green technology and a broader expansion of renewable energy sources.

Additionally, the study offers new insights into the complex relationship between clean energy and economic growth, emphasizing their interdependence in addressing climate change. This enhanced understanding of the "green technological nexus" enriches existing literature and provides valuable direction for future sustainable development strategies. The findings not only reaffirm the growing significance of green technology in energy and water production but also highlight the urgent need for innovation and widespread adoption to combat 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.

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