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Transformative Technologies and Innovation in Climate Change Mitigation and Sustainable Environmental Stewardship. A Systematic Literature Review

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Abstract: This systematic literature review bears the objective of exploring the transformative potential of transformative technologies and innovations in climate change mitigation and environmental stewardship. The study provides an overview of the current research trends, practical implications, and implementation of transformative technology and innovation between 2018 and 2024. The methodology entailed a comprehensive search of scholarly databases resulting in the selection and analysis of the relevant studies. The findings reveal that transformative technology and innovations in mitigating climate change play a significant role in ensuring environmental stewardship and sustainability as they lower greenhouse gas emissions, reduce pollution levels, and ensure a strategic balance between profit, people, and environmental consideration in relation to natural resources exploitation. Additionally, it provides for a discussion on the benefits as well as challenges associated with the adoption of transformative technology and innovation to mitigate climate change such as cost implications. The review concludes with recommendations for future research and practical implications for the regulators and industry players.

Keywords: climate change, environmental stewardship, ecosystems, paradigm shift, policy formulation

I. Introduction

The world is experiencing unprecedented shifts in climate patterns and environmental degradation, with a profound impact on ecosystems and human societies. The pressing concerns emanating from climate change and environmental stewardship do require a consolidated effort across all societal sectors ranging from innovation, science, and technology to sustainably manage the environment (Gebre, Amekawa, & Fikadu, 2023).

Science plays a critical role in understanding the causes and effects of climate change as well as environmental degradation. Technology is critical in helping curb change in climate and enhance environmental stewardship as it provides ways to reduce greenhouse gas emissions, develop renewable energy sources, and increase energy efficiency. It also plays a critical role in the management of resources such as the conservation of water and reduction of waste. Innovation addresses climate change and environmental stewardship by developing new ideas, products, and services that play a critical role in solving the problem Abdul, Wenqi, & Tanveer, (2022). For instance, the development of green bonds and carbon credits that are to mobilize the private sector to invest in clean energy and motivate behavior change. Moreover, Innovation in climate change and environmental stewardship is essential for sustainable solutions development and should be promoted through investing in research and development, collaborations and partnerships across different sectors, opening data and information sharing, and educational awareness campaigns to raise awareness about the importance of climate change and economic stewardship.

1.1 Problem statement

Climate change is the long-term change in the average weather pattern on Earth, including shifts in temperature, precipitation, and other atmospheric conditions. The scientific community has a critical role in understanding and mitigating the impacts of climate change (Kurniawan et al. 2022).Climate change is caused by greenhouse gas emissions such as carbon dioxide, deforestation that reduces the number of trees leading to increased carbon dioxide levels in the atmosphere, and industrial activities that release pollutants that contribute to climate change. Climate change is a big issue across the world and Kenya just like other countries is facing its effects through erratic rainfall patterns which affect agriculture which is a crucial element in its economy that depends heavily on rain affecting crop production and food security (Gebre, Amekawa, & Fikadu, 2023). In addition, drought and scarcity of water in certain regions in Kenya have been brought about as a result of changes in climate affecting wildlife implicating the tourism industry as a critical component of Kenya's economy.

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Environmental stewardship entails responsible management of our ecosystems and resources. It requires us to safeguard biodiversity, reduce pollution, and conserve natural habitats. Science, technology, and innovation play pivotal roles in achieving these goals. Environmental stewardship bears principles of conservation that endeavors to protect and preserve natural habitat, the principle of sustainability that ensures activities do not deplete or harm resources to the extent of no natural replenishment, the principle of responsibility through accountability for environmental consequences and the principle of collaboration that seeks all stakeholders to collectively address environmental challenges Abdul, Wenqi, & Tanveer, (2022).

Kenya has adopted in its basic education act the Environmental Protection Education for Sustainable Development and has made strides to align the national circular with sustainable development goals along with the development goals of the UNESCO global program for sustainable development in education. The National Education for Sustainable Development policy has been developed in Kenya championed by NEMA which mandates all public entities to adopt environmental education and awareness at work. Moreover, the country effected a total ban on the importation, manufacture, and distribution of single-use plastic bags in 2017 which has been effective in reducing plastic pollution and enhancing environmental stewardship (Kariuki, Kathambi, & Inyega, 2023). Finally, the country has a significant investment in renewable energy such as solar, wind, and geothermal to cut its dependence on fossil fuels lowering greenhouse gases, and has a target of achieving 100% renewable energy by the year 2030.

1.2 Objectives of the conference paper

The main objective is to undertake a systematic literature review to examine the current trends and practical implications of transformative technologies and innovation in climate change mitigation and environmental stewardship between 2018 and 2024. The choice to focus on 2018 to 2024 is justified by;

By concentrating on recent publications the literature review can capture the most up-to-date trends and development

Diverse applications as innovations and transformative technologies have found application across various domains and recent research reflects this diversity offering insights into how these technologies are being used across different groups

Emerging challenges and solutions associated with the innovations and transformative technologies such as ethical considerations as recent research discusses these challenges and presents solutions

Relevance as the focus on recent publications the literature review remains highly relevant to the contemporary landscape as the findings and recommendations align with the most current trends and needs.

i. To explore and analyze the consequence of adopting transformative technology and innovations to mitigate climate change and sustainable environmental stewardship

ii. To examine the role of policy interventions and innovations to mitigate climate change and sustainable environmental stewardship

II. Literature review

The literature review synthesizes existing literature on science and technology and sustainable environmental stewardship. It examines the debate around the positive and negative consequences of climate change as well as theoretical frameworks. Key topics include transformative technology and innovations through; developing new paradigms, interdisciplinary collaborations, ethical considerations, harnessing innovations through; renewable energy, sustainable agriculture, and conservation technologies

2.1 Transformative Technology and Innovations

2.1.1 Developing New Paradigms

To address the complex challenges posed by climate change and environmental stewardship, a shift in paradigms is essential. Traditional reductionist approaches must give way to holistic and interdisciplinary perspectives that consider the interconnectedness of ecosystems. One way to foster a shift in paradigms is to promote the concept of transitioning from a reliance on fossil fuels to a greater emphasis on renewable energy sources by realizing the role of renewable energy in reducing greenhouse gas emissions, mitigating climate change, and promoting a more sustainable energy future (Voumik et al. 2023). Another way is to transform traditional agricultural practices into sustainable food systems by embracing agroecology, regenerative agriculture, and responsible food production to ensure food security while minimizing environmental degradation. (Ontiri, & Amuhaya, 2022)

It is also essential to transition from a linear "take, make, dispose" model to a circular economy that emphasizes resource efficiency, reuse, and recycling to eliminate waste and promote a closed-loop system where materials are continually reused, refurbished, remanufactured, and recycled to minimize environmental impact through reverse logistics (Nabango & Majale, 2022).

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A new shift is essential in transitioning from a focus solely on economic growth to a model of green growth that integrates environmental sustainability into economic development and recognizes that economic prosperity should be decoupled from environmental degradation and that sustainable practices can drive innovation and job creation.

2.1.2 Interdisciplinary Collaborations

The problems we face today are too multifaceted to be solved within the confines of one discipline. Collaboration across disciplines, such as ecology, engineering, economics, and social sciences, is imperative. This convergence of knowledge can lead to innovative solutions for mitigating climate change and promoting environmental stewardship (Smith, Singh, M, & Breeze Ceballos, 2023).

Interdisciplinary Initiatives such as collaboration between scientists, policymakers, economists, and social scientists to develop evidence-based policies and strategies to mitigate climate change, consider both scientific findings and the socioeconomic implications facilitate a holistic understanding of environmental issues and encourage the development of innovative solutions.

Collaboration between Architects, engineers, environmental scientists, and urban planners is essential to Integrate sustainable design principles, energy-efficient technologies, and ecological considerations into building projects to reduce environmental impact. Another strategy is Collaboration between engineers, physicists, environmental scientists, and policymakers to advance research on renewable energy technologies and collaborate on policy frameworks to transition from fossil fuels to sustainable energy sources.

Environmental engineers, economists, policymakers, and industry experts are to work together to implement circular economy principles to reduce waste, increase recycling, and minimize the environmental impact of consumption and production. Investing in Agroecology and Sustainable Agriculture where collaboration between Agronomists, ecologists, climate scientists, and social scientists is key to implementing farming practices that promote biodiversity, soil health, and resilience to climate change while ensuring food security and supporting rural communities (Cortez Tellez, 2022).

2.1.3 Ethical Considerations

Innovations in science and technology must be guided by ethical principles. This includes ethical considerations in research, such as the responsible use of emerging technologies, the just distribution of environmental benefits, and the ethical treatment of human and non-human stakeholders in research projects. Ethical considerations play a crucial role in shaping the direction, implementation, and consequences of scientific and technological advancements (Prinsloo, & Kaliisa, 2022).

Ethical considerations bear a significant principle of respect for human dignity and fundamental rights as they ensure that innovations uphold the rights of individuals, limit abuse from discrimination, privacy infringement, and exploitation, and maintain the dignity of an individual. Furthermore, ethical considerations are essential in maintaining equity and social justice through the avoidance of existing social inequities and aim to enable all access to the benefits of technological advancement including economic opportunities.

Ethical consideration bears a principle of sustainable environmental stewardship which considers the environmental impact of technologies, promotes sustainable practices, and minimizes ecological harm to maintain a balanced healthy ecosystem. Moreover, consideration of ethics emphasizes adherence to rules and regulations by ensuring innovations are in line with the existing regulations preventing unethical activities (Kitainge, 2022).

In Kenya, there is legislation that guides individual privacy and responsible use of data embodied in the Office of Data Commission under the Data Protection Act 2019 which governs the processing of personal information in Kenya. The intellectual property right under the Industrial Property Act and Copyright Act provides a legal framework for the protection of trademarks, patents, and other property rights. In addition, various laws such as environmental regulations provide information about products and services ensuring sustainable development, control of pollution, and managing natural resources. Research is also managed effectively as it is required to adhere to ethics enforced by the National Commission for Science, technology, and Innovation (NACOSTI) that oversees research in Kenya.

2.2. Harnessing Innovation and Technology

2.2.1. Renewable Energy

The transition to renewable energy sources is a pivotal aspect of climate change mitigation. Innovation in solar, wind, and hydropower technologies is essential for reducing carbon emissions and mitigating climate change. Technologies in renewable energy have come a long way in the contemporary world with new solutions that are innovative and constantly emerging. Most

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exciting renewable energy technologies that are changing how we use and generate energy include the use of solar power, use of wind power, hydroelectric power, geothermal power, and the use of bioenergy.

Bioenergy is obtained by converting biomass into energy through technologies such as the use of algae biofuels produced from algae grown in large quantities in tanks and ponds and the use of waste to energy where waste materials are converted into energy for instance solid waste burnt to generate electricity. in Kenya, bioenergy is a dynamic field that has ongoing efforts to enhance its contribution to the national energy portfolio. The Bioenergy Association of Kenya (BEAK) has collaborations with stakeholders to promote the use of sustainable energy solutions.

Geothermal power entails harnessing heat from the core of the earth through the use of binary cycle power plants and enhanced geothermal systems. Binary cycle power plants make use of heat exchangers to transfer heat from geothermal water to a secondary liquid with a boiling point that vaporizes and subsequently drives a turbine. Enhanced geothermal systems drill deep into the earth's crust injecting water into the rock to create steam used to generate electricity. As of 2023, Kenya has a geothermal capacity of 891 megawatts which accounts for half of the country's electricity generation. The geothermal plants in Kenya are operated by the Kenya Electricity Generating Company (KENGEN) and other independent power producers. Kenyan geothermal plants were built in olkaria, menengai, eburu and silali-bogoria.

Hydroelectric power is generated through harnessing the power of moving water through innovations such as the use of tidal power and pumped-storage hydroelectricity. Tidal power is generated by harnessing the power of ocean tides as turbines are installed underwater to generate electricity as tides move in and out. Pumped storage hydroelectricity is used by electric power systems for load balancing. In demand periods water is pumped from a lower elevation reservoir to a high elevation one while in high demand season, water is pumped back to the lower reservoirs. In Kenya, hydroelectric power is a significant source of electricity as it accounts for 43% of the electricity generated. The power stations comprise the Seven Forks Hydro Station and the Turkwel power station

Wind power makes use of wind turbinesto generate electricity by harnessing the power of the wind by use of technologies such as offshore wind turbines and vertical axis wind turbines. The vertical axis wind turbines can be installed in multiple locations as they bear a small footprint compared to the horizontal axis ones. The offshore wind turbines are installed in water bodies such as oceans and lakes where wind speeds are much higher and consistent. Kenya has a wind power potential distributed across various regions mainly in the rift alley. Wind power accounts for 16% of Kenya's electricity generation with wind farms in Lake Turkana wind power station, ngong hills wind farm, and kipeto wind power station.

Solar power is a clean sustainable energy source that makes use of the photovoltaic effect of a solar cell to convert sunlight into electricity. Innovative technologies in solar power space include the use of floating solar panels and perovskite solar cells. Floating solar panels are mounted on water bodies to float. They do not take up space on land and reduce water evaporation in reservoirs. The perovskite solar cells make use of perovskite mineral that has a unique mineral structure with a high-efficiency potential

2.2.2 Sustainable Agriculture

Sustainable agriculture is an approach to farming that aims to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. It involves integrating environmentally friendly practices, economic viability, and social responsibility into the entire food production process. Sustainable agriculture seeks to minimize the environmental impact of farming, promote biodiversity, support local communities, and ensure the long-term health of agricultural systems. Innovations in sustainable agriculture can help reduce the environmental impact of food production. Precision farming, organic agriculture, and agroforestry are examples of sustainable approaches that minimize resource consumption and promote ecosystem health.

Sustainable agriculture practices include the adoption of practices such as; crop rotation where types of crops grown at a specific field are altered to improve soil erosion; cover cropping through planting of cover crops to reduce soil erosion and improve soil health. Agroforestry is an essential practice where trees are integrated into agricultural landscapes to provide windbreaks and ecosystems (Gebre, Amekawa, & Fikadu, 2023). Organic farming is essential by avoiding the use of synthetic chemicals and putting emphasis on natural processes in the management of soil and crops. Furthermore, water conservation is an essential practice through employing efficient irrigation schemes such as the use of drip irrigation, and water harvesting to conserve water.

2.3. Conservation Technologies

Conservation technologies encompass a range of innovative tools and approaches designed to promote the sustainable use of natural resources, protect biodiversity, and mitigate environmental degradation. These technologies aim to balance human activities with the preservation of ecosystems and contribute to the overall goal of environmental conservation.

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Geographic Information Systems (GIS) technology allows for the mapping, analysis, and visualization of spatial data related to ecosystems, biodiversity, and land use. It aids in habitat mapping, landscape analysis, and planning for conservation efforts. Remote sensing technologies use satellite or aerial imagery to monitor and assess changes in land cover, vegetation, and ecosystems. It provides data for monitoring deforestation, assessing habitat health, and identifying areas of conservation concern (Weerasingha, & Ratnayake, 2022).

Unmanned Aerial Vehicles such as drones offer a cost-effective and flexible way to collect high-resolution imagery and data for conservation purposes. They play a significant role in monitoring wildlife, mapping ecosystems, and conducting surveys in hard-to-reach or sensitive areas. Camera traps are motion-activated devices equipped with cameras to capture images or videos of wildlife in their natural habitats. They monitor animal behavior, track populations, and study elusive or nocturnal species.

DNA Barcoding and Genomic Technologies involve identifying species through short DNA sequences, while genomic technologies provide insights into genetic diversity and adaptation. They enhance biodiversity assessments, track wildlife trafficking, and understand species evolution. Specialized drones designed for conservation purposes, equipped with sensors, cameras, or other tools. They are used to conduct aerial surveys, mapping, and monitor wildlife populations and habitats (Zhu et al. 2022).

Sustainable aquaculture technologies promote responsible and efficient fish farming practices. They are essential in recirculating aquaculture systems, genetic improvements, and precision aquaculture contribute to sustainable seafood production (Aunget al. 2023).Precision agriculture is an essential technology that involves using technology to optimize crop yields, reduce resource inputs, and minimize environmental impact. It makes use of Sensor technologies, GPS, and data analytics to help farmers make informed decisions about irrigation, fertilization, and pest control.

Blockchain for Conservation is essential as Blockchain technology can be used to create transparent and secure systems for tracking and verifying transactions related to conservation efforts. It provides leeway for Combating illegal wildlife trade, ensuring the authenticity of sustainably sourced products, and facilitating transparent funding for conservation projects(Munir, 2022).

III. Methodology

The methodology in this systematic literature review is majorly qualitative as a result of the collection, analysis, and synthesis of the existing qualitative as well as quantitative research studies and their findings. The focus is on gathering and interpreting textual information, identification of patterns, themes, and trends, and providing a comprehensive summary of the existing knowledge. The methodology for this systematicliterature review is designed to provide a comprehensive examination of the transformative technologies and innovation in climate change mitigation and environmental stewardship focusing on publications from 2017 to 2024 because of their relevance to the current trends, government policies, and implementation. The systematic approach ensured a rigorous and comprehensive search of relevant scholarly publications, enabling the section and analysis of studies that address the research objective of this review.

A study by Wang et al. (2023) on climate change; strategies for mitigation and adaptation posits that the sustainability of the earth is increasingly threatened due to human activities caused by increased carbon dioxide and other greenhouse gas emissions. The need to transition to renewable energy is a noble course to mitigate change in climate and adaptation to changes in climate requires a set of strategies to foster resilience. Carbon quantification, pricing, and modeling are significant areas that are to be developed further to address climate change.

A study by Gielen et al., (2019) on Global Energy Transformation: A Roadmap to 2050 determines that the increased utilization of renewable energy along with intensified electrification could be decisive factors that enable the world to meet its key climate goals by the year 2050. The study highlights the immediate cost-effective deployable options to limit global temperatures through the use of policy guidelines and technology to ramp up electricity in collaboration with renewable energy to reduce the use of fossil fuels that are responsible for greenhouse gas emissions.

A review by Barasa, et al., (2021) on climate-smart agriculture research and applications in Africa, advocates for the integration of climate change towards the planning and implementation of sustainable agricultural strategies, thus identifying synergies and trade-offs within the three pillars of CSA (known as food security, adaptation, and mitigation). The CSA approach enhanced the reduction in soil erosion, addressed generation, and carbon sequestration, promoted the conservation of biodiversity, and provided other public goods that accrue to society.

A review undertaken by Shaikh, (2017) on sustainable development of green technologies determined that Green technologies have a promising future in meeting the needs of economic sustainability. But, environmental and social sustainability factors need to be reinforced mutually. Both the environmental and economic impact and efficiency of technology should be analyzed before

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the implementation of technologies. It should be a win-win situation when economic and sustainable growth are highly emphasized.

IV. Findings

Effective policy and governance frameworks are essential to reposition science, technology, and innovations for sustainable research. This section will explore the role of government policies, international agreements, and regulatory mechanisms in promoting sustainability and responsible research practices.

Environmental Regulations and Standards where governments establish regulations to control and manage the environmental impact of research and innovation activities. This is done to ensure that research and technological developments adhere to environmental standards, minimizing negative effects and promoting sustainable practices (Chen, Dimitrov, & Pun, 2019).

Governments provide Incentive policies for Sustainable Innovation, such as tax breaks or subsidies, to promote sustainable innovation to encourage businesses and researchers to invest in sustainable practices and technologies that contribute to environmental and social goals(Owen, Brennan, & Lyon, 2018). Policies on international agreements and collaborations are essential as governments engage in international collaborations and agreements on science, technology, and innovation to foster global cooperation, knowledge exchange, and joint efforts to address transboundary issues such as climate change, biodiversity loss, and public health crises.

In Kenya, the environmental management and coordination regulations of 2006 apply to water used for domestic, industrial, and agricultural purposes to regulate the discharge of effluent and provide guidelines and standards for the disposal of pollutants. The Environmental Management and Coordination (Air Quality) Regulations of 2014 provide for prevention, control, and deterring air pollution by prohibiting certain forms of pollution, providing guidelines on levels of pollution that are permissible, and issuing emission licenses (Mungai, Ndiritu, & Rajwani, 2020). In addition, section 93 of the Environment Management and Coordination Act prohibits the disposal of materials that are hazardous to the environment, and a person convicted of this offense is bound to pay the cost of removal of the material and restoration costs. Under section 11 of the Land Act 2012 the National Lands Commission has the obligation of identifying ecologically sensitive areas within the public lands, demarcate, and take justified action to prevent environmental degradation and climate change. The EMCA empowers the National Environment Management Authority ((NEMA) to make regulations that provide for labeling, classifying, and handling hazardouschemicals (Shah, & Atisa, 2021).

V. Limitations of the systematic literature review

Publication bias Despite the search strategies employed there exists bias toward the inclusion of published studies. Unpublished or grey literature such as conference abstracts might contain relevant information not captured in this review

Temporal bias as the focus of the publications from 2017 to 2024 excludes earlier works or misses ongoing research with long-term impacts

Heterogeneity is a result of the diverse nature of studies in the field in terms of their designs, characteristics of participants, and outcomes that make it hard to draw definitive conclusions.

Researcher bias as a result of systematic process review that is subjective in nature at various stages including data synthesis introduces a degree of researcher bias.

VI. Conclusion

Repositioning science, technology, and innovations is essential for addressing the challenges of climate change and environmental stewardship in dynamic ecosystems. This paper has discussed the urgency of these issues, the need for new paradigms, interdisciplinary collaborations, and ethical considerations. It has also highlighted key areas where innovation and technology can make a significant impact. Practical case studies demonstrate the successful application of these principles, and the role of policy and governance is underscored. Only through a concerted effort to reposition these key elements can we hope to achieve a sustainable future in the face of dynamic environmental challenges.

VII. Data availability statement

The literature review made use of publicly available data from peer-reviewed sources like journals/ articles and conference papers. All cited references are included for transparency. The review searched scholarly databases like the ACM digital library following a defined criteria explained under the methodology section. There was no original data collection instead the study analyzed and

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synthesized existing works to provide an overview. The specific sources used for this review can be accessed through their respective publishers, digital libraries, or by contacting the authors directly.

Declaration of interest

The author declares no competing interests

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