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Promotion and Dissemination of Small-scale Renewable Energy Technologies and Its Implication on Sustainable Forest Management: Lesson from Ethiopia

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ABSTRACT

Small-scale renewable energy technologies (RETs), such as improved cook stoves (ICS), solar power, and biogas, are recognized as crucial for mitigating deforestation and greenhouse gas emissions. While various organizations have distributed these RETs throughout Ethiopia for diverse purposes, limited evidence exists on their actual impact and the challenges hindering widespread adoption. This paper reviews existing research and key informant interviews to identify both the contributions and barriers specific to these RETs. The findings demonstrate that promoting selected RETs significantly decreases household biomass consumption, which in turn lowers forest degradation and greenhouse gas emissions. Specifically, using ICS and biogas technologies can reduce annual carbon dioxide equivalent emissions by 0.56 to 5.67 million tons and wood fuel consumption by 0.3 to 3.1 million tons. However, the potential wood fuel savings from currently disseminated biogas plants and ICS offset less than 7.2% of Ethiopia's overall annual biomass energy demand. Several obstacles impede the broader adoption of RETs, including technical, financial, market, institutional, and infrastructural limitations. This study suggests that greater sector integration, robust financial institutions, capacity-building centers, active community engagement, and the development of renewable energy sources are essential for wider dissemination of RETs.

INTRODUCTION

Globally, it's estimated that forests cover 4.06 billion hectares and contain approximately 668 gigatons of above and below-ground biomass (FAO, 2020). Despite this, the total global tree-growing stock has slightly declined from 560 billion cubic meters in 1990 to 557 billion cubic meters in 2020, largely due to a net decrease in forest area. Consequently, carbon stock in these forests has also decreased, falling from 668 gigatons to 662 gigatons between 1990 and 2020 (FAO, 2020; UN, 2021). Studies suggest that if current deforestation rates persist, an estimated 2.76 billion megagrams of carbon stored in Ethiopian forest vegetation could be released into the atmosphere within the next 50 years (FRL, 2016; Meragiaw et al., 2021). A primary driver of forest loss, particularly in developing nations like Ethiopia, is the heavy reliance on fuelwood for energy (Girma et al., 2024).

Ethiopia's rapidly growing population is driving increased fuelwood demand, which, in turn, intensifies deforestation and forest degradation, hindering sustainable forest management (Wassie, 2020; Abebaw, 2024). This reliance on wood-based biomass for energy, coupled with inefficient technologies, is a major contributor to both deforestation and greenhouse gas (GHG) emissions (Belachew et al., 2022; Kefalew et al., 2021; Tiruye et al., 2021). Traditional fuels like charcoal, fuelwood, dung cakes, and agricultural residues remain dominant in Ethiopia's energy mix, presenting significant health and environmental hazards (Mekonnon, 2022; Seboka et al., 2023).

Fuelwood collection is also a significant driver of forest degradation across Sub-Saharan Africa, including Ethiopia (Mperejekumana et al., 2024). Ethiopia experienced substantial annual forest loss of approximately 140,000 hectares between 1990 and 2010 (Dresen, 2014). Consequently, under a business-as-usual scenario, Ethiopia's GHG emissions are projected to rise dramatically, from 150 to 400 Mt carbon dioxide equivalents (CO_2e) between 2010 and 2030 (Kefalew et al., 2021).

Ethiopia is actively pursuing renewable energy as a solution to address widespread energy inefficiency and limited access to modern energy services like electricity (Amare, 2014; Kamp and Forn, 2016; Arega and Tadesse, 2017). The country is committed to developing RETs for a sustainable future. Specifically, biogas plants, solar photovoltaic panels, and ICS are being promoted and implemented (Marie et al., 2021). This focus on sustainability reflects a broader global trend, heightened by the 2015 United Nations Sustainable Development Summit (Fashina et al., 2018). This summit emphasized the need for collaboration among various stakeholders to adopt cleaner cooking solutions (Hewitt et al., 2018). Consequently, numerous researchers have underscored the importance of disseminating and adopting RETs, recognizing their socio-economic and environmental advantages at all levels (Wassie and Adaramola, 2019).

Numerous studies indicate that Ethiopia has abundant renewable energy potential, which can meet its rising energy demand and spur sustainable economic growth (Tiruye et al., 2021). The Ethiopian National Biogas Program shows that a single biogas digester can conserve approximately 0.3 hectares of forest each year by lowering fuelwood use and can also mitigate up to 4 tons of CO_2e annually through carbon sequestration and emission reductions (GIZ, 2014). Moreover, the ICS program, among various stove initiatives in Ethiopia, achieves roughly a 40% fuelwood reduction over traditional stoves. This translates to an annual CO_2 emission saving of 11,800 tons, equivalent to the carbon storage of over 30 hectares of forest (Dresen et al., 2014).

To address fuelwood consumption and greenhouse gas emissions, a variety of strategies are being implemented, which include promoting ICS and encouraging changes in cooking behaviors (Mamuye et al., 2018). In Ethiopia, the national ICS program has already achieved the dissemination of around 9 million ICS, with the ambitious goal of distributing 31 million by 2030. This paper provides a detailed assessment of ICS, biogas, and solar photovoltaic (PV) technologies, evaluating their impact on sustainable forest management and greenhouse gas mitigation. The study also explores the various challenges that hinder the adoption of ICS, biogas, and PV, such as technical, sociocultural, financial, institutional, and informational barriers.

METHODS

This research combined a comprehensive review of recent publications and documents with insights from key informant interviews (KII) with stakeholders and energy officials at both regional and federal levels in Ethiopia. Articles were sourced from international databases including Web of Science, Scopus, Library Genesis, SCI-Hub, and Google Scholar. Additional data came from books, conference proceedings, and working papers focusing on the adoption of renewable energy technologies (biogas plants, solar panels/ photovoltaic cells, and improved cook stoves) across Ethiopia. This collected literature was rigorously reviewed, screened, and organized to extract relevant qualitative and quantitative data.

A detailed literature review then explored barriers hindering the spread of these technologies and their impact on sustainable forest management and greenhouse gas reduction. The findings from this material were synthesized using a narrative approach and presented in tables, figures, and summaries. Finally, to meet the study's objectives, systematic analysis tools were applied to the reviewed articles, allowing for the creation of case studies and the extraction of qualitative and quantitative data following the data collection methods outlined in Figure 1.

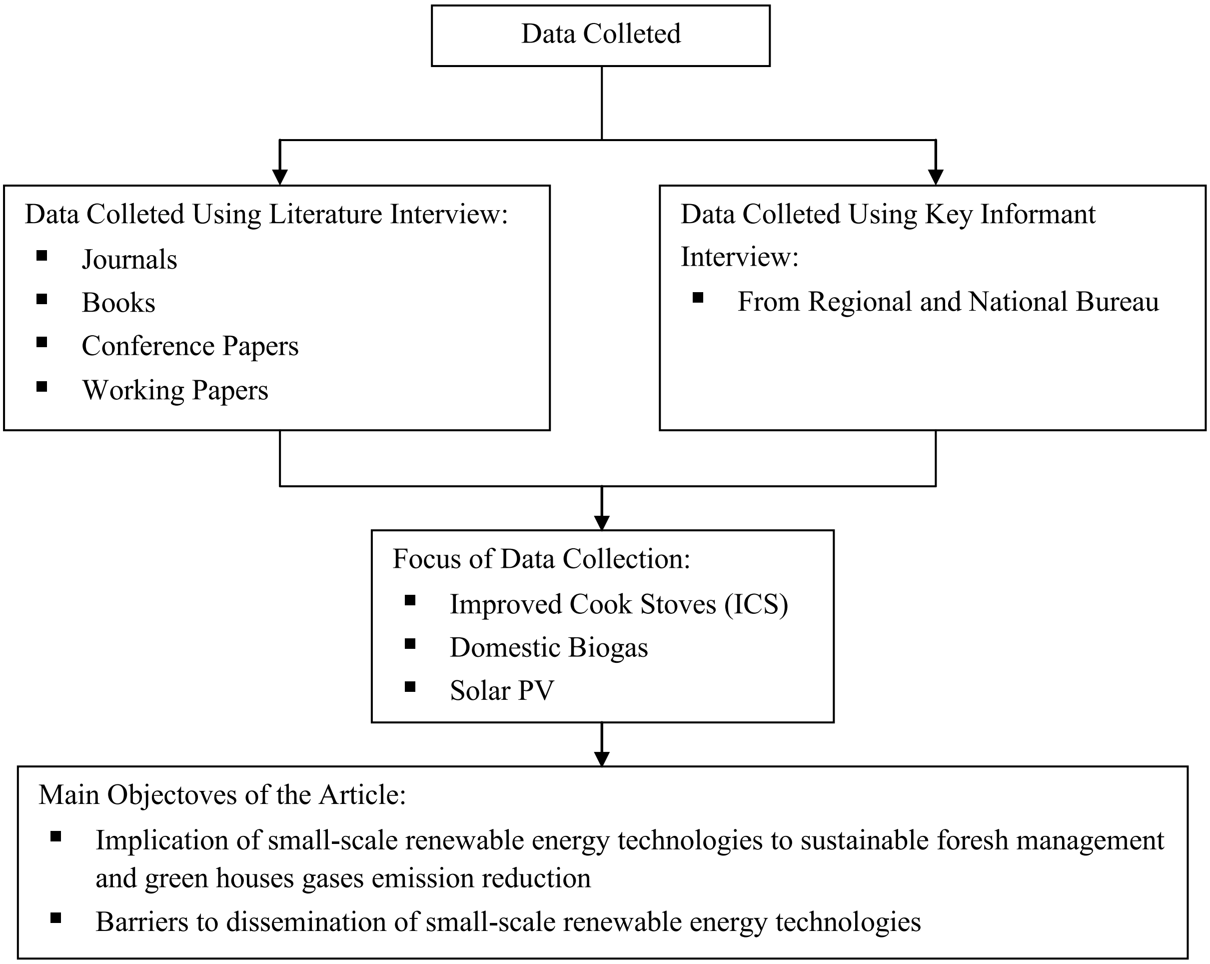

Figure 1. A process flow diagram for the search of articles and data collection method

The targeted RETs are biogas, ICS, and solar PV which are included in the result sections.

RESULTS AND DISCUSSION

Implication of Small-Scale Rets on Sustainable Forest Management and GHGS Emission Reduction

Africa's forests face severe depletion, ranking among the most degraded globally. In 2009 alone, approximately 3 million hectares were lost due to activities related to woodfuel production, collection, and use (Hall, 2024). Woodlands and forests function as both carbon reservoirs and carbon sinks; their role is dependent on their management and utilization (Pelletier et al., 2018; Domke et al., 2020). The depletion of natural forests for woodfuel extraction can diminish carbon sequestration capacity, potentially resulting in a net increase in CO2 emissions if mitigation strategies are not adopted. Current woodfuel extraction methods in African nations like Ethiopia pose a significant obstacle to achieving Sustainable Development Goal 15, which emphasizes forest protection, restoration, sustainable management, combating desertification and land degradation, and biodiversity conservation. Unfortunately, the effectiveness of stakeholders responsible for safeguarding and monitoring these forests has been limited (Gisladottir et al., 2020; Mensah et al., 2020).

Improved Cookstoves

By 2030, ICS is projected to save the residential sector 241 petajoules (PJ) of energy compared to traditional stoves, a 13.4% reduction achieved through ICS promotion and dissemination (Mondal et al., 2018). The majority of these savings, 233.2 PJ, will stem from decreased firewood demand, with an additional 7.7 PJ saved from other biomass sources. Given Ethiopia's high reliance on biomass energy to 2030, these energy savings offer benefits for GHG emissions and sustainable forest management. Specifically, increased ICS adoption could lower GHG emissions by 0.8 million metric tons (mmt) of CO2e in 2020 and 1.8 mmt of CO2e in 2030. This translates to a

3.5% and 5.8% reduction in GHG emissions respectively in 2020 and 2030, compared to a baseline scenario without ICS. The ICS scenario holds substantial promise for reducing GHG emissions and specifically is projected to help reduce about 5.8% of GHG emissions in 2030 relative to the reference pathway (Mondal et al., 2018).

Studies demonstrate that using ICS instead of traditional inefficient ones significantly reduces biomass consumption. This, in turn, combats forest degradation and alleviates health issues stemming from indoor air pollution (Adane et al., 2020). Research in East Africa, specifically Ethiopia, indicates that ICS can decrease household fuelwood use by 22% to 46% annually compared to traditional stoves (Hanna et al., 2016). However, actual fuel savings are influenced by stove type, design, food being cooked, cooking duration, and stove size (Hanna et al., 2016). Comparatively, Wassie and Adaramola (2019) found ICS to use 33% less fuel and produce 75% fewer CO2e emissions than traditional stoves.

Studies in Ethiopia have demonstrated significant benefits of using ICS. Gebreegziabher et al. (2012) found that households in the Tigray region using ICS collected approximately 70 kg less fuelwood and 20 kg less animal dung monthly, resulting in a yearly fuelwood saving of 840 kg per household. Further research by Beyene et al. (2015) indicated that ICS usage in rural Ethiopia saves an average of 634 kg of fuelwood and 0.94 tons of carbon equivalents per year. A study in the Kafa area (Deresen et al., 2014) highlighted ICS's dual role in reducing pressure on forests and mitigating climate change when used effectively. Specifically, an assessment of 11,000 “Mirt” stoves found a 40% fuelwood saving in injera baking compared to traditional stoves. This translated to an annual saving of 1.28 tons of fuelwood per household and a total reduction of 11,800 tons of CO2e emissions from 11,156 ICS used in the district.

Each ICS is estimated to decrease wood fuel consumption by 3.03 million tons. With 3.3 million ICS currently being used in Ethiopia, this translates to annual savings of 5.54 million tons of CO2e emissions (Wassie and Adaramola, 2019). The considerable fuelwood savings observed are particularly vital in regions facing fuel shortages, as they directly combat forest degradation. These findings highlight the significant role of ICS in supporting sustainable forest management, reducing greenhouse gas emissions, and easing pressure on diminishing forest resources. This ultimately strengthens climate change mitigation at both local and national levels.

Improved cook stoves are crucial for mitigating emissions from deforestation and forest degradation (Adane et al., 2021; Parker et al., 2016). For instance, a study by Kedir et al. (2019) in Southern Ethiopia compared the biomass consumption and emissions of ICS, Mirt, and Gonzie stoves against traditional stoves (see Table 1). Their findings revealed that the Gonzie stove reduced fuelwood usage by 34-54% compared to traditional open fires. Furthermore, Gulilat and Wedajo (2014) found that the Gonzie stove saved 41% of fuel when baking injera, compared to traditional methods. Variations in the firewood-saving performance of different ICS models likely stem from differences in stove design (Dresen et al., 2014) and the materials used in their construction (Mamuye et al., 2018).

Table 1. Summary of ICS contribution to fuelwood saving and emission reduction

Stove type	Fuel-saving	Emission reduction	Study Sites	References
Mirt stove	22-47.8%		Ethiopia	Dresen et al., 2014; Biratu, 2016; Kedir et al., 2019; Manaye et al., 2022
Tikikil stove	18%		Tigray Ethiopia	Manaye et al., 2022
Lakech	23%		Dodola, Ethiopia	Mamuye et al., 2018
Mirchaye	32%		Dodola, Ethiopia	Mamuye et al., 2018
Gonzie	51%		Jogo-Gudedo, Ethiopia	Assefa, 2016
Gonzie	34-54%		Southern Ethiopia	Kedir et al., 2019
ICS	29%		Bale Eco-region, Ethiopia	Gizachew and Tolera, 2018
Standard fuel-saving stoves could	50%	663.52 tons of carbon could be reduced.	Ethiopia	Addisu and Alemie, 2020
Mirt stove	50%		Ethiopia	Addisu and Alemie, 2020
Mirt	50%	14ha forest /ha/year 980 tCO_2/stove/year	Rural Ethiopia	Alemayehu, 2015
Gonzie	64%	18ha forest /ha/year 1269 tCO_2/stove/year	Rural Ethiopia	Alemayehu, 2015
Lakech	25%	7.3ha forest /ha/year 503 tCO_2/stove/year	Rural Ethiopia	Alemayehu, 2015
Mirt stove	31%		Dilla, Ethiopia	Yayeh et al., 2021
	22–31%		Ethiopia	Gebreegziabher et al., 2012
Mirt stove	634 kg	0.94 tons of carbon equivalent per year	Ethiopia	Beyene et al., 2015

Domestic Biogas

Several studies (Kefalew et al., 2021; Desta et al., 2020) have established that implementing small-scale biogas plants significantly curtails woodfuel reliance at the household and local levels. A case study in the Fogera district of Northern Ethiopia (Amare, 2015) provides concrete data: annual household fuelwood consumption fell from 3596 kg to just 1062 kg, achieving a remarkable 70% reduction. Before biogas implementation, these households consumed an average of 324 kg of charcoal yearly; this use completely stopped after the installation of biogas plants. Animal dung cake consumption for fuel also saw a dramatic decrease. While households had previously used between 138 and 230 kg annually, this fell to between 11.5 and 46 kg after biogas adoption, corresponding to an 80-92% reduction (Amare, 2015).

According to a study by Tajebe (2016), the dissemination of 10,678 biogas plants in the country from 2008 to 2014 led to substantial reductions in traditional fuel use. Specifically, it was estimated that 8,732 tons of charcoal and 27,162 tons of fuelwood were saved annually, along with the substitution of 66,463 tons of biomass and 485 tons of fossil fuel with biogas. The study calculated that, on average, a biogas user consumed 818 kg less charcoal and 2,544 kg less fuelwood yearly. This resulted in an estimated annual reduction of 64,684 tons of CO2e emissions from these plants. Likewise, Mengistu et al. (2016) found that biogas-user households in rural Ethiopia reduced their greenhouse gas emissions by an average of 1.9 tons of CO2e per plant per year, and saved about 1,038 kg of fuelwood per year. These results suggest that biogas plants offer a pathway to decreasing the country's dependence on forests for fuel, thus aiding in greenhouse gas reduction and climate change adaptation.

To update national figures, a conservative estimate of woody biomass savings and CO2e emission reductions from domestic biogas plants and ICS can be derived from empirical evidence. For instance, Wassie and Adaramola (2019) estimated that Ethiopia's 15,000 biogas plants save approximately 0.071 million tons of wood and reduce CO2e emissions by 0.13 million tons annually. However, the Ethiopian biomass energy strategy and action plan (MoWIE, 2014) reports that the country consumes about 60 million tons of biomass for energy each year, with fuelwood for cooking accounting for 81% of this total. Therefore, existing biogas and ICS programs are currently only meeting about 5.2% of the country's total biomass energy demand.

Research indicates that biogas adoption contributes to a partial shift in household energy sources, moving away from wood fuel towards renewable and cleaner alternatives. This trend supports the 'energy ladder' hypothesis, suggesting a progression from fuelwood to electricity with rising household income and improved access to renewable energy (Hosier and Dowd, 1987). Nevertheless, studies demonstrate that biogas adopters often continue to utilize fuelwood and animal dung. For instance, Amare (2015) observed in Ethiopia that while biogas-adopting rural households reduced fuelwood consumption, they still relied on it for baking “injera” and used animal dung for other cooking needs. Likewise, Laramee and Davis (2013) found that both biogas adopters and non-adopters primarily used firewood for cooking. These results confirm that efficient biogas utilization can significantly reduce reliance on wood fuels, thereby mitigating deforestation, environmental damage, and greenhouse gas emissions stemming from the unsustainable consumption of traditional biomass and fossil fuels.

Between 2005 and 2015, Ethiopia distributed 3.3 million ICS and 15,000 biogas digesters (Wassie & Adaramola, 2019), aiming to reduce fuelwood consumption and greenhouse gas emissions. Each ICS or biogas plant is estimated to save 0.918 tons of fuelwood and 4.719 tons of CO2e emissions annually. This equates to a yearly national woodfuel saving of 3,029,400 tons per ICS and 70,791 tons per biogas plant, resulting in a greenhouse gas emission reduction of 5,543,802 tons of CO2e per ICS and 129,548 tons per biogas plant each year.

Table 2. Summary of biogas contribution to fuelwood saving and emission reduction

No.	Fuel-saving	Emission/deforestation reduction /Money saving	Study Sites	References
1	275,209 kg of firewood and 113,863 kg of charcoal per year	417.768 tons of CO_2e and saved 44.7 ha of forest trees per year.	Arba-Minch Zuria district in South Ethiopia	Tekle and Sime, 2022
2	1856.78 kg per year	n annual Carbon dioxide (CO_2) emission reduction capacity of 2.75 tons per biogas plant	Central Rift Valley, Ethiopia	Kefalew et al., 2021
3	1423.06 kg	2.1 tons of CO_2 e per biogas plant annually	Wondo Genet district, Southern Ethiopia	Desta et al., 2020
4	Saving 3847.2192 kilogram	1612 kilogramCO2e/Household per year (70.47%)	Amhara National Regional State, Fogera District, Ethiopia	Amare, 2014

5	Annual savings of 3833.28 Birr from fuel wood, and Birr 1243.20 from charcoal, respectively.		Amhara National Regional State, Fogera District, Ethiopia	Amare, 2014
6	1.067 tons of firewood /biogas annually per year.	2160.93kg CO_2e (52.6%) of GHG emission per year per household.	Aletawondo Woreda, Sidama Zone, South Ethiopia	Woldesilassie and Seyoum, 2017
7		1.9 t of CO2e per digester per year.	Northern Ethiopia, the Case of Ofla and Mecha Woredas	Mulu, 2016
8		221.85 tons of CO_2 saved annually and 1.53 t CO2 e per biogas digester/year.	Gimbi District, Western Ethiopia	Wakjira et al., 2024

Solar PV

Small-scale solar technologies, including Solar Home Systems (SHS), solar cookers, and solar photovoltaic (PV) water pumps, offer significant environmental benefits in sub-Saharan Africa, despite limited research documenting these effects, particularly in countries such as Ethiopia. Often, they are assumed to reduce dependence on traditional biomass fuels, leading to decreased forest degradation and greenhouse gas emissions (Guta, 2018). Specifically in East Africa, solar PV technologies are largely used for electricity generation for lighting and water heating (Wassie and Adaramola, 2019; Guta, 2018). Crucially, these technologies produce virtually no greenhouse gas emissions and can deliver electricity to off-grid communities, including millions of rural households, schools, and clinics. This shift away from fuelwood for lighting and heating allows solar PV to play a critical role in mitigating deforestation and greenhouse gas emissions.

Despite efforts to expand solar PV technology in rural East Africa, Amankwah-Amoah (2015) contends that it has done little to decrease reliance on biomass for cooking. They attribute this to the continued prevalence of biomass fuel use in countries like Ethiopia, arguing that PV technology fails to address inefficient biomass consumption in rural households. Consequently, they advocate for substantial investment in alternative, biomass-efficient technologies to foster responsible forest management and ensure long-term energy security in East African nations.

Barriers to RETs Promotion and Dissemination

Studies indicate that the expansion and integration of Renewable Energy Technologies (RETs) in Ethiopia are significantly hampered by several barriers. These include policy inadequacies, technical limitations, quality control issues, a lack of standardization, and economic and financial constraints (SNV, 2018). A key obstacle is insufficient public awareness regarding RETs (Fashina et al., 2018). Despite supportive policies and strategic plans for the renewable energy sector, effective implementation measures are lacking (Mekuria, 2016). Furthermore, information and awareness gaps exist not only among the public but also among designers and promoters of RETs (Kassa, 2019; Tiruye et al., 2021). Policymakers are also hindered by the limited availability of comprehensive and current energy data and maps (Kamp and Forn, 2016; Tiruye et al., 2021). This data scarcity extends to most renewable resources beyond solar and wind, affecting both national and regional planning. Ethiopia also struggles with a deficit of technical knowledge and skills, evidenced by the reliance on foreign experts for the installation and maintenance of solar plants, except for small-scale solar home systems (Kassa, 2019). Finally, the limited development and adaptation of energy technologies within Ethiopia poses a major challenge (Tiruye et al., 2021).

The successful adoption and accessibility of renewable energy technologies within communities hinges on the quality of associated products (Kassa, 2019; Boke, 2022). However, ensuring quality control in a free market economy presents challenges, particularly as high-quality products often demand substantial upfront investment (Mekonnen, 2022). A concerning trend is the prevalence of importers who neglect quality certification, and investors choosing solar equipment certified by less stringent African standards. This has led to a surge of substandard renewable energy technology in the country. While these low-quality components appear cheaper initially, their frequent replacement ultimately increases costs and negatively impacts the overall performance and efficiency of solar PV systems.

Financial and institutional factors are crucial for the promotion of RETs. A major constraint is the high initial investment cost (Kebede and Mitsufuji, 2017). While banks and institutions offer loans to support RET development, the Ethiopian energy sector remains largely government-controlled. Strong institutional support is vital for effective RET planning, adoption, and dissemination, connecting stakeholders from project initiation to financing. Establishing localized institutions based on regional resource availability is a promising strategy. These institutions can facilitate stakeholder networking, assist with funding (grants and loans), provide capacity-building training, conduct resource assessment research, address policy issues, and contribute to strategy development.

Currently, community involvement and ownership in renewable energy projects in Ethiopia are nascent (Kassa, 2019; Kefalew et al., 2021). Fostering local participation in fundraising and ensuring community ownership are crucial for plant security. When communities are engaged from the outset and feel a sense of ownership, addressing maintenance and sustainability challenges becomes more manageable. Ethiopia possesses substantial renewable energy resources, potentially allowing it to satisfy its domestic needs and export energy throughout Africa and beyond. However, several challenges impede the sustainable development of renewable energy in the nation. The subsequent sections will explore these key obstacles, summarized in Tables 3, 4, and 5.

Barriers to Solar PV Promotion and Dissemination

Numerous studies (as summarized in Table 3) demonstrate that the adoption of solar PV systems continues to be hampered by various sociotechnical barriers. These barriers are shaped by local conditions, national political and financial structures (Müggenburg, 2012), and growing concerns over the quality of solar products imported from China to countries like Ethiopia (Karakaya and Sriwannawit, 2015). This mistrust leads consumers to prefer more expensive alternatives (Pode, 2013). Furthermore, solar PV systems sometimes face competition from technologies more suitable for specific geographic regions.

Inadequate management also significantly impedes technology diffusion, especially in rural areas. A key issue is unsuitable business strategies for the target market. Specifically, strategies for rural electrification in low-income economies, using solar PV, should differ significantly from those used in high-income economies (Pode, 2013), requiring financial schemes like fee-for-service and microcredit (Karakaya and Sriwannawit, 2015). Neglecting after-sales service is another major barrier to PV system adoption in rural areas. The remoteness of many rural electrification sites limits access to information, technical assistance, and infrastructure, underscoring the necessity of ongoing monitoring and maintenance services even after purchase (Karakaya and Sriwannawit, 2015; Pode, 2013).

Table 3. Summary of main solar PV promotion and dissemination barriers

Category of barriers	Major systemic problems	References
Institutional barriers	• Unclear standards and regulations • Tax exemption problem • Lack of working culture and trust between users, suppliers, and companies • No clear and coherent policy	Gebreslassie, 2021; Tiruye et al., 2021; Mekonnen, 2022
Market barriers	• The high upfront cost of solar PV • Subsidized kerosene fuel • Conventional marketing strategy (put items in the shop and pay upfront) • Poor promotion and dissemination strategy (such as suppliers being far away from rural users) • Lack of awareness among rural users • Poor solar PV supply chains.	Girma, 2016; Kebede and Mitsufuji, 2017; KII, 2022
Network barriers	• Poor integration of actors • Conflicting approach among actors • Poor interaction between users and suppliers	Kebede and Mitsufuji, 2014; Kamp and Forn, 2016; Kassa, 2019
Infrastructural barriers	• Lack of supportive infrastructure • Lack of maintenance service	KII, 2022
Financial barriers	• Lack of finance for investment by local companies • Unavailability of loan (microcredit) systems and institutions for rural solar users • Less investment interest from existing financial institutions	Pode, 2013; Karakaya and Sriwannawit, 2015; Kebede and Mitsufuji, 2017
Capacity barriers	• Lack of skilled manpower for maintenance service • Lack of technical know-how of policymakers and customs officers • Lack of capability of rural users to prevent or fix minor problems • Lack of research and capacity building	Kebede and Mitsufuji, 2017; KII, 2022

Economic barriers significantly limit the widespread adoption of residential solar PV systems. Specifically, the cost of solar home systems is prohibitive in rural areas of many developing countries in Asia and Sub-Saharan Africa due to high total expenses, substantial initial investment, and limited payment flexibility (Pode, 2013; Karakaya and Sriwannawit, 2015). Moreover, factors like the lack of financing options in some regions such as Ethiopia often necessitate financial support to incentivize the adoption. (Karakaya and Sriwannawit, 2015).

Barriers to Biogas Promotion and Dissemination

The adoption of biogas technology is hindered by various factors, preventing it from reaching its intended targets (Mengistu et al., 2016). A primary challenge is the significant upfront investment cost, particularly burdensome for rural communities (Table 4). Researchers propose financial incentives, such as subsidies and soft loans, as a possible solution (Yousuf et al., 2016). However, other barriers persist, including a lack of understanding about the technology, insufficient private sector participation, limited availability of essential resources like manure and water, and negative perceptions surrounding the use of human excreta (Kamp and Forn, 2016). Moreover, technological issues and land scarcity also contribute to the slow adoption rate (Kelebe, 2018).

Effective dissemination of biogas technology is hindered by existing institutional barriers. The current institutional structure of the National Biogas Program of Ethiopia (NBPE), limited to federal and regional levels, does not adequately support program implementation in the field. The program's reliance on pre-existing woreda-level government structures without sufficient modification in the woreda mines and energy offices has resulted in a broken chain of command between regional and woreda offices (Kamp and Forn, 2016; Mengistu et al., 2016; Kelebe, 2018). This suggests a need for a more robust and integrated institutional framework.

Technical obstacles hinder biogas adoption. Existing domestic biogas systems don't produce enough energy to satisfy most Ethiopian households' needs (Kamp & Forn, 2016). Critically, biogas cannot replace traditional injera baking, which represents a major component (50-60%) of household energy consumption. The National Biogas Program Ethiopia and SNV actively promote biogas by involving various stakeholders (Gebreegziabher, 2007; Tiruye et al., 2021). While the NBPE has moved from a solo approach to a collaborative multi-stakeholder model for biogas technology dissemination (Boers et al., 2008), local technical support hasn't improved noticeably, and the dependability of existing biogas plants is still a concern (SNV, 2019). Independent initiatives are exploring alternative biogas models and business strategies to overcome the limitations of the standard approach (Kamp & Forn, 2016). Whether the NBPE will incorporate these complementary efforts remains to be seen (SNV, 2019).

Table 4. Summary of key biogas promotion and dissemination barriers

Category of barriers	Major systemic problems	References
Technical barriers	• Lack of standards and quality control measures • Inadequate availability of materials(feedstock) • Insufficient local research and development work • Poor design and construction • Lack of technical skills and training • Lack of local system performance documentation • Low rate of functional installed biogas systems/short lifespans	Kamp and Forn, 2016; World Bank, 2019; KII, 2022 KII, 2022
Financial/economic barriers	• High initial investment cost • Lack of financial mechanism • Inadequate subsidy • High transaction cost • High-risk perception by financial institutions • Poor financial conditions and purchasing power for households	Kamp and Forn, 2016; KII, 2022;
Information barriers	• Poor dissemination of information regarding the technology and incentives are given by the government. • Lack of awareness regarding substrates other than cattle dung for biogas generation	Hameer and Ejigu, 2020; Sawo, 2024
Socio-cultural barriers	• Taste and traditions • Strong preference for cooking tradition	World Bank, 2019

	• Lack of knowledge and awareness • Lack of social acceptance	
Policy & Institutional barriers	• Poor implementation of policies and insufficient government incentives • Lack of institutional coordination and collaboration • Absence of competition for construction and deficiency in marketing campaign • Lack of information and knowledge sharing • Lack of monitoring and follow-up services • Poor understanding of ownership and responsibility of the biogas system • Limited private sector involvement • Lack of extension network of the Bureaus of Agriculture for a large-scale dissemination program	Kamp and Forn, 2016; World Bank, 2019; Gebreslassie et al., 2022; KII, 2022; Lohani et al., 2023; Smarte Anekwe et al., 2024

Knowledge gaps and lack of awareness, often stemming from user behavior, contribute to the underutilization of biogas plants in the country (Kamp & Forn, 2016). For instance, inadequate feeding of bio-digesters directly hinders biogas production. Furthermore, water scarcity and drought, prevalent in many regions of Ethiopia, pose a significant obstacle (Kamp & Forn, 2016). The traditional fixed-dome model requires a consistent daily input of equal parts manure and water (Kamp & Forn, 2016). While approximately 50% of current bio-digesters are connected to toilets to address this water demand, the contribution from these connections remains insufficient compared to the digester's daily needs.

Barriers to Improved Cookstoves Promotion and Dissemination

Lack of cohesive strategy and resource limitations are significantly hindering the adoption of ICS. Despite broad government involvement, a lack of capacity and coordination among stakeholders results in conflicting priorities. For example, the health sector emphasizes clean stoves with chimneys, while the energy sector prioritizes fuel efficiency (SNV, 2018). The SNV (2018) also identifies significant barriers including limited access to production resources, small-scale workshops using basic, inefficient production techniques, and inadequate transportation and distribution infrastructure. These factors limit the availability of ICS, increase their cost, and impede overall market growth. Existing distribution models are ineffective and overly focused on production capacity rather than supply chain development. The lack of incentives for distributors to reach customers, combined with poor marketing and weak market monitoring, further stifles market development. Furthermore, product design issues and financial constraints impede progress. Some stoves fail to meet user needs, emphasizing the need for improved monitoring and feedback during product development. Insufficient product development capabilities, particularly in testing and evaluation, also undermine the national ICS program's effectiveness. Limited financial resources at all levels of government (federal, regional, and Wereda) exacerbate these challenges (KII, 2022).

Table 5. Summary of main ICS promotion and dissemination barriers

Category of barriers	Major systemic problems	References
Institutional barrier	• Weak institutional capacity, inadequate funding & human resource • Unsatisfactory policy support • Dependence on donor funding and government subsidy.	KII, 2022; Smarte Anekwe et al., 2024
Market barrier	• Lack of access to production inputs • Lack of ICS market channels	KII, 2022;
Product barriers	• The problem of fulfilling customer requirements • Lack of suitability for local users	Lohani et al., 2023; Olabi et al., 2023
Economic and financial barriers	• Lack of access to long-term credit and/or high-interest rates	
Lack of cross-sectoral integration and policy alignment	• No meaningful integration among the diverse agencies, stakeholders, and the private sector to effectively develop and use RETs • The direct link between technology companies supplying the ICS and local users is almost non-existent. • Limited coordination of stakeholders	Kamp and Forn, 2016; Gebreslassie et al., 2022; KII, 2022; Sawo, 2024
Capacity barriers	• Lack of technical assistance and adequate pre/post-adoption training • Lack of proper management and maintenance of the technologies	KII, 2022

Lessons Learned and Policy Implications

1. Strengthening financial support mechanisms, such as subsidies and microfinance, to enhance affordability.
2. Expanding awareness campaigns and technical training to promote adoption and sustainability.
3. Integrating small-scale RETs into national energy policies and development plans for broader impact.
4. Encouraging public-private partnerships for improved distribution and maintenance services.

Conclusion

Ethiopia is experiencing a notable increase in the promotion and use of RETs, as demonstrated by this review. Between 2005 and 2015, substantial distribution efforts resulted in approximately 15,000 biogas plants, 3,300,000 ICS, and 40,000 Solar Home Systems reaching communities across the country. As a result, households and small businesses are significantly decreasing their dependence on wood fuel. This shift towards cleaner energy is reducing local CO2 emissions and encouraging households to adopt a more diverse energy portfolio with a significant proportion of renewable sources.

Studies show that using RETs significantly eases the strain on forests by lessening reliance on wood for fuel, thereby reducing forest degradation. Reduced wood burning and increased tree conservation contribute to lower greenhouse gas emissions. While RETs show potential to aid forest conservation and lower emissions, their overall impact on deforestation and climate change is currently modest and developing. For example, Ethiopian biogas plants could potentially save 0.071 million tons of wood and 0.129 million tons of CO2e annually. Improved Cook Stoves (ICS) in the same region could save an estimated 3.03 million tons of wood and 5.54 million tons of CO2e each year. The underutilization of RETs stems from various barriers to their promotion and dissemination. This review suggests leveraging current local successes to meet broader, long-term needs by addressing these barriers and accelerating nationwide RET adoption. The adoption of small-scale RETs has led to reduced fuelwood consumption, alleviating pressure on forests. Households using Mirt stoves reported a 50% reduction in firewood use, while biogas adopters nearly eliminated the need for wood-based cooking fuel. Solar energy systems have contributed to rural electrification, reducing reliance on kerosene and other biomass fuels.

To effectively address the growing demand for woodfuel and protect forest resources while mitigating climate change, a key policy recommendation from this review is the swift and extensive promotion and distribution of RETs, both in the short-to-medium term and in the long term. The national government should prioritize supporting this sector through appropriate financial and non-financial incentives to encourage the widespread adoption of these chosen RETs. Crucially, this effort must be accompanied by the establishment of maintenance service centers staffed by skilled technicians, robust monitoring and follow-up services, improved coordination and strengthening of institutional structures, and comprehensive community awareness campaigns.

Addressing challenges related to financing, awareness, and policy enforcement remains critical for further progress.

1. Strengthening policy frameworks and incentives for RET adoption.
2. Enhancing public awareness and technical capacity-building programs.
3. Expanding financial mechanisms to improve affordability.
4. Integrating RET initiatives with broader environmental and rural development strategies.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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