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Barriers to off-grid energy development: Evidence from a comparative survey of private sector energy service providers in East Africa

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Abstract

In light of recent growth in the off-grid energy sector due to the falling costs of solar PV technology, this paper considers barriers and opportunities for off-grid sector development in four countries in East Africa—Ethiopia, Kenya, Tanzania, and Uganda—with off-grid sectors that are varying in their maturity. We compare the perspectives of private companies in each of these locations relating to both constraints and opportunities, and place these in the context of the current development of off-grid energy in each country. Moreover, we measure trade-offs between different institutional designs that would aim to regulate and support the off-grid sector, using a discrete choice experiment (DCE) design. The study is based on a survey of nearly 200 such firms located in four East African countries . The survey reveals a set of common challenges, but also considerable variation within and across countries. We also find that the following impede development of the sector: lack of market information and technical capacity; insufficiently comprehensive regulation; and (in specific countries) informal sector competition (Tanzania), cost of doing business (Ethiopia), poor tariff policy (Tanzania), and lack of funding (Uganda). Moreover, firm responses emphasise the need for much greater policy support at all levels: subsidy, financing, access to foreign exchange, technical assistance for regulatory matters, and capacity building. The DCE sheds further light on these policy preferences and clarifies common threads and country differences. Finally, we argue that policy and the regulatory climate, as well as the implementation of those aspects, makes a big difference in firms' perceptions of opportunities and constraints in the sector. Though the off-grid sector appears to be growing in these countries, in large part due to falling costs and policy momentum, many obstacles remain and will continue to challenge achievement of SDG7 (sustainable, modern energy for all).

Key words: Off-grid market; barriers and opportunities; Discrete Choice Experiment; East Africa

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List of abbreviations

ADELE	Access to Distributed Electricity and Lighting in Ethiopia
DCE	Discrete Choice Experiment
DREAM	Distributed Renewable Energy-Agriculture Modalities
EEP	Ethiopia Electric Power
EEPCo	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
GDP	Gross Domestic Product
GOGLA	Global Association for the Off-Grid Solar Energy Industry
IPP	Independent Power Producer
KNES	Kenya National Electrification Strategy
KOSAP	Kenya Off-Grid Solar Access Project
KPC	Kenya Power Company
KPLC	Kenyan Power and Lighting Company
MoWIE	Ministry of Water, Irrigation and Energy
NEP	National Electrification Plan
PPP	Purchasing Power Parity
REA	Rural Electrification Authority
SHS	Solar Home System
SPP	Small Power Producer
TANESCO	Tanzania Electric Supply Company Limited

1 Introduction

Off-grid energy holds great potential to provide modern energy services, and the myriad benefits they provide, to lower- and middle-income country households located far away from the conventional energy grids(IEA, 2017;Sergi*et al*., 2018;Jeuland*et al*., 2021). The falling costs of solar panels and progress in developing new and more cost-effective battery technologies have made off-grid solutions the preferred least-cost technology for electrification in many rural settings (Glemarec, 2012;Bukari*et al*., 2021). Yet many of the same barriers that impede connections to the grid, including lack of affordability for the poor and low demand for electricity that impedes financial sustainability, also apply to off-grid energy sources (Lee *et al*., 2014). Moreover, off-grid technology faces an additional challenge in that it is largely driven by the private sector, in a domain where electricity service has typically been provided through public utilities, most of which deliver power well below the cost of production (Kojima and Trimble, 2016). This leads to challenges related to mobilising finance for new types of providers and service models. In addition, incumbent utilities possess considerable market power that increases risks for new service delivery models, for example if grid encroachment undermines private investments (Bhattacharyya, 2013). The end result is that the off-grid investment deemed necessary to meet SDG7 (sustainable, modern energy for all) electrification targets (e.g. in IEA,2017) is falling well short.

In low-income countries, the growing literature on the constraints and opportunities for greater off-grid energy development identifies the following key barriers: political and institutional dimensions; economic and financial factors; social dimensions; technical and management aspects; technology diffusion; and rural infrastructure (Ahlborg and Hammar, 2014;Weston *et al*., 2016;Bukari*et al*., 2021). Institutional challenges arise from the typically highly centralised and top-down nature of the power sectors in many countries, and their low human capacity for managing renewables(Haanyika, 2006;Bhattacharyya, 2013;Burke *et al*., 2019). This means that traditional utilities are poorly suited to pursue a decentralised investment strategy, but conversely create opportunities for new private actors. Political prioritisation and capacitation of key actors can help partly address institutional problems, but priorities can change, and skilled human capital often proves difficult to retain (Sergi*et al*., 2018).

Access to capital is a major economic and financial side-barrier to the growth of off-grid in low-income countries, as few energy consumers in these countries or settings can afford to pay the tariffs needed to recover investment and operating costs. This is particularly the case for mini-grid based electrification, and less so for solar home systems (SHS), though the ability to pay for quality service from the latter often remains limited. Even when large subsidies are provided, private developers do not always target poor users, and when they do (for example with well-targeted results-based financing schemes), they often promote solutions that primarily allow basic lighting and phone charging (Scott, 2017;Cross and Neumark, 2021). This substantially limits private sector participation and the development of sustainable business models (Barnes, 2007;Hazelton *et al*., 2014;Engelken*et al*., 2016). In addition, few consumers use energy for income generation or productive uses (Morrissey, 2018) at the levels needed to generate the revenues that energy system operators desire, owing to difficulties accessing needed equipment, credit, and markets for products (Peters *et al*., 2019). Donors and governments can of course subsidise services and facilitate the flow of capital, but have typically focused on the grid and on major or state-run utilities (Bhattacharyya, 2013; Davies and Tilleard, 2019;Zebra *et al*., 2021). They also often fail to sufficiently coordinate their efforts or to adequately consider the long-term sustainability of the subsidies they provide(Bukari *et al*., 2021).

An additional challenge in much of Africa is that infrastructure—roads, markets, etc.—is especially lacking and difficult to extend due to relatively low population density and difficult terrain. There are also technical difficulties relating to the structure of traditional housing, which is often unsuitable for wiring, and persistent gaps in the provision of maintenance personnel with adequate training, services, and replacement parts (Hazelton *et al*., 2014;Engelken*et al*., 2016). Lower-cost systems or lifeline tariffs, while affordable and therefore socially more acceptable, mostly fail to provide sufficient energy to spur economic activity, locking in low levels of consumption in a way that perpetuates energy poverty.

In spite of this growing literature on barriers, however, evidence on the perspective of the mostly private off-grid energy firms remains limited, and evidence regarding the views of these service providers on the need for supportive institutions and policies (e.g. regulatory approaches, availability of subsidies, access to finance)is mostly anecdotal (Bhattacharyya and Palit, 2016). Very little systematic evidence has been collected from large or representative samples of such organisations. In light of this gap in data and evidence, this paper draws on a survey of nearly 200 such firms located in four East African countries with off-grid sectors that are varying in their maturity. At one end of the scale, Kenya represents perhaps the most vibrant off-grid energy market in Africa, at the other extreme, development in Ethiopia is very nascent, despite that country's massive ambitions as expressed in its National Electrification Plan (NEP). Uganda and Tanzania lie somewhere in between. Our first contribution is to compare the perspectives of private companies in each of these locations, which relate both to constraints and opportunities, and to place these in the context of the current development of off-grid energy in each country. Our second contribution is to measure trade-offs between different institutional designs that would aim to regulate and support the off-grid sector, using a discrete choice experiment (DCE) design. Design features such as subsidy support, tariff regulation, grid connection policy, centralised versus decentralised licensing, and the availability of a foreign currency exchange were considered in this DCE.

2 Background: Overview of the off-grid energy sector in the study countries

This section describes the energy access situation in the four study countries, focusing especially on the role of off-grid energy and investments. These four East African countries provide an interesting range of experiences—among the least (Ethiopia) and most (Kenya, Tanzania, and Uganda)active off-grid markets in Africa—that are generally relevant to those of other countries of the subcontinent.

Basic country demographic, economic, and energy access statistics are presented in Table 1. Ethiopia is by far the most populous of the four countries and also the least urbanised. The purchasing power parity (PPP)-adjusted gross domestic product (GDP)*per capita* of Tanzania, Ethiopia, and Uganda is relatively similar, while Kenyan households are relatively richer on average. In terms of electricity access, the rate is also much higher in Kenya relative to the other countries, while access in Tanzania (especially in rural areas) is lowest. Urban electricity access in all four countries exceeds 70%, with Kenya and Ethiopia both above 90%, though the reliability of the power supplied is relatively poor (Ayaburi*et al*., 2020;Meles, 2020). Three of the four countries also boast relatively high shares of renewable energy in final consumption, the vast majority of which comes from hydropower. Tanzania has the lowest share of power from renewables(39%), while Kenya has 72% renewable power, over half of which is geothermal. Ethiopia and Uganda have the highest renewable shares, nearly all from hydropower (98% and 90%respectively). The energy intensity of these economies ranges from 5.4 megajoules per PPP-adjusted dollar of GDP (in Kenya) to 10.1 (in Uganda), though these intensities have generally been dropping in all countries over time(IEA *et al*., 2021). As shown in Table 1, international finance flows into the energy sector are about an order of magnitude higher in Kenya and Uganda than in Ethiopia and Tanzania. Below we discuss the features of the off-grid sector in each country in more detail.

Table 1: Summary of the energy access situation in the four study countries

Variable	Ethiopia	Kenya	Tanzania	Uganda
Population in 2020 (million)[1]	115.0	53.7	59.7	45.7
Urban share in 2020 (%)	22	28	35	25
Poverty headcount at 2011 US$1.9/day (%), and year[1]	30.8 (2015)	37.1 (2015)	47.9 (2017)	41.3 (2016)
GDP *per capita* (2020 US$, PPP-adjusted)[1]	2,421.9	4,576.2	2,780.1	2,293.5
% of population with electricity[1]	48	70	38	41
Urban	93	91	73	71
Rural	36	62	19	32
Renewable energy (% of total final energy consumption)[2]	98	74	39	90
Energy intensity (megajoules per 2017 US$, PPP-adjusted)	7.9	5.4	6.2	10.1
International financial flows for energy investment (2018 US$ million, PPP-adjusted)	34.7	257.6	13.2	236.3

Sources: ESMAP (2021), unless otherwise noted.

[1] From World Bank: data.worldbank.org.

[2] IRENA (2021).

2.1 Ethiopia

Ethiopia's power sector is highly centralised, and managed by the government. The Ethiopian Electric Power Corporation (EEPCo) was previously responsible for generation, transmission, and distribution, while the Ethiopia Electricity Agency regulated these activities. In 2013, EEPCo was unbundled into two independent state-owned entities—Ethiopia Electric Power (EEP), responsible for generation and transmission, and Ethiopian Electric Utility (EEU),covering distribution and sales(Kruger *et al*., 2019). Both entities report to the Ministry of Water, Irrigation and Energy (MoWIE). Historically, Ethiopia has relied heavily on hydropower and maintained very low subsidised electricity tariffs, such EEU and EEP, which have traditionally operated at a loss and contributed to the country's debt burden, while performing poorly and failing to substantially improve rural electricity access. This situation has been changing, with a series of tariff hikes in recent years (Hassen *et al*., 2022).

These policy changes have coincided with the government making electricity access a high-level policy objective. The overall level of access in the country has been rising (to 48% as of 2020), but there is a need for this progress to accelerate to meet national goal of universal access by 2025 (IEA *et al*., 2021). Urban access has now surpassed 90%, but ensuring rural access, particularly in mountainous or remote areas, is more difficult. The federal government acknowledges the challenge in its NEP 2.0, a forward-looking policy document that emphasises the essential role of off-grid solutions (MoWIE, 2019). NEP 2.0 is among the clearest examples of an electricity access strategy that offers an integrated perspective on grid and off-grid solutions. In this plan, over one-third of electricity connections are to be obtained from off-grid solutions in 2025, which would represent the addition of 6 million household connections to standalone solar solutions and mini-grids (supplementing 8.2 million new grid connections). The appropriateness of each of these modalities is based on geospatial least-cost electrification analysis, and plans are made for many of the off-grid households (5 million) to connect to the grid

after 2025.[1]The overall cost of the investments and technical assistance needed is estimated to be US$6 billion (of which US$2.5 billion is specifically for the off-grid component). While grid expansion will be implemented by EEU, the off-grid scale-up is expected to be based on coordination and partnership of public and private efforts.

The NEP 2.0 off-grid programme emphasises the need for speed, nationwide coverage, improved service (i.e. moving beyond pico-lights), commercial viability and affordability, and an enabling ecosystem of policies. The off-grid sector in Ethiopia is in its very nascent stages, and two initiatives were recently launched: the Access to Distributed Electricity and Lighting in Ethiopia (ADELE) programme and the Distributed Renewable Energy-Agriculture Modalities (DREAM) project (AfDB, 2022;World Bank, 2022). Together, the programmes focus on mobilising public, private, and philanthropic financing to increase access to electricity services for households, commercial and industrial users, and social institutions, as well as on improving the productivity of smallholder farmers through solar-powered irrigation and other services.

The above efforts appear promising, but the number of private off-grid energy providers at the time of our survey in Ethiopia was extremely low, and those that existed primarily marketed small-scale solutions: pico-solar and SHSs. A number of barriers to investment have been identified. Consumers' access to credit is a serious problem, and access to mobile money is extremely low. The closed economy, meanwhile, largely prevents foreign companies from being involved in the distribution of solar systems and limits the availability of foreign exchange and finance (USAID, 2019a). The licensing process for mini-grids in particular is cumbersome, and specific policies for off-grid technologies have been drafted but remain under discussion, including aspects related to tariffs. As a result, most activity remains limited to very small devices. The Global Association for the Off-Grid Solar Energy Industry (GOGLA) (2021) reports that slightly more than 200,000 solar lights and SHSs were being sold every six months; most of these were pico-lights, with capacities below 1.5 Wp(USAID, 2019a). Concerning mini-grids, there were only two companies operating such systems in Ethiopia in 2018, each of which had a very small number of projects (USAID, 2019a).

2.2 Kenya

Until the mid-1990s, the power sector in Kenya was dominated by a small number of utilities—the Kenyan Power and Lighting Company (KPLC), the Kenya Power Company (KPC), and three river valley development authorities, with KPLC managing the overall system. In the mid-1990s, a set of reforms unbundled generation and transmission assets, made KPC (which later became KenGen) independent, and generally began to encourage greater energy sector competition (Sergi*et al*., 2018). New agencies were subsequently created in 2006: the independent Energy Regulatory Commission and the Rural Electrification Authority (REA), with a mission to promote energy access. Although the pro-market nature of these reforms tended to disincentivise expansion of the grid into poorer and rural areas, Kenya today boasts one of the highest electricity access levels in Africa and one of the most rapid rates of electrification, with 70% of its population connected, and 62% in rural areas. Demand for energy is growing quickly owing to the country's comparatively high income, and this necessitates greater reliance of fossil fuel sources than seen in neighbouring countries. The government objective, as described in the 2018 Kenya National Electrification Strategy (KNES), is to achieve universal electricity access in 2022 via grid and mini-grid intensification, densification, and expansion, complemented with reliance on standalone solutions where the former remains difficult (USAID, 2019b).

Concerning off-grid electricity access specifically, Kenya was the market where off-grid solar technology first took hold in Africa (it represented nearly 40% of the African SHS market in 2010, and only China had a larger number of such systems at the time), driven by innovative business model development, an accommodating regulatory environment, early adoption of mobile money, and key entrepreneurs(Ondraczek, 2013;Cross and Neumark, 2021). This development received rather minimal government support—mostly limited to institutional electrification and value added tax exemptions for private

[1] Moreover, about 3.3 million households are envisioned to be 'pre-electrified' before 2025 with fully private off-grid solutions while they await the grid rollout.

firms—and modest support from donors. REA, for example, has mostly been responsible for electrifying trading centres, schools, health centres, and water pumping projects (Sergi*et al*., 2018).[2] Kenya today represents the most mature market for off-grid energy in East Africa (GOGLA, 2021), and intense competition has led to innovations in PAYGO financing and other scalable business models (Amankwah-Amoah, 2015;Muchunku*et al*., 2018).

Given the largely private and unsubsidised aspect of this market, the technologies available to households have had to be very affordable; indeed, the vast majority of off-grid solutions deployed support rather basic consumption services (lighting, phone charging, radios, and televisions). Between 2010 and 2018, for example, the number of Kenyans estimated to be using off-grid solutions grew from 1 million to 10 million; most of the systems being used were smaller than 100 Wp, but the total installed solar capacity was about 49 megawatts (Ondraczek, 2013;IRENA, 2021;Wagner *et al*., 2021).Most recently, market growth has plateaued as the market for connections has approached saturation, at levels of about 1 million solar lights sold every six months alongside over 150,000 SHSs (GOGLA, 2021).[3]At the same time, the appliance market continues to experience strong growth (USAID, 2019b). Finally, last-mile electrification is strongly dependent on donor assistance, especially through the World Bank-supported Kenya Off-Grid Solar Access Project (KOSAP).

Given the high costs of grid extension into remote and sparsely populated areas of the country, KNES has also strongly emphasised the role of mini-grids in supporting universal electrification goals. The early approach to mini-grids in Kenya was largely public, but Kenya has more recently been an early adopter of privately developed and operated mini-grids, with two companies in particular having attracted significant investment (Power hive and Powergen), and more than 60 mini-grids established as of 2018 (USAID, 2019b). Nonetheless, regulatory uncertainty—especially around licensing and grid encroachment risks—somewhat discouraged such developments for a while, as the country made only slow progress in developing mini-grid regulations (Energy Sector Management Assistance Program. 2017; Quinn, 2019;USAID, 2019b).Important questions also remain about the viability of the mini-grid business model, given their high capital requirements (at least compared to SHS technology). KOSAP is also supporting mini-grid investments via a public–private partnership model involving private developers and KPLC (121 mini-grids serving 27,000 households), but companies have complained that a lack of private ownership will prevent them from leveraging these assets to obtain further financing (USAID, 2019b).

2.3 Tanzania

Tanzania's electricity utilities were nationalised after independence, and the power sector in the country has been state-dominated since that time through the Tanzania Electric Supply Company Limited (TANESCO). There have been various attempts to open generation to independent power producers (IPPs) and to unbundle and privatise TANESCO in the early 1990s and 2000s, but these were plagued by legal, transparency, and implementation problems. The privatisation and unbundling project was abandoned in 2005, but several new institutions focusing on rural electrification were created in 2007, and TANESCO today purchases power from several IPPs. Though the power sector remained very centralised, the Electricity Act of 2008 initiated a new era of commitment to private sector participation in the off-grid domain (Sergi*et al*., 2018).

Tanzania today has one of the lowest electrification rates in East Africa and, despite progress since the Electricity Act of 2008, an especially low rate of rural electrification, which rose from only 5% in 2014 to nearly 20% in 2020 (Ahlborg and Hammar, 2014;IEA *et al*., 2021). Given the cost of extending the grid to reach the country's highly dispersed population, decentralised solutions have long been an essential element in the country's electrification strategy, with important municipalities still relying on disconnected small grids powered with diesel generators. The market for off-grid solar, especially standalone SHS technologies, initially began largely as a spill-over from Kenya, and coverage with such systems

[2] This has mostly been achieved via grid extension, though the share of such off-grid PV projects has risen sharply since 2014 (Sergi *et al*. 2018).

[3] These are clearly conservative estimates, as the GOGLA data only cover 54% of manufacturers selling in Kenya.

continues to lag behind those in that country. Nonetheless, as of 2017, about two-thirds of electrified rural households relied on off-grid solutions, including about 3 million people with Tier 1 or Tier 2 access to basic lighting and electricity service, and a slightly smaller number with access via SHS or mini-grid connections (USAID, 2019c). As of 2018, over 100 solar mini-grids had been established (IRENA, 2018;USAID, 2019c), which nonetheless remained lower than those of older hydro and diesel projects (Mini-Grids Partnership, 2020).As in Kenya, the market for appliances is also growing steadily.

Despite recent progress, major challenges in the country relate to the lack of human capital and planning capacity, a highly vertically integrated electricity system, donor dependency, insufficient finance, and a lack of private sector interest, due in part to a policy environment that has proven unpredictable despite substantial early promise (Ahlborg and Hammar, 2014;IRENA, 2018;Sergi*et al*., 2018;USAID, 2019c). Specifically, Tanzania was seen as an early leader in establishing a regulatory framework for streamlined licensing of larger off-grid generation projects such as mini-grids, when the Electricity and Water Utilities Regulatory Authority developed the small power producer (SPP) framework. The establishment of this policy helped inspire early financial support from development finance institutions and donor agencies; indeed Tanzania's off-grid market is perceived to be less competitive than Kenya's, and more strongly supported by donors (Ondraczek, 2013). The SPP framework has undergone several revisions to 'effectively support mini-grid development and provide key lessons for enabling private sector participation in the sector', based on an iterative process of engagement with the private sector, utilities, ministries, and non-governmental organisations(IRENA, 2018). These updates clarified rules relating to interconnection to the grid; compensation for grid buyouts; allowance for negotiated tariff-setting with future customers; and the application of technology-specific and size-specific feed-in tariffs for hydro- and biomass-based electricity generation for sales to the national utility.

Despite the initial clarity offered by the regulatory framework and the positive policy changes promoted through 2018, market growth had slowed considerably by that time, and the number of customers connected remains limited relative to the scale of the electrification challenge. This seems partly due to the lack of robust competition and higher costs seen in the SHS segment of the market (relative to Kenya), and (for larger projects) to weak government enforcement capacity and the apparent prioritisation of grid expansion and large generation capacity additions (Mini-Grids Partnership, 2020;Ministry of Energy, 2020). In recent data, about 175,000pico-solar lights (59%) and SHSs (41%) were being sold every six months in Tanzania, indicating recovery of these sales following a decline in 2019 (GOGLA, 2021). There is also a robust complementary market for appliances among off-grid solar consumers, which regionally is only behind that in Kenya.

Finally, several risks relating to permitting timelines, tariff-setting (if sufficient numbers of customers lodge complaints), regulatory uncertainty, and grid buyouts have all discouraged private entry into the mini-grid market and debt financing from commercial banks (IRENA, 2018), and the sector remains highly government-dependent (Mini-Grids Partnership, 2020;Creti*et al*., 2021). These risks were heightened following a policy directive in July 2020 from the Energy Ministry, in which all mini-grid operators in the country were ordered immediately to reduce their tariff rates to levels at or below those of TANESCO for all customer groups. This policy change was detrimental to the finances of most developers and introduced a level of deep uncertainty and distrust with the government and regulators, which is likely to undermine private sector investment in the sector.

2.4 Uganda

Uganda has long been an interesting case in Africa for considering alternative power sector institutions. It was the first country in the region to unbundle generation, transmission, and distribution into separate utilities, and the structure of the sector is among the most sophisticated in Africa (Eberhard *et al*., 2016). Over time, unbundling and privatisation has led to improved system performance, with distribution efficiency (i.e. reduced technical losses) and collection rates (i.e. lower commercial losses) especially increasing. Despite the recent progress, Uganda today continues to have a relatively low rate of rural electrification, at about 32% as of 2020 (IEA *et al*., 2021). Nonetheless, Uganda's Rural Electrification Agency, which is under the Ministry of Energy and Minerals, undertook a master-planning exercise in 2018 using a least-cost approach

that emphasised the importance of off-grid solutions. This strategic document mostly argued for continued grid extension as the primary mode of electrification, but identified a key role for role for SHS solutions (serving about 5.3 million households by 2030) and mini-grids (~70,000 households by 2030) (UOMA, 2020). Somewhat ironically, then, the relative strength of the national level institutions and utility in Uganda have created a situation where the country's government institutions also have limited awareness of, and commitment to, off-grid energy (FHI360, 2017).

Nonetheless, Uganda appears relatively well-positioned for further investment given the large number of sites deemed suitable for mini-grid deployment that are inaccessible to the grid, such as the hundreds of small, inhabited islands on Lake Victoria. The government has initiated bundled tenders to facilitate such projects, though licensing procedures, tariff approvals, and lack of clear regulation around grid encroachment are considered important risks. There are only 34 mini-grids known to be installed in the country, serving about 20,000 households (Mini-Grids Partnership, 2020), and a lack of mini-grid regulatory policy has led to worries about licensing, tariffs, and costs. On the other hand, Uganda is one of the most dynamic SHS markets in East Africa (perhaps only lagging behind Kenya). In recent data covering about 78% of manufacturers selling in Uganda, about 111,000SHSs were being sold every six months—numbers that represent some decline since 2019 (when about 400,000 such systems were being sold), perhaps due to the strict COVID-19 lockdowns in the country and their impacts on household income (UOMA, 2020;GOGLA, 2021).

As in other countries, a number of challenges are impeding further growth of the off-grid sector. These include a lack of access to capital, low availability of credit for consumers, somewhat low consumer confidence in the quality of available SHS products and services (due to insufficient quality certification), uncoordinated policies and taxes and a generally favourable enabling environment, and human capacity constraints (FHI360, 2017). Affordability for rural and dispersed consumers is also a significant problem.

3 Methods

3.1 Sample selection and composition

The original objective of the study was to survey barriers and opportunities facing private sector companies involved in the provision of off-grid energy technologies in Ethiopia, where this study was first conceived. It was quickly determined, however, that the number of such companies was small in that country, and that a comparative study including firms in other major off-grid markets in East Africa would be of interest to obtain a richer, comparative perspective on this question. As such, a listing of private sector enterprises involved in delivering energy generation or other energy sector technologies was undertaken, covering each of the four national capital cities: Addis Ababa (Ethiopia), Kampala (Uganda), Nairobi (Kenya), and Dar es Salaam (Tanzania). From this list, in order to have sufficiently large samples in each country to analyse country-specific patterns, a sample size of 50 firms with off-grid energy activities or interests was targeted for participation.

The number of relevant off-grid firms was not large, so interviews generally proceeded with the exhaustive set of all such companies that gave their consent to participate. Additional firms with energy sector activities, even if not off-grid, were included to complete the sample in Ethiopia in particular. These were sampled randomly from the list of firms, once the off-grid enterprises were exhausted. In Ethiopia, where the sector is nascent, the final number of participating firms was 41; in Kenya, Tanzania, and Uganda, final sample sizes were 50, 50, and 49 respectively.

3.2 Survey administration

Surveys were mostly administered through face-to-face interviews, but COVID-19 constraints in Kenya and Uganda led to a small number of surveys taking place via phone (n=6 in Kenya and n=10 in Uganda). The survey instrument covered the following sections: a) introduction, administration information, and consent; b) respondent characteristics; c) basic information on the organisation; d) perceptions of the off-grid sector in the country, and (for those aware of it) of the off-

grid sector in Ethiopia; e) off-grid energy projects and experience of the company; f) a DCE allowing firms to specify their preferred institutional arrangements for the sector; g) challenges facing their organisation; h) general organisation performance, costs, and revenues; and i) enumerator observations. The data collected offer a rich perspective on the diverse experiences of these companies.

Survey questions and responses were recorded using tablets by enumerators in each country, who had reviewed the questionnaire and been trained on its intent prior to data collection. Pre-testing took place with a small number of respondents in Ethiopia prior to the launch of full data collection, which allowed correction of programming errors and deficiencies. The full data collection took place in late 2021, during the months of September and October.

The DCE design warrants additional explanation. The purpose of this exercise was to understand the attitudes of off-grid firms regarding a number of policy supports and regulatory structures for the sector. In accordance with the original envisioned purpose of the study, as described above, the attributes considered were specified based on preliminary and exploratory data collection with a number of such firms in Ethiopia, and were specifically tailored to concerns expressed in those discussions. From a longer list of potential attributes, the following were deemed most salient: capital subsidies (from donors or government); tariff regulation; licensing regulation; easing of constraints on foreign currency availability; and grid encroachment policies. These various attributes were specified to have a set of levels as summarised in Table 2. An optimal design for identifying main effects of each attribute level required a minimum of 18 choice tasks with two alternatives, which were obtained using Stata software and blocked into three sets of six tasks. Each respondent then completed one randomly selected block of these six choice tasks, choosing between two options with various combinations of the attribute levels, or opting out of them entirely.

Table 2: Attributes and levels included in the DCE

Attribute	Level 1	Level 2	Level 3	Opt-out value
Subsidy %	10%	25%	50%	0%
Tariff regulation	None	Cost recovery	Grid rate	None
Licensing regulation	All centralised	Centralised only above capacity threshold	Decentralised	Decentralised
Foreign currency availability	25,000 US$	50,000 US$	100,000 US$	0
Grid encroachment policy	No policy	Net metering (at grid rate)	Buyout (of capital asset)	No policy

4 Results

4.1 Description of the sample

Respondent and firm characteristics for the sample are presented in Table 3. Respondents across countries were in their mid-30s on average (slightly older in Ethiopia, and slightly younger in Uganda and Kenya). In Ethiopia, Kenya, and Uganda, the respondents were also highly educated, with the vast majority having completed university degrees; the Tanzanian sample stands out as having much lower education (more than 50% at secondary level or lower). On average, these respondents had 6.3 years of experience working with the organisation enrolled in the survey, and 5.6 years working on off-grid energy. While respondents in Ethiopia had spent the longest time with these organisations, they had the least off-grid experience (3.5 years on average), perhaps reflecting the nascent nature of this sector in their country.

The energy firms included in the survey were about 10 years old, on average, with those in Kenya and Ethiopia somewhat older (13 years); the organisations of these two countries also had more average experience in off-grid energy (about 11 years, versus three years in Tanzania and seven years in Uganda). Only the sample from Uganda contained non-profits (n=2) or hybrid organisations (n=2). Most rented their offices; rental costs were by far the highest in Nairobi (at US$1,680 per month on average) and lowest in Dar es Salaam (US$300 per month), which largely reflects the larger size of the firms (in terms of employees) in the Nairobi sample. There was considerable variation in these rental costs across firms, however, reflecting the large variation in their relative size (e.g. 98 employees per firm in Kenya on average, versus only four in Tanzania). The organisations were mostly sole proprietorships or limited liability companies, though multi-ownerships were somewhat common in Uganda. Male workers comprised about 72% of the labour force of these organisations, slightly lower in Kenya (68%) and Uganda (70%) and higher in Tanzania (77%) and Ethiopia (73%).

About 55% of the organisations identified off-grid energy as one of their main sectors of activity. This share was lowest in Ethiopia (41%) and highest in Kenya (98%) (Figure 1). Large proportions also identified work in energy efficiency (54%), energy for public services (23%), and other specific energy uses (e.g. water pumping) (29%); non-energy activities were mentioned by 37% of firms. Thirty-five percent are part of an off-grid energy association. We asked them to identify the energy products or technologies that provided their organisations with the most revenue. Nearly half identified standalone SHSs as this product, and this was also true across the four countries, although in Ethiopia there is also an equal share (32%) of firms receiving their greatest revenue from generators (Figure 2).[4] Between 6%–9% of all sample firms identified each of the following other products as their primary revenue source: generators, pico-solar devices, batteries, appliances, and mini-grid connections.

Table 3: Description of sample enterprises and respondents

Variable	Overall	Ethiopia	Kenya	Tanzania	Uganda
Respondent characteristics					
Age	35.7(9.14)	40.5(11.7)	33.4(7.65)	35.9(10.1)	33.6(4.68)
Respondent is male	0.73	0.80	0.66	0.80	0.65
Education					
Secondary or less	0.17	0.07	0.00	0.58	0.02
Some higher education	0.12	0.07	0.02	0.26	0.12
Completed university	0.55	0.85	0.98	0.16	0.86
Masters or PhD	0.15	0.32	0.06	0.02	0.24
Experience with organisation (years)	6.3(5.4)	9.6(8.3)	5.3(4.8)	5.2(3.5)	5.7(3.4)
Experience in off-grid sector (years)	5.6(5.0)	3.5(5.6)	6.4(5.7)	5.5(4.1)	6.5(4.0)
Organisation characteristics					
Year of start-up	2010 (11.1)	2007 (13.6)	2007 (13.6)	2014(8.3)	2013(4.8)
Fully private[1]	0.98	1	1	1	0.92
Office in the capital city					
Own office space	0.12	0.07	0.15	0.04	0.20
If own, value (US$ thousands)	390(506) 878(1,367)	1014(609) 717(676)	No data 1,679(2,505)	No data 299(155)	155(175) 838(549)

[4] This reflects the somewhat different sampling strategy employed in Ethiopia. Relatively few Ethiopian firms participated in the off-grid market; hence, we included firms working in related activities, e.g. sellers of generators.

If rent, monthly cost (US$)					
Type of company[2]					
Sole proprietorship	0.33	0.44	0.02	0.60	0.29
Limited liability company	0.55	0.56	0.92	0.30	0.45
Other	0.12	0.00	0.08	0.10	0.26
Time in off-grid sector (years)	7.8(8.4)	11.0(10.7)	10.9(9.7)	3.1(4.5)	6.8(5.1)
Number of employees in country	47.7(175.0)	20.5(21.8)	97.8(296.9)	4.2(6.1)	65.4 (162.9)
Overall	36.7(160)	14.4(18.5)	80.6(304.1)	2.9(2.8)	49.1(91.8)
Off-grid only	71.8(19.6)	73.3(20.5)	67.8(18.5)	76.7(25.5)	69.6(11.1)
Percentage male	231(183)	100(39.2)	323(129)	91(83)	340(211)
Entry wage for locals (US$/month)					
Member of off-grid association	0.35	0.44	0.38	0.14	0.49
Access to credit					
Applied for loan in past year	0.26	0.39	0.27	0.26	0.14
Could obtain loan if needed	0.85	0.85	0.69	0.98	0.88
Likely to add workers next year	0.43	0.63	0.73	0.17	0.21
Highest selling energy technology					
Mini-grid connections	0.06	0.02	0.14	0.00	0.06
SHSs	0.49	0.32	0.54	0.62	0.47
Non-solar generator	0.09	0.32	0.00	0.03	0.00
Pico-solar device	0.07	0.17	0.06	0.03	0.03
Batteries	0.07	0.02	0.08	0.03	0.15
Appliances	0.07	0.00	0.00	0.21	0.09
Solar pumps	0.07	0.02	0.10	0.05	0.12
Other	0.08	0.12	0.08	0.05	0.09
Financing					
% debt	14.8(21.9)	21.2(31.9)	22.2(23.0)	4.4(9.5)	13.8(14.4)
% equity	82.9(24.2)	77.2(32.6)	76.7(26.4)	95.6(9.5)	80.8(19.1)
% grants	3.3(11.1)	1.6(6.0)	6.9(16.8)	0.0(0.0)	5.7(13.6)
Profitability					
Modal revenue bracket (US$/year)	10–100k	100–500k	10–100k	10–100k	100–500k
Modal cost bracket (US$/year)	10–100k	100–500k	10–100k	10–100k	100–500k
Firm loses money on off-grid	0.18	0.073	0.37	0.00	0.26

N	190	41	50	50	49

Note: Standard deviations reported in parentheses for non-binary variables.

1 Omitted categories are non-governmental organisation or non-profit, and hybrid.

2 'Other' includes multi-owner proprietorship, general partnership company, limited partnership, and cooperative.

Figure 1: Main business activities, overall and by country (Note: Multiple answers were possible)

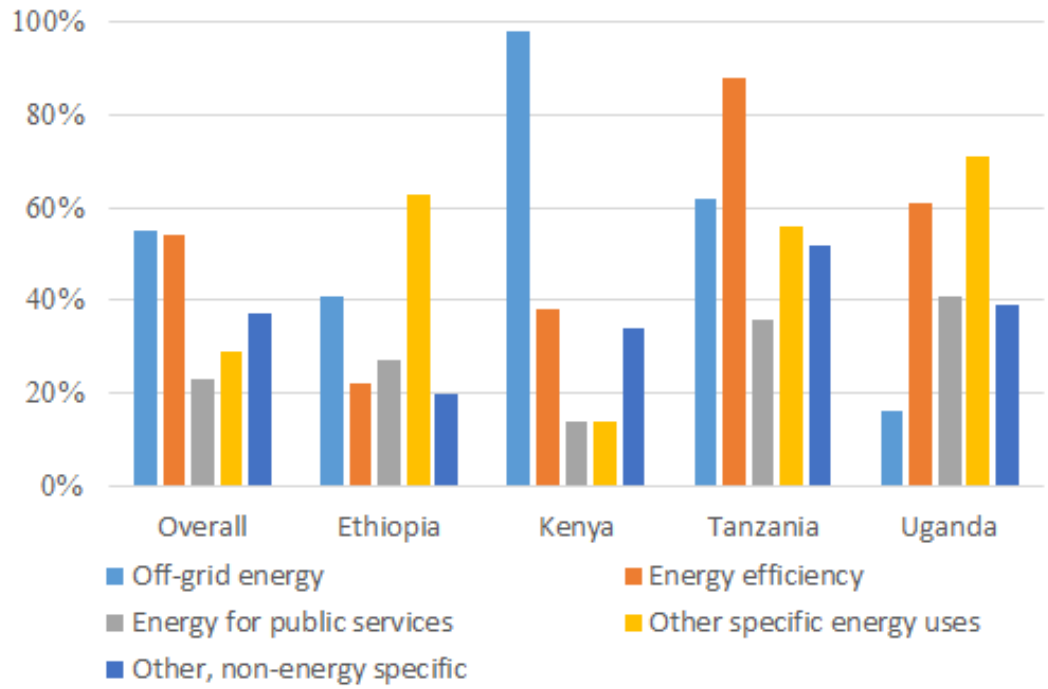
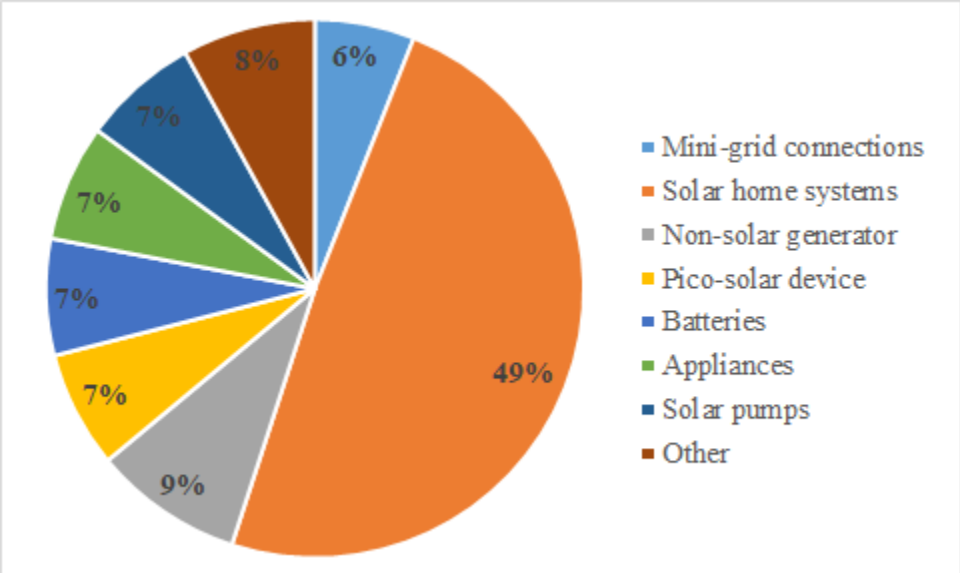


Figure 2: Main source of revenue for each surveyed company (full sample)



Finally, in terms of business prospects and status, very few organisations appeared to access debt finance, either in the form of simple loans (only 26%) or by identifying debt financing as a share of their overall portfolio of resources (15%). Equity financing makes up the majority of resources (83%), followed by debt and then grants, which provided a very small share of organisations funds (3%). That financial portfolio helps explain many of the financial headwinds facing the sector. About 18% of these organisations also reported using other parts of their business to subsidise their off-grid activities, though the subsidies usually amounted to less than 10% for the majority (about 70%) of these firms. The modal cost and revenues brackets identified demonstrate the competitive and break-even nature of the sector, in that revenues do not clearly outweigh costs overall or in any country.

4.2 Comparison of perceptions of the off-grid sector, challenges faced, and policy needs

We next consider firms' perceptions of the regulations of off-grid energy in each country and of the barriers to more investment, as well as policy needs and opportunities. Here it is important to interpret the responses in light of the composition of the sample, specifically the fact that about half of the sample primarily markets SHSs, with relatively few companies supplying mini-grid connections. One would expect somewhat lower familiarity with regulations in such a sample, and a distinct perspective across these different companies regarding major sector constraints. That said, on average, respondents said they were just better than moderately familiar (on a Likert scale ranging from 'extremely familiar' to 'not familiar at all')with their national regulations, with familiarity closest to 'very familiar' in Kenya and 'less than moderately familiar' in Ethiopia (Table 4). The clarity of regulations is similarly judged as a bit better than slightly clear, with clarity ranked highest in Tanzania and lowest in Kenya. Governments are judged to have capacity to implement the regulations about midway between moderate and weak capacity, with weakest capacity in Tanzania. Thus, clarity in regulations does not necessarily indicate ability to implement them.

The most commonly identified barriers to greater off-grid investment identified by respondents were lack of information needed to assess the market (30% of respondents), lack of comprehensive regulations (25%), lack of technical capacity (22%), import restrictions (20%), and lack of financing or informal sector competition (and lower quality products) (18%) each. The results for these most commonly identified barriers are summarised in Figure 3, and we discuss the particular barriers highlighted in each country further below.

Table 4: Perceptions of policy framework and barriers in the off-grid energy sector

Variable	Overall	Ethiopia	Kenya	Tanzania	Uganda
Perceptions of regulations					
Familiarity with national off-grid regulations[1]	2.8(1.3)	3.3(1.5)	2.4(0.88)	3.0(1.5)	2.8(1.0)
Perception of clarity of off-grid regulatory framework[2]	2.8(1.1)	2.7(0.89)	3.2(0.92)	2.3(1.4)	2.8(0.88)
Perception of capacity of government to implement existing off-grid regulations[3]	2.6(0.8)	2.3(0.74)	2.6(0.69)	2.7(1.0)	2.5(0.62)
Perceptions of corruption[5]	3.3(1.5)	4.6(0.8)	3.0(1.2)	2.3(1.5)	3.7(1.2)

Perceptions of bureaucracy[5]	3.3(1.5)	4.1(1.2)	3.3(1.4)	2.1(1.4)	4.0(1.0)
Perceived policy needs[4] Subsidy Facilitated access to finance Technical assistance for regulatory aspects Knowledge exchange/ capacity building Access to foreign currency Top-ranked policy need Second-ranked policy need	 4.4(0.9) 4.5(0.8) 4.2(1.0) 4.2(0.9) 4.2(1.1) Finance Subsidy	 4.2(1.2) 4.5(1.0) 4.2 (1.2) 4.1(1.1) 4.8(0.8) Capacitybuilding Finance	 4.5(0.6) 4.4(0.8) 4.3 (0.9) 4.1(0.7) 3.6(1.2) Finance Subsidy	 4.7(0.9) 4.7(0.9) 4.7(0.9) 4.7(0.9) 4.5(1.2) Subsidy Currency	 4.0(0.6) 4.3(0.6) 3.6(0.8) 3.8(0.8) 3.8(0.8) Finance Subsidy
Perceptions of opportunities Increased in past year Decreased in past year Due to Δ private capital Due to Δ public capital	 0.51 0.40 0.79 0.74	 0.32 0.53 0.93 0.83	 0.68 0.30 0.91 0.50	 0.38 0.58 0.46 0.94	 0.63 0.19 0.92 0.69
N	190	41	50	50	49

Note: Standard deviations reported in parentheses for non-binary variables.

[1] Measured on a scale of 1 to 5: extremely familiar (1); very familiar; moderately familiar; slightly familiar; not familiar at all (5).

[2] Measured on a scale of 1 to 5: extremely clear (1); mostly clear; somewhat clear; mostly unclear; not clear at all (5). The mean reported here excludes 37 respondents who responded with 'don't know'.

[3] Measured on a scale of 1 to 4: very strong capacity (1); moderate capacity; weak capacity; very weak capacity (4). The mean reported here excludes 28 respondents who responded with 'don't know'.

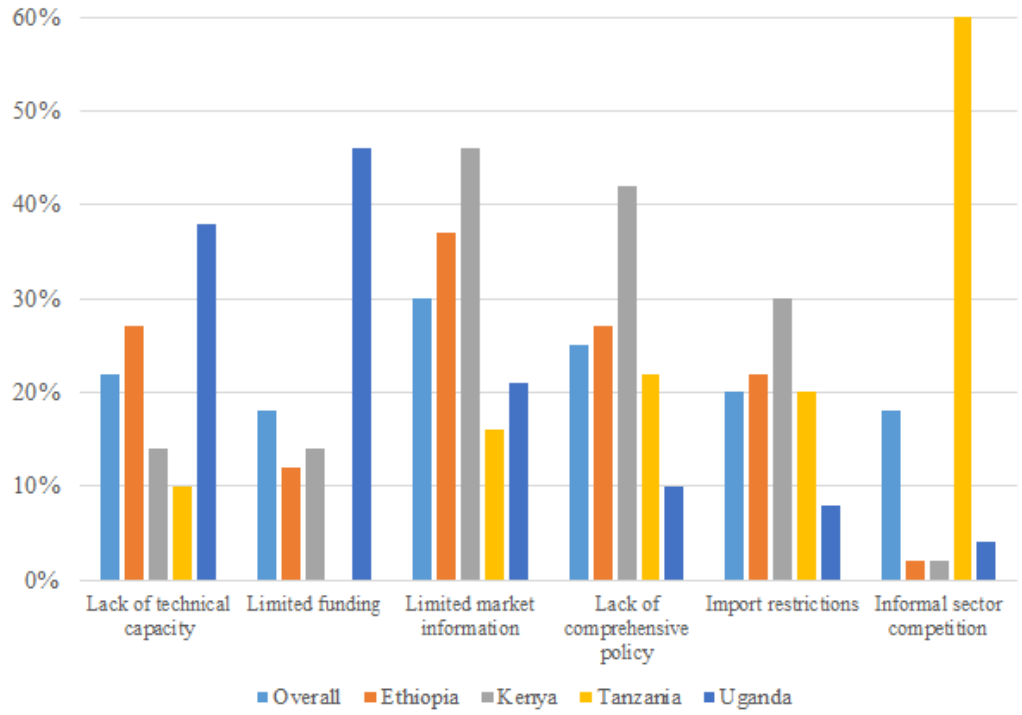
[4] Measured on a scale of 1 to 5: harmful (1); neither helpful nor harmful; somewhat helpful; helpful/almost essential; essential (5).

[5] Measured on a scale of 1 to 5: not an issue (1); slight issue; moderate issue; big issue; very big issue (5)

In Ethiopia, the highest shares identified lack of information needed to assess the market (37% of respondents) and high cost of doing business (29%) as major barriers. In Kenya, the top two barriers were lack of information needed to assess the market (46% of respondents) and lack of comprehensive regulations (42%). In Tanzania, the most severe barrier by far was informal sector competition (60%), followed by poor tariff policy (34%). Finally, in Uganda, the top three issues were

limited funding (46%) and lack of technical capacity and economic uncertainty (38% each). Both corruption and bureaucracy or red tape were judged as slightly closer to being moderate issues than big issues on average, with the greatest problems in Ethiopia and the least in Tanzania. Nonetheless, the respondents' organisations remained somewhat optimistic about opportunities in the sector, with 51% saying that opportunities had recently increased in spite of COVID-19-related obstacles. There was variation in the sample, though, as 40% said opportunities were diminishing (with 9% saying they were unchanged). Perceived opportunities were also clearly declining in Ethiopia and Tanzania, whereas they were increasing in Uganda and Kenya. This may reflect the political instability in Ethiopia at the time of the survey, and the recent centralisation of the energy sector in Tanzania.

Figure 3: Main impediments to off-grid business identified in the survey, overall and by country (note: multiple answers were possible)



Considering potential policy support, five different types of support were mentioned to respondents: subsidy support, access to finance, technical assistance on regulatory matters, knowledge exchange and capacity building, and access to foreign exchange. Of these, all were considered to be between helpful/almost essential and essential for the sector to flourish, with the first two particularly vital. There was some variation in the relative rankings across countries, however. In Kenya and Uganda, the top two policy needs—finance and then subsidy—were similar to those in the overall sample. In Ethiopia, knowledge exchange and capacity building were deemed most important, followed by finance. Finally, in Tanzania, subsidy was ranked first, followed by access to foreign currency.

4.3 Preferences for institutional supports to the sector

We used DCE to obtain a more quantitative understanding of relative perceptions of institutional supports and regulatory frameworks for the off-grid energy sector. Table 5 presents the results from a mixed logit specification that allows individual-specific random parameters for all attributes. The overall results generally conform to expectations regarding the direction of these preferences, and nearly all mean estimates are statistically distinguishable from zero. In particular, off-grid firms prefer higher grant subsidy support (relative to lower support), a tariff policy that imposes the grid rate (relative to a cost recovery or no tariff policy), a decentralised or threshold-based centralised licensing regulation regime (relative to a

fully centralised one), more foreign currency availability (relative to less), and a buyout grid encroachment policy (relative to no encroachment policy). On the latter, net metering is also favoured over no encroachment policy. The tariff preferences are surprising; we expected that firms would prefer not to have regulators limit their ability to constrain the electricity tariffs they would charge. These results may, however, reflect a desire for policy certainty, since a lack of tariff policies has often led to changing rules and regulations and a frequent need to negotiate tariffs on a project-by-project basis, which is costly for firms and leads to non-competitive dynamics in the sector when some firms have more influence over the regulator. Alternatively, it may be due to the fact that most of the sample is not involved in setting electricity tariffs (i.e. mini-grid respondents were a minority of the sample).

Table 5: Preferences for different off-grid policy attributes; mixed logit specification

Attribute	Overall	Ethiopia	Kenya	Tanzania	Uganda
Mean of coefficients					
Subsidy %	1.19***(0.28)	3.73***(1.22)	0.88 (0.63)	0.79* (0.47)	1.37***(0.51)
Tariff: Grid rate	0.36***(0.11)	1.27***(0.44)	0.93***(0.25)	-0.12 (0.22)	0.29 (0.21)
Tariff: Cost recovery	0.17 (0.11)	0.84 (0.54)	0.50** (0.23)	-0.35* (0.19)	0.13 (0.21)
Regulator: Centralised	-0.43***(0.11)	-0.15 (0.48)	-0.75***(0.26)	-0.50***(0.19)	-0.39* (0.21)
Regulator: Centralised only above threshold	-0.12 (0.14)	0.14 (0.54)	-0.50 (0.23)	0.28 (0.22)	-0.53**(0.27)
Foreign exchange allowance (US$ thousands)	0.004**(0.001)	0.005 (0.006)	0.008**(0.003)	0.004* (0.002)	-0.0005(0.003)
Grid encroachment: Net metering	0.24* (0.12)	-0.64 (0.54)	0.29 (0.25)	0.29 (0.20)	0.46* (0.26)
Grid encroachment: Buyout	0.31***(0.11)	-0.84 (0.56)	0.17 (0.30)	0.40** (0.19)	0.64***(0.23)
St. dev. of coefficients					
Subsidy %	0.12 (0.59)	1.42 (1.72)	0.007 (3.10)	0.086 (1.0)	0.002 (0.87)
Tariff: Grid rate	0.23 (0.29)	0.026 (0.57)	0.50 (0.50)	0.61* (0.33)	0.042 (0.33)
Tariff: Cost recovery	0.20 (0.37)	1.79** (0.82)	0.45 (0.40)	0.14 (0.34)	0.053 (0.37)
Regulator: Centralised	0.18 (0.25)	1.05** (0.049)	0.016 (0.41)	0.097 (0.33)	0.50* (0.29)
Regulator: Centralised only above threshold	0.93***(0.17)	1.21** (0.57)	1.25***(0.42)	0.71** (0.30)	0.86***(0.31)
Foreign exchange allowance (US$ thousands)	0.007***(0.002)	0.015**(0.007)	0.006 (0.007)	0.001 (0.004)	0.008**(0.004)
Grid encroachment: Net metering	0.69***(0.21)	1.09 (0.73)	0.011 (0.91)	0.39 (0.41)	1.11***(0.32)
Grid encroachment: Buyout	0.37 (0.24)	0.92* (0.53)	0.63 (0.43)	0.020 (0.48)	0.65* (0.34)
N	2904	390	717	897	900
Log likelihood	-939.5	-105.8	-210.1	-289.0	-293.3

LR X^2 (p-value)	21.85(0.0052)	17.0(0.029)	7.9(0.44)	4.2(0.83)	16.9(0.031)

Note: Subsidy percentage and foreign exchange allowance attributes are continuous variables; all others are binary indicators. The omitted categories are as follows: tariff: no regulation; regulator: decentralised; grid encroachment: no policy. Standard errors of estimates reported in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

The heterogeneity in these preferences across respondents in the sample is mostly limited to a few attributes and levels, as shown by the estimated standard deviations. The preference for a centralised regulation regime for large projects, the desire for more foreign currency support, and the extent of preference for a net metering grid encroachment policy all have statistically significant variation within the sample. For the first of these, it generally seems that firms prefer a decentralised regime, but some firms may recognise that more centralised regulation is necessary for larger projects such as mini-grids, while others continue to resist it. Regarding the desire for increased access to foreign exchange, firms that are less able to engage in debt financing may need this more than others to obtain equipment needed for their projects and products. Finally, the variation in preferences for net metering may reflect variation in the gap between grid tariff levels (which are usually low and subsidised) and firms' own tariffs (higher) in different locations, since those with a lower wedge between these rates would view net metering in more favourable terms.

In addition, there is more heterogeneity in the results across countries.[5] Recognising that the statistical precision of the estimates declines considerably when analysing these different subsamples (and that the overall models are not statistically significant in Kenya and Tanzania), it is nonetheless apparent that, on average, a relatively higher emphasis is placed on the subsidy support in Ethiopia (and less so in Uganda) than in the other countries. Tariff regulation at the grid rate is most favourably viewed in Ethiopia and Kenya, whereas regulation at a cost recovery level is negatively viewed in Tanzania (there are not very strong tariff preferences in Uganda, where the grid rates are unsubsidised). There is a relatively consistent negative perception of a fully centralised licensing regime (and, in Uganda and Kenya, for a centralised regime for large projects), except in Ethiopia, where there are no strong preferences for a particular licensing regime. Firms in Ethiopia and Uganda expressed the greatest need for additional foreign exchange. Finally, in line with the higher grid tariffs there, Uganda was the one country where firms had a clearly positive view of a net metering policy, while the buyout policy was also viewed positively in Uganda and in Tanzania. Firms in Ethiopia and Kenya had weaker opinions on grid encroachment policy, which may reflect the lack of mini-grid operators in Ethiopia and the history of unregulated private sector off-grid energy activity in Kenya.

We also analysed the DCE data using a latent class logit, which allowed us to identify different preference groupings within the sample based purely on the choices respondents made. The goal of this exercise is to identify whether respondents cluster into discrete groups that respond more strongly to specific attributes. Table 6 presents results for three classes and six classes, which are the best-fitting models according to Akaike information criteria (AIC) and Bayesian information criteria (BIC) respectively.[6]The three-class model includes two classes that value larger grant subsidies to support off-grid investment (Classes 1 and 3). The first of these otherwise mainly favours having enhanced access to foreign exchange and a grid encroachment policy that entails the buyout of assets; this class forms roughly a third of the sample (34.5%) and pays the most attention to financial incentives. Class 3 is larger (40.2% of the sample) and values clear tariff policies (either grid rate or cost recovery regulation, rather than no tariff regulation), as well as decentralised licensing arrangements. Consistent with these preferences, this class also favours a net metering approach to grid encroachment. Finally, the smaller Class 2 (25.3% of the sample) does not respond strongly to higher subsidies; instead, this class strongly prefers grid rate tariff regulation and a centralised licensing process, but only for larger installations. This class most likely includes more competitive (perhaps primarily SHS and pico-lighting) firms that already have a well-established foothold in the market and do not need subsidy or foreign exchange support.

[5] Within country heterogeneity is also different across countries, as shown by the variegated pattern of statistical significance in the standard deviations of the random parameter estimates across countries.

[6] The AIC is a statistic that penalises a model for including parameters according to the formula $2k - 2\ln(L)$, where L is the likelihood function and k is the number of parameters. The BIC, meanwhile, is similar to the AIC, but includes a different penalty term: $\ln(n)k$, where n is the sample size.

Table 6: Latent class analysis of DCE data

	Three-class model		
Attribute	**Class 1**	**Class 2**	**Class 3**
Subsidy percentage	1.67***(0.52)	0.15 (1.19)	1.26* (0.68)
Tariff: grid rate	-0.42 (0.29)	1.23***(0.36)	0.46* (0.26)
Tariff: cost recovery	-0.48 (0.29)	-0.084 (0.38)	0.49** (0.24)
Regulator: centralised	0.15 (0.22)	-0.86**(0.37)	-0.93***(0.26)
Regulator: centralised only above threshold	-0.48 (0.32)	1.29** (0.51)	-0.85**(0.35)
Foreign exchange allowance (US$ thousands)	0.015***(0.004)	0.004 (0.005)	-0.005 (0.004)
Grid encroachment: net metering	0.039 (0.26)	-0.50 (0.42)	0.84***(0.25)
Grid encroachment: buyout	0.89***(0.31)	0.17 (0.32)	-0.13 (0.29)
Class share	0.345	0.253	0.402

	Six-class model					
Attribute	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**
Subsidy percentage	4.27* (2.23)	27.3* (14.4)	-0.38 (0.50)	18.1* (9.23)	10.4 (8.84)	2.85***(1.01)
Tariff: grid rate	0.76 (0.52)	-8.2 (4.68)	0.62***(0.19)	3.74* (1.96)	-9.77* (5.18)	-0.97* (0.54)
Tariff: cost recovery	1.69** (0.71)	-4.36* (2.24)	0.15 (0.16)	-1.48 (1.21)	-11.1 (6.85)	-0.41 (0.41)
Regulator: centralised	-1.46**(0.60)	9.04** (4.24)	-0.82***(0.19)	-2.22* (1.16)	-8.21 (6.00)	1.30** (0.59)
Regulator: centralised only above threshold	-2.52***(0.84)	19.45* (10.1)	0.010 (0.21)	0.38 (1.25)	-18.6 (13.9)	0.83 (0.51)
Foreign exchange allowance (US$ thousands)	-0.012 (0.01)	0.24* (0.12)	0.002 (0.003)	-0.026 (0.02)	0.16* (0.09)	0.01 (0.01)
Grid encroachment: net metering	0.92 (0.61)	-6.57 (4.02)	0.62***(0.21)	-6.10**(2.92)	3.14 (2.56)	-0.95* (0.50)
Grid encroachment: buyout	-1.30 (1.05)	-13.29*(7.08)	0.38** (0.18)	1.45 (0.94)	14.2 (9.8)	0.31 (0.40)
Class share	0.125	0.116	0.481	0.070	0.087	0.120

Note: Six-class model selected according to the AIC goodness-of-fit criterion; three-class model is more appropriate according to the BIC. Subsidy percentage and foreign exchange allowance attributes are continuous variables; all others are binary indicators. The omitted categories are as follows: tariff: no regulation; regulator: decentralised; grid encroachment: no policy. Standard errors of estimates reported in parentheses. *** p<0.01; ** p<0.05; * p<0.1.

The six-class model leads to somewhat different groupings and patterns. According to this model, four classes respond strongly to larger subsidy incentives (Classes 1, 2, 4, and 6), and these comprise a smaller share(43.1% overall) of the sample relative to the three-class analysis. The largest class (Class 3, with 48.1% of respondents) in this case has preferences that mainly revolve around grid encroachment compensation, either with net metering or buyout of assets, and is generally averse to centralised regulation. This class is thus mainly concerned about interference by the central government and power distribution utility. The four classes that favour subsidy supports can be differentiated by their preference for cost recovery tariff regulation and decentralised licensing (Class 1, 12.5% of the sample); foreign exchange access and centralised licensing coupled with general aversion to both tariff or grid encroachment policies (Class 2, 11.6% of the sample); preference for grid rate tariff regulation and decentralised licensing (Class 4, 7.0% of the sample); and centralised licensing coupled with aversion to grid tariff and net metering regulations (Class 5, 12.0% of the sample). Thus, we can see there is little consistency in the policy preferences of much of the respondent sample, even if all four of these classes are pro-subsidy. Finally, Class 5 (8.7% of the sample) would mostly like greater access to foreign exchange and is also averse to tariff regulation.

5 Discussion and conclusions

In light of recent growth in the off-grid energy sector due to the falling costs of solar PV and battery technology, this paper considered barriers and opportunities for off-grid sector development in four countries in East Africa: Ethiopia, Kenya, Tanzania, and Uganda. We used a survey of nearly 200 organisations—nearly all in the private sector—to understand their perceptions of constraints limiting the sector's growth, prospects for the future, and the need for supportive policies. The survey reveals a set of common challenges, but also considerable variation within and across countries. In particular, we find that organisations consider national regulations to be moderately clear but could be further improved, while capacity to implement regulations is somewhere between moderate and weak. Meanwhile, many barriers impede development of the sector, especially lack of market information and technical capacity, insufficiently comprehensive regulation, and (in specific countries) informal sector competition (Tanzania), cost of doing business (Ethiopia), poor tariff policy (Tanzania), and lack of funding (Uganda). These various perceptions translate into a somewhat more positive outlook among firms in Kenya and Uganda, and a more negative one in Ethiopia and Tanzania. In Tanzania, there has been a strong history of engagement to create comprehensive policy, but the current perception is that recent changes have led to uncertainty in the sector and an unfavourable climate for investment, particularly of larger off-grid installations. In Uganda, the very strict COVID-19 lockdown created significant economic uncertainty, but there is now hope that the situation will improve. In Ethiopia, the sector remains primitive and political uncertainty has engendered greater pessimism than is seen in other countries.

Moreover, firm responses emphasise the need for much greater policy support at all levels: subsidy, financing, access to foreign exchange, technical assistance for regulatory matters, and capacity building. The DCE sheds further light on these policy preferences and clarifies common threads, as well as country differences. For example, off-grid firms generally prefer higher grant subsidy support, a tariff policy that imposes the grid rate, a decentralised or threshold-based centralised licensing regulation regime, more foreign currency availability, and a buyout grid encroachment policy (though some prefer a net metering approach, perhaps due to higher grid rates in countries like Uganda). The tariff preference for grid rates, while unexpected, may reflect a desire for policy certainty, or may reflect the dominance of SHS companies within the sample. The highest emphasis is placed on subsidy support in Ethiopia (and the least in Uganda). Tariff regulation at a cost recovery level, meanwhile, is especially negatively viewed in Tanzania.

An inevitable conclusion of this analysis is that the policy and regulatory climate, and the implementation of those aspects, makes a big difference in terms of firms' perceptions of opportunities and constraints in the sector. To the extent that these translate into different business decisions and models, they have potentially large impacts on the types of technologies that will be promoted and on the ability to meet energy access goals and targets. Though the off-grid sector appears to be growing in each of these countries (in large part due to falling costs and policy momentum), it is more vibrant in some countries (Kenya especially) than in others, while different business segments may achieve greater success owing to specific

policy and regulatory environments (e.g. mini-grids in Tanzania, at least historically, or the SHS systems in Uganda). Nonetheless, many obstacles remain, and these will continue to challenge achievement of SDG7: sustainable, modern energy for all.

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The views expressed in this Working Paper do not necessarily reflect the UK Government's official policies.