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Delivering an off-grid transition to sustainable energy in Ethiopia and Mozambique

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Abstract

Background: Off-grid and decentralized energy systems have emerged as an alternative to facilitate energy access and resilience in a flexible, adaptable way, particularly for communities that do not have reliable access to centralized energy networks both in rural and urban areas. Much research to date on community energy systems has focused on their deployment in Europe and North America. This paper advances these debates by looking at how community energy systems can support energy transitions in Africa. Specifically, it asks: what role can community energy systems play in the energy transition in East and Southern Africa?

Results: This article investigates the potential for community energy to foster sustainable and just energy transitions in two countries in East and Southern Africa, namely Ethiopia and Mozambique. To do so, it explores transformations in Ethiopia and Mozambique's energy systems through the lens of energy landscapes. This concept enables us to situate energy transitions within recent developments in energy governance and to understand current and future possibilities for change through the involvement of communities that currently lack access to reliable and clean energy. Our results show that when countries face the prospects of lucrative energy investments in natural gas or large hydropower, renewables are often deprioritized. Their suitability to address energy challenges and access gaps is de-emphasized, even though there is little evidence that investment in large-scale generation can handle the energy needs of the most disadvantaged groups. Initiatives and policies supporting community-focused renewable energy have remained limited in both countries. They tend to be designed from the top-down and focused on rural areas when they exist.

Conclusions: Energy transitions in Ethiopia and Mozambique, and many other countries with significant gaps in access to centralized energy systems, require putting inclusivity at the forefront to ensure that energy policies and infrastructure support the well-being of society as a whole. As long as investments in off-grid energy continue to depend on international organizations' goodwill or development aid programs outside the ambit of national energy plans, energy access gaps will remain unaddressed, and there will not be a genuine and just transition to sustainable energy.

Background

Introduction

Off-grid and decentralized energy systems have emerged as an alternative to facilitate energy access and resilience in a flexible, adaptable way, particularly for communities

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that do not have reliable access to centralized energy networks in rural, peri-urban, and urban areas. Renewable off-grid energy systems are often portrayed as providing sustainable solutions, supporting local economies and as capable of playing a central role in sustainable and community-centered energy transition [1]. Because of their decentralized nature, they can facilitate the delivery of Sustainable Development Goal 7, notably through the involvement of a range of stakeholders in energy production and management. This includes for instance private off-grid energy providers, local governments, non-governmental organizations, international organizations, and communities and individuals. Research on community energy in Europe and North America has shown that decentralised energy technologies enable flexible delivery and governance models, whereby communities can play a role in energy projects' design, operation, and maintenance. However, community energy systems (whether off-grid, grid-connected, or hybrid) are characterized by diversity, and no single model provides a ready-made solution for their development and implementation [2]. Despite their implicit promises regarding participation and community involvement, decentralised energy systems do not necessarily create the conditions for more democratic and just energy transitions [3–5].

In this paper, we explore the role that community energy systems can play in the energy transitions of Ethiopia and Mozambique. These two countries have made significant progress in advancing energy access in recent years. We pay particular attention to how these two countries support the development of off-grid renewable energy and community-centered energy projects. In the next section, we introduce the concept of energy landscapes as an analytical lens to analyze the dynamics of change in the energy systems of Ethiopia and Mozambique and its suitability to explore the potential of off-grid community-centered energy programmes in enabling just energy transitions. Section 3 introduces our two case studies and methodology. Section 4 examines the dynamics of change in Ethiopia and Mozambique's energy landscapes and community energy's role. Section 5 offers a comparative discussion of our findings and their relevance for research on East and Southern African energy transitions. Section 6 concludes.

Governing energy landscapes for a just energy transition in East and Southern Africa

Many African governments are faced with the social and technical imperative to enable a transition to a low-carbon economy while simultaneously addressing energy access needs [6, 7]. Energy transitions depend on complex interactions between processes of governance (e.g., regulations and policy frameworks), material transformations of technologies and resource flows, and changes in everyday practices. Many institutions influence the energy system, including national, local, regional governments, utility companies (public or private), independent power producers (IPPs hereafter), international governmental and non-governmental organizations, communities, households and individuals. Policy frameworks establishing renewable energy targets or providing financial and institutional support to particular energy sources and modes of energy provision shape the trajectory of energy transitions and influence different actors' ability to participate in energy governance [8, 9]. Thus, energy transitions pose underlying political questions regarding how and by whom they are managed and justified and regarding different groups' uneven exposure to their harms and benefits [10, 11]. Energy transitions are shaped by distinct historical and political processes, which in African countries have involved colonial histories of settlement, planning and market formation [12–14].

Therefore, understanding energy transitions calls for accounting for the historical path dependencies embedded in energy systems. These include, for instance, considering how historical processes of colonialism and decolonization have shaped current energy provision landscapes; how this legacy is still manifest in contemporary infrastructure networks coverage; how these historical trajectories have influenced the institutional arrangements that underpin energy provision today; and how they have enabled specific international and domestic actors to shape national and local energy trajectories. Understanding these dependencies is a means to assess current barriers to transforming energy systems in Mozambique and Ethiopia and to identify potential avenues for change. In contrast to the often techno-managerial orientation of studies on sociotechnical transitions, Newell and Phillips [15] argue that an analysis of the political-economic relations underpinning these transitions is needed. Their account of Kenya's energy transition over the past decade emphasises the "structural and disciplinary power of capital and global institutions to set the terms of transition" [15, p. 39]. Their analysis attends to the politics, power and social relations that produce these different outcomes—for instance, why certain actors, interests and classes are privileged above others in the context of Kenya's energy transition. These power dynamics limit the power of state actors while shaping the distributional politics of transitions. Other scholars have built on this approach, including van den Bold [10], who examines the implications of reforms in the Senegalese electricity sector for accumulation processes in a context of efforts to improve environmentally sustainable development through renewable energy generation.

Issues of politics and power shaping energy transitions in the context of East and Southern Africa and sub-Saharan Africa at large relate to households and individuals' strategies to access different energy services through a variety of configurations of centralised and non-centralised systems of production and delivery. At least in principle, central governments across the region intend to expand the 'formal' modernist electric grid throughout their territories, especially as part of pledges for Sustainable Energy Access For All by 2030 [16, 17]. The rural population's sheer size creates inherent difficulties connecting most households in rural areas through the centralised system. In practice, grid-based electrification tends to reach only specific segments of the rural population, often close to urban settlements. In contrast, the quality of provision in urban areas continues to be poor [18, 19]. This leads many households to combine different energy sources to satisfy their needs. Consumption of biomass (including firewood and charcoal) remains a staple for cooking in most rural households, alongside home solar systems for lighting or battery charging. For peri-urban and urban households, the same energy sources are present but in different proportions and through other providers (public, private and community-based). This diversity of configurations poses challenges of integration and coordination across multiple registers of energy access, some of which rely on off-grid renewable energy technologies, some of which don't [20].

At the same time, this diversity shows that communities can play an essential role in energy transitions, mainly if governance frameworks facilitate their participation, as demonstrated by existing research. For instance, Yadoo and Cruickshank [21] link the strength of community-based organizations in community energy management in Nepal to the recognition of the role of communities at the national level. In contrast, Smits and Bush [22] show that renewable energy projects often fail when communities are not involved in their design, deployment and governance in their work in Laos. This leads them to conclude that schemes that overlook communities' needs and existing expertise in resource management are unlikely to be successful. In the case they study, remote communities have built local economies around the supply of pico-hydro technologies components and repair and maintenance services. However, top-down solar energy schemes did not integrate this local know-how and economies and proved ill-suited to the needs of communities. Despite its potential to improve energy access, there are few examples of community energy schemes in East and Southern Africa [23]. In countries such as Kenya and Malawi, the potential of community energy to enable more decentralised forms of energy governance have been highlighted, but more efforts need to be made to ensure that this comes with tangible benefits for the communities involved [24]. The possibility of aligning social and environmental benefits has long been an important justification for the participation of communities in the development of energy infrastructures [25]. Still, community energy also requires guaranteeing a degree of autonomy to the communities involved.

Regulations, policy frameworks, and strategies encouraging community-focused energy projects can include or marginalize particular groups and energy users. The previous examples show that the more embedded in existing practices of energy access and the more reliant on local communities, the more likely renewable energy technologies are to become stable features of energy landscapes and support broader transitions towards clean energy. At the same time, relying on pre-established community organizations also enhances risks of group capture and intra-communities unequal access to energy [26]. Identifying agents of change in energy governance (particularly within communities) is thus essential. Still, it needs to be done to promote the voice of those traditionally excluded from decision-making and suffer the most significant energy access gaps.

Recent work on energy landscapes has moved away from a managerial conception of transition to explore the multifaceted ways in which transitions occur. Several scholars, both within and outside Africa, have argued that the scale-up of renewables energy technologies (RETs) across the continent requires more than a shift in investments and technology types; it calls for greater attention to understanding the socio-technical dynamics of transitions [27], including the geographic, socio-cultural and political dimensions of sustainable energy access [28]. Such dimensions include the socio-technical pathways for innovation and green growth [29]; issues of consumer identity in the uptake of RETs [28], the social practices of energy use in domestic settings [30]; social relations and uneven power dynamics (based on class, 'race' and gender-based exclusions for instance); and a range of everyday practices of energy access that unfolds within various registers of 'informality' [31]. To understand the role of communities in energy transitions, we also need to understand the practical impact their inclusion will have on the ground, shaping the material provision of energy and how people interact with energy.

The concept of energy landscapes engages with this complexity and the spatial aspects of energy transitions. Research mobilising this concept has focused on considering the complex relationships between landscapes, infrastructures and development priorities that shape energy projects and create controversies (for recent overviews, see [32, 33]). The notion of energy landscapes resonates with landscape ideas in large socio-technical

Table 1 Key SDG7 indicators, source: ESMAP Tracking SDG7

Sustainable development indicators for SDG7	Ethiopia	Mozambique
Population (2019)	112.1 million	30.37 million
GDP/capita (2019)	855.76 USD	503.57 USD
Proportion of population with access to electricity (SDG 7.1) (2018)	46.70%	34.90%
Proportion of population with access to clean cooking (SDG 7.1) (2018)	7.20%	6.30%
Renewable share in final energy consumption (SGD 7.2) (2017)	89.80%	60%
Energy intensity per unit of GDP (SDG 7.3) (2017)	9.7 MJ/USD	13.2 MJ/USD

systems, which refer to the broader contextual processes that shape the development of a given technology [34]. Focusing on the manifestation of political and institutional structures in space, Castán Broto [35] defines energy landscapes as the social, material, cultural and political aspects of energy production, transmission, and usage in different localities. Energy landscapes reflect the spatial arrangements of energy systems accumulated over time in particular places. They represent the interaction of energy governance with material and technological flows and people's everyday use of energy [35]. The landscape perspective enables a holistic understanding of the interactions between the actors involved in energy governance and the context in which they operate. Adopting a landscape perspective enables moving beyond normative understandings of energy systems and their governance to understand the practical impact that governance arrangements will have both on patterns of resource use (renewable or not) and on the practices of energy use that shape people's lives. In particular, it enables examining the political unfolding of transitions in space, with specific attention to the geographical factors that condition it [36].

Methodology and case studies

A preliminary step to understanding the potential of community energy is to disentangle how energy landscapes have historically evolved and changed in the countries in which we work and to situate community energy within these changing landscapes. Our analysis draws on a collaborative review of academic and policy literature in Ethiopia and Mozambique. These two countries have advanced energy access goals, with a clear policy commitment to universal energy access. However, in both countries, community energy has remained peripheral to electrification strategies until recently. As policy interest in community energy has increased (although suspended in Ethiopia during 2020–2022 due to the civil war), questions have emerged about the role of community energy in these two countries' energy transition.

The team of co-authors includes some of the key experts on energy transitions in both countries. The methodology focused on comparing the experiences of both countries through a series of collective dialogues held occasionally since 2017 and every month between April 2019 and Sept. 2021. Independent country investigations, including a review of available grey literature, current legislation and regulations, and informal interviews with policymakers, were conducted to produce two reports on each country's energy policy landscape. The team of co-authors discussed these reports to elucidate the different comparative factors that shape energy transitions in Ethiopia and Mozambique.

Following the concept of energy landscapes, the analysis focuses on salient features of energy governance and how these are translated into a system of energy resource flows and energy uses that can help assess the potential for community energy in each country. Electrification is generally considered a key strategy to facilitate renewable energy transitions in both countries and has received the most attention in our analysis. Still, sustainable electrification must be examined alongside other energy access strategies, such as household and individual strategies to access cleaner fuels for cooking, which community energy programmes could support. In what follows, we first examine the landscape of energy governance at the national scale in each country. We then deploy a landscape perspective to comparatively explore the impacts of these governance arrangements on resource flows and the everyday practice of energy use. We analyse how this shapes the potential for energy transitions, including community energy systems, as a critical component of national energy landscapes.

Ethiopia and Mozambique are large countries in their respective regions of Africa, each facing enormous energy access challenges. Table 1 summarises the latest SDG7 indicators for each country.

Both countries have deployed electrification programmes that have enabled access to electricity for millions of people. Figures suggest that over 7 million people in Mozambique and nearly 35 million people in Ethiopia have gained access to electricity in the last decade through grid and off-grid provision. Nevertheless, these figures have to be balanced with assessing the service

provided. For instance, service cuts are frequent in both countries, and many people live under the network without having reliable access to it because of financial or institutional hurdles [37, 38]. Furthermore, the immense gains from improved access to electricity are still mitigated by disappointing figures regarding access to clean fuels, particularly for cooking. Both countries remain highly dependent on biomass as the primary fuel for cooking for most urban and rural households.

Both Mozambique and Ethiopia have a recognized potential to transform the energy system using renewables. Hydropower plays a crucial role in both countries. Mozambique hosts one of the largest hydropower plants in Africa, Cahora Bassa, and new developments downstream from Cahora Bassa are expected to generate an additional 1500 MW capacity (i.e., the Mphanda Nkuwa hydropower project). Ethiopia has built numerous hydropower dams in recent years and envisages large hydropower projects as the essential means to address the country's chronic energy shortages. However, the uptake of other renewables in electricity generation, such as solar or wind, has been slow. In Mozambique, a sparsely populated country, modern renewables have long been part of the country's strategy to deliver energy access in remote areas, mainly through the Energy Fund (Fundo de Energia, FUNAE). In Ethiopia, renewables such as wind and solar have created new livelihood opportunities, especially when linked to productive uses for small and medium enterprises.

In both countries, energy policy must also adapt to the impacts of climate change. Mozambique needs to develop flexible approaches to infrastructure provision in a challenging context—as demonstrated by cyclone Idai in 2019, which caused the displacement of over 150,000 people and considerable infrastructure damages. Droughts in Ethiopia, which occur every 3–5 years, will intensify under climate change and substantially impact the country's capacity to produce hydroelectricity and food [39]. In 2011, the Ethiopian government launched its ambitious Climate Resilient Green Economy (CRGE) strategy, which embeds climate responsible principles and practices its ambitious development plans [40]. The motivation behind the CRGE is to prevent a further decline of ecological services (as livelihoods depend on those) and to harness the country's natural resources. Hence, the challenge brought about by climate change is seen as a barrier to development and an opportunity for transforming the economy. Renewable energy development is seen as a driver of this economic transformation.

Mozambique and Ethiopia also face violent sociopolitical conflicts. In Mozambique, an armed conflict has sprouted in the northern area of Cabo Delgado since 2017, led by a local Islamist group. The conflict intensified in early 2021 [41]. In Ethiopia, the recent war in the Tigray region and other parts of the country have affected the country's economic and social development. These armed conflicts are likely to impact the lives of millions of people and the energy futures of both countries.

Results

This section explores the dynamics of change in Ethiopia and Mozambique's energy landscapes. Specifically, we look at how changing governance (i.e., regulatory, political and legislative context) in both countries shapes energy resource flows and communities' access to energy. Attending to these political and material processes of change enables us to understand how energy landscapes are reconfigured through political choices and everyday energy access and use practices. This conditions the possibilities for the inclusion of communities in renewable energy transitions.

Energy governance in Mozambique

At the opening of the solar power plant of Cuamba in northern Mozambique in 2021, Max Elias Tonela, the Minister of Mineral Resources and Energy (MIREME), declared: "We intend to invest in a mixed model of public–private partnerships, to promote the development of infrastructure in a more efficient, faster way and without recourse to public financing or debts to the State." This language, now common among politicians in Mozambique, reveals a generalized strategy of diversification of forms of energy governance and a desire to facilitate the entry of private producers into energy governance. This approach, however, clashes against the realities of an institutional history dominated by state actors.

The leading state actor in energy governance in Mozambique is MIREME, responsible for energy policy and planning, monitoring sector performance, and governance. In May 2017, the Parliament approved the creation of the Energy Regulatory Authority (Autoridade Reguladora de Energia, ARENE) to separate regulatory and policy functions in MIREME. The new regulatory body has the mandate to regulate electricity tariffs, promote and monitor competition, and monitor and enforce the terms and conditions of the licenses or concessions in the power sector. MIREME oversees the operation of the two central institutions governing the provision of electricity, Electricidade de Moçambique (EDM) and the Fundo de Energia (FUNAE). At the same time, ARENE upholds quality standards (see Fig. 1).

EDM is the state-owned, vertically integrated utility tasked with delivering universal energy access by 2030 through the management and extension of the National Power Grid. EDM was created in 1977, combining 26 dispersed production and distribution units to overcome

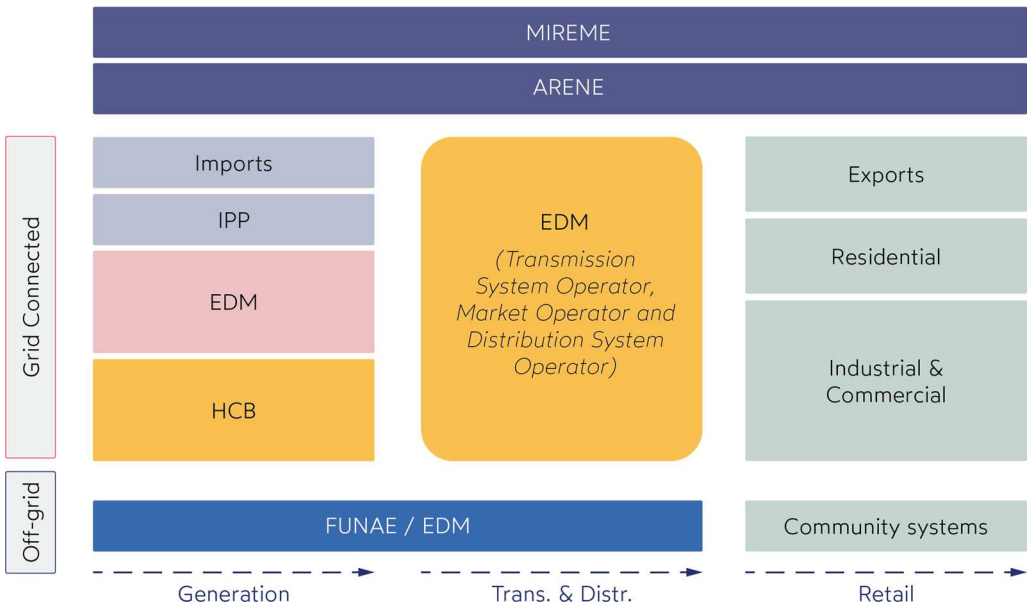

Fig. 1 Institutions regulating the power sector in Mozambique (own elaboration, adapting a design from World Bank, 2017)

the fragmentation that characterized the colonial systems of energy governance [42]. The Energy Fund (Fundo de Energia, FUNAE) is a public body created in 1997 to promote low-cost energy alternatives, renewable energy, and sustainable management of energy resources. EDM supports national state-building efforts focusing on grid expansion (mostly in urban and peri-urban areas) and large-scale energy infrastructures, with support from the donor community, regional partners, and foreign investors. The grid has expanded substantially in the last decades, reaching 30% of the population in 2019, up from 8% in 2006 [43]. FUNAE leads rural electrification efforts by promoting renewable energy and off-grid technologies mobilizing funding from donor programs. The creation of two separate agencies (one for grid expansion and one for off-grid rural electrification) has implications for the transformation of Mozambique's energy landscape. For instance, FUNAE's mandate has so far meant that off-grid electrification efforts have been directed towards facilitating access to electricity in remote settlements deemed to be beyond the energy grid. Therefore, renewable energy systems have been essentially mobilised in rural settings, following strategies predominantly driven by international donor agencies. This makes it difficult for communities to ensure their needs are prioritised in these projects.

In addition, successive regulation reforms have opened up the energy governance structure to private sector participation, enabling foreign investors to shape energy trajectories. The Electricity Law (Law 21/1997 of 1 October) was approved in 1997 and governs the licensing of power projects and power-related activities in production, transmission, distribution, trading, and import and export of electricity. Its main objective was to open the energy sector to private investors through concession contracts. The law introduced Power Purchase Agreements (PPAs) to coordinate electricity generation with the electrification efforts by EDM. In turn, Hidroeléctrica de Cahora Bassa (HCB), which manages the 2075 MW hydropower plant of Cahora Bassa in Tete Province, is the largest power generation company in Southern Africa. HCB works as an IPP, a private company with a majority state-owned capital. HCB supplies EDM and other companies internationally. The majority of HCB's capacity, 64%, is committed to South Africa's national electricity utility (ESKOM) via a long-term PPA until 2029 (EDM, 2018). In addition, Mozambique approved the Public–Private Partnership (PPP) Law in 2011 to incentivize private actors' participation in the energy sector. Central Solar de Mocuba (CESOM) is an IPP operating a 40 MW solar power plant in Mocuba, Zambezia province. CESOM is majority-owned by a Norwegian solar energy company (Scatec Solar), while EDM has a 25% stake. The solar power plant is directly connected to the grid and has entered a 25 years power purchase agreement with EDM. A second 40 MW solar power plant in Metoro, Cabo Delgado province, is expected to be built by 2022. In June 2021, the Government of Mozambique circulated a draft of a new Electricity Law for consultation, which emphasizes the role of the private sector in the country's

aspirations to achieve universal energy access, and further develops the concession system.

However, so far, public–private collaborations have strongly favored a regime of resource extraction and are not focused on enabling renewable energy transitions. For example, EDM and MIREME work with foreign mining and infrastructure companies in hydrocarbon-based revenue streams. Qualitative research suggests a close relationship between government officials and the extractive sector [35]. Chivangue and Cortez [44] observed that senior MIREME officials (appointed by Frelimo, the political party in power since independence) control companies that service the extractive industries. MIREME also has strong links with international mining and energy conglomerates and donor institutions. Renewable energy has attracted much less attention and government support than the extractive sector. Power et al. [45] argue that the involvement of international finance has created opportunities for resource rents that do not translate into tangible improvements of quality of life among Mozambique's population. As foreign investors have generally prioritized high-carbon projects, there are increasing demands to regulate the energy sector so that existing projects deliver meaningful benefits to local communities. In Mozambique, the prioritization of extractive industries poses challenges to reconfiguring energy governance towards the greater inclusion of communities, constraining the possibilities of just energy transitions.

For the most part, the deployment of smaller-scale off-grid renewable energy technologies has remained relatively marginal in Mozambique's energy landscape, driven mainly by grants from donors and linked to FUNAE's strategy for rural electrification [see also 46]. Only in the last few years, private actors have started to regard renewable projects as add ons that they can develop in tandem with established fossil-fuel projects to ensure compliance with the increasing pressure to demonstrate local benefits. In that sense, Mozambique's energy landscape is characterized by the co-constitutive nature of high-carbon and low-carbon energy developments [47]. The national government has published a draft new regulation on off-grid energy deployment for consultation in April 2021. The draft reinforces existing assumptions confining off-grid energy to rural areas and lacks any provision to facilitate small power producers and cooperatives' entry into the energy market. Therefore, current regulations and policies do not enable the emergence of community-led approaches to energy provision and management, particularly in urban areas where off-grid energy technologies have not been promoted as solutions to address energy access gaps in a sustainable way.

This hinders the reconfiguration of Mozambique's energy landscapes towards renewable energy transitions. The drive towards the diversification of energy governance frameworks in Mozambique and the inclusion of IPPs remains tied to a vision of energy generation, transmission, and distribution managed by prominent operators and linked closely to high-carbon, large-scale energy schemes. The best hope for community energy projects is to tie them to ongoing fossil-fuel projects as a means to comply with public demands and to demonstrate some local benefit from otherwise extractive (and export-oriented) projects. FUNAE and EDM are exploring some alternative pathways in partnership with international donors. However, further assessment is needed to evaluate how such global priorities align with local demands.

Energy governance in Ethiopia

As in the Mozambican example, state control characterizes energy governance in Ethiopia. The Ethiopian energy sector operates under a framework comprised of the federal government and its various agencies, autonomous regulatory bodies, federal level laws and policies, and international institutions that provide finance. The Ministry of Water, Irrigation and Energy (MoWIE) is in charge of the energy sector and has federal and regional branches that implement energy policies and regulations. The Ethiopian Energy Authority (EEA) and the Ethiopian Electric Power (EEP) manage the generation and transmission of electricity, while the Ethiopian Electric Utility (EEU) handles distribution, sales, and customer services. In 2013, new legislation unbundled the vertically integrated Ethiopian Electric Power Corporation (EEPCo) into the EEP and the EEU (see Fig. 2).

Recent policy reforms have attempted to open up the energy sector to private-sector providers and private finance (particularly for large dam building projects). Still, there is less enthusiasm from the private sector to enter the energy market than in Mozambique. IPPs' participation in the energy market is supported by electricity operations regulations (49/1999). In 2018, the government approved a legal and regulatory framework overseen by the Ministry of Finance and Economic Cooperation (MOFEC) to promote private sector investment that has supported a pipeline of PPPs in the power sector. The government is currently working with key sector stakeholders to review existing commercial and banking regulations that may impact IPPs, and a dedicated IPP unit has been established at the EEU. The goals of recent reforms are to spur off-grid, renewable energy provision and address energy access gaps through the participation of non-state actors, such as private companies and cooperatives.

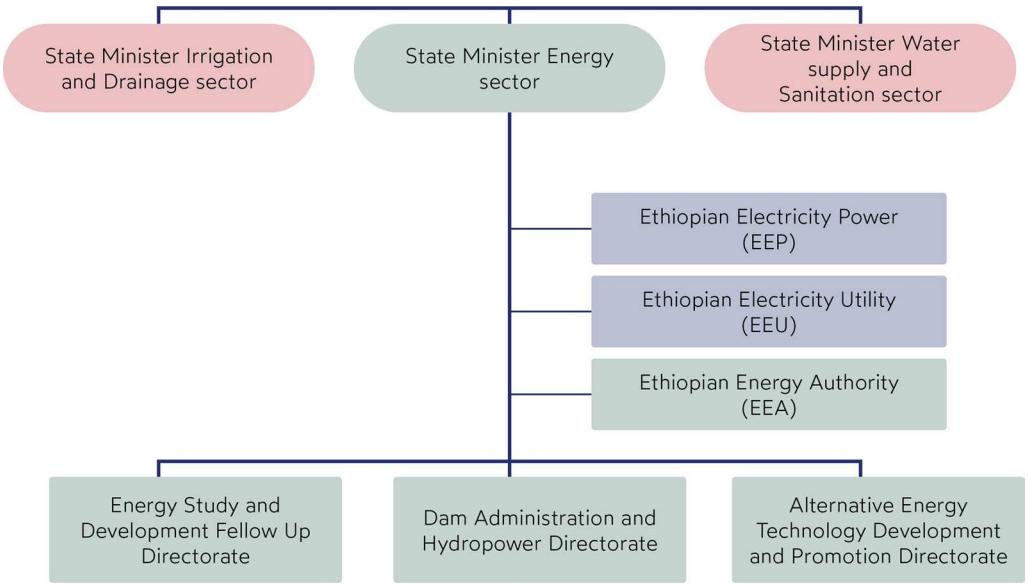

Fig. 2 Key institutions involved in the energy sector in Ethiopia, with particular attention to the electricity sector (own elaboration)

While in Mozambique, the government, via FUNAE, is the main actor in off-grid electrification, in Ethiopia, off-grid development is on a project basis, ad hoc and fragmented, and led mainly by private and community actors [48]. Nevertheless, some state actors have occasionally played a key role in expanding off-grid projects. For example, the national public telecommunication utility, Ethio-Telecom, deploys off-grid solar systems as part of its rural mobile infrastructure program (in 2012, it possessed more than 85% of the nationwide installed solar systems) [49]. The Ministry of Health implemented a nationwide project for the universal electrification of health centers and posts.

Ethiopia's National Electrification Program, approved in 2017, which aims to achieve 100% electrification by 2025, includes a framework for national electrification to overcome the sector's perceived fragmentation and facilitate the coordination of on-grid and off-grid developments. The framework has explicit provisions for the involvement of IPPs and cooperatives in electricity delivery through public funding. The Program's vision includes a pre-electrification component whereby mini-grids- especially solar- could be used to provide access to around 5 million people residing within 2.5–25 km of the existing grid until those communities finally gain access to the leading grid network.

Off-grid technologies deployment is, in sum, widely perceived as a secondary or intermediary operation to ensure energy access as the grid networks develop. Moreover, the role of communities is rarely considered, let alone analyzed in-depth in existing strategies. Yet, non-state organizations play a critical role in expanding off-grid development. For instance, Dalelo [50] stressed the role of schools as important actors in disseminating solar energy know-how. Kebede et al. [51] showed the importance of NGOs in renewable energy development, highlighting the role of the Solar Energy Foundation in the diffusion of solar home systems in the mid-2000s, as they established a solar training school, a micro-credit system, and solar centers. If Ethiopia's energy landscape is shaped by centralised state provision and uncoordinated, smaller scale efforts to provide renewable energy where it is needed, the energy transition remains in the government's grip and dominated by large-scale hydropower production.

In summary, an extractivist orientation in Mozambique has fostered private involvement in large-scale, extractivist projects. In Ethiopia, the state actors remain dominant in energy governance. If experimental off-grid projects exist in both countries, sometimes linked to government programmes (coordinated by FUNAE in Mozambique and linked to development programmes in Ethiopia), off-grid expansion remains dependent on grants and development finance and are not driven by beneficiary communities. There are fewer efforts to develop local capacities for the endogenous development of energy projects and to support community participation. Likewise, support for cooperatives and small enterprises is still lacking. Instead, the energy transition remains tied to international investment priorities in Mozambique and national development projects in Ethiopia, leaving little space to mobilize community energy as a tool for the

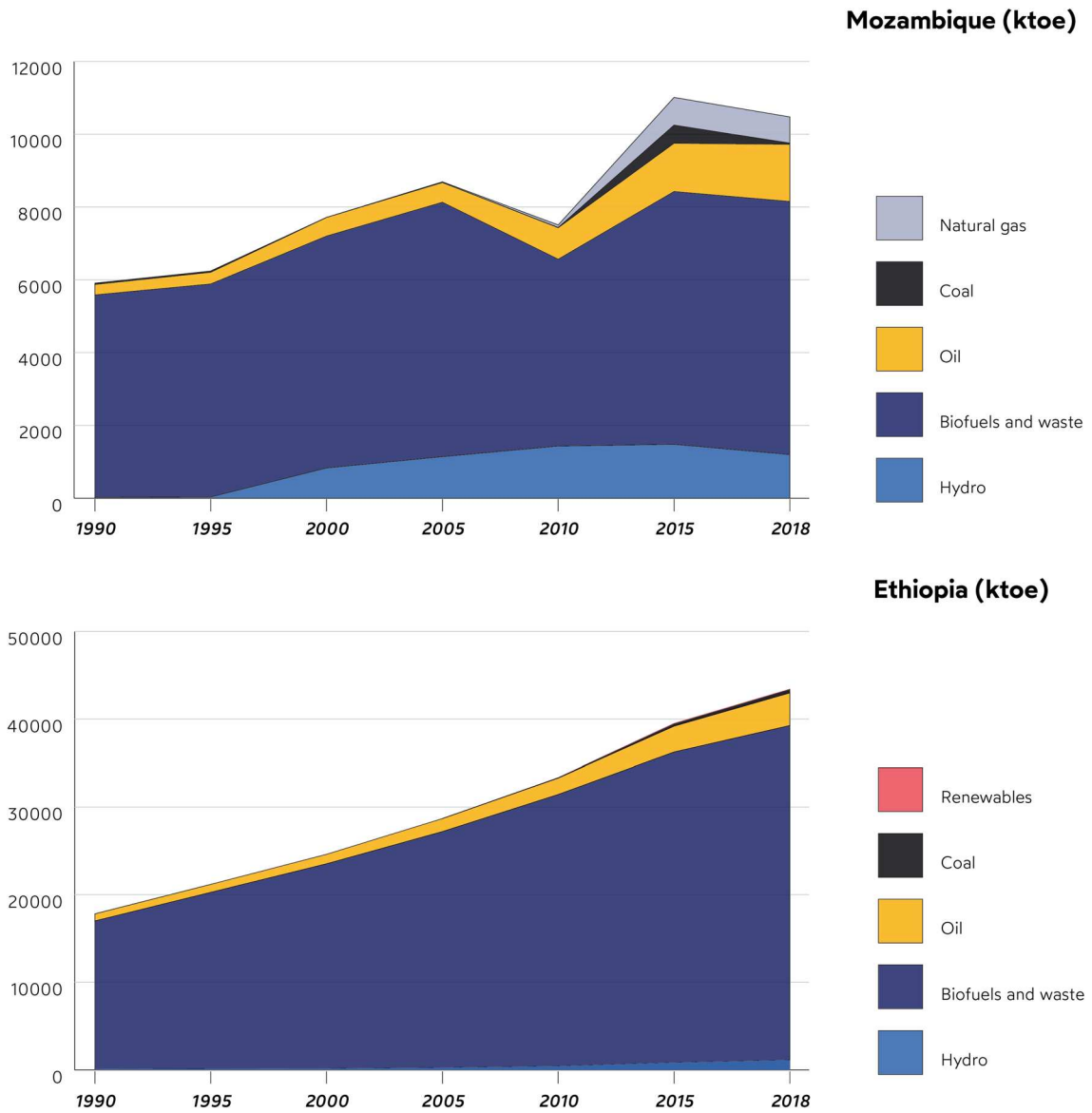

Fig. 3 Total Energy Supply (TES) by source in Mozambique and Ethiopia in 2018 (own elaboration using Data from IEA World Energy Balances, 2020)

reconfiguration of national energy landscapes towards renewable energy.

Impact on energy landscapes

Understanding how governance regimes in both countries influence the nature and possible transformation of energy landscapes requires us to look at their impacts on energy resource flows and people's everyday access to energy. When it comes to energy resource flows, it is important to understand who controls such flows, how, and for what purpose. Mozambique and Ethiopia have a lot in common, partly because of their centralized model of economic planning. Both countries are highly dependent on biomass (Fig. 3). As per 2018 data, as many as 28 million people in Mozambique and 104 million people in Ethiopia rely on solid fuels like firewood and charcoal to meet their cooking and heating needs, directly impacting health, people's time and forest resource depletion [52]. Enhancing access to clean cooking technologies remains a policy priority for both countries, but there are limited opportunities to do so. Programmes to deliver improved cookstoves and measures to facilitate access to electricity for cooking and productive uses have shown efficiency gains. However, they have not significantly reduced the

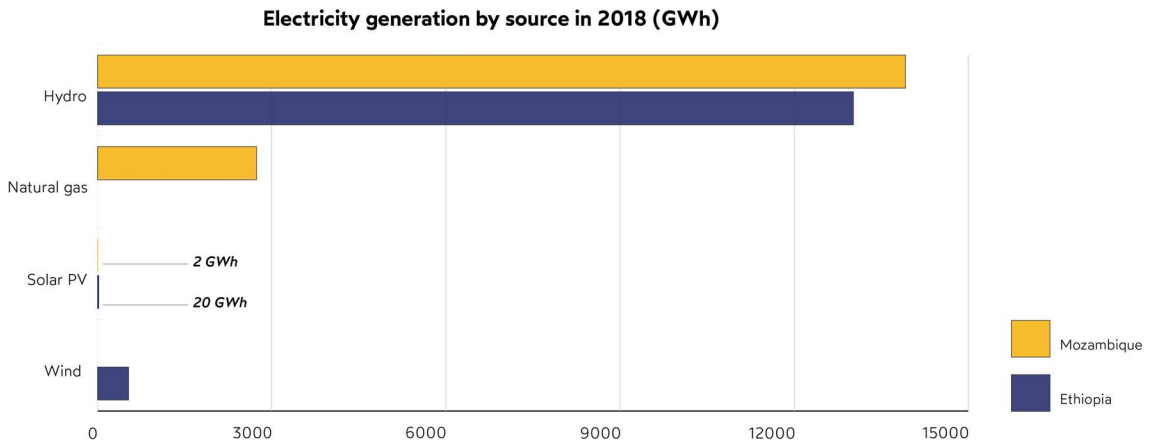

Fig. 4 Electricity generation by source in 2018 in Mozambique and Ethiopia (own elaboration using data from IEA World Energy Balances 2020)

importance of biomass as a critical feature of both countries' energy landscapes because households lack reliable and affordable alternatives.

In both countries, hydropower is the primary source of electricity (Fig. 4). In Mozambique, hydropower accounted for about 83% of all electricity generated in 2020 [53]. The Cahora Bassa dam generates most of Mozambique's hydropower, while other hydropower projects are deployed at different scales [54]. While these projects have a firm grasp over the political imagination of Mozambicans (many of whom see Cahora Bassa as a national symbol), they invariably have negative impacts on local communities and ecosystems [55]. Even small-scale hydraulic projects are designed in a top-down fashion, with very little—if any—involvement from local communities in managing resource flows.

Ethiopia is known as the 'Water Tower of Africa' [56], and hydro infrastructures generate over 95% of the electricity in the country (IEA, 2020). Successive Ethiopian leaders have put water control at the heart of the state's development agenda, because it is essential for food and energy security. Since the 1970s, economic growth has gone hand-in-hand with increased electricity demand [57], and controlling water resources has been an imperative for the country. Since the 2010s, the Ethiopian state has embarked on an extensive dam-building program, perhaps "the most ambitious dam program in African history" [39, p. 5]. When the International Energy Agency president, Fatih Birol, called hydropower 'the forgotten giant of clean electricity' at the World Economic Forum in 2021, he referred to Ethiopia as one of four countries leading the growth of hydropower globally. Increases in generation capacity are also expected to help Ethiopia access foreign exchange by exporting electricity to neighboring countries (Djibouti, Sudan, Kenya, Burundi, Tanzania, Rwanda, Uganda, Yemen, Egypt) [58]. The construction of dams has raised new geopolitical tensions in the Nile Basin, particularly with Egypt and Sudan [59].

In its 2017 National Electrification Program, the Ethiopian government proposed increasing its hydropower capacity to 13.5 GW by 2040, making Ethiopia the second largest hydro producer in Africa. As in Mozambique, policies focusing predominantly on the control of hydraulic resource flows have had detrimental impacts on local communities, many of which still lack access to electricity despite living close to these mega-infrastructures and suffering their negative impacts, such as the loss of grazing land and the destruction of forests [60]. The multiple negative impacts of hydropower projects on communities have been documented, including increased risk of drowning, displacement of people, and loss of livelihoods- especially because of the loss of arable land [61]. For now, Ethiopia's energy landscape has been primarily defined by a strong reliance on hydropower. This might change in the future as the country has broadened its strategy to expand the generation capacity of wind and geothermal energy. As in Mozambique, there are concerns about the future of hydropower under climate change. Ethiopia is vulnerable to drought, particularly its lowlands in the South. Drought can impact water levels, agricultural production, soil degradation, energy production, resource management, and migration [62]. Observers have called for diversifying the Ethiopian energy mix and emphasize the need to invest in alternative energy sources [56], building on potential synergies between hydro, solar, and wind systems [63].

As Fig. 4 shows, natural gas is changing Mozambique's energy landscape. In 2010, the US company Anadarko found substantial natural gas reserves in Cabo Delgado, in the far north of the country, later selling the assets to

the French oil and gas company Total in 2019. According to the IEA, "Mozambique's ambitions for economic and social development depend in large measure on its ability to develop its large natural gas resources" [64]. For example, since 2015, PPAs have facilitated the entry of thermal gas plants, and as of 2018, natural gas accounted for over 16% of the electricity generated in the country. However, the discovery of gas mainly attracted interest from financial investors internationally with limited interest in the region's development. A series of lucrative contracts for liquid natural gas (LNG) projects are intended to supply international markets. The impacts of these contracts are visible on the ground: hundreds of residents have been displaced, and local fishing communities lament the loss of ecosystems and livelihoods. The region has been affected by increasing instability deriving from violent conflicts. Since 2017, the militant Islamic movement, Ansar al-Sunna, locally known as Al-Shabaab, has destabilized the region through violent attacks, killing hundreds and displacing tens of thousands, culminating with an attack in Palma in March 2021 [65]. At the 7th Mozambique Mining, Oil & Gas and Energy Conference and Exhibition in April 2021, most prospective investors expressed concern about how violence had changed the context of both gas and coal exploitation.

The reality is that violence and the exploitation of fossil fuel resources go hand in hand. The model of exploitation of energy resources for export, with little or no benefit for local communities, has been well documented in Mozambique. For example, during the 2000s, mining operations in Moatize-Minjova, Senangoe, and Mucanha-Vanduzi (all in the Province of Tete) aimed to take advantage of the country's coal reserves, estimated at 24 billion tonnes [66]. The global commodities supercycle in the mid-2000s motivated investments in coal operations at the Moatize coalface primarily through export-oriented energy projects led by Vale, a Brazilian mining giant, shaping energy flows within Mozambique and beyond its frontiers, with limited benefits for the communities that hosted those projects [67]. As in the case of natural gas, the impacts of mining projects on the local communities have been devastating.

In Mozambique and Ethiopia, 'modern' renewables such as solar, wind and geothermal hold great promises: to deliver the Sustainable Development Goal 7, to support the countries' plans for inclusive development, and to move away from resource exploitation as the main engine of development. During COP26, the Mozambican prime minister declared that the country hopes to generate 62% of its grid power from renewable energy sources by 2030.[1] However, their uptake is slow at best. In Mozambique, renewable energy flows have been predominantly mediated and supported by energy access programmes, notably those led by FUNAE. However, the disconnect between programme design and users' needs limits the transformative capacity of off-grid electrification and hinders the possibilities for structural changes in both countries' energy landscapes. As previously mentioned, energy resource flows are mediated by various infrastructures and technologies, including off-grid technologies and payment technologies. In a study on solar technology deployment in Mavonde, Manica Province, Power and Kirshner [67] highlight the disparity between solar technology deployment efforts and users' capacity to pay for solar energy. The study reported that households living far from urban centers were often unable to repay loans offered by FUNAE to install solar home systems (SHS). The study found that users felt that SHS was ill-fitted for their living conditions, for instance, taking up too much space in their homes. Kumar et al. [68] draw similar conclusions, arguing that FUNAE's projects are often designed in a top-down fashion. These studies show that renewable energy flows are mediated by the adaptability of particular technologies to users' needs, income, and practices, which determine whether and how the introduction of particular technologies (in this instance, solar energy) can bring about significant changes in energy infrastructure landscapes. While off-grid technology deployment can encourage community involvement in energy governance, the Mozambican experience shows that existing approaches to rural electrification largely neglect communities' needs, knowledge, and practices.

In Ethiopia, since the early 2000s, the government's energy access strategy has contributed to the uptake of renewable energy, including solar, in the national energy mix. Between 2005 and 2011, 2.7 million improved biomass stoves were distributed, with the national universal access program planning to distribute 3 million solar cookers, 65 micro-hydropower plants, and 26,000 biogas digesters in 2014 [63]. Ethiopia has connected 33% of its population to the national grid and 11% with off-grid solutions—mostly mini-grids and solar PV systems. Since 2012, wind farms have been installed to compensate for the shortfalls of hydroelectric power in the dry season, but wind energy remains marginal in the national energy mix [63]. The recently launched National Electrification Program (2017) constitutes a fundamental change in the management of resource flows in Ethiopia because it encourages the participation of new actors (e.g., IPPs,

[1] https://clubofmozambique.com/news/mozambique-commits-to-halt-and-reverse-forest-loss-and-land-degradation-by-2030-and-to-a-new-renewables-target-as-part-of-its-energy-transition-204129/

cooperatives) and the promotion of solar and bioenergy into the national energy mix. Yet, its impacts on the country's energy landscape remain to be seen.

We see deliberate efforts to diversify the energy mix in both countries and reduce the heavy dependence on hydropower because of its social, economic, and environmental impacts and the growing risk of drought under climate change. Despite these efforts, there are apparent factors limiting the uptake of renewables. Perhaps, the most visible has been the limited capability of locally developing and manufacturing energy technologies and the absence of policies to support domestic production [69]. Current efforts to facilitate off-grid projects (through a draft regulation in Mozambique and development plans in Ethiopia) may increase the uptake of renewables. Still, these efforts do not yet envision that people can participate directly in the governance of small-scale energy projects, nor do they intend to support the development of local skills for energy management and engineering.

With regards to energy access and everyday practices of energy use, approaches centered on communities' needs and focused on the development of flexible off-grid renewable energy technologies can offer avenues to address energy needs in a just way and to build decentralised energy systems to tackle climate-related challenges. Decentralized systems are often viewed as more resilient to disruptions and extreme weather events and less vulnerable to system malfunctions than centralized fossil-fuel-based systems [70]. In Mozambique, the widespread use of biomass for cooking raises health issues [52] and environmental challenges [71, 72]. However, cultural preferences and enduring energy practices around these sources mean that it is not easy to replace them with renewable energy technologies [73]. Kumar et al. [68] show that solar energy technologies are mainly used for lighting and water heating while cooking with charcoal continues even when solar technologies are available. Beyond energy users' preferences, everyday practices of energy use are also shaped by income levels. Proactive state-led programs, such as those led by FUNAE have had mitigated impacts on changing such practices. They have led to the emergence of a sizable yet nascent market for standalone off-grid solutions dominated by private solar companies [67]. Yet, due to the low purchasing power of many households, the market has been dominated by low-quality products traded in informal (untaxed) markets. Such experiences have diminished confidence in solar technologies. High-quality, branded solar products are available in Mozambique, but prices are unaffordable for most of the population. Some enterprises offering high-quality products have adopted the pay-as-you-go option to reduce upfront payment requirements and, thus, enhance affordability. Yet, these enterprises remain small, targeting consumers located in urban and peri-urban areas of large cities and overlooking rural communities.

Until its recent National Electrification Program, Ethiopia did not prioritise the electrification of rural areas. Instead, it focused on investing in large-scale infrastructures to supply the most productive sectors of the economy and the urban regions [74]. As a result, most Ethiopians lack access to modern energy fuels such as electricity and LPG and are directly dependent on biomass (Fig. 2). The growing interest in renewable energy has not changed this situation [58, 75, 76]. Firewood, crop residues/leaves and cow dung are the primary sources of domestic energy consumption for most of the population (over 90%) [63]. Deforestation and soil erosion due to population growth and increased fuelwood demand threaten energy access even to these rudimentary fuels, both in Mozambique and Ethiopia [76, 77]. In Ethiopia, and similar to what we observe in Mozambique, urban households with physical access to grid electricity might not use the network because it is too expansive [58]. The National Electrification Program might attempt to reshape existing practices, providing the country's populations with new energy sources, but this requires the large-scale deployment of off-grid technologies and the institutional involvement of communities. Furthermore, the Program mainly envisages off-grid solar energy as transitional technologies, supplying electricity to communities until grid network expansions reach them (circa 2030). This makes it difficult to see how solar energy can be embedded in Ethiopia's energy landscapes in any durable way.

Energy access challenges mean that the cost of accessing energy is unevenly distributed within and across communities. Those dynamics create unjust energy landscapes in both Mozambique and Ethiopia. Moreover, users' preferences (e.g., for different types of cookstoves or technologies), income, and the reliability and accessibility of existing energy infrastructures influence the possibilities for renewable energy transitions. Unaffordability and intermittent supply mean that people experience uneven access to its services even when they have grid connections. Concurrently, people may combine electricity and charcoal to access services. This means that people resort to multiple strategies to access energy. Castán Broto et al. [78] highlight how different forms of energy (e.g., charcoal, energy from street lighting, networked electricity through prepayment) co-exist and are mobilized in people's everyday lives.

For example, charcoal remains the principal household source of energy for cooking in urban areas. Even when communities, and households within these communities,

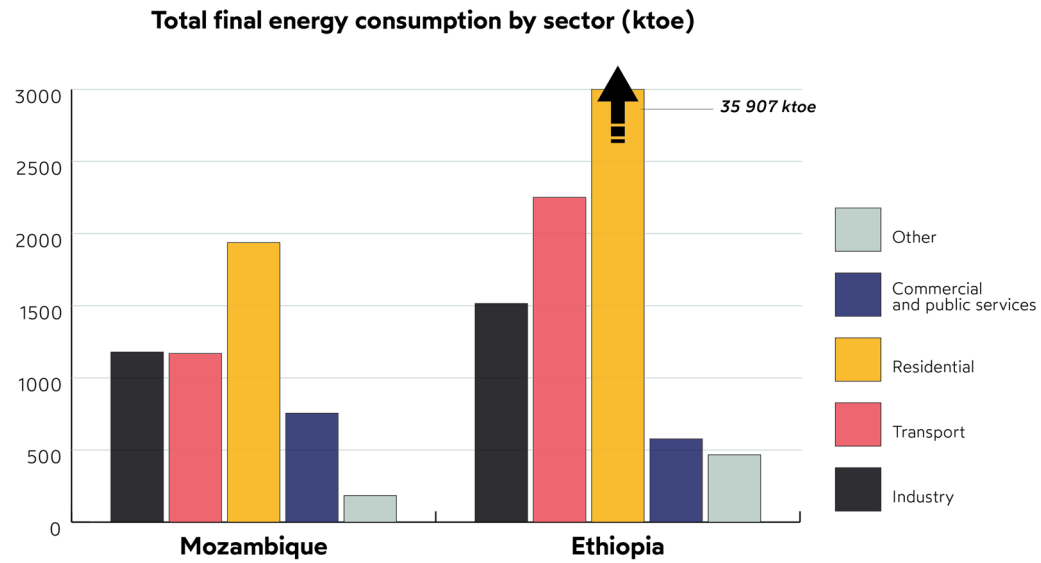

Fig. 5 Total final energy consumption by sector in Mozambique and Ethiopia in 2018

earn higher incomes, charcoal remains a vital energy source [79]. The persistence of charcoal for cooking poses significant challenges to any attempt at introducing renewable and clean energy technologies for cooking. Still, it also needs to be understood as an essential component of enduring energy practices, enacted and maintained by individuals and local communities in the context of their livelihoods [42]. While many people are involved in the supply chain of charcoal, most benefits are not captured by communities but by external agents [80]. Programs focusing on the distribution of improved cookstoves have attempted to reduce indoor air pollution and improve combustion efficiency. Still, their limitations in delivering a low carbon transition are well documented [81–83]. In Ethiopia, for instance, a study in Debre Markos Town (in northwest Ethiopia) found that almost all households still use traditional biomass for cooking [84]. The study also found that people have strong beliefs regarding the benefits of using biomass fuels for cooking. For example, people often report that food cooked with charcoal tastes better. Similarly, when it comes to solar technologies, Kebede and Mitsufuji [49] found that the diffusion of solar technologies faces cultural barriers related to taste and perceptions of good cooking and good food. That said, recent studies have also shown that the energy landscape for cooking can rapidly change in some places. For instance, in Addis Ababa, the ownership of electric cooking has increased quickly over the past 5 years, meaning that biomass use is also rapidly decreasing [85].

Coupling energy access with productive uses of energy (e.g., for business and livelihoods development) can be a way to accelerate renewable energy transitions, but the definition of productive uses has to be extended to address the multiple ways in which energy can provide benefits to households and local communities [86]. Figure 5 shows that the residential sector accounts for the largest share of total final energy consumption. However, when defining the residential sector, we need to encompass many home-based businesses, remote work, and other economic activities that put energy at the centre of people's livelihoods. Community energy projects could support a local energy system that sustains local livelihoods across locations and sectors. Thus, community energy may be vital to address the energy needs of groups that are not accounted for in formal statistics and existing development programmes. For example, as a general rule, women tend to operate in smaller and less energy-intensive enterprises [87].

In summary, energy transitions in Mozambique and Ethiopia will depend on how local energy needs can be met with existing technologies and the provision of alternatives to using polluting fuels for cooking. The Addis Ababa experience shows that new technologies such as electric cooking appliances can rapidly reshape energy landscapes, pending these technologies are affordable and suit users' needs. Perceptions on the merit of particular technologies are not homogeneous but shaped by structural drivers of inequality, conventions of practice, and individual experiences, all of which enable or hinder the uptake of off-grid, community-centered energy developments in Ethiopia and Mozambique.

Table 2 Comparative analysis of the energy landscapes in Mozambique and Ethiopia

Energy landscapes in	Governance context	Energy flows	People's energy access
Mozambique	Inclusion of IPPs and international investors in energy provision and policy strategies So far, off-grid development has been separated from main electrification strategies and depends on bilateral and multilateral assistance Limited national capacity for energy development The spatial separation of energy development strategies creates different rural and urban energy systems	Natural gas and hydropower continue to be the primary sources of electricity, fuelled by a focus on exports Most households depend on biomass Local biomass (Charcoal and firewood) markets disconnected from energy strategies	Fuels such as charcoal and firewood are embedded in the architecture, built environments, and local practices. Gender roles also shape them Limited recognition of the diversity of productive energy uses and how they are inserted into people's lives Increasing interest in off-grid technologies
Ethiopia	Increasing attempts to introduce IPPs in energy provision alongside a strong state that shapes development trajectories The close relationship between energy and development strategies, based on water and irrigation	High priority to hydropower resource development Most households depend on biomass Strong emphasis on universal energy access through off-grid technology deployment in peri-urban and rural areas, mobilising a range of energy sources (solar, biogas, mini-hydro) Existing yet limited emphasis on wind energy development	Households' preference for biomass with the limited but existing shift to solar household systems (e.g., Addis Ababa) Income, cultural norms and gender shape the adoption of clean energy technologies such as improved cookstoves and solar PV systems

Discussion

Empirically, our investigation showed some similarities and substantial differences between Mozambique and Ethiopia's energy landscapes. Energy transitions depend on the interplay between energy governance, flows of energy, and the way people's energy needs are met on a daily basis. Table 2 summarizes how these three aspects of energy landscapes shape the development of off-grid, community-centered renewable energy projects.

The structures of energy governance in both countries prioritize the development of a centrally managed grid. The state plays a central role in shaping energy governance in both Mozambique and Ethiopia. Accordingly, both national states control the development of policies and regulations. However, the last decades have seen an increasing interest in facilitating the entry of IPPs, first in Mozambique and most recently in Ethiopia. We also observe a strong orientation towards participating in an international energy market via hydropower (in Ethiopia) or the exploitation of fossil fuel resources (in Mozambique) in both countries. The extent to which current electricity policies can benefit local populations is a key discussion point in both countries—both of which have a commitment to universal energy access and have made advances in electrification policies. Yet, this goal has not fundamentally shaped the large-infrastructure generation model of energy policies. IPPs have been seen as part of a system based upon large-scale generation within existing infrastructure networks, with limited options for small producers or producers interested in developing off-grid networks. There are also no apparent alternatives to address the continued dependence of both countries on biomass.

What are the implications for the development of off-grid energy in each country? In Mozambique, the involvement of international and bilateral organizations has supported some off-grid projects but mainly directed towards remote, rural populations. In Ethiopia, the alignment of other development goals such as health with energy has enabled the development of off-grid renewables. In both cases, however, modern renewables such as wind and solar remain marginal, reaching negligible segments of the total population. As climate change-related events such as droughts and floods increase in frequency and impact, new values may be attached to renewables, such as resilience and flexibility. In any case, renewables, especially off-grid renewables, are still considered an add-on to current policy strategies, which remain focused on natural gas (Mozambique) and hydropower (Ethiopia). Thus far, the recognition of the wide range of productive uses that energy could meet, especially when targeting disadvantaged populations whose needs are rarely recognized, has been limited. Moreover, the armed conflicts in Cabo Delgado (Mozambique) and Tigray (Ethiopia) hamper both countries' economies and compromise the development of renewable energy in those regions.

Community energy deployment requires challenging the role of the government as a provider of services, looking instead into the potential for communities to deliver energy on their terms and with a certain degree of autonomy (albeit this does not exclude collaborating with governments and the private sector). Community energy offers a framework to develop local technology implementation and management skills to create close relationships between communities and their infrastructure. However, current legislative and governance frameworks in Ethiopia and Mozambique constrain the possibility of engaging communities in deploying off-grid energy systems.

Conclusions

This paper explored how contemporary energy landscapes in Mozambique and Ethiopia shape the possibilities for community-focused off-grid energy transitions in both countries. The lens of energy landscapes [35] shows how diverse interactions between governance arrangements, energy flows, and people's everyday needs shape energy transitions. These different elements form the context within which new technologies and energy delivery models—in this case, off-grid energy systems—are introduced and shape the possibilities for change.

Our analysis suggests that when countries face the prospects of lucrative energy investments in natural gas or hydropower, renewables are deprioritized. Their suitability to address current energy challenges is de-emphasized. As long as investments in off-grid energy continue to depend on international organizations' goodwill or their insertion in other development programs, there will not be a genuine transition to sustainable energy. However, recent policy developments in Ethiopia and Mozambique show a keen interest in upscaling the development of off-grid renewable energy. There are different ways in which these ambitions can be realised to benefit local communities. For instance, investing in a range of skills development and capacity building initiatives around decentralised energy (within national and local government departments, but also through education programmes) can help develop and maintain community energy projects. Regulations allowing IPPs, smaller domestic companies, cooperatives and community organizations to enter the off-grid energy market can help build a local ecosystem of energy producers and suppliers that caters to different groups' needs (from low-income to higher-income customers). This needs to go hand in hand with programmes that support local capacity building for the production and maintenance of

renewable energy technologies to ensure that renewable energy transitions benefit and are driven by local actors. Aligning governments' strategies for off-grid electrification with participatory frameworks to ensure the inclusion of local communities, local businesses and local authorities in the design, delivery and maintenance of energy projects enable the creation of community-centered renewable energy schemes that respond to local needs. Reshaping policy and institutions to move away from centralised energy production and provision and allow more flexible energy production and delivery will take time, particularly as both Mozambique and Ethiopia experience enduring armed conflicts. However, off-grid renewable energy technologies have the potential to address energy access gaps rapidly and sustainably, provided technology users and programme beneficiaries are put at the centre of off-grid electrification efforts.

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Author contributions
MG and CC produced the initial country-level reports on energy governance that formed the basis of this paper. VCB and ER wrote the initial paper draft and conceptual framing of the paper. MG, CC, IB, LST, CZ, LH, and JK contributed to paper development and manuscript writing. YM, MP, DM, DJ, and SR provided expertise on energy governance in East Africa and off-grid energy governance that fed into the key arguments exposed in the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials
The materials used in this article consist of policy documents and conversations with policymakers in both countries. They are not archived online.

Declarations

Ethics approval and consent to participate
This research has received ethics approval from the University of Sheffield (application 033231).

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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