Article:

Gebreslassie, M.G., Bekele, G., Bahta, S.T. et al. (7 more authors) (2024) Developing community energy systems to facilitate Ethiopia's transition to sustainable energy. Energy Research & Social Science, 117. 103713. ISSN 2214-6296

https://doi.org/10.1016/j.erss.2024.103713

Energy Research & Social Science 117 (2024) 103713

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

Developing community energy systems to facilitate Ethiopia's transition to sustainable energy

Mulualem G. Gebreslassie [a,b,*], Getachew Bekele [c], Solomon T. Bahta [a], Akatew H. Mebrahtu [a], Amare Assefa [c], Fana F. Nurhussien [a], Dawit Habtu [c], Adugnaw Lake [c], Vanesa Castan Broto [d], Yacob Mulugetta [e]

[a] *Center of Energy, Ethiopian Institute of Technology-Mekelle, Mekelle University, P.O. Box 231, Mekelle, Ethiopia*
[b] *Materials and Engineering Research Institute, Sheffield Hallam University, Howard St, Sheffield S1 1WB, UK*
[c] *Addis Ababa Institute of Technology, Addis Ababa University, King George VI Street, Addis Ababa, Ethiopia*
[d] *Urban Institute, University of Sheffield, Winter St, Sheffield S3 7ND, UK*
[e] *Department of Science, Technology, Engineering and Public Policy, University College London, Shropshire House, London WC1E 6JA, UK*

ARTICLE INFO

Keywords:
Community energy
Community engagement
Business models
Technology
Energy access

ABSTRACT

In Ethiopia, renewable energy offers people an affordable, dependable, and eco-friendly power supply while decreasing the carbon footprint. However, delivering a renewable future for the country requires a massive change in social practices and systems of provision. The slow progress of renewable development is hindering the transition to a cleaner energy future. Over 80 % of people live in rural areas where it is expensive to reach them *via* grid networks in Ethiopia, requiring off-grid alternatives.

Community energy systems, which are off-grid energy systems in which communities play a key role, offer alternative strategies to close the country's energy access gap. However, community energy systems remain underdeveloped in Ethiopia. There is a need to understand the opportunities for community energy and the barriers that hinder its development in Ethiopia, and their role in energy transitions.

This paper adopts an experimental lens to understand the diverse dimensions of community energy projects through how they are made, maintained, and lived. Using a comparative analysis of three multi-method, qualitative case studies, this paper argues that the political context poses the biggest obstacle to the development of community energy in Ethiopia despite these projects' tangible benefits.

The analysis indicates that community energy projects allow communities to be involved in all stages of project development. In every project, communities assume project management responsibilities after commissioning. However, these projects encounter challenges in resourcing capital, managing supply chains, and building necessary skills among community members to understand business models to ensure sustained operation of the systems.

1. Introduction

As countries grow economically and in population, their energy use increases due to higher demand. Ethiopia has experienced significant growth and is now the second-most populous country in Africa, with over 120 million people [1]. With an average GDP growth rate of over 9 % in the last decade, Ethiopia is one of the fastest-growing economies in Africa. This growth has led to increased energy demand, prompting Ethiopia to implement policies like the National Electrification Program (NEP 2.0) to prioritize renewable energy development [2]. The government has invested in hydropower, wind power, and solar energy to reduce reliance on harmful sources like solid biomass and coal. Ethiopia has made remarkable progress in expanding electricity access. In the last 30 years, the percentage of people with electricity access has risen from 12.5 % in 2000 to 51 % in 2020, with grid energy systems making the greatest contribution to this effort [3]. These actions support global efforts towards low-carbon and sustainable energy futures [4]. This includes improving efficiency in both energy generation and usage and facilitating energy access to its people through greener and renewable sources [5] [6,7]. Universal access to clean energy is,

* Corresponding author at: Center of Energy, Ethiopian Institute of Technology-Mekelle, Mekelle University, P.O. Box 231, Mekelle, Ethiopia.
E-mail address: M.Gebreslassie@shu.ac.uk (M.G. Gebreslassie).

https://doi.org/10.1016/j.erss.2024.103713
Received 14 February 2024; Received in revised form 20 July 2024; Accepted 2 August 2024
Available online 15 August 2024

however, still out of reach.

Providing electricity access to millions of people remains a daunting task for policymakers, developers, development partners, and rural communities in Ethiopia [8] [9]. Access to essential lighting in rural households is a luxury few can afford. Development stakeholders, local governments, and publicly funded community energy projects collaborate to provide electricity for households in rural Ethiopia, providing essential light and power outlets for charging devices such as flashlights, mobile phones, and radios [8]. All efforts to develop the energy infrastructure and achieve the targets have also been hampered by COVID-19 and the continuous conflicts in Ethiopia's regions such as Tigray, Amhara, and Oromo [3,10]. This is having a significant impact on the country as financial resources and the government's focus have shifted towards buying weapons to manage internal conflicts. This is the country's tragic reality where existing energy projects remain suspended, and there is limited planning for developing the energy sector to achieve the SDG 7, outlined as one of the UN's 2030 sustainable development goals [3].

In rural Ethiopia, most energy currently comes from biomass sources like wood, which has been used for cooking, lighting, and heating for centuries [11]. There is a need to transition to renewable energy sources such as solar, wind, hydropower, and bioenergy to reduce emissions and promote sustainable energy. This shift is driven by global challenges like energy access, environmental degradation, security, climate change, and economic sustainability [12]. Off-grid energy systems offer a flexible and adaptable alternative for communities lacking reliable access to centralized energy networks [13], which also has the potential to play a crucial role in Ethiopia's push for renewable energy adoption. They are seen as key in the country's transition to sustainable energy, with the goal under the NEP 2.0 targets to electrify 35 % of the entire population with off-grid solutions like solar and mini-grids [2].

Community energy systems are one type of localized off-grid systems that use renewable sources such as solar, wind, hydro, and biomass to produce and distribute energy for consumption within a community [14]. Community energy in rural villages also benefits community institutions, such as churches and primary schools. Community energy systems are being implemented in industrialized countries, especially in Europe, to give communities greater autonomy over their energy production and consumption [15,16]. In some countries, such as Denmark and Canada, community energy initiatives aim to achieve renewable energy targets and enhance energy efficiency [17,18]. The European Union has prioritized community energy in its strategy and policy. The United States has been slower to create energy communities due to its reliance on top-down strategies [19–21] [22]. Renewable energy sources are considered essential for achieving the necessary changes to address the African energy and climate crisis, but there are disagreements about how to implement them [23] [24] [6,7]. Malawi and South Africa, for example, have pioneered policies to put communities at the center of renewable energy developments [25,26] [27], but the empowerment of communities within energy developments remains a practical challenge [15].

Community energy systems are key to the renewable transition but remain underdeveloped in Ethiopia. Research on community energy systems in developed countries is well-documented, but detailed studies on their development and impact on energy access in Ethiopian communities are lacking. The contribution of community energy systems in Ethiopia is minimal as they need comprehensive plans, development, and implementation of incentives, such as feed-in tariffs and simplifying administrative procedures for local energy projects [28,29]. Community energy requires a regulatory framework promoting renewable energy investment and community involvement [30]. Green energy funds, access to international climate finance, private sector investments, and community awareness are essential for financing and ownership. Microfinance can help local communities invest in renewable energy projects [31,32]. However, beyond these general insights from international community energy experiences, there is limited evidence of what contribution community energy can make to the transition to renewable energy in Ethiopia and how it operates in practice.

The paper aims to reflect the inherent limitations of delivering community energy projects across the life cycle, and at the same time, understand how it facilitates different processes of change- and potentially a transition. It provides the first comparative study of community energy systems in Ethiopia, using a multi-methods analysis of the perspectives of stakeholders in three pioneering projects and the background documentation available in each case. The paper asks two research questions: How does community energy facilitate transitions, and what barriers prevent the development of community energy projects? Section 2 presents the methodology, including the theoretical perspective used to analyze the operation of these projects in the context of experiments that seek to reconfigure infrastructures [33]. Using this framework, the analysis is presented in three empirical sections that explain how community energy projects are made (Section 3), maintained (Section 4), and lived (Section 5). The discussion in Section 6 explores the ancillary changes caused by these projects and their potential to redefine the context of the transition, despite significant barriers related to the political context, the available skills to maintain the projects among the communities, and the disruptions in supply chains.

2. Methodology

The argument in this paper is based upon the comparative analysis of three cases of community energy projects that have been implemented and are fully operational in the regions of Tigray, Amhara, and Sidama, in Ethiopia. The following sub-sections present detailed information about the description of the case studies, the data collection methods, and the framework for analysis.

2.1. Description of study area

Ethiopia has 17 community energy systems powered by hydropower, solar, or wind energy [34]. After a systematic review, we selected three projects for in-depth analysis, aiming to explore variations in the political economy shaping the project, the local cultures, the energy sources and technologies available, and the demands covered by the project. We selected two solar-powered cases in the regions of Amhara and Tigray and a micro-hydro project in Sidama (see Fig. 1).

The regional government financed the Gira Tsatse solar project in Tigray and later transferred ownership to the community. This project powers 200 households with a capacity of 20.4 kW, but its application is limited to lighting, charging, television, and radio. The Bura Micro hydro plant, owned by the community and serves nearly 300 households, was financed by GIZ. It supports various applications, including lighting, charging, cooking, milling, and businesses such as barbers. Bahir Dar University facilitated the development of the Mesino Tebita solar project through funding support from GIZ and serves at least 65 farmers. The ownership has been transferred to the community, but the University still provides support to ensure its service sustainability. This project powers only irrigation and drinking water applications.

2.2. Source of data

The analysis used primary and secondary data sources. Primary data was gathered through structured questionnaires from 151 households in the three case studies who have benefited from community energy systems. A sample of households benefiting from the projects was selected to ensure diverse representation, for example, by actively including women-headed households. Due to the small population size of 565 users in the three case studies, approximately 26.7 % were chosen for interviews based on available resources and their homogeneity in culture, income levels, and access to technology within the communities of each case study. As the case studies were purposely selected to represent different ethnicities and cultures, the local languages were

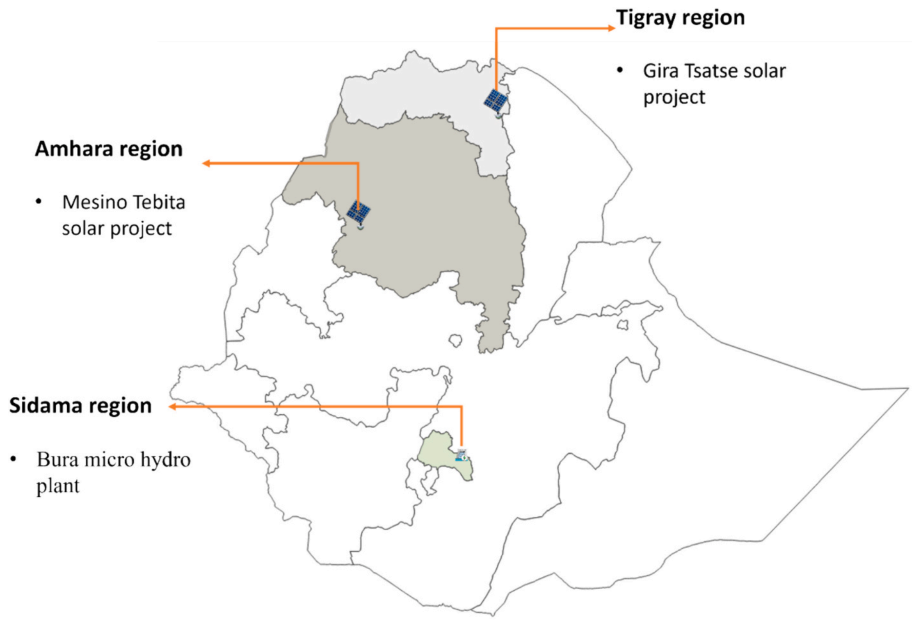

Fig. 1. Location of the case studies in Ethiopia.

Tigrigna and Amharic. Local data collectors proficient in local languages and English were hired to conduct in-person interviews with households in all three case studies. They received training on conducting the survey (See Appendix A) and used their language skills to translate the English-based questionnaire into the local language during interviews. The data collectors then translated the local language-based data into English and was crosschecked for accuracy and consistency during the analysis.

The study also gathered information by interviewing six community energy experts and local energy agency administrators responsible for the three case studies. Experts were selected based on their historical involvement in the design, development, deployment, and continuous support of the selected community energy systems. In the Tigray region case study, the authors interviewed three experts and one energy agency administrator using the topic guide (See Appendix B) through audio recordings in the local Tigrigna language with their consent. The interviews ranged from 35 to 65 min, depending on the interviewee's knowledge of the projects and the depth of discussions. The recorded interviews were translated and transcribed into English. In the other case studies, experts required to work in their own time, and thus were given a questionnaire in English as they understood the language but were allowed to fill it out in the language, they felt comfortable with, in this case, the local Amharic dialect, to enable them to provide accurate and more detailed information. The researchers cross-checked, translated, and recorded the data for analysis.

The secondary data consisted of a systematic review of academic and policy publications, current legislation, and regulations from both national and international sources. The secondary data helped to frame the interviews and contrast the analysis.

2.3. Data analysis procedures

Community energy systems are defined differently by various researchers, from systems serving single households to medium-sized systems managed locally through entities like cooperatives [22] [35]. They involve decentralized systems developed with high community involvement in consumption, as well as citizen or community ownership and participation in renewable energy projects [36] [27]. In Ethiopia, community energy is not clearly defined in official documents, but recent research describes it as mini-grid systems owned, managed, or used by households in a community [34]. Thus, community energy projects cannot be understood as ready-made fixtures of the energy system, but rather they are experiments that seek to reconfigure energy systems and energy use practices through their development and implementation. Studies in experimental urbanism have explored the mechanisms whereby experiments activate change, particularly through the constitution of experiments in the long term. Bulkeley et al. [33] proposed a framework to understand how experiments are made, maintained, and lived: processes of embedding the experiment into the territory that activates their potential for change. This study followed the same framework to analyze the making, maintenance, and living of the selected community energy systems (See Fig. 2).

Interview transcripts and academic and policy reviews were analyzed by following the framework across the three case studies and cross-referencing them with existing literature. Researchers used various qualitative data analysis techniques to gain a deep understanding of the challenges and opportunities in community energy development from the communities that have experienced from the inception to commissioning and utilization of the systems. First, a thematic analysis helped to map the recurrent motives, repeated across interviews. A content analysis of specific terms was used to gather quotes about finance, governance, maintenance, and different energy uses. Linking the forms of expression with the subject positions enabled an analysis of the performative aspect of the arguments. These observations were integrated according to the framework in three stages for each experiment in which it was made, maintained, and lived and compared across the three case studies.

The following empirical sections (Sections 3, 4, and 5) present an interpretative summary of the data to describe the challenges faced during the community energy systems' making, maintaining, and living stages.

3. Making community energy

The making of community energy projects requires going through multiple stages, including inception, community engagement, conflict resolution during decision-making, and implementation of the project's technologies and networks. Table 1 outlines the similarities and differences observed in creating community energy systems across the three case studies. The following sections provide further detailed information on these aspects.

Fig. 2. Community energy as transformative experiments [33].

3.1. Inception of the community energy projects

Community energy projects require key factors such as project initiation, acquiring land, financial support, and integration into the built environment. They start with a community vision to meet local energy needs and shift away from traditional fuels. The government's strategic priorities tend to determine their locations alongside feasibility considerations. The project sites were opportunistically chosen based on resource availability for the Bura micro hydro plant and Mesino Tebita solar project. In contrast, the Gira Tsatse Solar project site was selected randomly from a pre-feasibility study conducted by the regional energy office for community energy development. Land acquisition for renewable energy (*e.g.*, micro-hydropower, solar panels) can be challenging and requires identifying suitable locations.

> "Visiting an existing community energy system as part of knowledge exchange inspired us to develop the Gira Tatse solar project."
>
> Tigray Energy Agency expert

Negotiations with local landowners and community members must occur to acquire land for a community energy project. For example, in the case of the Gira Tsatse community energy project, the rural administration in Tigray provided land for implementation at the start of the project. Unfortunately, the allocated location in Tigray didn't receive the required six hours of sunlight between 9 AM and 3 PM for optimal energy generation. After discussing potential locations for the community project, a farmer generously offered his land, believing it would be a successful site. The regional Mining and Energy agency wrote a letter backing the project and requesting that the local government administration find replacement land for the farmer. The local land administration bureau issued the certificate, and the project was subsequently implemented.

The local energy agency was instrumental in developing the Sidama Bura Micro hydro plant by conducting preliminary studies on the river's power potential and community energy demands. Using these studies, they successfully secured financial support from GIZ to fund the project. The Mesino Tebita solar plant was a different project, and Bahir Dar University was responsible for developing it with funding from GIZ.

Funding sources include government grants, NGO donations, private investments, crowdfunding, or partnerships with energy developers and utilities. NGO donations, including GIZ and the Obama Foundation, fund most community energy projects in Amhara and Sidama. Meanwhile, the energy project in Tigray received financial support from the regional state government, which was influenced by the success of a renewable energy initiative in Amhara funded by the Obama Foundation.

3.2. Community engagement and influence in the projects

Community involvement is critical in conceiving, developing, and utilizing community energy projects. Actively engaging with the community ensures that their needs and interests are taken into consideration, builds trust, and enhances the project's success and sustainability. Involving community members in the planning stage allows them to contribute their perspectives, priorities, and needs.

> "I have been involved in the project since day one, leading tasks such as road paving, community communication, and organizing meetings."
>
> Gira Tsatse elected committee member

Discussions with managers and households show that existing social structures (such as local councils) support the involvement of communities in such projects and play an instrumental role in the sustainability of community energy. Engagement strategies ensure that all community groups' unique needs and interests, including those marginalized or underrepresented, are met in the project design. In each case, the community participated in the project's feasibility study by identifying problems and contributing to construction through initial capital (*e.g.*, about $14/household in the case of the Tigray project). Additionally, they need to find suitable land, pay an initial cost, and cover boundary and line extension expenses.

Fig. 3 shows that each project mobilized in-kind contributions from the community, such as labor, but only Gira Tsatse relied on financial contributions from the community. GIZ fully funded both projects.

In the case of Gira Tsatse, a board with five members (two women and three men) was set up from the project's inception by engaging different community segments and then electing the members. These segments include elders, youth, and local officials. The board members were responsible for facilitating discussions with project workers and government officials on matters related to the project, such as land

Table 1
Comparative analysis of the *making* of community energy in the three case studies.

Making of community energy	Case studies		
	Gira Tsatse	Mesino Tebita	Bura
Inception	The community contributed land while the regional government, through the energy agency, financed the entire project with small capital contribution from the community	Bahir Dar University developed the project with funding from GIZ	The energy agency in the region conducted a feasibility study and obtained financing from GIZ to cover the project costs.
Engagement	The communities contributed in kind and initial capital to the project, although it was a small amount. They also paid for their individual houses' boundary and line extension expenses. Community board members were set up to facilitate engagement and management of the project.	GIZ covered all financial expenses, while the communities made some in-kind labor contributions. Elected community committee members oversee project engagement and management.	GIZ covered all financial expenses, while the communities made some in-kind labor contributions. Elected community committee members oversee project engagement and management.
Conflict	Some minor conflicts do occur within the community, and the elected members are at the center of resolving such issues	The key sources of conflict in this community were the perception of the project as sole ownership, transparency, lack of accountability, and violation of the rules.	Some minor conflicts do occur within the community, and the elected members are at the center of resolving such issues
Technology	The technologies used in these three case studies are imported, which causes delays and impairs maintenance schedules due to a lack of spare parts.		

acquisition, cost-saving measures, demand prioritization, community involvement in project activities, material dispatch, and quality control. This responsibility spanned from the feasibility study to project commissioning. The administrations in Bura and Mesino Tebita are similar, with seven elected committee members overseeing the project management and other activities. There is strong interest in the projects, and committee members are frequently requested to extend the network to settlements that could not be connected due to limitations in technical capacity.

When determining operational and maintenance expenses in a community, concerns about equal contributions and accommodating low-income members may arise. However, the communities in the Gira Tsatse (Tigray) and Bura (Sidama) regions have addressed this issue by covering costs for those who cannot afford to pay while Bahir Dar University is providing operational and maintenance support for the Mesino Tebita (Amhara) solar energy project.

Respondents reported that the community energy projects were inclusive and did not exclude specific groups such as people with disabilities, children, and women. However, none of the projects collected evidence to demonstrate this. The projects benefit communities that have lacked access to electricity for an extended period, but project assessments revealed a need to expand the systems and improve the quality of the electricity supply. Expanding the community energy systems and upgrading the power capacity through additional solar panels and turbines would facilitate the expansion of energy access.

3.3. Local disputes

Poor communication can lead to disagreements among community members, developers, and stakeholders, resulting in misunderstandings and conflicts. Nevertheless, the surveys in each case study suggest that the community is highly committed to the projects. They were proactively contributing to their success, making efforts beyond investing upfront finances. The community energy projects were developed smoothly because the management worked closely with community members.

When disputes occurred in the Gira Tsatse solar project and Bura micro hydro plant, elected members were central in resolving the issue, working with the community members who originally selected them and who respected their leadership. In the case of the Mesino Tebita solar project, the key source of conflicts reported by the communities was the perception of the project as sole ownership. Lack of transparency, lack of accountability, violation of community regulations, and lack of community participation in meetings were also sources of conflict in this community.

However, some local communities far from the development sites expressed dissatisfaction with being left out of the energy projects. In the Tigray region, a local administration located far from the chosen development site requested the solar project to be implemented in their district. Through collaboration with regional offices and community representatives, the issue was resolved, and the Gira Tsatse community energy system was successfully developed in the originally selected site. In the Sidama region, nearby communities that are not yet connected continue to request access to the energy project, but the project lacks the capacity to accommodate them.

Fig. 3. Funding contributions for the different community energy projects.

3.4. Access to technologies

Ethiopia relies entirely on foreign technologies for its energy infrastructure development [37], which is the source of additional challenges. These issues were raised in all the case studies. For instance, the solar technology for a project in the Tigray region took more than six months to clear customs due to the inclusion of radio wave meters that required clearance from a security authority, further delaying the importation process. Survey participants pointed out that it is difficult to quickly find spare parts due to the reliance on imported technologies. End users have expressed concerns about the quality of these imported technologies.

The current customs policy favoring renewable energy technologies is insufficient to facilitate these projects' development. Such customs policy favors duty-free solar lanterns and small lighting technologies. However, importing large solar panels does not receive this benefit. Import taxes raise the costs of these technologies, which hinders their widespread use and slows the growth of renewable energy-based energy systems as the communities that need them cannot afford their prices.

4. Maintaining community energy systems

Maintaining community energy systems involves managing their overall operation, ensuring the sustainability of financial flows, and responding to disruptions. Table 2 outlines the similarities and differences observed in key aspects of maintaining community energy systems across the three case studies.

Table 2
Comparative analysis of the maintenance of community energy in the three case studies.

Maintenance	Case studies		
	Gira Tsatse	Mesino Tebita	Bura
Management	Five elected community members manage the project. Two additional personnel handle minor maintenance and financial management, while the regional energy agency provides support for extensive maintenance.	A local person is hired to oversee the project management and do minor maintenance, while Bahir Dar University is responsible for extensive maintenance of the systems	The project is managed by seven elected committee members from the community, while the regional energy agency requests support from GIZ for extensive maintenance
Disruption	Damaged meters and non-functional power consumption readers are the main causes of disruption because of the lack of skilled maintenance experts and spare parts.	During the rainy season, GIZ's maintenance process is often delayed due to a lack of spare parts, leading to disruptions.	The primary cause of project disruptions is the absence or delay of spare parts.
Business models	There is a lack of understanding of viable business models, and the tariff collected between $0.18 and $0.36, depending on the number of rooms, is not enough for maintenance expenses. The money collected is mainly used to pay the two hired personnel.	There is a lack of understanding of viable business models, and communities have no monthly contribution	There is a lack of understanding of a viable business model, and the $0.36/lamp/month is insufficient for extensive maintenance expenses.

4.1. Management of the energy systems

Expertise in energy management is essential to maintaining a sustainable community energy system. In community energy projects, the community largely manages the energy systems with assistance from regional energy agencies. Once the projects are commissioned, the community takes over ownership, with continued support from the regional energy agency for technical and management tasks.

All three regions prioritize community involvement in managing energy projects (see Fig. 4), but each has a unique approach. In Gira Tsatse, the Tigrayan government supported the community initially and then transferred ownership. The project is now managed by a committee of five community members (three men and two women). They were selected based on community involvement, including gender, age, and social standing. The committee's duties include auditing, hiring personnel, and acting as a link between the community and regional energy agency for project support and future requirements. One technician is hired to manage the energy systems and perform minor maintenance tasks. The committee is currently addressing all matters related to project administration, such as paying technical workers and negotiating fees with the community and local authorities.

Community-driven management is also prioritized in the Mesino Tebita and Bura projects. However, while the former always had a strong focus on active engagement, the latter resulted from a joint government-NGO collaboration, and only later was ownership devolved to the community. In Bura, the administrators elected seven committee members to oversee the project management and other activities. This committee manages projects and performs light maintenance. For significant maintenance tasks, the regional energy agency seeks help from GIZ. This highlights the role of external support in maintaining energy systems. The government bodies (district's energy professionals) occasionally supervise this project's continuity.

> "The regional energy office plays a vital role in supporting the community by overseeing energy projects and maintaining their services. It provides repairs within the region's capacity and seeks assistance from non-governmental institutions for repairs beyond its capabilities."
>
> Sidama Energy Agency expert

Mesino Tebita prioritises community self-management and involves locals in decision-making. Local militias also support the project, while Bahir Dar University plays a crucial role in major repairs. The district administration provides support, and Bahir Dar University oversees the system with GIZ funding. A community member with knowledge of the local area manages the day-to-day operations. Minor repairs are done locally, while more extensive repairs are outsourced to Bahir Dar University.

The local administration is crucial in supporting energy project management in the three case studies. Other stakeholders take a larger role in managing and operating the Bura and Mesino Tebita energy projects. These examples highlight notable differences in the community's ability to govern the systems and to respond to technical and natural failures.

4.2. Disruption of supply

> "Finding spare parts at local markets and finance are key challenges to sustain the community energy systems."
>
> Sidama Energy Agency expert

Energy supply can be interrupted by technical failures or infrastructure damage. In the Tigray region, it is mainly interrupted by

Maintenance	Bura	Mesino Tebita	Gira Tsatse
Operation, repair, disruption management	✔	✔	✔
Ensuring continuity of governance	✔	✔	✔
Regular support, e.g., monthly payments	✔		✔
Understanding the business model			

Fig. 4. Communities' engagement and knowledge in maintaining the projects.

household electric meter failures. On-site inspections found damaged meters and non-functional power consumption readers, which were not repaired on time due to a lack of skilled technicians and spare parts. Potential supply interruptions in the future could occur due to a lack of funds for maintenance and replacement of spare parts after damage. The civil war also impacted operation of the project because of the security situation faced by the community, members of the management and lack of access to spare parts.

> "The main challenges include not being able to quickly fix failures, ensuring 24/7 electricity supply, and limited geographical coverage."
>
> Bura micro hydro plant community member

To protect the off-grid energy system, the community is taking proactive measures such as organizing fundraising events and seeking support from various entities. Responses from the survey participants showed a desire to support the off-grid community energy system by arranging a telethon to raise funds for replacing solar batteries and improving system security. Power outages in the Sidama region are most common during the rainy season. The disruption typically happens during the periods when GIZ maintains the Bura project.

The Mesino Tebita project has not been affected by external factors such as natural disasters or political events, unlike the projects in the other regions. However, there are ongoing challenges stemming from limited community awareness, inadequate training, and insufficient spare parts, as shown in Fig. 4. Delays in maintenance occur due to the logistical time required to transport replacement parts to Bahir Dar University, which often results in energy supply interruptions.

4.3. Business models

To effectively explore and develop community energy projects, it's essential to understand the business models that communities may use. External bodies such as regional governments and NGOs typically provide the initial capital for these projects. After projects are finished, the community takes ownership of the energy systems and must sustain them with compelling business models. Yet, discussions with managers and households reveal that they lack of understanding of business models (see Fig. 4), and often collect money without a clear sustainability plan.

In Tigray, a finance employee oversees power usage and payment collection, with the community paying monthly fees between \$0.18–\$0.36, depending on the number of rooms in their houses. The committee supervises the funds in an account, and the technician and financial personnel receive payment from a savings account supported by the community and subject to committee approval. Smart electric meters are linked to a central power station, which sets an initial unit price for monthly payments.

However, uncertainty remains about whether the current tariff structure can sustain the energy systems due to inadequate understanding of viable business models. The Mesino Tebita system is solely used for irrigation and drinking water, so there is no monthly payment. The community should contribute monthly to ensure the project's long-term sustainability and productivity. However, in the Bura project, the committee charges a tariff of \$0.36/lamp/month for lighting and provides free or discounted services to vulnerable groups to support energy accessibility. The revenue collected is utilized for technician salaries and O&M costs.

> "We have no knowledge of business models and the community lacks support on this front."
>
> Tigray energy agency expert

The case studies demonstrated that tariffs alone cannot cover significant maintenance expenses, such as replacing solar energy system batteries or damaged mini-hydro project turbines. This lack of funding could severely impact the systems' ability to withstand major failures caused by aging equipment or natural disasters. For energy projects to be sustainable and resilient, stakeholders must change how profits are calculated and create an effective business model that covers operation and maintenance costs.

5. Living community energy

In Ethiopia, traditional energy systems were not tailored to serve all users. Instead, they were designed to provide energy generated from a central source to users without considering the marginalized communities who are already at a disadvantage and bear the brunt of the negative impacts of the system. Rural villages have transmission lines and desire access to the grid to receive electricity, a commodity that stakeholders, particularly policymakers, should acknowledge and treat accordingly. Communities in these conditions often describe their circumstances by saying "It is DARK under the LAMP".

Community energy is a potential solution to energy access problems in remote areas of Ethiopia by prioritizing social benefits and involving communities in managing and owning off-grid systems. This model could support the sustainable energy transition and enable communities to access electricity actively. The surveys show that community energy projects benefit individuals and households. They provide access to electricity using off-grid solar systems and micro-hydro projects, allowing for easier and more comfortable nighttime tasks. Residents can also charge their mobile phones at home, saving time and money by eliminating the need to travel to distant towns for charging. Table 3 outlines the similarities and differences observed in living community energy systems across the three case studies.

5.1. Changes in the energy patterns of the community

Before implementing the community energy projects, the communities in the selected case study projects used traditional fuels and essential lighting sources such as wood, animal dung, and agricultural waste for cooking and other activities. They used wood, solar lanterns,

Table 3
Comparative analysis of living community energy in the three case studies.

Living community energy	Case studies		
	Gira Tsatse	Mesino Tebita	Bura
Energy patterns	The community's energy usage has changed, but it's only limited to basic needs like lighting, charging, and television.	The community uses energy only for irrigation and drinking water; it does not have access to lighting, cooking, charging, or television services.	The community's energy usage has significantly changed due to using electricity for various purposes, including lighting, cooking, charging, TV, milling, and business operations.
Contribution to sustainability	Energy use is restricted to lighting, charging, and television, which has little impact on sustainability due to the ongoing use of fuelwood for cooking.	Energy is only used for irrigation and drinking water and does not significantly contribute to sustainability.	The project reduces fuelwood use, promotes afforestation, and improves community health.

kerosene, and sliced vehicle tires for lighting. The community had to spend a lot of time and energy using biomass fuels like fuelwood and animal dung, which cost them 5 % to 10 % of their income for fuel purchases. They mainly relied on income from agriculture and family remittances. At the same time, small businesses, poultry, cattle, and sheep breeding were the primary sources of income for Mesino Tebita project members in the Amhara region.

Most Bura project beneficiaries are engaged in agriculture, even though only a few community members are involved in agri-business. Some families rely solely on remittances sent by their children working in the city or abroad. Similarly, the Gira Tsatse communities predominantly rely on agriculture for their income. Previously, people used to spend their hard-earned money on buying fuel for everyday needs. However, the community energy systems have introduced cleaner energy sources, altering the previous energy patterns and reducing dependence on external fuels.

The Bura project provides power to households and essential community institutions such as health centers, churches, and schools and facilitates access to information and entertainment through radio and television. Furthermore, using micro-hydro power plants has enabled these institutions to carry out public activities at night, thereby improving the quality of their services. Installing a flour milling machine in the village has dramatically reduced the time and cost women spend on milling grains. The presence of electricity has enabled community members to read spiritual books and serve their church during the night, which they argue promotes spiritual well-being. Access to electricity allows people to charge their mobile phones and flashlights, making participating in nighttime activities easier.

The projects also support new electric-based businesses like hair salons, flour milling stations, and music shops, which contribute to the community's growth and development. This business has reduced travel time to nearby villages by providing various services. They have also improved communication by enabling access to mobile phones, television, and radio. In the Sidama region, where coffee is the primary source of income, the community uses radio and mobile phones to get daily updates on coffee prices. This enables them to decide when to take their crops to the nearby city coffee collection sectors.

> "Currently, we use firewood, charcoal, and animal dung for cooking and baking. We use electricity for lighting and charging devices like mobile phones and radios."
>
> Gira Tsatse community member

The Mesino Tebita project provides solar powered drip irrigation and drinking water to communities in the Amhara region. The Gira Tsatse solar project in the Tigray region is limited to providing electricity for lighting and basic needs. Still, it could be expanded to support cooking, heating, and milling activities.

Women and children are primarily responsible for collecting biomass fuels like firewood, cow dung, and agricultural residues, often having to travel long distances to find them. This takes up a significant amount of their time and effort. Setting up community energy sources immensely helped promote gender equality and prevent conflicts that may arise due to resource limitations such as wood. The shift from biomass-based to clean energy holds great promise for providing universal access to clean energy in rural areas of Ethiopia.

In addition, the projects provide educational opportunities for children by providing lighting for nighttime study, which previously was difficult due to economic challenges and health problems. Households save time and money as they no longer need to collect wood or spend so much on kerosene. These projects offer uninterrupted electrical power independent of any national grid, which is especially valuable during conflicts or other disruptions. These systems also improve children's education by reducing the need for firewood collection, and access to information through radio and TV helps improve communication with distant relatives.

5.2. *The community energy's contribution to sustainability*

Community energy projects provide households with safe and clean alternatives, replacing hazardous sources like fuel, wood, and kerosene. This reduces health risks for women, such as eye and respiratory problems, and provides economic and environmental benefits, such as reduced emissions, increased energy security, and greater self-sufficiency.

Community-owned off-grid energy systems are sustainable and affordable and reduce ecological degradation by reducing the use of fuelwood and contributing to afforestation. These projects can overcome challenges and promote equitable clean energy solutions through community benefits agreements and stakeholder support, highlighting their importance in sustainable energy transition efforts. One contention is that community energy projects empower communities, facilitate participation, and strengthen local institutions. However, the fragmented and relatively isolated nature of these projects makes it difficult to evaluate this objective beyond the reported benefits reported by direct beneficiaries of these projects.

6. The potential of community energy for sustainable energy transitions

6.1. *Community energy for energy transition*

The energy transition involves shifting from traditional and fossil fuel-based energy sources to cleaner and more sustainable alternatives [38]. The energy transition will require electrifying different sectors in rural communities, including lighting and heating, to replace biomass-based systems with electric alternatives. To transition rural communities to electric systems, it is essential to prioritize providing immediate access to light and a few power outlets to each home. Cooking and space heating can follow. However, it is too early to rely on existing small-scale community energy systems in rural Ethiopia. In rural villages, cooking and heating can be accomplished through efficient, innovative, and low-power-consuming electrical appliances as part of the energy transition.

Although Ethiopia has considerable renewable energy resources like solar, hydro, wind, biomass, and geothermal, the country fails to utilize them fully. However, the country's energy strategy now includes off-grid energy systems where community energy system is a part, which could be a transformative solution to energy poverty, capacity constraints, regulatory risks, and political instability, ultimately aiding the nation's deployment of its essential energy resources.

Community energy's role in this context is thus facilitating experimentation with alternatives for electricity provision. These alternatives redefine existing structures of governance by creating new committees and rules of management, involve community members actively in the operation and maintenance of energy systems, helping to popularize these technologies, and redefine the use of energy in communities, demonstrating the potential of electrification to the point that communities not served by these projects may mobilize to reclaim such access when they observe them in operation. By placing a strong emphasis on meeting the energy needs of marginalized groups and aligning with sustainable development objectives, community energy systems have the potential to play a pivotal role in accelerating Ethiopia's inclusive and clean energy transition while fostering social equity and resilience in the energy sector. In doing so, these experiments provoke small shifts in the energy policy landscape that, over time, may add up to a more fundamental transition to universal renewable access.

Community energy projects also redefine existing infrastructure models by understanding how a post-networked structure can help decentralize energy generation and distribution, increasing resilience, reducing transmission losses, and giving local communities greater control over their energy supply [13]. One key advantage of these projects is their ability to boost local economies [39–42], even when they faced supply chain challenges and protests. Initiatives that involve constructing, maintaining, and operating energy infrastructure can create job opportunities and promote economic growth. This can lead to improvements in small businesses and agriculture, positively affecting community well-being. To ensure social equity, sustainable energy transitions must prioritize inclusivity and fairness, as advocated by [43]. The surveyed community energy projects align with this principle by providing low-income and marginalized communities with affordable and dependable energy, combatting energy poverty, and advancing social equity.

The development of massive off-grid/community energy projects can significantly contribute to the country's sustainable energy transition by addressing multiple critical aspects. Studies, such as [13,44,45], have shown that community energy projects in Ethiopia have significant potential to promote sustainable energy transition in several areas, including improving access to energy, generating energy at a local level, stimulating economic development, promoting energy equity, reducing negative environmental impacts, and building capacity.

6.2. Unlocking the potential of community energy for sustainable energy transitions

The research also shows, however, that many barriers remain in practice to fully unlock the potential of community energy for sustainable energy development in Ethiopia. Funding models are still heterogeneous and ODA-reliant, demonstrating that there is still not a consolidated investment space to facilitate their development. Such funding structure will depend on the consolidation of effective regulatory frameworks, ensuring long-term maintenance of energy infrastructure and encouraging community involvement and ownership as noted in sources [41,42,46,47]. To ensure the sustainability of the projects, it is essential to address the replacement of components such as batteries and the lack of skilled personnel for ongoing maintenance. This can be addressed by supporting communities through capacity building and implementing practical business models. Fundraising activities involving the community, donors, and government support can also be helpful.

Private sector involvement has been limited due to a lack of incentives and complicated import procedures. Although a duty-free policy for lantern technology is in place, it hasn't gained the trust of private investors, and there are no such policies for more large-scale technologies like photovoltaic systems. Therefore, private investors are demanding government subsidies to invest in the sector. The projects encountered delays in custom clearance, precisely due to categorizing radio wave meters as communication technology, causing hesitation among private sector involvement.

The cases demonstrate that a cooperative approach involving local communities is essential. This can be achieved by offering incentives and actively engaging with communities and other stakeholders instead of solely relying on initial financial support from the government and NGOs. Effective community and stakeholder engagement are key factors in the success of an energy transition. The participation and support of local communities in implementing renewable energy projects is crucial. To ensure a smooth transition, it is essential to address the social and economic impacts of this change and to involve all stakeholders in a holistic approach towards a sustainable and clean energy future.

7. Conclusions

The paper aims to explore the challenges in implementing community energy projects and how they contribute to processes of change and potential transition. Characterizing community energy systems as a form of infrastructure experimentation enables an analysis of the different ways in which they may shift the conditions of transition by activating and demonstrating new ways of thinking about how to make energy projects, the conditions of maintenance, and how they are lived and integrated into people's lives.

In rural Ethiopia, providing electricity through grid systems to most of the population who live in remote areas is costly. Thus, community energy systems provide a unique, well-suited alternative, but their slow development is slowing progress towards a sustainable energy future. Thus, the chapter also sought to understand the barriers to their progress by comparing three cases of community energy projects in practice. Looking at the different implementation processes and how they are perceived by experts and managers of that system, in dialogue with the findings of a user survey, the research reveals the complex balance that such experimental projects face.

Community energy systems led to positive changes in the three case studies analyzed, resulting in reduced emissions from using fuelwood and increased forestation in their surroundings. The communities played an active role throughout the project and took over its management once it was completed, helping develop local governance structures. Neighboring communities have observed the benefits and conflicts, and when they arise, they tend to reflect that people feel excluded and want to join in on these benefits.

However, political contexts have shown huge differences in the three cases and significantly impact the development of energy projects. The case in Tigray, where the regional government is isolated from the national one, relies strongly on communities' financial support and regional funds, while the other projects provide experimentation grounds for international organizations, universities, and NGOs. External support was needed on an *ad hoc* basis beyond the project's establishment because of the difficulties of dealing with unexpected external shocks.

Sustainable business models and the operation and maintenance of energy systems remain significant challenges for the communities. To overcome these challenges, stakeholders can implement proven solutions such as recognizing community energy in official government documents, providing capacity building for local personnel from the community to support effective operation and maintenance, encouraging cooperative financing with match funding from communities, and incentivizing private sector involvement in community energy development. However, there is a need for developing appropriate skills for the management of these projects, including developing a better understanding of the business models that sustain them.

The in-depth focus on three case studies of community energy questions the representativity of this study, regardless of the authors' efforts to select diverse case studies that represent a variety of implementation conditions across the country. The implementation of community energy projects depends on local-dependent variables, and hence, significant uncertainties are associated with the context dynamics. While the experimental approach in this paper can be further extended to other case studies, there is potential to focus on delivering large-scale comparative research with simpler surveying instruments by focusing on the limiting conditions of off-grid development with techniques such as mapping the finance flows to off-grid development across the country, following and investigating the constitution of supply chains, and surveying the energy literacy skills across the county. In any case, the experimental approach taken by implementation agencies is particularly suited to a context of uncertainty in which simply assembling these complex projects is already a successful achievement.

CRediT authorship contribution statement

Mulualem G. Gebreslassie: Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Getachew Bekele:** Writing – review & editing, Methodology, Investigation, Funding acquisition, Data curation. **Solomon T. Bahta:** Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Akatew H. Mebrahtu:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Amare Assefa:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Fana F. Nurhussien:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Dawit Habtu:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Adugnaw Lake:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation. **Vanesa Castan Broto:** Writing – review & editing, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Yacob Mulugetta:** Writing – review & editing, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

The authors acknowledge the UK Research and Innovation and the Global Challenges Research Fund for funding this research under the grant reference number ES/T006358/1. For the purpose of open access, the author has applied a Creative Commons Attribution (CC BY) license to any Author Accepted Manuscript version of this paper arising from this submission.

Appendix A. Energy landscape household questionnaire

To be responded by communities in Ethiopia, Malawi and Mozambique, which have access to community energy projects

This research Questionnaire is prepared to collect data to understand the energy landscape in Ethiopia, Malawi and Mozambique. The data will be used for academics as well as to local, national, and international stakeholders who are interested in the development of community energy. Thus, we kindly request your support to freely fill the questionnaire and be part of the solution to address the different issues around community energy projects.

Note: Any information provided by respondents will be kept confidential.

Demographical data

Region	**District**
Interview ID	**Gender**
Age group (under 18, 18–34,35–64, 64 and over)	**Name of the project**
Number of members of the household	**Additional information**
HH Connection (Y/N)	**Connection Duration**

QUESTIONS ABOUT THE HOUSEHOLD

1. What are your energy needs and how are they met?

   Prompts:

   1.1. What fuels do you use and for what uses (*e.g. fuels: electricity, charcoal, kerosene, LPG, CNG, oil, firewood, animal dung; e.g. uses: cooking, transport, productive, other*)? Where do you get them from? (*e.g., collection, purchase from wholesalers or retailers, donors*)
   1.2. What do you use electricity for? Where do you get electricity from? (*e.g.*

2. Can you estimate what percentage of household income is used for fuels and for electricity?
   2.1. What is the source of income? (*e.g., Casual Labour/Salaried Employment/Self-employed business/ commercial farming/ other*)

BENEFITS FROM THE COMMUNITY ENERGY PROJECT

3. Can you explain how the community energy project benefits you?
   3.1. Personal benefits

3.2. Benefits to the household
3.3. Public uses (*e.g., schools, public facilities*)
3.4. Productive uses/uses to make a living (*e.g., industrial uses, commercial uses*)
4. Are there any challenges in accessing and benefiting from the community energy project?

HISTORY OF THE COMMUNITY ENERGY PROJECT

5. Can you describe how you joined the community energy project? Do you know who started it?
   5.1. What kind of key events have shaped its development? For example, has the project been affected by natural disasters? By political events?
6. What do you think made it possible? (*e.g., donation, institutional leadership*)
   6.1. What have been the main difficulties faced by the project?

GOVERNANCE AND MANAGEMENT

7. How is the system managed and maintained?
   7.1. Who is responsible for day-to-day management?
   7.2. Who is responsible for repair and maintenance and how does it take place?
8. Are you involved in any decisions about the community energy project? Can you explain what forms of engagement you have and how it happens?
   8.1. What actions could help you to be more involved?
9. How are tariffs established and how do they work for users?

DIVERSITY

10. To what extent does the community energy project address the needs of vulnerable groups (*e.g. women, children, elderly, disabled people, people from minority ethnic groups?*)
    10.1. Do members of vulnerable groups participate in taking decisions about the project? How?

CONCLUSION
Thank you so much for your valuable contribution to our research.
Do you have any comments or questions?
Thank you

Appendix B. Interview guide for managers/project officers

To be responded by project managers/project officers and other stakeholders implementing community energy projects in Ethiopia

This interview guide focuses on the energy landscape in Ethiopia: what facilitates or prevents community energy projects. The data will be used for academics as well as to **local, national, and international stakeholders** who are interested in the development of community energy. We kindly request your support to participate in this interview and be part of the solution to address the different issues around community energy projects.

Note: Any information provided by respondents will be kept confidential.

Region	**District**
Village	**Gender**
Name of Respondent	**Role or Position**
Name of Project	**Project Duration**

Energy Governance

1. To what extent does existing energy policy support community energy projects, in your opinion?

- *What policy aspects support off-grid development?*
- *What aspects of energy policy hinder off-grid development?*
- *Are there policy gaps to support off-grid development?*

2. Can you give an account of how this community energy project came about?

- *What are the key characteristics of the community energy project? What services does it provides? To how many households, businesses, others?*

3. What institutions oversee community energy delivery and what are their roles?

- *How was the project developed? Who are its partners? What brought them together?*
- *Was the local community consulted prior to approval of the off-grid energy system development? How?*

4. How are the communities/end users involved in the energy project?

- *In what ways are they involved? At what stage? (For example, communities can be involved in the design/layout, in planning, and in the governance of the community energy project)*
- *To what extent do communities influence the community energy project?*
- *Are women involved in the community energy project? How do you involve them?*
- *Are there other disadvantaged groups involved in the community energy project? How?*
- *Is there anything that would prevent people from participating in the community energy project? (e.g. age, ethnic group, gender, having a disability)*

5. Are there local community-based social structures that influence/support the development of off-grid projects in your community?
6. How did you assess the energy needs of the community?
7. What kind of business model does this project use?

- *How did you come up with this business model and does it fit the current situation?*
- *Is it effective? Are there any challenges?*

8. How was land secured for the community energy project?

- *How was the land acquired?*
- *Were there land-related challenges?*

9. What challenges did you face during setup and installation of the community energy project?

- *Possible challenges include challenges in the conception of the project, access to technologies, lack of institutional support, local disputes, lack of capacities, maintenance issues, etc.*
- *How did you manage these challenges?*

Energy Flows

10. What are the kind of energy resources used by households not connected to the community energy system?
11. What are the positive impacts that this energy project has brought to the community?

- *To the households connected to the energy system*
- *Households not connected?*

12. Do you feel that the development of the community energy system has helped to change the energy patterns of this community?

Energy Choreographies

13. Is the off-grid system properly integrated into the current infrastructure and housing structures?

- *How was it integrated?*
- *Any difficulties?*

14. Are there any challenges for new entrants of community energy technologies?

- *How are they managed?*

15. Have there been any events that caused disruption to the community energy system?

- *What happened and when?*
- *What helped to manage this disruption? How did the community help?*

16. How does the community energy project address different needs from the population, in particular, the needs of those who may be more vulnerable?

- *What aspects of people's vulnerability are considered?*
- *For example, to what extent the project considers the needs of:*
  a. *Women*
  b. *Young people and the elderly*
  c. *People with disabilities*
  d. *People with the lowest incomes*
  e. *People from different ethnic groups or different origin than the majority of the community*

17. What are the future plans for the community energy project?

References

[1] World Bank, The World Bank in Ethiopia, Accessed: Sep. 28, 2023. [Online]. Available, https://www.worldbank.org/en/country/ethiopia/overview, 2023.
[2] MoWIE, "National electrification program 2.0: integrated planning for universal access. Technical report." Ethiopian Ministry of Water, Irrigation and Energy, 2019.
[3] M.G. Gebreslassie, S.T. Bahta, Ethiopia needs peace to accelerate its SDG 7 achievements, World Dev. Perspect. 30 (2023) 100507, https://doi.org/10.1016/j.wdp.2023.100507.
[4] M.J.B. Kabeyi, O.A. Olanrewaju, Sustainable energy transition for renewable and low carbon grid electricity generation and supply, Front. Energy Res. 9 (2022) 1032, https://doi.org/10.3389/fenrg.2021.743114.
[5] T. Simelane, M. Abdel-Rahman, Energy Transition in Africa, Africa Institute of South Africa, 2012.
[6] P. Newell, J. Phillips, Neoliberal energy transitions in the south: Kenyan experiences, Geoforum 74 (2016) 39–48, https://doi.org/10.1016/j.geoforum.2016.05.009.
[7] C. Farand, Campaigners Urge African Union to Stop Fossil Fuel Proliferation on the Continent, 2020.
[8] A.W. Yalew, The Ethiopian energy sector and its implications for the SDGs and modeling, Renew. Sustain. Energy Transit. 2 (2022) 100018, https://doi.org/10.1016/j.rset.2022.100018.
[9] G.A. Tiruye, A.T. Besha, Y.S. Mekonnen, N.E. Benti, G.A. Gebreslase, R.A. Tufa, Opportunities and challenges of renewable energy production in Ethiopia, Sustainability 13 (18) (2021) 10381, https://doi.org/10.3390/su131810381.
[10] M.G. Gebreslassie, Comparative assessment of the challenges faced by the solar energy industry in Ethiopia before and during the COVID-19 pandemic, Wiley Interdiscip. Rev. Energy Environ. 11 (2) (2022) e418, https://doi.org/10.1002/wene.418.
[11] M.T. Boke, S.A. Moges, Z.A. Dejen, Optimizing renewable-based energy supply options for power generation in Ethiopia, PLoS One 17 (1) (2022) e0262595, https://doi.org/10.1371/journal.pone.0262595.
[12] J. T. Murphy, "Making the energy transition in rural East Africa: is leapfrogging an alternative?," Technol. Forecast. Soc. Change, vol. 68, no. 2, pp. 173–193, Oct. 2001, doi: https://doi.org/10.1016/S0040-1625(99)00091-8.
[13] M. G. Gebreslassie *et al.*, "Delivering an off-grid transition to sustainable energy in Ethiopia and Mozambique," Energy Sustain. Soc., vol. 12, no. 1, p. 23, May 2022, doi: https://doi.org/10.1186/s13705-022-00348-2.
[14] L. Kiamba, et al., Socio-economic benefits in community energy structures, Sustainability 14 (3) (2022) 1890, https://doi.org/10.3390/su14031890.
[15] A. Ambole, K. Koranteng, P. Njoroge, D.L. Luhangala, A review of energy communities in sub-saharan Africa as a transition pathway to energy democracy, Sustainability 13 (4) (2021) 2128, https://doi.org/10.3390/su13042128.
[16] B.P. Koirala, Y. Araghi, M. Kroesen, A. Ghorbani, R.A. Hakvoort, P.M. Herder, Trust, awareness, and independence: insights from a socio-psychological factor analysis of citizen knowledge and participation in community energy systems, Energy Res. Soc. Sci. 38 (2018) 33–40, https://doi.org/10.1016/j.erss.2018.01.009.
[17] M. Haji Bashi *et al.*, "A review and mapping exercise of energy community regulatory challenges in European member states based on a survey of collective energy actors," Renew. Sust. Energ. Rev., vol. 172, p. 113055, Feb. 2023, doi: https://doi.org/10.1016/j.rser.2022.113055.
[18] G.S. Denis, P. Parker, Community energy planning in Canada: the role of renewable energy, Renew. Sust. Energ. Rev. 13 (8) (2009) 2088–2095, https://doi.org/10.1016/j.rser.2008.09.030.
[19] N. van Bommel and J. I. Höffken, "Energy justice within, between and beyond European community energy initiatives: a review," Energy Res. Soc. Sci., vol. 79, p. 102157, Sep. 2021, doi: https://doi.org/10.1016/j.erss.2021.102157.
[20] G. Yiasoumas, et al., Key aspects and challenges in the implementation of energy communities, Energies 16 (12) (2023), https://doi.org/10.3390/en16124703.
[21] H. Busch, S. Ruggiero, A. Isakovic, T. Hansen, Policy challenges to community energy in the EU: a systematic review of the scientific literature, Renew. Sust. Energ. Rev. 151 (2021) 111535, https://doi.org/10.1016/j.rser.2021.111535.
[22] S.J. Klein, S. Coffey, Building a sustainable energy future, one community at a time, Renew. Sust. Energ. Rev. 60 (2016) 867–880, https://doi.org/10.1016/j.rser.2016.01.129.
[23] J. Senyagwa, Africa Energy Outlook 2022, 2022.
[24] IRENA, *World Energy Transitions Outlook 2022: 1.5°C Pathway*. 2022. [Online]. Available: https://www.irena.org.
[25] C.S. Kaunda, Energy situation, potential and application status of small-scale hydropower systems in Malawi, Renew. Sust. Energ. Rev. 26 (2013) 1–19, https://doi.org/10.1016/j.rser.2013.05.034.
[26] P. M. Dauenhauer and D. F. Frame, "Sustainability analysis off-grid community solar PV projects in Malawi," in 2016 IEEE Global Humanitarian Technology Conference (GHTC), IEEE, 2016, pp. 113–120. doi: https://doi.org/10.1109/GHTC.2016.7857268.
[27] M. Röder, N. Stolz, and P. Thornley, "Sweet energy – bioenergy integration pathways for sugarcane residues. A case study of Nkomazi, district of Mpumalanga, South Africa," Renew. Energy, vol. 113, pp. 1302–1310, Dec. 2017, doi: https://doi.org/10.1016/j.renene.2017.06.093.
[28] T.N. Do, P.J. Burke, K.G. Baldwin, C.T. Nguyen, Underlying drivers and barriers for solar photovoltaics diffusion: the case of Vietnam, Energy Policy 144 (2020) 111561, https://doi.org/10.1016/j.enpol.2020.111561.
[29] M. Moner-Girona, et al., Adaptation of feed-in tariff for remote mini-grids: Tanzania as an illustrative case, Renew. Sust. Energ. Rev. 53 (2016) 306–318, https://doi.org/10.1016/j.rser.2015.08.055.
[30] J. Rijpens, S. Riutort, B. Huybrechts, Report on REScoop Business Models, 2013.
[31] S. Hall, K.E. Roelich, M.E. Davis, L. Holstenkamp, Finance and justice in low-carbon energy transitions, Appl. Energy 222 (2018) 772–780, https://doi.org/10.1016/j.apenergy.2018.04.007.
[32] J. Cloke, A. Mohr, E. Brown, Imagining renewable energy: towards a social energy systems approach to community renewable energy projects in the global south, Energy Res. Soc. Sci. 31 (2017) 263–272, https://doi.org/10.1016/j.erss.2017.06.023.
[33] Harriet Bulkeley, Vanesa Broto, Gareth Edwards, An Urban Politics of Climate Change Experimentation and the Governing of Socio-Technical Transitions, 1st edition, Routledge Tylor and Francis, 2015 [Online]. Available: https://www.routledge.com/An-Urban-Politics-of-Climate-Change-Experimentation-and-the-Governing-of/Bulkeley-Broto-Edwards/p/book/9781138791107.
[34] M.G. Gebreslassie, The role of community energy and the challenges in a state-led model of service provision in Ethiopia, in: Community Energy and Sustainable Energy Transitions: Experiences from Ethiopia, Springer, Malawi and Mozambique, 2024, pp. 147–169, https://doi.org/10.1007/978-3-031-57938-7_7.
[35] S. Wirth, Communities matter: institutional preconditions for community renewable energy, Energy Policy 70 (2014) 236–246, https://doi.org/10.1016/j.enpol.2014.03.021.
[36] J.C. Rogers, E.A. Simmons, I. Convery, A. Weatherall, Public perceptions of opportunities for community-based renewable energy projects, Energy Policy 36 (11) (2008) 4217–4226, https://doi.org/10.1016/j.enpol.2008.07.028.
[37] M.G. Gebreslassie, Development and manufacturing of solar and wind energy technologies in Ethiopia: challenges and policy implications, Renew. Energy 168 (2021) 107–118, https://doi.org/10.1016/j.renene.2020.11.042.
[38] E. Bellos, "Sustainable energy development: how can the tension between energy security and energy transition be measured and managed in South Africa?," J. Clean. Prod., vol. 205, pp. 738–753, Dec. 2018, doi: https://doi.org/10.1016/j.jclepro.2018.08.196.
[39] A. W. Yalew, "The Ethiopian energy sector and its implications for the SDGs and modeling," Renew. Sustain. Energy Transit., vol. 2, p. 100018, Aug. 2022, doi: https://doi.org/10.1016/j.rset.2022.100018.
[40] A. W. Yalew, "Economic contributions and synergies of biogas with the SDGs in Ethiopia," Energy Nexus, vol. 3, p. 100017, Dec. 2021, doi: https://doi.org/10.1016/j.nexus.2021.100017.
[41] P. Block, K. Strzepek, Power ahead: meeting Ethiopia's energy needs under a changing climate, Rev. Dev. Econ. 16 (3) (2012) 476–488, https://doi.org/10.1111/j.1467-9361.2012.00675.x.
[42] G. A. Tiruye, A. T. Besha, Y. S. Mekonnen, N. E. Benti, G. A. Gebreslase, and R. A. Tufa, "Opportunities and challenges of renewable energy production in Ethiopia," Sustainability, vol. 13, no. 18, Art. no. 18, Jan. 2021, doi: https://doi.org/10.3390/su131810381.
[43] M. A. H. Mondal, E. Bryan, C. Ringler, D. Mekonnen, and M. Rosegrant, "Ethiopian energy status and demand scenarios: prospects to improve energy efficiency and mitigate GHG emissions," Energy, vol. 149, pp. 161–172, Apr. 2018, doi: https://doi.org/10.1016/j.energy.2018.02.067.
[44] G. Bekele and B. Palm, "Feasibility study for a standalone solar–wind-based hybrid energy system for application in Ethiopia," Appl. Energy, vol. 87, no. 2, pp. 487–495, Feb. 2010, doi: https://doi.org/10.1016/j.apenergy.2009.06.006.
[45] T. Nigussie, W. Bogale, F. Bekele, and E. Dribssa, "Feasibility Study for Power Generation Using off- Grid Energy System from micro Hydro-PV-Diesel Generator-Battery for Rural Area of Ethiopia: The Case of Melkey Hera Village, Western Ethiopia," 2017. doi: https://doi.org/10.3934/ENERGY.2017.4.667.
[46] S. Baurzhan and G. P. Jenkins, "Off-grid solar PV: is it an affordable or appropriate solution for rural electrification in sub-Saharan African countries?," Renew. Sust. Energ. Rev., vol. 60, pp. 1405–1418, Jul. 2016, doi: https://doi.org/10.1016/j.rser.2016.03.016.
[47] K. Araújo, "The emerging field of energy transitions: Progress, challenges, and opportunities," Energy Res. Soc. Sci., vol. 1, pp. 112–121, Mar. 2014, doi: https://doi.org/10.1016/j.erss.2014.03.002.