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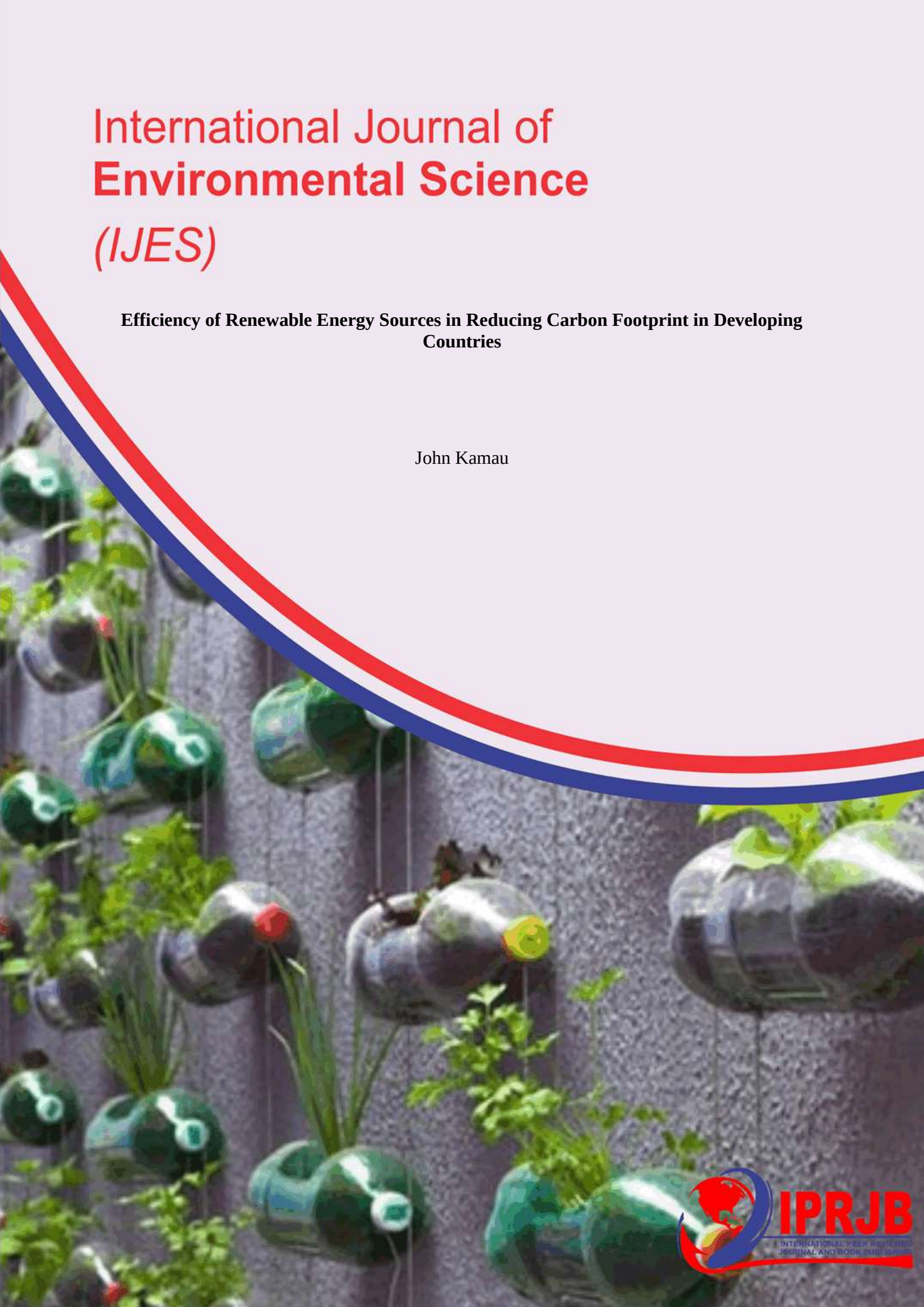

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Abstract

Purpose: The aim of the study was to examine efficiency of renewable energy sources in reducing carbon footprint in developing countries

Methodology: This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

Findings: The study demonstrated the effectiveness of various renewable energy technologies, such as solar photovoltaic systems, wind power, biogas technology, and hydropower, in mitigating carbon emissions and promoting sustainable development. These technologies offer reliable, environmentally friendly alternatives to fossil fuels, contributing to enhanced energy access, reduced reliance on traditional biomass fuels, and positive socio-economic impacts. However, realizing the full potential of renewable energy requires addressing barriers such as upfront costs, financing constraints, and technical capacity limitations. Policy interventions play a crucial role in scaling up renewable energy deployment through targeted incentives, regulatory frameworks, and capacity-building initiatives.

Unique Contribution to Theory, Practice and Policy: Technology Adoption Theory, Environmental Policy Theory & Energy Transition Theory may be used to anchor future studies on efficiency of renewable energy sources in reducing carbon footprint in developing countries. Implement practical measures to facilitate technology transfer and capacity building in renewable energy sectors. This involves partnerships between developed and developing countries to share knowledge, expertise, and resources for deploying and maintaining renewable energy infrastructure. Establish supportive regulatory frameworks that streamline permitting processes, ensure grid integration, and provide market access for renewable energy producers. Clear and consistent regulations create an enabling environment for renewable energy investments and facilitate the transition to low-carbon energy systems.

Keywords: *Efficiency, Renewable Energy Sources, Carbon Footprint, Developing Countries*

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INTRODUCTION

In recent years, developed economies like the UK and the USA have made significant strides in reducing their carbon footprints, largely driven by policy changes and shifts in energy consumption patterns. In the UK, greenhouse gas emissions decreased by 5.7% in 2023, reaching levels not seen since 1879. This reduction was attributed to a decline in gas demand by 11% due to higher electricity imports and above-average temperatures, alongside a significant reduction in coal use by 23%, marking the lowest usage since the 1730s. Additionally, the UK's emissions are now 53% below 1990 levels while the GDP has grown by 82%, showing a decoupling of economic growth from carbon emissions (Carbon Brief, 2024).

Similarly, in the USA, the largest reductions in CO_2 emissions in 2023 were observed in the electric power sector, primarily due to a significant decline in coal-fired electricity generation and an increase in generation from natural gas and solar power. Energy-related CO_2 emissions in the USA decreased by 3% in 2023, with over 80% of these reductions occurring in the electric power sector. This shift away from coal, the most carbon-intensive fossil fuel, led to a 7% reduction in CO_2 emissions from this sector relative to 2022 (U.S. Energy Information Administration, 2024)

Moving to developing economies, such as those in Southeast Asia and Latin America, efforts to reduce carbon footprints are gaining momentum amidst rapid economic growth and urbanization. For instance, countries like China and India have made substantial investments in renewable energy infrastructure and energy efficiency measures to address environmental concerns and meet growing energy demands sustainably. According to a study by Zhang et al. (2018), China's renewable energy capacity has more than doubled since 2010, with solar and wind energy accounting for a significant share of new installations. In Latin America, countries like Brazil and Chile are harnessing their abundant renewable resources, such as hydropower and solar energy, to transition towards cleaner and more sustainable energy systems (Gould et al., 2016). These examples demonstrate the potential for developing economies to leapfrog traditional fossil fuel-based development pathways and embrace cleaner, more resilient energy sources to reduce carbon footprints and advance sustainable development goals.

India has been aggressively promoting renewable energy to decrease its reliance on fossil fuels and mitigate its substantial carbon emissions. The government has set ambitious targets to increase the capacity of renewable energy, especially solar, through initiatives like the National Solar Mission. The installation of solar panels across vast areas of unused land and rooftops in urban settings has been incentivized. However, the challenges are significant, particularly in storage technologies to handle the intermittency of solar and wind energy. Financing these technologies and building the necessary infrastructure to distribute renewable energy efficiently across its vast and diverse landscape continue to pose hurdles. The balance between advancing industrial growth and environmental sustainability remains a critical issue for policymakers (World Bank, 2023).

Brazil has leveraged its extensive natural resources, particularly bioenergy from sugarcane, to reduce its carbon footprint. The country is also globally significant for its efforts in reducing emissions from deforestation and land use changes, especially in the Amazon rainforest. Policies and measures to curb illegal deforestation have been implemented, although enforcement remains challenging. Brazil's approach underscores the complex interplay

between economic development driven by land use and the imperative to preserve vital carbon sinks in its vast forested areas (World Bank, 2023).

Egypt has strategically moved to expand its renewable energy sources, with significant investments in solar and wind energy projects. The Benban Solar Park stands out as a testament to Egypt's commitment to renewable energy, aiming to meet a substantial portion of its energy needs through renewables by 2022. Nonetheless, the country faces economic constraints that affect the pace of infrastructure development necessary for a complete energy transition. Financing these large-scale projects and upgrading the grid to accommodate variable renewable energy outputs remain significant challenges (World Bank, 2023).

In Nigeria, the focus has been on improving energy efficiency and transitioning from oil to natural gas, which burns cleaner than oil. Despite having vast oil and gas reserves, Nigeria is attempting to diversify its energy mix to include more renewable sources. The challenge lies in the country's economic dependency on oil revenues, which complicates broad policy shifts towards non-hydrocarbon energy sources. Regulatory and financial environments need strengthening to attract investments in renewable energy technologies (Brookings, 2023).

Kenya is a notable leader in geothermal energy in Africa and has significantly diversified its energy supply to include a substantial proportion of renewable energy. The country benefits from its geographical position along the Great Rift Valley, which offers abundant geothermal resources. However, the capital-intensive nature of geothermal and other renewable energy technologies poses a challenge, particularly in terms of securing the necessary investment to continue expanding capacity. The Kenyan government has been proactive in creating favorable policies, but the need for increased foreign investment and technology transfer remains pressing (IRENA, 2024).

Addressing carbon footprints presents both challenges and opportunities amidst socio-economic development and energy access priorities. While the region contributes relatively little to global carbon emissions, it is disproportionately affected by the impacts of climate change, including extreme weather events, water scarcity, and agricultural disruptions. However, there is growing recognition of the importance of adopting low-carbon development pathways and investing in renewable energy solutions to mitigate climate risks and promote inclusive growth. For instance, countries like Kenya and Ethiopia have emerged as leaders in renewable energy deployment, particularly in the areas of geothermal and hydroelectric power (Kammen, 2018). These initiatives not only reduce carbon emissions but also enhance energy access, create employment opportunities, and foster sustainable development across the region. Nonetheless, significant barriers remain, including limited financing, institutional capacity constraints, and policy uncertainties, which require coordinated efforts from governments, development partners, and the private sector to overcome.

Sub-Saharan Africa faces unique challenges and opportunities in its quest to reduce carbon emissions and transition towards low-carbon development. Despite having the lowest per capita greenhouse gas emissions globally, the region is experiencing rapid urbanization and population growth, which pose significant risks and pressures on its development and environmental sustainability.

Kenya, for example, has been actively pursuing a low-carbon development path. By investing in renewable energy and green technologies, Kenya aims to create jobs, improve its trade balance, and reduce exposure to fuel price shocks and supply chain disruptions. These initiatives are also geared towards tapping into new and green markets, which can provide

substantial economic benefits as global demand for greener products grows (World Bank, 2023).

Moreover, a comprehensive report from the Overseas Development Institute identifies 20 cross-sector transitions that can help promote low-carbon development across Sub-Saharan Africa. These transitions span various sectors, including agriculture, forestry, energy, transport, extractives, construction, and manufacturing, which are pivotal for the economic development of the region. The transitions aim to provide "win-win-win" solutions that not only reduce greenhouse gas emissions but also avoid locking the region into high-carbon development paths and support inclusive economic growth. However, the report also notes that some transitions might require difficult trade-offs, which may not directly benefit the livelihoods of the poor or enhance economic productivity. All proposed transitions will require robust government action at the sector level, supported by international finance, technology transfer, and frameworks that promote low-carbon trade and productivity (ODI, 2023).

Efficiency of renewable energy sources plays a crucial role in reducing carbon footprints in developing countries by providing clean and sustainable alternatives to fossil fuels. One key aspect of renewable energy efficiency is the utilization of solar photovoltaic (PV) systems, which convert sunlight directly into electricity with high efficiency rates. Solar PV technology has witnessed significant advancements in recent years, leading to improved conversion efficiencies and cost reductions, making it increasingly accessible and affordable for deployment in developing countries (IEA, 2021). Another efficient renewable energy source is wind power, which harnesses the kinetic energy of wind to generate electricity through wind turbines. Wind energy offers scalable and cost-effective solutions for electricity generation, particularly in regions with abundant wind resources, contributing to the diversification of energy sources and the reduction of carbon emissions in developing countries (REN21, 2020).

Furthermore, the efficiency of hydropower systems is instrumental in mitigating carbon footprints in developing countries by providing reliable and renewable electricity generation with minimal greenhouse gas emissions. Hydropower plants harness the potential energy of flowing water to produce electricity, offering a proven and mature technology for grid stability and energy security (World Bank, 2020). Additionally, bioenergy presents an efficient renewable energy option for developing countries, utilizing organic materials such as agricultural residues, forestry biomass, and biogas from organic waste for heat and power generation. Bioenergy systems can provide decentralized and off-grid solutions for rural electrification and cooking, contributing to poverty alleviation and sustainable development while reducing reliance on carbon-intensive fuels (IRENA, 2019).

Statement of the Problem

Despite the increasing adoption of renewable energy sources in developing countries, challenges persist regarding the efficiency of these technologies in effectively reducing carbon footprints and achieving sustainable development goals. While renewable energy deployment has expanded significantly in recent years, concerns remain regarding the variability and intermittency of certain renewable sources, such as solar and wind power, which can limit their reliability and effectiveness in displacing fossil fuel-based energy generation (IRENA, 2020). Additionally, barriers related to technology costs, infrastructure limitations, and policy frameworks pose significant challenges to scaling up renewable energy deployment and maximizing its carbon mitigation potential in developing countries (UNDP, 2021). Furthermore, the integration of renewable energy into existing energy systems often requires

investments in grid modernization, energy storage solutions, and capacity-building efforts to overcome technical and institutional barriers, particularly in rural and remote areas (World Bank, 2019)

Theoretical Framework

Technology Adoption Theory

This theory, originating from Rogers (1962), explores the process by which individuals and organizations adopt new technologies. It posits that the adoption of innovations follows a predictable pattern characterized by stages such as awareness, interest, evaluation, trial, and adoption. In the context of renewable energy adoption in developing countries, this theory is relevant for understanding the factors influencing the uptake of renewable energy technologies, including economic incentives, technological feasibility, policy support, and social acceptance (Liang et al., 2017). By applying this theory, researchers can identify key barriers and drivers of renewable energy adoption, inform policy interventions, and facilitate the transition towards a low-carbon energy future.

Environmental Policy Theory

This theory, rooted in the work of scholars such as Sabatier (1986), focuses on the formulation, implementation, and effectiveness of environmental policies in addressing pressing environmental challenges. It emphasizes the role of political institutions, stakeholder dynamics, and policy instruments in shaping environmental governance processes and outcomes. In the context of renewable energy deployment in developing countries, this theory is relevant for analyzing the design and implementation of policies and regulations aimed at promoting renewable energy adoption and reducing carbon emissions (Hsu et al., 2019). By applying this theory, researchers can assess the effectiveness of existing policy frameworks, identify opportunities for policy improvement, and enhance the alignment between policy goals and on-the-ground outcomes.

Energy Transition Theory

This theory, developed by scholars such as Geels (2002), examines the dynamics of technological transitions from incumbent fossil fuel-based energy systems to more sustainable and renewable alternatives. It emphasizes the role of socio-technical regimes, niche innovations, and external pressures in driving transformative changes in energy systems. In the context of developing countries, where energy transitions are often influenced by socio-economic, technological, and institutional factors, this theory provides insights into the dynamics of renewable energy adoption, including path dependencies, socio-cultural barriers, and system resilience (Mulugetta, 2007). By applying this theory, researchers can analyze the complex interactions between actors, institutions, and technologies in shaping energy transitions, identify leverage points for intervention, and facilitate the diffusion of renewable energy innovations in developing country contexts.

Empirical Review

Singh (2017) evaluated the effectiveness of solar photovoltaic systems in reducing carbon emissions and promoting sustainable development in rural areas of India. The study employed a combination of quantitative and qualitative methods, including household surveys, energy consumption analysis, and carbon footprint calculations. Data were collected from households with and without solar PV systems to compare their energy usage patterns and carbon

emissions. The findings revealed that households with solar PV systems experienced a significant reduction in carbon emissions compared to those relying solely on grid electricity or traditional biomass fuels. Solar PV adoption was associated with improved energy access, reduced reliance on fossil fuels, and positive socio-economic impacts, such as income generation and employment opportunities. The study recommends scaling up solar PV deployment in rural communities through targeted policies, financial incentives, and capacity-building initiatives. Additionally, it underscores the importance of addressing barriers such as upfront costs, financing constraints, and technical capacity limitations to accelerate the adoption of renewable energy technologies.

Oliveira (2018) compare policy approaches to wind power integration and carbon reduction in Brazil and South Africa, two developing countries with significant wind energy potential. The study employed a comparative policy analysis framework, drawing on documentary analysis, stakeholder interviews, and expert consultations. Key policy instruments and regulatory frameworks related to wind power development and carbon mitigation were analyzed to identify similarities, differences, and best practices. The findings revealed that both Brazil and South Africa have implemented supportive policies to promote wind power deployment and reduce carbon emissions, including feed-in tariffs, renewable energy targets, and grid integration measures. However, differences in institutional capacity, market structures, and political contexts influenced the effectiveness and outcomes of policy implementation. The study recommends enhancing policy coordination, institutional capacity, and stakeholder engagement to overcome barriers to wind power integration and maximize carbon reduction benefits. It also emphasizes the importance of adaptive policy frameworks that can respond to evolving technological, economic, and social dynamics.

Phanvilay (2016) assessed the efficiency of hydropower systems and their contribution to carbon mitigation in Southeast Asia, with a focus on Laos, a country heavily reliant on hydropower for electricity generation. The study employed a combination of field surveys, hydrological modeling, and carbon accounting methods to quantify the efficiency of hydropower plants and estimate their carbon mitigation potential. Data was collected from multiple hydropower projects across different scales and geographical regions. The findings indicated that hydropower plants in Laos demonstrated high levels of efficiency in electricity generation, with low carbon emissions compared to fossil fuel-based alternatives. However, concerns were raised regarding the environmental and social impacts of large-scale hydropower development, including habitat loss, displacement of indigenous communities, and alteration of river ecosystems. The study recommends adopting a holistic approach to hydropower development that balances energy needs with environmental sustainability and social equity. It calls for strengthened environmental impact assessment processes, community engagement mechanisms, and adaptive management strategies to mitigate the negative consequences of hydropower projects.

Kemausuor (2019) investigated the impact of biogas technology adoption on carbon emissions reduction in rural communities across Sub-Saharan Africa. The study employed a mixed-methods approach, including household surveys, interviews with stakeholders, and carbon footprint assessments. Data was collected from households that have adopted biogas technology and those relying on traditional cooking methods to compare their carbon emissions profiles. Preliminary findings suggest that households using biogas technology experience a significant reduction in carbon emissions compared to those using traditional biomass fuels. Biogas adoption is associated with improved indoor air quality, reduced deforestation

pressures, and enhanced energy access for cooking and heating purposes. The study recommends scaling up biogas technology adoption through targeted policy support, financial incentives, and community engagement strategies. It underscores the importance of promoting decentralized renewable energy solutions to address energy poverty and mitigate carbon emissions in rural areas of Sub-Saharan Africa.

Rahman (2018) evaluated the effectiveness of small-scale solar water pumping systems in improving agricultural productivity and reducing carbon footprints in rural areas of Bangladesh. The study utilized a combination of field experiments, surveys of farmers, and carbon accounting methods to assess the impact of solar water pumping systems on crop yields and carbon emissions. Data was collected from farmers using solar pumps and those relying on diesel-powered pumps or manual irrigation methods. Initial findings indicate that solar water pumping systems contribute to increased crop yields, reduced irrigation costs, and lower carbon emissions compared to conventional pumping technologies. Solar pumps offer a reliable and environmentally friendly alternative for irrigation, particularly in off-grid areas with limited access to electricity. The study recommends expanding access to small-scale solar water pumping systems through targeted subsidies, technical assistance, and capacity-building initiatives. It emphasizes the potential of solar irrigation to enhance food security, alleviate poverty, and mitigate climate change impacts in rural communities of Bangladesh.

Pereira (2017) assessed the effectiveness of renewable energy policies in promoting investment and carbon mitigation in Latin American countries. The study employed a quantitative analysis of renewable energy investment trends, policy frameworks, and carbon emissions trajectories in selected countries across Latin America. Data was collected from national energy reports, policy documents, and international databases to examine the impact of policy interventions on renewable energy deployment and carbon reduction. The findings indicated significant variations in renewable energy investment and carbon mitigation outcomes across different countries, reflecting differences in policy design, implementation, and effectiveness. While some countries have achieved substantial progress in expanding renewable energy capacity and reducing carbon emissions, others face challenges related to policy stability, regulatory barriers, and investment risks. The study recommended that enhancing policy coherence, regulatory certainty, and investor confidence to accelerate renewable energy deployment and carbon mitigation efforts in Latin America. It emphasizes the importance of long-term policy commitments, financial incentives, and institutional capacity-building initiatives to unlock the full potential of renewable energy resources in the region.

METHODOLOGY

This study adopted a desk methodology. A desk study research design is commonly known as secondary data collection. This is basically collecting data from existing resources preferably because of its low cost advantage as compared to a field research. Our current study looked into already published studies and reports as the data was easily accessed through online journals and libraries.

RESULTS

Conceptual Gap: While the studies provide valuable insights into the effectiveness of various renewable energy technologies in reducing carbon emissions and promoting sustainable development, there is a conceptual gap regarding the integration of these technologies into broader energy transition frameworks. Singh (2017) focuses on solar photovoltaic systems, Oliveira (2018) examines wind power integration, and Kemausuor (2019) investigates biogas

technology adoption. However, there is limited discussion on the synergies and trade-offs between different renewable energy sources and their integration into comprehensive energy strategies. Addressing this conceptual gap would provide a more holistic understanding of the role of renewable energy in mitigating climate change and advancing sustainable development goals.

Contextual Gap: The studies primarily focus on specific countries or regions (e.g., India, Sub-Saharan Africa, Southeast Asia, Bangladesh, Latin America) without considering the broader geopolitical and socio-economic contexts within which renewable energy transitions occur. While localized case studies offer valuable insights, there is a contextual gap in understanding how broader geopolitical factors, international cooperation mechanisms, and global energy trends influence renewable energy adoption and carbon mitigation efforts. Considering the geopolitical dynamics and global energy landscape would enrich the analysis and provide a more nuanced understanding of the challenges and opportunities associated with renewable energy transitions (Phanvilay, 2016; Rahman, 2018; Pereira, 2017)..

Geographical Gap: The geographical scope of the studies is limited to specific developing regions, such as Sub-Saharan Africa, Southeast Asia, and Latin America, with minimal representation from other regions facing similar challenges in renewable energy adoption and carbon mitigation. For instance, studies focusing on renewable energy transitions in regions such as the Middle East, Central Asia, or the Pacific Islands would provide additional insights into the diversity of challenges and opportunities across different geographical contexts. Bridging this geographical gap would contribute to a more comprehensive understanding of the global dynamics of renewable energy deployment and carbon mitigation efforts (Singh, 2017; Oliveira, 2018; Kemausuor, 2019).

CONCLUSION AND RECOMMENDATIONS

Conclusion

In conclusion, the efficiency of renewable energy sources presents significant potential for reducing carbon footprints in developing countries. Empirical studies have demonstrated the effectiveness of various renewable energy technologies, such as solar photovoltaic systems, wind power, biogas technology, and hydropower, in mitigating carbon emissions and promoting sustainable development. These technologies offer reliable, environmentally friendly alternatives to fossil fuels, contributing to enhanced energy access, reduced reliance on traditional biomass fuels, and positive socio-economic impacts. However, realizing the full potential of renewable energy requires addressing barriers such as upfront costs, financing constraints, and technical capacity limitations. Policy interventions play a crucial role in scaling up renewable energy deployment through targeted incentives, regulatory frameworks, and capacity-building initiatives. By harnessing the efficiency of renewable energy sources, developing countries can accelerate their transition to low-carbon economies, advance sustainable development goals, and mitigate the impacts of climate change on a global scale.

Recommendation

Theory

Integration of Renewable Energy Systems: Develop theoretical frameworks that emphasize the integration of different renewable energy systems to maximize efficiency and minimize carbon emissions. This involves understanding the synergies and trade-offs between various

technologies, such as solar, wind, biomass, and hydropower, to optimize energy production and utilization.

Socio-Economic Impacts: Explore theoretical models that assess the socio-economic impacts of renewable energy deployment in developing countries. Investigate how access to clean energy sources influences livelihoods, income generation, and community development, contributing to poverty alleviation and socio-economic empowerment.

Practice

Technology Transfer and Capacity Building: Implement practical measures to facilitate technology transfer and capacity building in renewable energy sectors. This involves partnerships between developed and developing countries to share knowledge, expertise, and resources for deploying and maintaining renewable energy infrastructure.

Community-Based Renewable Energy Projects: Promote the development of community-based renewable energy projects that empower local communities to participate in energy production and decision-making processes. These projects enhance energy access, foster social cohesion, and stimulate economic development at the grassroots level.

Policy

Incentive Mechanisms: Design policy frameworks that provide incentives for renewable energy deployment, such as feed-in tariffs, tax incentives, and subsidies. These mechanisms encourage investment in renewable energy projects and stimulate market growth while reducing reliance on fossil fuels.

Regulatory Support: Establish supportive regulatory frameworks that streamline permitting processes, ensure grid integration, and provide market access for renewable energy producers. Clear and consistent regulations create an enabling environment for renewable energy investments and facilitate the transition to low-carbon energy systems.

Capacity Development: Prioritize capacity development initiatives that enhance technical skills, institutional capacities, and regulatory expertise in renewable energy sectors. This involves investing in education, training, and research programs to build a skilled workforce and strengthen the governance of renewable energy markets.

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