



Evaluating Emissions Reduction by Replacing Diesel Generators with Solar-Powered Water Systems in Manyara, Tanzania

Hassani Amiri^{1*}, Clarence Paul Kisiki¹, Tulinave Burton Mwamila¹

¹Department of Water Supply and Sanitation Engineering, Water Institute, P. O. Box 35059, Dar Es Salaam, Tanzania

*Corresponding Author: hassanamiri1713@gmail.com

Received Date: 17/08/2025 / Published Date: 30/06/2026

© Water Institute

Abstract

This study evaluates the environmental, energy, and economic impacts of transitioning from diesel-powered generators to solar-powered water supply systems across 71 rural schemes in the Manyara Region, Tanzania. Diesel generators, historically the primary energy source, have contributed significantly to greenhouse gas (GHG) emissions and operational inefficiencies. Using a mixed-methods approach and applying IPCC Tier 1 methodologies, the study quantified GHG emissions from historical diesel consumption and compared them with post-transition performance data from solar systems. Findings reveal that the shift to solar energy eliminated 734,832.81 kg of CO₂ emissions annually, with an 80.3% reduction (590,563.38 kg CO₂) when factoring in residual generator use. Solar systems improved operational efficiency, increasing daily pumping hours from 5–7 under diesel to 10–11 hours, resulting in enhanced water output and elimination of ongoing fuel costs. Economically, although solar installations required higher initial capital investment, the systems demonstrated long-term cost savings through reduced fuel and maintenance expenses. Remaining challenges include a 14% dependence on diesel for backup, technical capacity gaps, and limited monitoring data. Overall, the study reinforces the sustainability of solar-powered water schemes and offers empirical support for scaling renewable energy adoption in line with Tanzania's climate targets and SDGs 6 and 7.

Keywords · Circular economy; Clean energy; Climate resilient WASH systems; Renewable energy; Sustainable development.

1. Introduction

Greenhouse gas (GHG) emissions are widely recognized as the primary driver of global climate change, with carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) being the most dominant contributors (IPCC, 2021). The energy sector, especially through the combustion of fossil fuels such as diesel, is a significant source of these emissions.

Diesel generators, often used in off-grid or backup power systems, contribute not only to GHG emissions but also to air pollution, noise, and long-term environmental degradation (Energy Agency, 2022). In many developing countries, especially in sub-Saharan Africa, diesel generators remain a critical component of rural energy infrastructure due to unreliable grid access. However, their environmental cost and

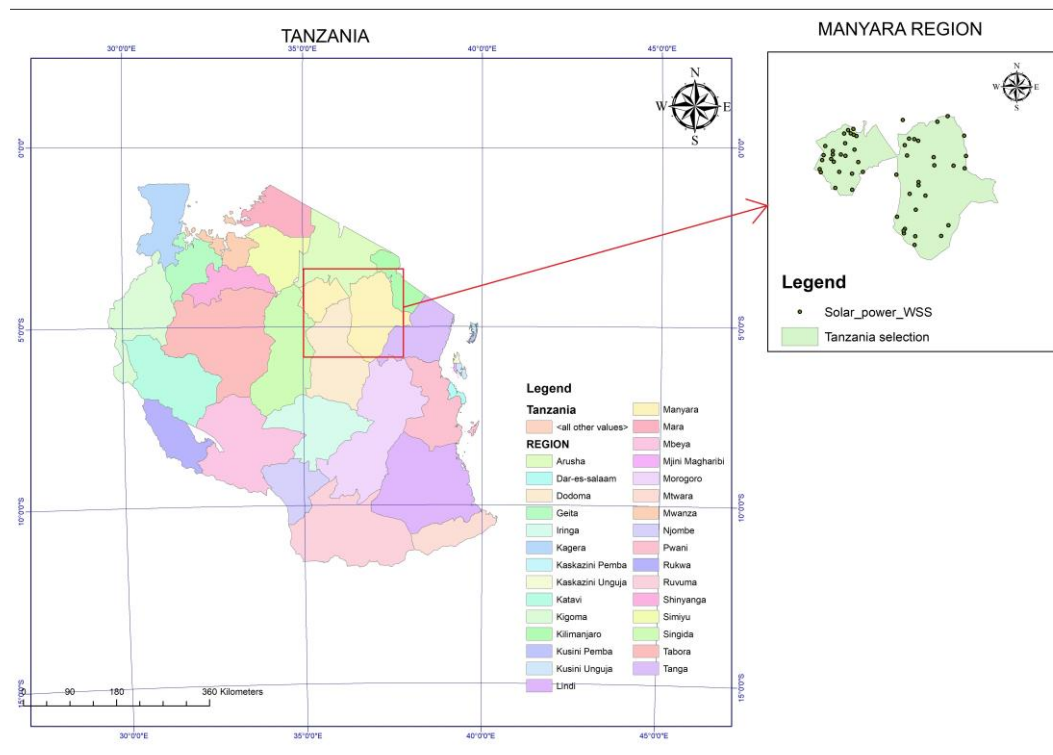


Figure 1: Location of the Study Area

operational inefficiency raise major concerns for sustainable development and public health.

Reducing emissions from diesel generators is essential for both climate mitigation and improving local air quality. Diesel exhaust contains fine particulate matter and nitrogen oxides, which are harmful to human health and ecosystems. Furthermore, reliance on imported diesel fuel creates economic burdens for low-income countries and hinders energy independence (UNEP, 2020). In contrast, solar photovoltaic (PV) systems offer a clean, renewable alternative for powering water schemes and other rural infrastructure. By displacing diesel generators, solar energy reduces direct carbon emissions, lowers operating costs, and enhances energy access, especially in remote areas. Solar-powered water supply schemes are particularly impactful in semi-arid regions, where reliable access to clean water is both a development priority and a challenge under climate stress.

Despite the known benefits of solar energy, limited empirical studies have quantified the actual

GHG reductions achieved by transitioning from diesel-powered to solar-powered systems especially within the context of rural water schemes. Globally, most research focuses on the potential of solar PV in grid-connected urban areas or large-scale commercial applications (Renewable Energy Agency, 2022). In Africa, where over 600 million people lack access to electricity (Energy Agency, 2022), there is growing interest in decentralized solar solutions, yet the documentation of their environmental benefits, particularly in displacing diesel generators in water infrastructure, remains sparse. In Tanzania, while initiatives promoting renewable energy have gained traction, there is a noticeable gap in localized research assessing the quantitative impact of solar interventions on GHG mitigation in rural service delivery systems.

This study seeks to fill this research gap by evaluating the GHG emissions reduced through the transition from diesel generators to solar-powered water schemes in the Manyara Region of Tanzania. By providing empirical evidence, this research aims to contribute to national and regional efforts toward low-

carbon development and inform future policy and investment in sustainable rural infrastructure.

This research aims to evaluate the carbon footprint of solar-powered water systems in Tanzania's Manyara Region to assess their overall sustainability. The study will specifically quantify the carbon offset achieved by these systems and evaluate their delivery efficacy in providing reliable water access. By integrating these findings, the research seeks to provide a comprehensive assessment of the systems' long-term sustainability. The resulting evidence is intended to inform integrated energy and water policy for sustainable rural development.

2. Materials and Methods

2.1 Study Area

The Manyara Region is located in the northern part of Tanzania, forming part of the country's northern highlands (Figure 1). Geographically, it lies between latitudes 3° and 6° south and longitudes 35° and 38° east. The region is bordered by Arusha Region to the north, Kilimanjaro and Tanga Regions to the east, Dodoma to the south, and Singida and Simiyu Regions to the west. The regional capital is Babati, which also

Manyara experiences a semi-arid to sub-humid climate, characterized by two main rainfall seasons: the short rains from October to December and the long rains from March to May. Average annual rainfall ranges from 400 mm in lowland areas to about 1,200 mm in the highlands. Temperatures are generally moderate, with average daily temperatures ranging between 18°C and 30°C. The climatic conditions greatly influence water availability and agricultural productivity, and in other hand support climate-resilient infrastructure such as solar-powered water schemes essential for sustainable development in the region.

2.2 Data Collection and Computations

2.2.1 Water Supply Scheme

A total of 71 water supply schemes are present within the study area. Initially, most of these schemes relied predominantly on fossil fuel-based power, with 58 schemes operating solely on generators and 13 functioning under gravity-fed systems. However, following a transition to renewable energy, 58 schemes now operate on solar power, with 16 running entirely on solar without backup, 26 supplemented by grid electricity, 15 using backup generators and 1 scheme

$$\text{Fuel (Liters)} = \frac{\text{Electricity Demand (kWh)}}{\text{Generator Efficiency} \times \text{Energy content of Diesel} \left(\frac{\text{kWh}}{\text{Liter}} \right)} \quad (1)$$

serves as the administrative and commercial center.

According to the 2022 Tanzania Population and

using both solar, grid electricity and diesel generator, while the remaining 13 schemes remain gravity-fed. Data were obtained through structured interviews with

$$\text{CO}_2(\text{kg}) = \text{Diesel consumed (liters)} \times \text{Emission factors} \left(\frac{2.65 \text{ kgCO}_2}{\text{liter}} \right) \quad (2)$$

Housing Census, the Manyara Region has a population of approximately 1.9 million people, with a significant proportion living in rural areas. The population density varies across the region, with Babati Urban, Babati Rural, and Hanang' Districts being among the most populated. The population is characterized by a youthful demographic structure, with agriculture being the primary livelihood for most households.

scheme operators, review of maintenance logs, and official records from the Oikos East Africa collaborating with rural water supply and sanitation authority in Manyara Region. Key operational parameters, including daily pumping hours, system efficiency, and backup power usage frequency, were documented to assess the impact of the energy transition on reduction of GHG emissions.

2.2.2 Estimation of Diesel Fuel Consumption for Generator

As it was observed, a total of 58 schemes used diesel generators and 13 schemes were operated under

Table 2: Emission factor used to calculate the carbon dioxide emissions from Different Sources (Amakom et al., 2022)

S/N	Emission Source	Emission Factor
1	Diesel	2.653 kg CO ₂ /L

Source: Annual Carbon Footprint from Local Electricity Generation in Federal University of Technology, Owerri, Imo State, Nigeria (2022)

gravity before transitioning to solar powered schemes. To estimate the historical diesel fuel consumption for the water supply schemes prior to their transition to solar power, an indirect calculation method was employed through making the use of available data and reasonable assumptions since there were no complete fuel consumption logs for the period between 2022 and

2.2.3 Determination of GHG Emissions from Diesel-Powered Water Pumping

To estimate the greenhouse gas (GHG) emissions attributable to 58 diesel generators used in the water

supply schemes, the volume of diesel fuel consumed was combined with standardized emission factors provided in Table 1. The primary GHGs considered was carbon dioxide CO₂, as of all the GHG, CO₂ has the largest share, forming around 77% of total GHG (Arinah and Albakri, 2014). The methodology aligned with IPCC Tier 1 guidelines for stationary combustion

Table 1: Total amount of electricity produced by solar systems and other systems to run water supply schemes

Scheme	Total Electricity consumed from solar (kWh)	Total Electricity consumed from backup (kWh)
	1194580.116	190329.0695
	86%	14%

2024. Since the scale of each scheme remained unchanged. It was assumed that the amount of electricity required to pump water remained consistent before and after the transition of the power technology since the scheme coverage remained the same. Monthly solar energy consumption data (kWh) recorded by the Community-Based Water Supply Organizations (CBWSOs) under supervision of Oikos East Africa for the current solar-powered systems were used as a proxy for the equivalent electricity demand previously met by diesel generators. A typical diesel generator with efficiency of 35% was considered on the computation, which implies that only 35% of the fuel's energy content is converted to usable electricity and the energy content of diesel was approximated to 10 kWh per liter of diesel (MacKay, 2009).

emissions by (Eggleston, 2006) using equation 2 to estimate CO₂ Emissions.

2.2.4 Energy Consumption by Solar-Powered Systems

Energy consumption data for the 58 solar-powered water supply schemes were obtained from monthly operational records maintained by the respective Community-Based Water Supply Organizations (CBWSOs) under supervision of Oikos East Africa as seen in table 2. Each scheme was equipped with solar generation meters and inverter logs, which recorded daily energy production (kWh) and energy utilized for pumping. For schemes with hybrid systems, additional data on grid electricity consumption and generator runtime were extracted from utility bills and fuel logs. The monthly solar

energy consumption for each scheme was aggregated to determine annual energy usage, enabling an assessment of the solar systems' efficiency and their contribution to reducing GHG emissions compared to the previous generator-dependent operations.

3. Results and Discussion

3.2.1 Water Supply Scheme

The analysis of the 71 water supply schemes reveals a significant shift from fossil fuel-dependent generators to sustainable energy sources. Previously,

diesel generators emit approximately 2.65 kg of CO₂ per liter of fuel, contributing significantly to climate change. Studies, such as one conducted in Africa by (Burney et al., 2010), demonstrate that solar-powered water systems can reduce CO₂ emissions by 95–100% compared to diesel alternatives.

3.2.2 Water Production

The transition from diesel-powered to solar-powered water supply systems in the study area has led to a substantial increase in water production. By 2021, the targeted villages in Manyara Region had an

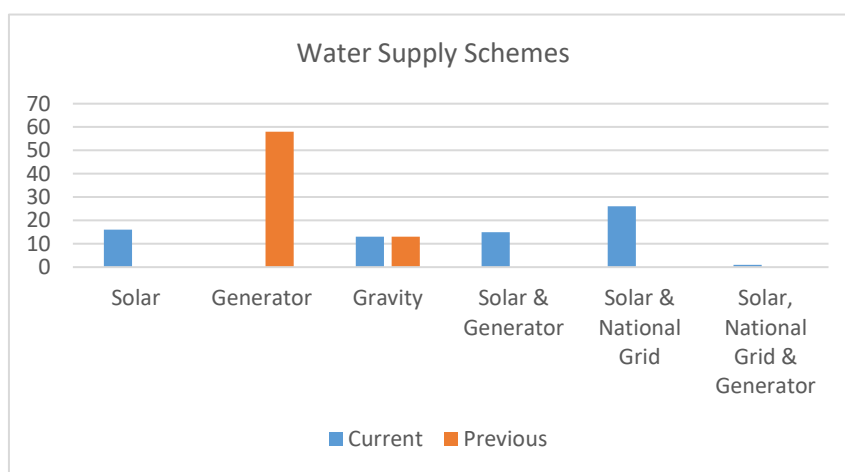


Figure 2: Power Technology Transitioning in Water Supply schemes

58 schemes (82%) relied entirely on diesel generators and 13 (18%) operated under gravity-fed systems. Following the transition to renewable energy, 58 schemes (82%) now utilize solar power, of which 16 schemes (27%) operating entirely on solar without backup, 26 schemes (45%) combining solar with grid electricity, 15 schemes (26%) using solar with backup generators and 1 scheme use both solar, grid electricity and generator backups. The remaining 13 schemes (18%) out of 71 schemes continue to operate under gravity-fed systems as presented in Figure 2.

The transition from diesel generators to solar power in water supply schemes delivers substantial environmental, economic, and operational benefits. By replacing diesel-powered systems, solar energy eliminates direct greenhouse gas (GHG) emissions, including CO₂, CH₄, and N₂O, which are produced during fuel combustion. According to the IPCC (2006),

estimated population of 328,726 people, with a projected annual water demand of 2,999,627.56 m³, based on the Tanzania ministry of water design manual volume I (MoW, 2020). Under the previous system, which relied on diesel generators, the water schemes produced only 1,003,148.40 m³ per year meeting just 33% of the total water demand as seen in Figure 3. This limited output was primarily due to the high operational costs, frequent breakdowns, and limited run-times of diesel generators, which constrained the consistent delivery of water.

Following the adoption of solar-powered pumping systems, water production has significantly improved to 1,671,914.00 m³ per year as seen in figure 3. This increase has raised the demand coverage from 33% to approximately 56%, with the consideration that, the same sources are used. The improved water production capacity is attributed to the operational

reliability and longer service hours enabled by solar technology, which allows the pumps to run more consistently throughout the day without the fuel limitations associated with diesel.

Following the adoption of solar systems, operational GHG emissions were extensively reduced as seen in figure 5, which shows a comparison between scheme using generator only and the one using solar

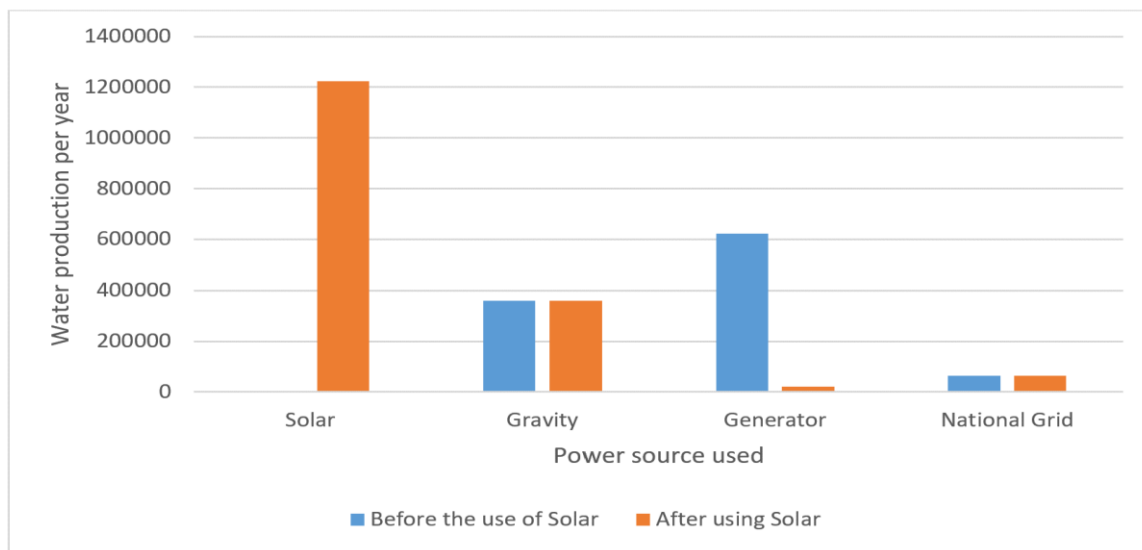


Figure 3: Water production before use of solar power and after adopting solar power

These findings are consistent with other studies that have assessed the impact of solar-powered systems on rural water supply. This improvement aligns with findings by (Meyer and Von Solms, 2018) who reported a 60–80% boost in water supply after solar transitions in South Africa, attributing gains to uninterrupted pumping. Similarly, Water Mission-Tanzania (2017) observed a 50% demand coverage increase in Tanzanian solar schemes, while (Armstrong et al., 2017) noted that solar systems in eight African countries consistently outperformed diesel pumps in reliability and output.

3.2.3 Greenhouse Gas (GHG) Emission Reductions

The transition from diesel-powered to solar-powered water schemes in the Manyara Region resulted in a substantial reduction in greenhouse gas (GHG) emissions. Prior to the transition, diesel generators consumed an estimated 276,981.83 liters of fuel annually, producing approximately 734,832.81 kg of CO₂ emissions (734.83 tCO₂e). Figure 4 show emission produced from each scheme.

The solar energy generation produces no direct emissions. However, due to the presence of diesel backup systems, an additional 54,379.73 liters of diesel is still consumed annually, contributing 144,269.43 kg of CO₂ emissions (144.27 tCO₂e). This represents a net reduction of 590,563.38 kg of CO₂ per year, equivalent to an 80.3% decrease in annual emissions compared to the previous fully diesel-dependent system.

These findings align with (Olatomiwa et al., 2015) who reported a 75–90% reduction in CO₂ emissions when replacing diesel generators with hybrid solar PV systems in rural Nigeria. Similarly, (Kaundinya et al., 2009) found that solar water pumping in India reduced diesel consumption by 80–95%, depending on system design and solar resource availability. The observed 86.3% reduction in the Manyara Region falls within this range, reinforcing the global potential of solar energy in mitigating GHG emissions from decentralized water supply systems.

3.2.4 Economic Benefit of the Intervention

The reduction of greenhouse gas (GHG) emissions achieved by transitioning from diesel

generators to solar-powered water schemes not only benefits the environment but also presents an economic opportunity through carbon credit markets. Under international climate finance mechanisms, each tonne of CO₂ avoided (1 tCO₂e) is equivalent to one carbon credit, which can be traded in a voluntary or compliance carbon markets (World Bank, 2023).

Carbon finance is a viable strategy to enhance the

590.56 tCO₂e could theoretically generate an equivalent number of carbon credits that worth over \$56,693.76 per year, providing a potential revenue stream to offset the upfront costs of solar infrastructure and fund further renewable energy projects.

3.2.5 Energy and Economic Performance

This transition has also led to substantial

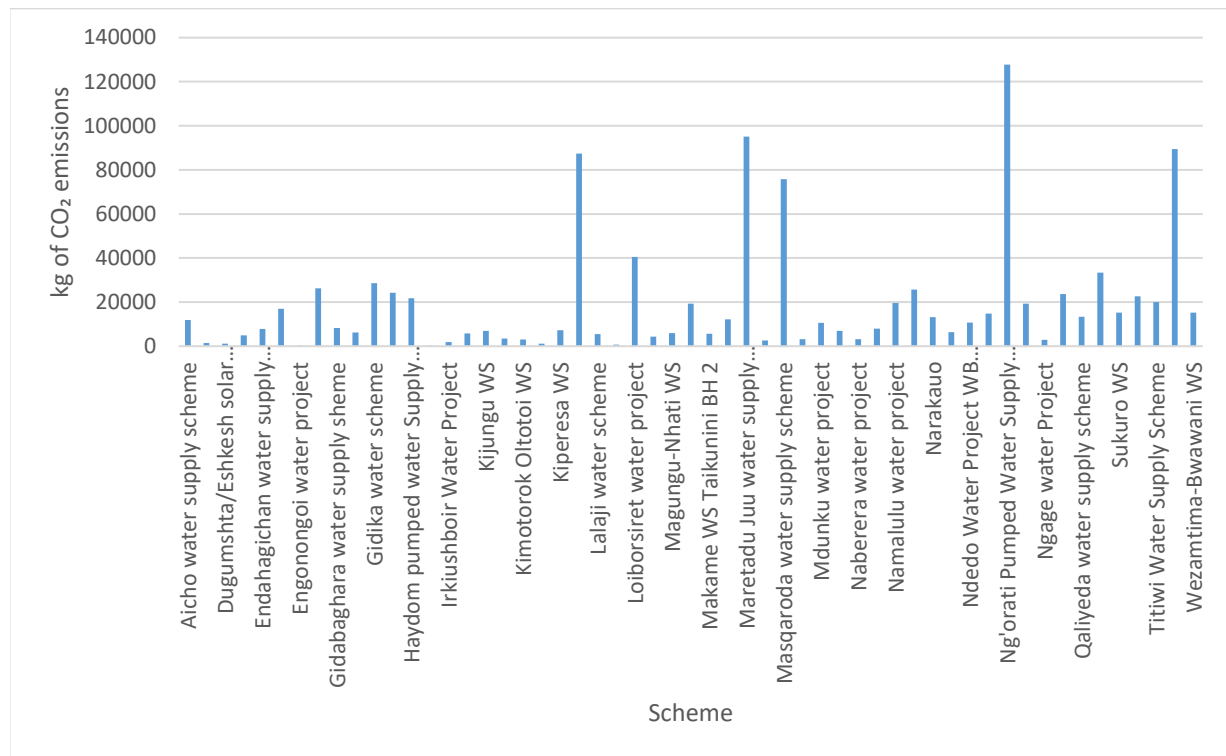


Figure 4: Quantity of CO₂ emissions produced in each scheme

financial sustainability of solar water initiatives, as demonstrated by similar projects in East Africa (GIZ, 2023). The credits are typically monetized through platforms such as the Verified Carbon Standard (VCS) or Gold Standard, where buyers (corporations, governments, or NGOs) purchase credits to compensate for their own emissions (Hamrick and Gallant, 2017). As per ICIS Carbon Market Coverage (ICIS, 2024), the prices for eligible credits averaged \$96 per tCO₂e. Projects in developing countries, particularly those aligned with the Clean Development Mechanism (CDM) or Article 6 of the Paris Agreement, often attract premium pricing due to co-benefits like rural development and improved health (UNFCCC, 2021). Therefore, the annual reduction of

improvements in both energy efficiency and economic performance. Under the previous diesel-based system, an estimated 969,436.43 kWh of electricity was generated annually, consuming approximately 276,981.84 liters of diesel fuel. Due to the high operational costs of diesel, generators were limited to 5–7 hours of daily operation, restricting water production. In contrast, the solar-powered system now operates for 10–11 hours daily, resulting in increased water production and an annual energy consumption of 1,194,580.12 kWh, a 23.2% increase in energy utilization without additional fuel expenses as seen in figure 6. This extended operation time underscores the reliability and cost-effectiveness of solar energy, as it

significantly reduces fuel costs and reduces operational downtime.

(Girma et al., 2015) observed a 30% increase in water supply reliability after switching to solar pumps in Ethiopia, attributing the improvement to longer operational hours and reduced fuel dependence. Similarly, (Mboumboue and Njomo, 2016) reported that solar water pumping systems in Cameroon achieved 20–25% higher energy output compared to diesel systems, with significantly lower long-term

leads rural water access to the availability and reliability of energy. Consequently, the success of national water coverage targets is contingent upon parallel progress in rural electrification, whether through grid extension or decentralized solar-powered mini-grids. Conversely, the national energy strategy's heavy reliance on climate-vulnerable hydropower exposes water services to disruptions from droughts, underscoring the need for a diversified energy mix incorporating solar and natural gas to enhance water security. These results demonstrate that sectoral silos

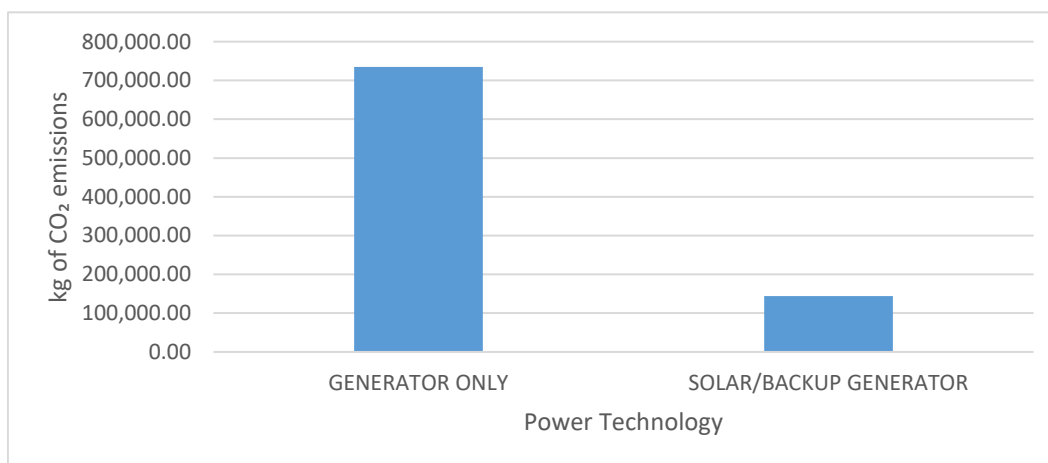


Figure 5: Quantity of CO₂ Emission (kg of CO₂) previously (Using Generator) and Currently (Using Solar)

costs. The economic benefits are further emphasized by (Odou et al., 2020), who found that solar-powered schemes in Niger reduced water production costs by 40–60% over a five-year period due to minimal maintenance and zero fuel expenditure. The Manyara Region's experience reinforces these trends, demonstrating that solar energy not only enhances water supply efficiency but also offers a more sustainable and economically viable solution for rural communities.

3.2.6 Policy Implications on Rural Water Governance and National Energy Strategy

The analysis reveals that the efficacy of Tanzania's rural water and energy strategies is critically interdependent, necessitating integrated nexus governance. A primary finding is that the policy-driven shift towards modernized water services, particularly motorized boreholes and piped systems, inadvertently

in planning and financing lead to suboptimal outcomes; therefore, a mandatory cross-sectoral approach is imperative. This would involve co-locating water and energy infrastructure projects, developing blended finance models, and implementing Water-Energy Nexus Impact Assessments to build a resilient foundation for sustainable rural development.

3.2.7 Challenges and Limitations

Despite the significant reduction in greenhouse gas (GHG) emissions achieved by transitioning to solar-powered water schemes, several challenges and limitations were encountered. First, the intermittency of solar energy necessitated the continued use of diesel backup systems, which accounted for 14% of the original emissions, highlighting the dependency on conventional fuel during periods of low solar irradiance or system malfunctions. This issue is consistent with findings by (Szabó et al., 2016), who

noted that hybrid systems in sub-Saharan Africa often initial capital investments. Challenges such as reliance

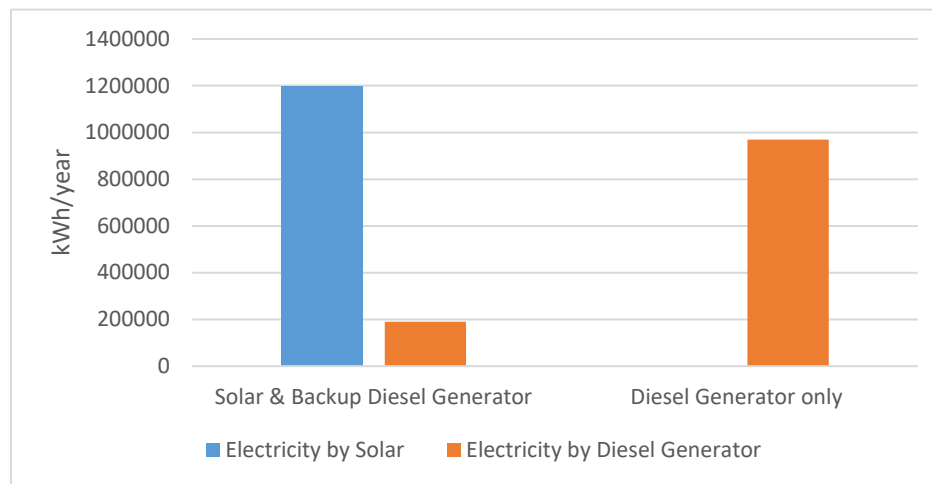


Figure 6: Electricity produced for each power technology

require supplementary diesel generation due to seasonal weather variability. Second, high initial capital costs for solar photovoltaic (PV) installations and battery storage posed financial barriers. Additionally, maintenance and technical capacity gaps were observed, as local operators lacked specialized training in solar system upkeep, leading to occasional inefficiencies. Finally, data limitations, such as reliance on estimated diesel consumption records rather than real-time fuel monitoring, may have introduced minor inaccuracies in emission calculations. These constraints suggest that while solar energy offers a viable pathway for emission reductions, further improvements in energy storage, financing mechanisms, and technical training are needed to maximize its sustainability.

4. Conclusion

The transition from diesel generators to solar-powered water schemes in Manyara Region has proven to be a transformative intervention for climate mitigation and rural development. By replacing diesel-dependent systems, solar energy reduced annual CO₂ emissions by 80.3%, equivalent to 590,563.38 kg of CO₂, while simultaneously extending daily operational hours and improving water supply reliability. Economically, solar systems eliminated fuel expenses and lowered long-term maintenance costs, despite

on backup generators due to reduced solar irradiance during rainy season and technical capacity gaps highlight the need for improved energy storage and local training. Nonetheless, this study underscores the viability of solar energy as a sustainable alternative for rural water infrastructure, supporting Tanzania's climate commitments and offering a replicable model for other regions. Future efforts should focus on scaling solar adoption, enhancing hybrid systems, and securing financing to maximize environmental and socio-economic benefits.

Author Contributions: Hassani Amiri prepared the Outline, carried out Analysis, interpreted the results, wrote the original draft, and responded on the review and editing. Clarence P. Kisiki and Tulinave B. Mwamila provided the review and editing of the manuscript draft in writings, Visualization and Supervision. All authors have read and agreed to the published version of the manuscript.

Acknowledgements: The author acknowledges with deep gratitude the Almighty God for His grace, wisdom, and strength throughout the academic journey. Sincere appreciation is extended to the OIKOS East Africa for data provision and financial support. The author is also thankful to Rural Water Supply and Sanitation Authority (RUWASA)-Manyara for official hosting and technical support, as well as to

the Water Institute and its staff for providing a conducive learning environment.

Conflict of interest: The authors confirm that this research was performed with no conflict of interest.

Sponsors: Oikos East Africa provided both relevant technical data and financial support for the research.

Data availability: All relevant data are included in the paper or it's Supplementary Information.

5. References

- Amakom, C. M., Ogungbenro, O. A., Iheonu, N. O., Nkwoada, A., Iwueke, D. C., Anya, J., and Okoye, J. (2022). Annual Carbon Footprint From Local Electricity Generation in Federal University of Technology, Owerri, Imo State, Nigeria. *Environmental Health Insights*, 16. <https://doi.org/10.1177/11786302221136732>
- Antonio, G., and Patricia, E. (2021). United Nations Climate Change Report 2021. https://unfccc.int/sites/default/files/resource/UNFCCC_Annual_Report_2021.pdf Accessed August 8, 2025.
- Armstrong, A., Mahan, J., and Zapor, J. (2017). Solar pumping for rural water supply: life-cycle costs from eight countries.
- Burney, J., Woltering, L., Burke, M., Naylor, R., and Pasternak, D. (2010). Solar-powered drip irrigation enhances food security in the Sudano-Sahel. *Proceedings of the National Academy of Sciences of the United States of America*, 107(5), 1848–1853. <https://doi.org/10.1073/pnas.0909678107>.
- Eggleston, H. S. (2006). 2006 IPCC guidelines for national greenhouse gas inventories. Institute for Global Environmental Strategies.
- Energy Agency, I. (2022). World Energy Outlook Special Report Africa Energy Outlook 2022. www.iea.org/tandc/ Accessed August 8, 2025.
- Girma, M., Assefa, A., and Molinas, M. (2015). Feasibility study of a solar photovoltaic water pumping system for rural Ethiopia. *AIMS Environmental Science*, 2(3), 697–717. <https://doi.org/10.3934/environsci.2015.3.697>.
- GIZ. (2023). Study on carbon market opportunities and technologies for Seven Eastern Africa Countries. www.promethium.co.za Accessed August 8, 2025.
- Hamrick, K., and Gallant, M. (2017). Unlocking potential: state of the voluntary carbon markets 2017. Forest Trends' Ecosystem Marketplace.
- Hassan, Q. F. (2023). Solar Powered Water Pumping System for a Rural Village. *Ecological Engineering and Environmental Technology*, 24(2), 214–223. <https://doi.org/10.12912/27197050/157094>.
- International Energy Agency. (2022). International Energy Agency (IEA) World Energy Outlook 2022. International Information Administration, 524. <https://www.iea.org/reports/world-energy-outlook-2022> Accessed August 8, 2025.
- Kaundinya, D. P., Balachandra, P., and Ravindranath, N. H. (2009). Grid-connected versus stand-alone energy systems for decentralized power-A review of literature. In *Renewable and Sustainable Energy Reviews* (Vol. 13, Issue 8, pp. 2041–2050). <https://doi.org/10.1016/j.rser.2009.02.002>.
- Kristen, C., Isack, A., and Elisekile, M. (2018). Study of solar-powered prepaid water systems in Tanzania.
- Little, M., Richter, A., Eales, A., and Müller-Karpe, Z. (2023). A review of the standards, methodologies, technical needs and available resources related to digital monitoring, reporting and verification for modern cooking devices in the context of carbon finance. Modern Energy Cooking Services (MECS).

<https://www.gov.uk/research-for-development-outputs/a-review-of-the-standards-methodologies-technical-needs-and-available-resources-related-to-digital-monitoring-reporting-and-verification-for-modern-cooking-devices-in-the-context-of-carbon-finance> Accessed August 8, 2025.

- Mboumboue, E., and Njomo, D. (2016). Potential contribution of renewables to the improvement of living conditions of poor rural households in developing countries: Cameroon's case study. *Renewable and Sustainable Energy Reviews*, 61, 266–279. <https://doi.org/https://doi.org/10.1016/j.rser.2016.04.003>.
- Meyer, J., and Von Solms, S. (2018). Solar Powered Water Security: An Enabler for Rural Development in Limpopo South Africa. *IEEE Access*, 6, 20694–20703. <https://doi.org/10.1109/ACCESS.2018.2805367>.
- Odou, O. D. T., Bhandari, R., and Adamou, R. (2020). Hybrid off-grid renewable power system for sustainable rural electrification in Benin. *Renewable Energy*, 145, 1266–1279. <https://doi.org/10.1016/j.renene.2019.06.032>.
- Oji, C., Soumonni, O., and Ojah, K. (2016). Financing Renewable Energy Projects for Sustainable Economic Development in Africa. *Energy Procedia*, 113–119. <https://doi.org/10.1016/j.egypro.2016.07.158>.
- Olatomiwa, L., Mekhilef, S., Huda, A. S. N., and Ohunakin, O. S. (2015). Economic evaluation of hybrid energy systems for rural electrification in six geo-political zones of Nigeria. *Renewable Energy*, 83, 435–446. <https://doi.org/10.1016/j.renene.2015.04.057>.
- Renewable Energy Agency, I. (2022). Renewable power generation costs in 2021. www.irena.org Accessed August 8, 2025.
- Shame, B. H., Ubaidillah, Tjahjana, D. D. D. P., Arifin, Z., Aziz, M., Harwijayanti, W., and Haji, M. M. (2024). The renewable energy research contribution of Tanzania: A review. *Communications in Science and Technology*, 9(1), 65–86. <https://doi.org/10.21924/cst.9.1.2024.1348>.
- Sharma, V. (2022). Sustainable Energy System: Case study of Solar Water Pumps. *Journal of Artificial Intelligence, Machine Learning and Data Science*, 1(1), 112–115. <https://doi.org/10.51219/jaimld/vibhu-sharma/45>.
- Szabó, S., Moner-Girona, M., Kougias, I., Bailis, R., and Bódis, K. (2016). Identification of advantageous electricity generation options in sub-Saharan Africa integrating existing resources. *Nature Energy*, 1(10). <https://doi.org/10.1038/nenergy.2016.140>.
- URT. (2021). National Climate Change Response Strategy (2021-2026). United Republic of Tanzania, Vice President's Office, Division of Environment, 146.
- US Environmental Protection Agency. (2024). Greenhouse Gases Equivalencies Calculator - Calculations and References. US Environmental Protection Agency, 1–29. <https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references> Accessed August 8, 2025.
- World Bank. (2023). State and Trends of Carbon Pricing 2023. <https://doi.org/10.1596/978-1-4648-2006-9>