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"Don't cook or iron with it": Heterogeneities and coping strategies for accessing and using electricity in the informal settlements of Kampala, Uganda

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ABSTRACT

Uganda has one of the highest energy access deficits in the world, so low-income households improvise to access electricity, often through heterogeneous infrastructure arrangements. This study investigated energy heterogeneity in Uganda's informal settlements, expressed through the coping strategies that households adopt to access and use electricity. The paper is based on fieldwork conducted in Nakulabye slum, Kampala over a period of two months in 2022. We find ubiquitous multiplicity of electricity infrastructures and access options in the as households ration electricity, practice energy stacking, use illegal connections, or forego grid access. Such coping strategies offer households convenience, cost-savings and flexibility, but over prolonged periods of time, they can become the primary means of accessing electricity. This may cement the disenfranchisement of informal settlements from the grid, obscure the energy challenges they face and spur complacency in service provision and policymaking. The grid remains the idealized electricity source for most households, and future energy landscapes will likely feature the grid supplemented through coping strategies that reveal the energy expectations and practices of the urban poor. Augmented with existing measures, coping strategies portray a more accurate picture of energy access, demand, and consumption in informal settlements and advances our understanding of these issues. This can inform effective service provision that is attuned and responsive to the urban poor's energy needs and promote an equitable urban agenda.

1. Introduction

This study investigates energy heterogeneity in Uganda's slums,[1] expressed through the improvisations and coping strategies that households and businesses adopt to access electricity and maintain that access. The paper contributes to ongoing debates on heterogeneous socio-technological systems in Global South cities, specifically electricity infrastructure in poor urban communities where resources are very limited, and residents hold little power in the city [1]. Given the centrality of energy to human survival, prosperity and wellbeing, energy poverty inspires different responses from affected individuals, households, and communities. These responses may be direct or indirect, and they are often a combination of short-term temporary fixes (coping strategies) and longer-term permanent responses (adaptive strategies) [2] to the inadequacies of the available energy options [3–5].

Increasingly, coping strategies for accessing social services are simultaneously forged outside of and alongside mainstream provision systems, involve multiple actors playing different roles, and span different technologies of varying capacities and sophistication. For such reasons, heterogeneous socio-technological systems in southern cities have been a subject of discussion and analysis recently [4,6–8]. Some of these discourses argue for a departure from the "modern infrastructure

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[1] We use the term "slum" instead of "informal settlement" to align with local nomenclature. During the field work, the term "informal settlement" often elicited confusion, therefore, we chose to use terminology that, although problematic and carrying derogatory connotations sometimes, was understood by the community with whom we were working and the audience that we hope to reach with this article.

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ideal" [6] which presumes universality in access and usage of urban infrastructure, an ideal which engenders the "splintering urbanism" phenomena [9] in southern cities. Uganda's energy sector was built on these principles: electricity is primarily generated from large, centralized hydropower plants linked to a main grid, and policy focusing on ramping up large hydropower generation and extending the main grid to rural areas [10,11]. Uganda's cities and their functionality were built around such infrastructure modalities, with the general premise that to access services, all urban dwellers would tap into the same transport links, electric grid, piped water, and sewer networks.

However, different groups and demographics of urban dwellers experience, interact with, and benefit from infrastructure systems differently [4,7]. In this sense, the ideal modern 'networked city' entrenches marginalization in urban spaces, especially in southern cities where income inequality is stark and pervasive, and some demographics have been priced out of accessing centralized infrastructure and services. This has prompted growing calls for multi-scalar approaches that consider heterogeneity in urban energy systems as "spatially distinct constellations" within and between neighbourhoods [7]. Indeed, the variegation of experiences of energy infrastructure in a southern city can often be represented by a grid delivering electricity of sufficient quality, reliability, and cost for affluent city dwellers, while simultaneously failing to work for or meet the needs of low-income residents living in informal settlements. Disenfranchised and excluded from accessing grid electricity, slum households either forego some energy needs, improvise with alternative energy sources, or adopt other coping strategies.

In analyzing coping strategies, the paper's focus is not on any specific technologies, actors, or power relations. Rather, it is on the end user (in this case the household), how they strategize to access electricity and how these patterns amount to heterogeneity within a given site, i.e., the slum settlement. By focusing on the end user, this work also advances our understanding of electricity access in Uganda's slums, a topic on which little is known although, since many of these communities have been priced out of formal grid access, they could be considered "off grid, under grid communities" [12]. Sensitivity to this fact could shape energy transitions for cities like Kampala where inequality is prevalent and most (60 %) of the urban population is living in slums [13].

The paper's intention is to draw lessons from the coping strategies used by slum dwellers and consider how they could inform the provision of appropriate electricity services. Uganda has one of the highest energy access deficits in the world [14], therefore widening access to electricity in the country remains a top priority, and this will call for pragmatic evidence-based solutions. We posit that understanding coping strategies in highly dynamic and deprived settings like slums is one of the most effective ways of achieving these goals, by providing a case for tailored policy solutions, energy governance strategies, and co-production of energy solutions that are attuned to different city residents' energy needs, capabilities, and aspirations. Secondly, identifying the different channels through which the urban poor meet their energy needs outside of or complementary to formal provision channels could flush out hidden gaps in contemporary service provision, by interrogating the reasons and motivations behind adopting specific heterogeneous electricity access mechanisms. Thus, the paper's objectives are to determine how households in Kampala's slums access electricity, how they respond to inadequate grid electricity supply, why those specific coping strategies are relied upon, and finally how the strategies can inform policy that offers context-specific energy solutions for urban poor communities.

2. Coping strategies through the lens of socio-technological heterogeneity

We draw on the concept of Heterogeneous Infrastructure Configurations (HICs), proposed by Lawhon et al. [8], to understand coping strategies for accessing infrastructure and associated services in the global south. The concept defines infrastructure in southern cities as "geographically spread socio-technological configurations which involve many different technologies, relations, capacities and operations, entailing different risks and power relationships" [8,p. 722]. It therefore considers the diversity of mechanisms through which social services can be provided and recognizes the role of formal or informal infrastructures and institutions, state and non-state actors as hybrid service offerings, particularly for the poor [15]. Heterogeneity goes beyond physical infrastructures and encompasses the structures and processes that impact and shape infrastructure provision, how infrastructure is accessed by whom, and who derives utility from it. In settings where the 'modern infrastructure ideal' reigns supreme, often, HICs emerge as a response to needs left unmet by formal service providers, typically over prolonged periods of time [4,5,16]. Heterogeneity can arise due to cooperative or conflictual processes, unequal social and power dynamics, or conflicts between various actors involved in promoting infrastructure access and usage. These processes can hinder certain groups' access to essential infrastructure, leading them to create alternative infrastructure arrangements and improvisations in order to mitigate or circumvent these tensions. [17]. In this sense, heterogeneity also exposes linkages between material, space, and people, and social and political relations that govern different configurations [4].

Electricity access in southern cities exhibits such heterogeneous patterns, where access involves multiple actors, varied energy technologies and access mechanisms, and governance arrangements [6]. The energy stories presented by Munro [18] reveal an extensive mix of electricity sources used in Uganda's urban households, and although taken from a medium-sized city in northern Uganda, they are archetypes of energy access means in many urban households across the country. The choice of alternatives used also signals diversity in energy needs or capabilities in the city and between different locales, neighbourhoods, and communities. The uncertain and irregular nature of slum dwellers' livelihoods significantly impacts their access to electricity, consumption patterns, and strategies for dealing with this situation. They may opt to limit their use of grid electricity, explore alternative technologies and providers for obtaining electricity, or employ a combination of multiple energy sources for cooking. Another element of heterogeneity within slums is the existence of electricity provision and access that extends beyond the control and involvement of city councils and licensed utility companies. Electricity may be accessed via "human infrastructure" or "people as infrastructure" [19], made possible by strong social networks in the community. For a small fee or no fee, households with access to the grid or other electricity sources extend their infrastructure to the unconnected or those without access [18], adding a crucial social dimension to electricity access but also exploitative and unsafe practices to the least wealthy in the slum settlement. Evidently, heterogeneity appears to be salient in most coping strategies and improvisations used. As discourse on theorizing heterogeneous urban infrastructure systems gains momentum, there is a need to empirically demonstrate the manifestations of these heterogeneities across different infrastructure systems on the ground, especially in highly dynamic and deprived settings like slums [20]. This paper presents one such case. It investigates the coping strategies used to access and use electricity in a slum in Uganda's capital Kampala and demonstrates that these strategies are a clear part of heterogeneous energy arrangements.

3. Research design

3.1. Empirical context

Uganda's electricity provision is private sector-driven and primarily grid-based, and last mile distribution is done by a private utility company (Umeme) operating on a 20-year concession, a model which has priced out the poor (the domestic tariff is currently $20 cents/kWh^2) and contributed to the widening electricity access gap between affluent and poor neighbourhoods. The political economy of electricity supply places least priority on low-income communities like slums, whom the utility considers a risky consumer group due to their unreliable payment

profiles [21]. As a result, slum dwellers organize alternative experimentations or means of accessing energy to adapt or cope with an unavailable, limited, or unreliable grid supply [16,22–25]. Munro and Bartlett [26] call this the "innovate to survive" strategy, where the urban poor must constantly innovate and find creative solutions to meet their daily energy needs. They define "energy bricolage", a typification of urban households' use of whatever resources and materials are at hand to meet electricity needs, with the households being "bricoleurs who make creative and resourceful use of available materials to craft a post-modern energy landscape that is neither traditional nor modern but rather the fragmented product of different social and economic processes" [26,p. 72].

Slum residents actively engage in organizing, negotiating, and facilitating diverse methods to obtain electricity for their homes and businesses, in response to unreliable electricity provision from formal service providers. While affluent urban households rely on grid electricity along with high-capacity diesel generators or rooftop solar systems, low-income households adopt a combination of low-capacity and fragmented electricity solutions, some of which are temporary and only experimental. Consequently, these households supplement the grid with traditional lighting sources such as candles or paraffin, pico-solar home systems, solar lanterns, batteries, and smaller and frequently second-hand diesel generators [27] — creating energy constellations that provide a "spectrum of service levels" as described by ESMAP's multi-tier framework for energy access [28]. An understanding of these arrangements in slums is important and timely, as Uganda's private utility Umeme's concession draws to a close in March 2025, after which it is speculated that the government will form a state-owned utility and take over electricity distribution [29].

3.2. The case study: Nakulabye slum, Kampala

Nakulabye is one of over 60 documented slums in Kampala, and it is also one of the oldest where it is believed that people started settling as early as the 1920s [13]. Today, it has an estimated population of 40,000 people and 8000 households residing in nine administrative zones or villages (the lowest administrative unit in urban Uganda). Nakulabye sits on 163 acres of land and borders major roads, Makerere University (Uganda's oldest and largest university) and the Kasubi Royal Tombs (an important cultural site that is the burial grounds of the last four kings of Buganda) as shown in Fig. 1. As such, it is near the main grid network and enjoys relatively stable land tenure security compared to other slums in Kampala. Today, the slum is a vibrant and established settlement whose housing structures serve as residences (45 %), business enterprises (14 %), and mixed-use where the residence also engages in business activity (36 %) [30]. These housing units are very small, with an average of 1.8 rooms per structure. Most residents rent their premises and 37 % of households are headed by women. Nakulabye is also one of the few slums in Kampala which host a considerable number of non-nationals — 7 % of households belong to refugees and migrants mainly from D.R. Congo, Ethiopia, and Eritrea [30]. As with most other slums, it is prone to flooding, faces significant service and infrastructure gaps, and the state of electricity access is largely unknown. All these factors informed the selection of Nakulabye as the case study slum for this study.

3.3. Methods and materials

The study took a mixed methods approach, and data were collected through household surveys (n = 450), focus group discussions (FGDs), and key informant interviews. With the household as the unit of analysis, and using probability sampling, the sample size was determined for a 5 % confidence interval, 95 % confidence level, and 15 % error margin. As time and resources allowed, 28 additional households were surveyed, bringing the total to a round figure of 450 households. Households were randomly sampled based on administrative divisions and spatial grids

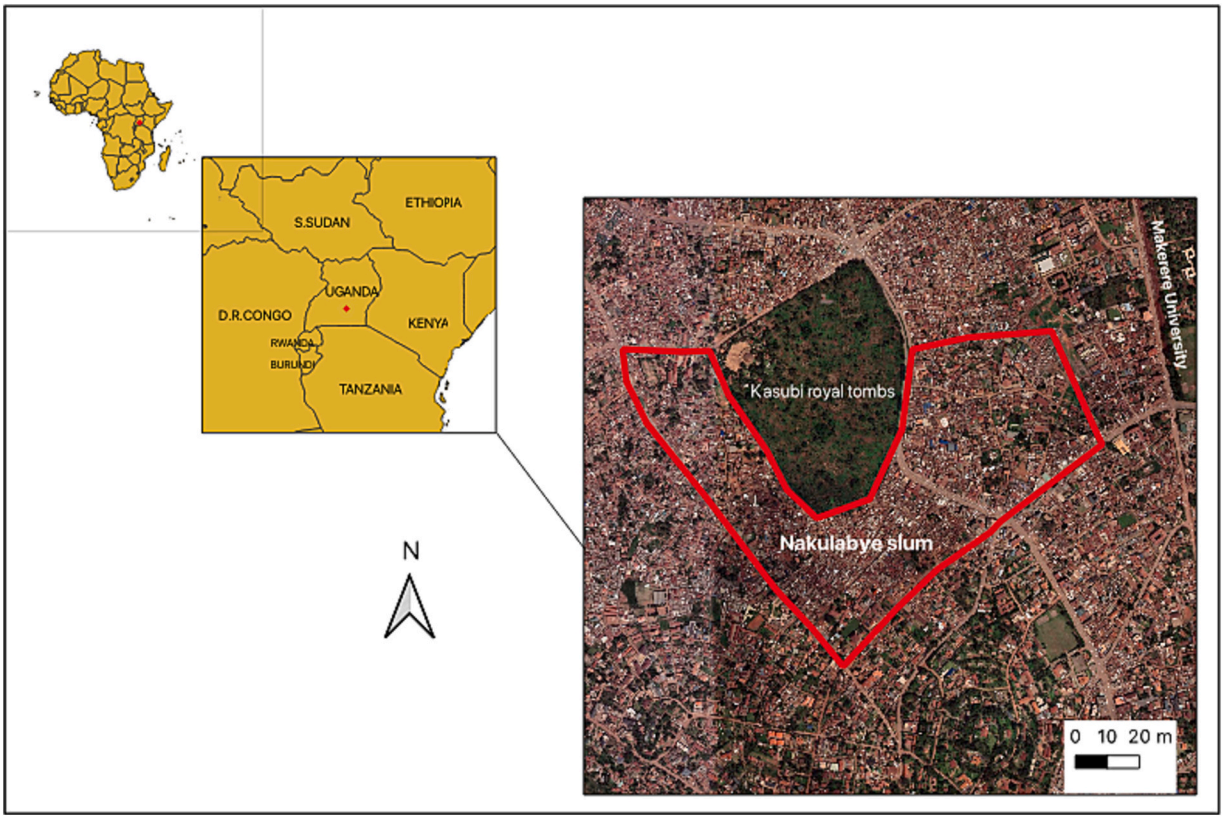

Fig. 1. Location and layout of Nakulabye slum, Kampala.

generated in QGIS, and the survey was administered using KoboToolbox [31]. The survey consisted of structured questions asking respondents of their experiences of accessing and using electricity in their households, including where and how they sourced energy, what they used electricity for, and how they responded to the energy challenges they faced. The results were analysed and visualised in Microsoft Excel and R. Each FGD was guided by a thematic discussion guide and lasted about one and a half hours, while each interview was semi-structured and lasted about one hour. Participants in the interviews were purposively recruited based on their knowledge of the subject matter, while participants in the FGDs were identified and recruited during the surveys or recommended by local council leaders and community guides. The interviews and FGDs were recorded, translated from Luganda to English, transcribed, coded and analysed in NVivo. Field data collection took place between September and November 2022. This period is at the tail end of a dry season and the beginning of a rainy season; therefore, we witnessed first-hand the difficulties and disruptions brought on by settlement-wide power outages following heavy downpours, and the difficulties of navigating through the slum via the degraded or flooded access roads.

3.4. Study limitations

The study uses data collected from only one slum settlement, out of the over 60 documented slums in Kampala. Case studies are suitable where resources are scarce, or where it is not practical or logistically possible to cover all possible study populations [32], and they allow the use of multiple research methods and data sources that offer a manageable way to engage with research that is socially complex and intricate [33]. However, there are obvious downsides to case study research like issues of validity and generalizability; that is to what extent Nakulabye slum is representative of other slums in Kampala and whether findings are applicable to other slums. We acknowledge these shortcomings and recognize that slums are not homogeneous therefore the findings from this study should not be generalized. On the other hand, given the study topic, insights can be broadly applied or inform policy and decision making for other slums or similar low-income communities. We also highlight the sensitive nature of some topics covered, for instance, on illegal electricity access and finances, and the interpretivism, subjectivity and bias that influences most qualitative research [34]. There are also possible sampling and data collection errors. Sampling using spatial grids required accurate co-ordinates which relied on good satellite connectivity — the GPS on the mobile tablets we used for the survey did not pick up accurate coordinates whenever there was cloud cover, vegetation, precipitation, or dense housing. These inaccuracies were alleviated by the community guides' knowledge of different neighbourhoods, and the settlement walks and formal introductions to local council leaders that we undertook before data collection. There were also households which could not be surveyed on the designated days e.g., the housing structure was locked with occupants away at work, or there was no adult present at the time of the survey. For these cases, the enumerator went back to the location at the end of the day's data collection and a few households completed the survey over the weekend. Statistical data on slums in Uganda are limited and outdated, and the sampling frame used in this study was from data provided by local NGOs ACTogether Uganda and the National slum Dwellers Federation of Uganda, who mobilized slum dwellers to map and profile their communities in 2013 [35]. To our knowledge, this is the latest and only dataset on slums in Uganda. Finally, we recognize our positionality, any biases associated with this and the potential impacts on data collection, analysis, and interpretation.

4. Results

4.1. Electricity access in the slum

As will be discussed in this section, all households in the slum settlement used multiple energy sources as illustrated by Fig. 2. However, the grid remains the main source of electricity for most, and 93 % of households in Nakulabye slum were connected to the grid (called grid-connected households from here on) while 7 % of households were not connected (called unconnected households from here on). Forty two percent of the unconnected households had never been connected to the grid before while over half of them (58 %) had had a grid connection in the past that was later removed for reasons such as:

- too expensive and no longer affordable to keep
- disconnected by the utility, landlord or *kamyufu* (informal electricity provider)
- moved house and could not relocate electrical installations like metering or wiring
- the grid connection attracted higher rent charges so they removed it.

For households which had never been connected to the grid, the main reasons for remaining unconnected were: high costs associated with getting connected and using grid electricity, landlords not providing a grid electricity option, inadequate housing and limited access to premises, while others were too far from the grid network. One unconnected business (a grocery kiosk) did not need electricity because the business does not run at night, and another household had arranged for an informal connection from a neighbour but had not started using it. In this paper, we refer to formal/informal electricity access or connections in the context of the *Uganda Electricity Act* which outlaws the "diversion of energy and damage to supply lines, interference with electrical installations", and "installation of electrical wiring" without obtaining an installation permit issued by the sector regulator [36,pp. 50–51]. Despite near-universal grid connection in the slum, both the connected and unconnected households used other energy sources alongside or in addition to the grid when they were not able to access or use grid electricity, for various reasons.

4.1.1. Energy sources used by grid-connected households

In an environment characterized by unreliable, expensive, and unpredictable grid electricity supply, most households adopted a practice known as energy stacking, where they supplemented their grid supply with alternative sources for various purposes such as lighting, phone charging, ironing clothes, radio and TV usage, and cooling. Among the households connected to the grid, 4 % (primarily residential and mixed-use households) utilized solar home systems (SHSs), 2 % (comprising businesses and mixed-use households) utilized diesel generators, 20 % used solar lamps and torches, 41 % resorted to paraffin or candles, 7 % utilized dry cell batteries, and 5 % utilized rechargeable lamps and phone flashlights. Additionally, two households (both residential) made use of lead-acid batteries, locally referred to as "car batteries," as a means of lighting and phone charging, often repurposing old car batteries for this purpose. As expected, based on existing evidence, households with higher incomes tended to employ a greater number of energy sources (three or four sources) compared to those with lower incomes — see Fig. 3. Among households earning a monthly income of over 300,000 shillings (>$80), 39 % utilized at least three energy sources, whereas only 11 % of households with a monthly income below 300,000 shillings (<$80) employed the same level of energy diversification. Across all income groups, the highest proportion of households used two energy sources.

4.1.2. Energy sources used by unconnected households

Unconnected households used a range of offgrid energy sources as shown in Fig. 2, including solar lamps or torches, paraffin or candles, mobile phone torches, lead acid and dry cell batteries. Thirteen percent of unconnected households also used more than one energy source (not including cooking fuels). In addition, the energy sources used were investigated specifically for lighting, phone charging and clothes ironing as shown in Table 1. Candles, dry cell batteries and paraffin make up the

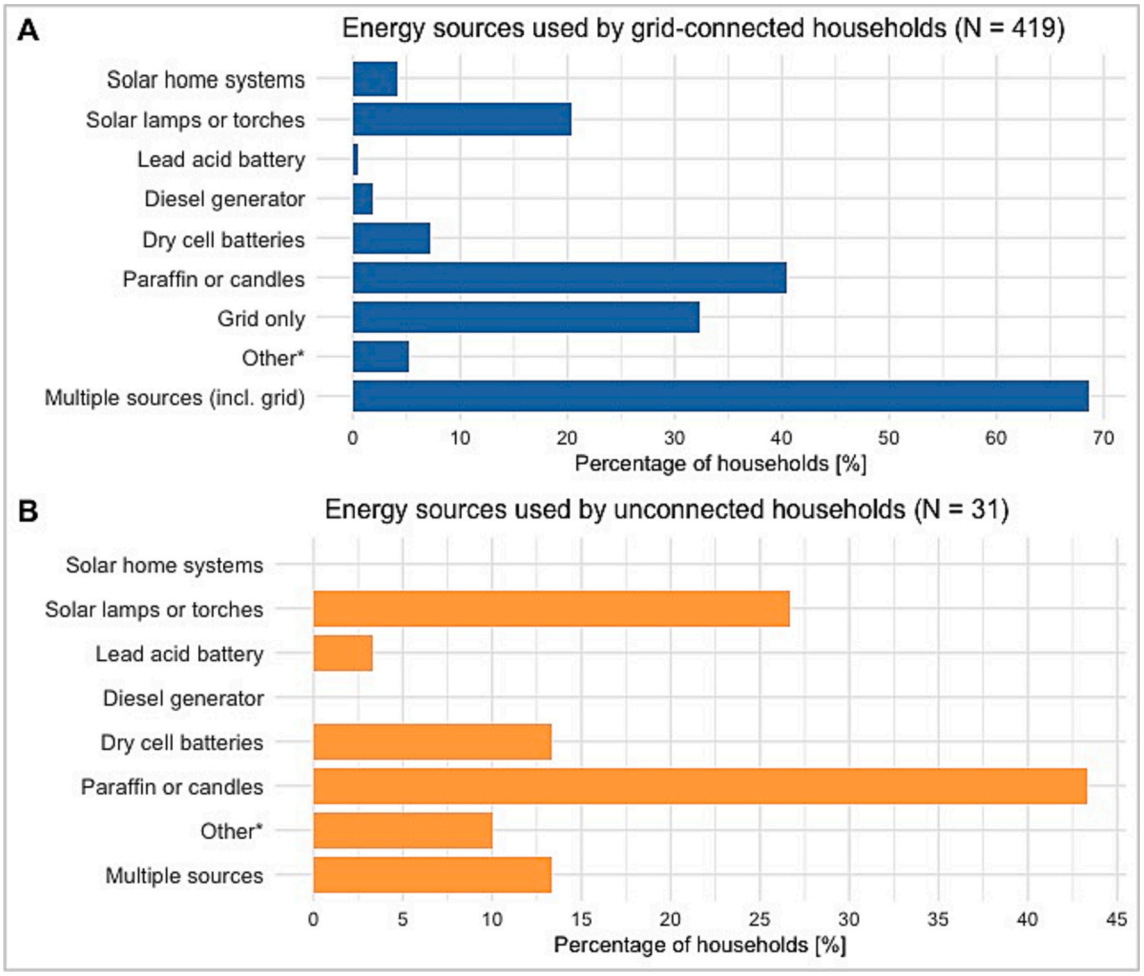

Fig. 2. Energy sources used by households in the slum (excludes cooking fuels).

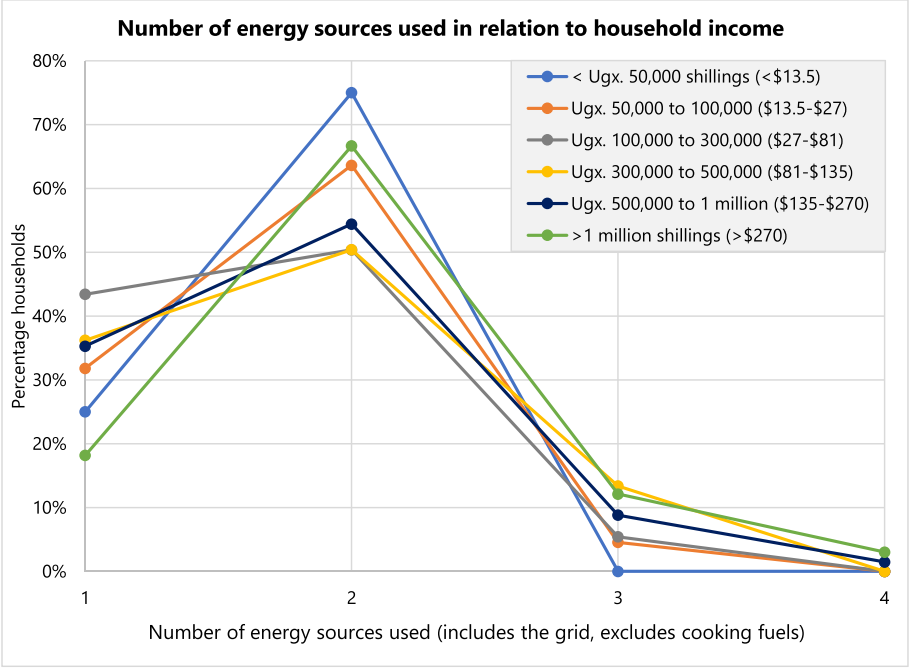

Fig. 3. Energy stacking (excluding cooking fuels) in relation to monthly household income. Generally, higher income households tend to use more energy sources than lower income households.

Table 1
Energy sources used by unconnected households for lighting, phone charging, and ironing clothes.

Lighting (N = 31)		Phone charging (N = 31)		Ironing clothes (N = 31)	
Candles	55 %	Friends or neighbours	65 %	Launderette kiosk	26 %
Dry cell batteries	35 %	Charging kiosks	19 %	Charcoal iron	13 %
Mobile phone torch	26 %	Charge at work	9 %	Friends or neighbours	6 %
Solar lamps or torches	19 %	Lead acid battery	3 %	Multiple sources	3 %
Paraffin	13 %				
Lead acid battery	3 %				
Multiple sources	45 %				

bulk of lighting sources with the usage of 'modern' lighting sources minimal. For example, only one unconnected household used a lead-acid battery and only two unconnected households used solar devices. Mobile phones were charged at a friend's or neighbour's, or at a kiosk for a small fee (between 500 and 1000 shillings per charge i.e., $13 cents and $26 cents). Those who ironed their clothes did it at a *dobbi* (a local launderette kiosk) for a fee, some used a charcoal iron, and the rest ironed at a friend's or neighbour's house.

4.2. Coping strategies for accessing and using electricity in households

In this section, we present the coping strategies that households rely on to access electricity and use it (and the temporal and spatial dimensions to electricity usage). The concept of coping strategies has been widely applied to resilience, livelihoods and food security studies [2]; in food security for instance, coping is examined as responses to shocks and stresses like prolonged droughts, pests and diseases, or low farm yields. In this paper, by "coping strategies" we mean the energy access or energy use practices that households adopt in response to or in circumvention of energy provision deficits. Thus, while the strategies we present manifest in everyday experiences and the energy use practices of households [5,25,37,38], we opine that it is the motivations and reasons for adopting them that makes them 'coping strategies'.

Both grid-connected and unconnected households responded to and coped with using the strategies summarized in Fig. 4. However, not all households were always able to respond or adopt coping strategies, especially following sudden events like power outages or disconnections for non-payment. During power outages, some households simply waited until electricity was restored, especially businesses like hair salons or carpentry and metals works workshops whose operations almost entirely rely on electricity. Other households whose electricity was disconnected for non-payment, waited until they got or saved enough money to buy electricity units. More details on coping to access and use electricity are presented next.

4.2.1. Strategies for accessing electricity

Coping strategies for accessing electricity included using alternative energy sources and stacking as earlier discussed, rationing electricity usage across space, time and application, using informal/illegal connections, or foregoing grid access entirely. Sudden power outages prompted more creative strategies: grocery kiosks and pubs selling cold beverages used ice blocks to chill their drinks, and one hairdresser at hair salon stated: "*I ask customers to go and sit under the sun to dry their hair, but they usually complain and the next time they don't come back. It's also risky for them because such direct exposure to the sun can cause health disorders*". Other households leaned on their social networks, by borrowing or obtaining lighting sources on credit from neighbourhood kiosks or charging phones at a neighbour's or kiosk, or ironing clothes at a launderette kiosk for a small fee. Infrastructure breakdown, likely from

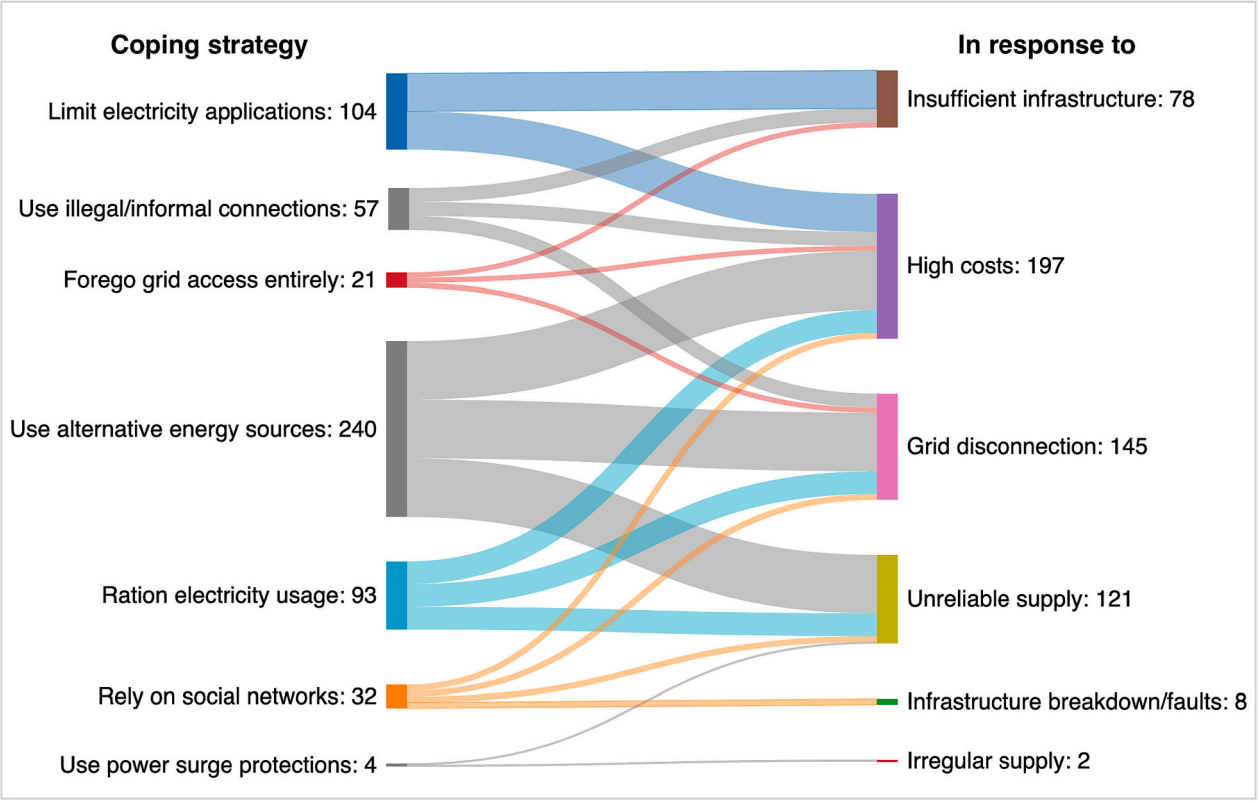

Fig. 4. Strategies used by households in response to insufficient electricity access and provision in the settlement (the numbers are cumulative percentages of the branches on each node, N = 450).

protracted neglect and limited maintenance from the utility was visible in many parts of the slum; with old, loose electric meters and wiring, and potentially overloaded transformers, issues which are aggravated by constant tampering to affix informal connections. Some parts of the slum, especially those in the centre and further away from main roads had insufficient infrastructure, such that for some, the nearest electric pole or transformer was several households away. To deal with electrical faults, some reached out to their landlords or to a *kamyufu*, and other households who had the means pooled together resources to fix faults or organize alternative electricity sources. A landlady revealed, "*When our transformer blew up, we reported to the utility for months but nothing was done, and no one came to fix it. So we decided that each household contribute 100,000 shillings ($27), and we hired an electrician who fixed it.*". Similarly, a sports bar and pub proprietor whose neighbours were businesses recalled, "*We organized as a group [of businesses] and bought a generator to improve our security [at night] when grid supply goes off*".

4.2.2. Strategies for consuming and using electricity

Other households coped through their usage of electricity and the applications for which they used electricity, primarily in response to high tariffs and with intent to minimize their electric bills. To limit electricity consumption, 22 % of households used electricity only for low-consumption tasks like lighting and phone charging and purposely avoided high consumption tasks like cooking, while 14 % limited the number and type of appliances they owned and used. Further, 11 % of households limited the frequency with which they did some tasks, for instance ironing clothes or boiling drinking water in an electric kettle was typically done in bulk and only on specific days of the week. Eight percent of households used energy efficient appliances, primarily "energy saver" light bulbs, but beyond lighting there was no other significant usage of energy efficiency measures as most appliances were old, second-hand, and inefficient (Fig. 5).

Many households also limited their electricity usage by stretching their electricity units to last longer (typically to last through the month). Some limitations are self-imposed, and others are imposed by landlords or the *kamyufu*, stipulated by shared metering arrangements or informal connection agreements. In the latter, a circuit breaker is installed to cut off supply when a high-consumption appliance is used or the informal network trips on its own from overloading. In any case, the limitation is not only on how electricity is accessed but also on how or what it can be used for. Some businesses with expensive equipment and appliances installed power surge protectors, to manage irregular grid supply, power

Fig. 5. A second-hand fridge and CRT-TV used by a business. (Nakulabye slum, Kampala. October 2022). Photo: Penlope Yaguma (2022)

surges and voltage spikes.

> "They [landlord or informal provider] tell you, 'Don't iron clothes and don't cook on an electric coil'. All the houses are on one [electrical] line, and we each pay 20,000 shillings ($5) per month. Sometimes they switch off the power at 6AM in the morning and put it back at 6PM in the evening so you don't even have electricity all day. If you attempt to cook, it goes off, because we have all been told that we should not cook or iron clothes. They don't even come [to the house] to switch off the power, it just goes off on its own. As soon as you try to cook or even put a kettle to make tea, it goes off for everyone on the line, so no one can cook on it, all you can use is lights and maybe a small TV. And you have nowhere to go to and report or complain because they tell you in the beginning when they first connect you that you should only use the lights and TV but no ironing or cooking." – *Participant in the focus group discussion (Female resident and business owner).*

4.2.3. Rationing electricity usage across space and time

Electricity was also rationed across time and space: temporally, 31 % of households used electricity only at or during specific times of the day, 20 % of households switched off some appliances and only used them at specific times of the day, and a small number of households (4 %) only used grid electricity a few times a week. This practice is most common with energy-intensive applications. For instance, ironing clothes is only done on specific days of the week and only specific clothing like school uniforms or formal outfits are ironed, fridges are turned on during the day and turned off at night when temperatures are cooler, TVs are watched in the evenings and radios are listened to in the mornings and evenings only. Spatially, households also ration electricity usage across space, with grid electricity used only in specific spaces of the home or business premises. Some households used electricity in the interior of their premises only, some only on the exterior for security lights or to light an outdoor toilet and bathroom, and others only in specific rooms like the bedroom or sitting room (Fig. 6).

4.3. Heterogeneous electricity infrastructures in the slum

The coping strategies presented above engender heterogeneous electricity infrastructures in the slum, not just through the different energy sources and technologies used but also their capacities, risks associated with different infrastructure arrangements and the power dynamics that mediate access to different infrastructures. Based on recent and on-going discourse on heterogeneous infrastructure in southern cities [6,8], we identify four broad categorisations of electricity infrastructures observed in Nakulabye slum, Kampala that straddle the on-grid/off-grid and household-scale/community-scale continuum as shown in Fig. 7. Some access options utilized are grid-based, formal or informal, others are off-grid energy systems purchased by the end users for household use, while others are provided or donated by external actors for communal use.

4.3.1. Grid-based formal access

This is the standard form of accessing grid electricity offered by the utility, following the formal procedures to connect to the grid network. Formal grid access is also actualized using pre-paid or post-paid meters, or personal metering or shared metering arrangements, each with their own merits and risks. For instance, the success of shared metering arrangements relies on good inter-household relations, or between tenants and landlords. Formal grid supply provides electricity of sufficient voltage and safety for households, but the risks of unreliability, power outages and high costs remain. Given the low and irregular household incomes in slums, grid electricity consumption at the current tariff ($20 cents/kWh) translates to increased household expenditure, strained household budgets and risks of disconnection for non-payment. The power relations in this case involve the hierarchical, vertical relationship between the utility and consumers in slums, whom the utility considers a risky consumer group with low purchasing power and low consumption loads [21,39].

4.3.2. Grid-based informal access

Grid electricity is also accessed informally, usually provided by landlords or *kamyufu* (unlicensed electricians and providers in the settlement), and some households make the informal grid connections themselves or tap from neighbours. Informal electricity networks are unregulated; therefore, the quality of supply is not guaranteed and there are safety risks as informal connections are known to start fires, cause electrocutions or damage appliances [40]. Unlicensed grid access or tampering with electrical installations is illegal in Uganda, outlawed by Sections 86, 87, and 88 of the Electricity Act [36], therefore informal connection users risk fines and prosecution. The *kamyufu* are the primary mediators between the grid and consumers, with households often having no control over the supply, receiving sub-par service and unable to make demands to that end. The *kamyufu* or landlords also limit appliance usage on the informal network which limits the utility that can be derived from electricity. Despite these risks and shortcomings, informal connections were widely used in the slum (19 %) as they offer affordable and flexible electricity access for households who cannot afford formal access.

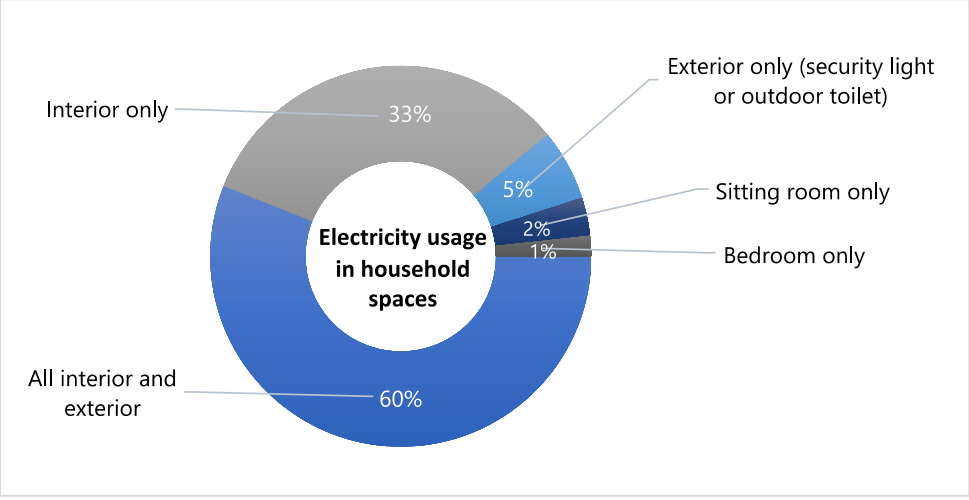

Fig. 6. Grid electricity connection and usage in household spaces. Some households use electricity only in specific parts of the home or business premises.

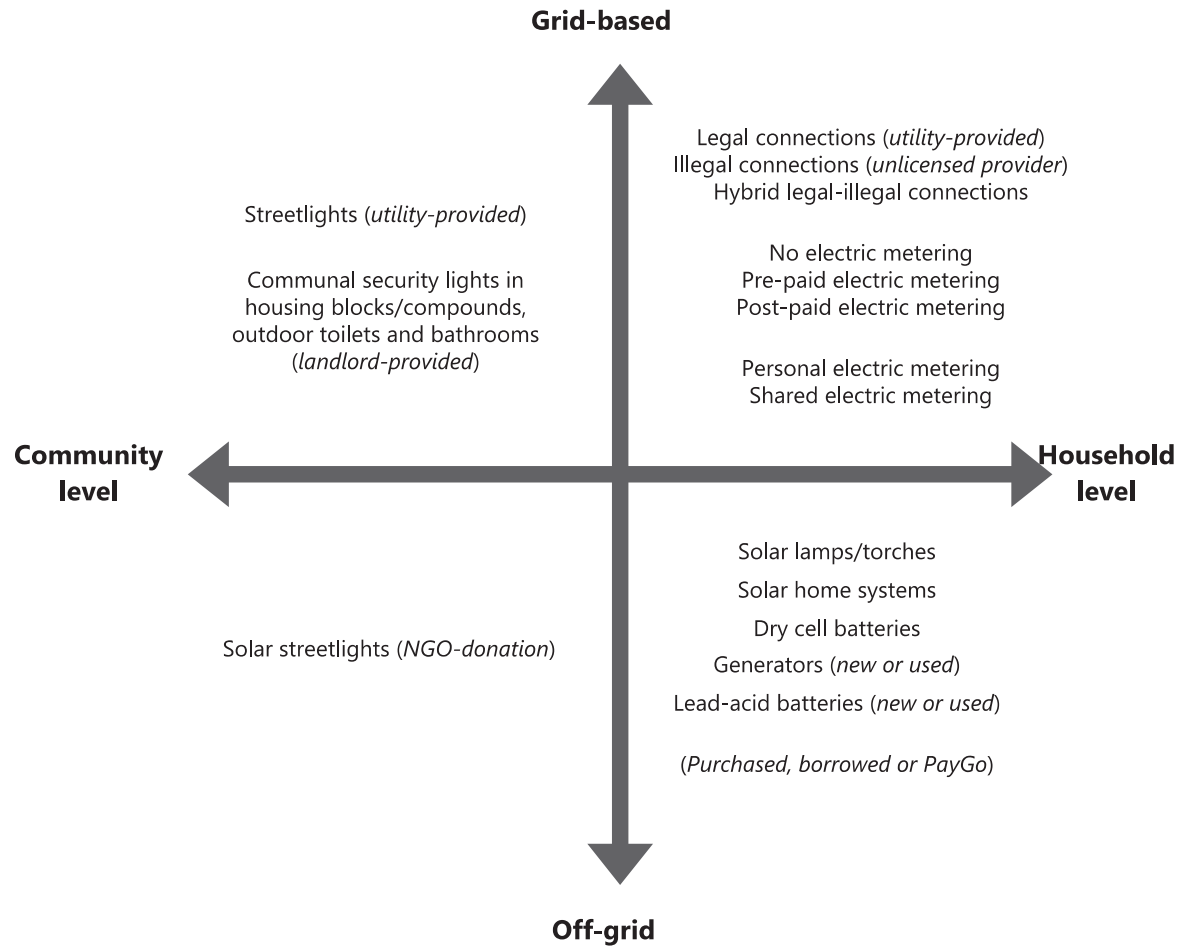

Fig. 7. Heterogeneous electricity infrastructure constellations observed in the slum. For various reasons multiple electricity sources and access mechanisms are employed by households in response to unavailable, limited, or unreliable grid electricity access.

4.3.3. *Off-grid household access*

The uptake of larger capacity off-grid electricity sources (SHSs, lead-acid batteries, or diesel generators) in the slum was low (10 %), and they were mostly used by businesses and mixed-use households. This is likely because of the high upfront costs of acquiring them, and for generators, the high fuel costs of running them. The SHS in Fig. 8 — Image (c) was purchased upfront and used by a mixed-use household which runs an electrical repair workshop on the verandah of the home. The household was connected to the grid, with the SHS used for lighter repair tasks like tests for faults while the grid connection was used for heavier repair tasks like soldering. The SHS had battery storage, so it was also used for phone charging and lighting at night. This particular SHS had been fully purchased so the owner was not in debt, but others who acquire SHSs on PayGo arrangements risk having their solar systems repossessed or being in debt if they default on their payments. The low capacity of SHS and unreliable solar resource is another risk of solar off-grid sources, and diesel generators require fuel, which places a financial strain on small businesses. Regardless, off-grid sources offer respite during power blackouts or when the grid cannot be accessed for other reasons.

4.4. *Grid-based and off-grid community-level access*

Community-level electricity access in the slum is primarily for streetlighting, and security lights in residential compounds and housing blocks or communal toilet and bathroom blocks. For both on-grid and off-grid streetlighting, streetlights are provided by external parties, while security lights are provided by landlords. In Nakulabye slum, the grid-based streetlights were donated and installed by the utility as part of their Pamoja project [41] — a pilot community engagement initiative to improve their relationship with the community, reduce crime in the slum, and curb illegal electricity usage. Most of the off-grid solar streetlights were provided by local and international NGOs working in the slum, either as part of wider community development projects or as donations. The most apparent risk with solar streetlighting is sustainability, not only in ownership of the streetlights but also in their safeguarding, repair, and maintenance. At the time of conducting the field work (October 2022), some streetlights' batteries had been missing for a while; other lights had malfunctioned and there was no plan to fix them. Most NGOs working in any slum often deliver such projects before they must move on to other settlements or the project ends. The success and longevity of community streetlighting depends on donor-recipient relations, and whether the community is empowered with knowledge and skills to ensure sustainability and inculcate a sense of ownership over the streetlights and to dispel common fears of theft and vandalism [42,pp. 168–170]. Still, streetlights have improved security in the slum especially in notoriously dark spots, eased movement at night, and encouraged businesses to remain open longer at night.

5. Discussion

Despite ubiquitous heterogeneous electricity infrastructures and a multiplicity of actors and coping strategies used to access electricity in Nakulabye, the grid remains the most idealized source of electricity for most households. This could in part explain the low uptake of off-grid sources like SHSs, and the prevalence of illegal connections. Off-grid solar systems, specifically PayGo SHS technologies, have received

Fig. 8. Some electricity infrastructures in the settlement. Image (a) shows formal grid connections and electric meters provided by the utility. Image (b) shows an illegal/informal grid connection running between two houses, provided by a kamyufu (unlicensed provider). Image (c) is a solar home system with battery storage, purchased by the user who runs an appliance repair business on the veranda of his home. Image (d) is a solar streetlight donated by an international NGO, along a major footpath in the slum. (Nakulabye slum, Kampala. October 2022).

considerable attention due to their potential to cost-effectively electrify millions of households and businesses in Uganda and Africa [43]. But their adoption and usage across rural and urban locales varies considerably and is context specific [44,45]. Uptake of SHSs in Nakulabye was low, but smaller, lower-capacity hand-held solar lamps and torches were widely used, therefore solar technology itself is not foreign to the settlement. We thus hypothesize that slums which are far from the city center and the grid, and less-established and illegitimate in terms of age or land tenure security are likely to have higher adoption of solar home systems compared to legitimate, more established, and grid-connected slum settlements which have the grid within reach, even if that grid access is illegal or risky. At the same time, the shortcomings of the grid and the utility's service provision are clear, so traditional sources like candles and paraffin still feature strongly in households' energy mix.

As a private utility, Umeme's primary interests lie in operating a financially viable utility, achieved through cost-reflective tariffs and minimal operating expenses [21]. In this respect, slum communities are a risky consumer group, therefore electricity provision, or operation, repair, and maintenance of infrastructure is not prioritized. Getting connected to the grid is expensive for many, and the process itself is long, tedious, and bureaucratic. Similarly, getting electrical faults and infrastructure repaired is a lengthy and sometimes unfruitful endeavour, which frustrates consumers and prompts them to employ different strategies in response. Umeme's presence and engagement with slum communities is also limited and usually occasioned by informal electricity access issues. Out of the coping strategies used in the slum, the utility mostly responds to informal electricity access, since it translates into direct financial losses for them. Starting around 2014, half the energy dispatched to slums in the Nakulabye area was lost, costing Umeme about $2 million in lost revenue annually [46]. In response, they launched the *Pamoja Project* in 2019, piloted in three slum settlements in Kampala, including Nakulabye [46]. To our knowledge, this is the first considerable effort from Umeme to establish a relationship with slum communities. The *Pamoja Project* aims to facilitate safe access to

electricity and curb informal electricity access in slums by training the *kamyufu* for certification, equipping youths with skills, and providing streetlighting. Other engagements between Umeme and slums have involved information campaigns [47], operations like the 2021 *Operation Komboa* to arrest, prosecute and fine illegal electricity users [48], or mass disconnections that cut off power supply from entire settlements [49]. Trust and provider-consumer relationships are a crucial ingredient for effective service delivery, especially in low-income communities where there is a power asymmetry between the utility and consumers [50–52]. Thus, high tariffs, slow or no responses to electricity faults reported, antagonistic encounters with the utility, mistrust and perceptions of neglect, are often the starting point for many coping strategies employed in slum communities.

Scholars have claimed that improvisations and informal practices of the urban poor are forms of everyday resistance, especially where there is imminent threat to their livelihoods, settlement or urban citizenship [53,54]. However, based on observations from this study, we argue that in the short term and in the most immediate sense, improvisations, coping strategies, and heterogeneity are first born out of a need to survive in the face of missing or inadequate service provision and to fulfil unmet energy needs. Then over prolonged periods of time, these improvisations are permanently adopted, and they may become forms of resistance to the available grid access options [55,56]. In Nakulabye, many households using illegal connections first acquired them because the utility took too long to formally connect them, or their applications for formal connection were denied or they simply could not afford the connection fees. Indeed, at the time of acquiring an informal connection, many saw it as a 'short-term', temporary strategy while they saved up money or waited on the utility to connect them. But after several months of using the connection and emboldened by persistent electricity provision gaps in the slum, many adopted the illegal connection as their de facto electricity access option. Similar trends can be observed in settlement and migration patterns, with people initially moving into the slum with intent to only stay temporarily but ending up living there for years.

The paper shows that there is a need to interrogate the role of coping strategies in low-resource settings and how best they can be exploited for long-term resilience, otherwise, over the long-term, coping can become a permanent way of life for the poor, sometimes in ways that maintain or worsen prevailing deprivation and inequality. Although evidencing innovation and adaptability in slums, successful coping strategies can also obscure the electricity challenges faced in these communities and encourage complacency of utilities, the city council, and policymakers, who may assume that slums have successfully coped and innovated outside of the formal energy provision structures and so no longer require bona fide electricity solutions that the rest of the city receives. For instance, sometimes faulty grid infrastructures like transformers are fixed by the community, and yet it is the responsibility of the utility. This is particularly so in settings where the capacity and resources of the utility and city council are already low, governance systems are not held accountable, and the political will to find solutions for the urban poor is weak. And yet, coping strategies often are just that; temporary, complex, insecure, and risky fixes that do not amount to long-term sustainability and resilience.

On the other hand, by revealing people's everyday electricity access practices and preferences, coping strategies offer a good starting point for effective and sustainable policy making and solutions that build on the momentum of the strategies already being used [2]. Beyond convenience and cost-savings, the coping strategies used in the slum offer households flexibility in vital but understated ways. "Connect-now-pay-later" options on informal access are accommodating of people's insecure income flows; off-grid energy sources favour the temporariness of life in the slum as they allow people to quickly pack up and move house if they need to; and workplaces enable people coming from unconnected homes to charge their phones at work. For the latter, secure employment brings with it the unexpected benefits of electricity for phone charging. This study revealed other unusual linkages between different phenomena. The phasing out of post-paid electric meters and introduction of pre-paid meters has inadvertently inculcated self-regulatory behavior in electricity usage, as households strive to stretch electricity units loaded to last through any given month. In other instances, pre-paid meters offer households a degree of 'disciplined autonomy' [38]. On the other hand, the gains accrued from such self-regulation are likely undone by households' minimal energy efficiency measures. A few households used energy-efficient lightbulbs ('energy saver' bulbs), but beyond lighting, there was no other significant usage or awareness of efficient electrical appliances. Many of the appliances used (especially fridges, televisions, and sound systems) are old and used, and lead acid batteries are used car batteries. Low-quality and second-hand appliances are imported into Uganda from Asia and Europe, and they have found significant uptake in low-income households across the country given their cheaper upfront costs compared to new appliances. The national standards body (Uganda Bureau of Standards) lacks the capacity or has simply not kept up with regulating electrical appliances on the market for efficiency and quality [57] and as such, most slum households use old inefficient cathode-ray-tube TVs, old fridges, and low-quality sound systems which drives their electricity consumption and energy bills up [58].

The trends in electricity access observed in the slum i.e., energy stacking, diverse infrastructure constellations, and the multiplicity of actors, scale and coverage of technologies concur with existing evidence and observations of socio-technological infrastructure systems in southern cities [4,18,27,59,60]. Of particular interest is the crucial role of non-state actors in filling the service delivery gaps left by the utility and city council, usually outside the purview of formal structures and processes. As [44] and others note, with these different infrastructure arrangements, the grid is not replaced, rather access to it is transformed and complemented, and grid supply is extended beyond the formal utility (through NGOs, informal providers, community organizations, and the households themselves). This manifested through grid-connected and unconnected households, and lower-income and higher-income households all using multiple energy sources, indicating that heterogeneity and stacking are not the preserve of any one demographic. However, coping strategies are differentially wielded by different socio-economic groups; for example with energy stacking, only higher-income households used four energy sources, suggesting greater heterogeneity among those with relatively higher incomes. Ultimately, the shortcomings of grid supply are felt by all households, and so they must all cope and adapt. With some households using as many as five energy sources, an "abundance" or availability of alternative energy sources has left some unconnected households contented with remaining unconnected, and this holds lessons for future electrification planning in Uganda's cities. This is critically important now, as Umeme's 20-year concession draws to a close in early 2025 and the government prepares to take over electricity distribution according to current speculation [29].

6. Conclusion

This paper demonstrates that in accessing and using electricity in their households, slum dwellers in Kampala, Uganda adopt various coping strategies, some quintessential of heterogeneous infrastructure configurations. Various means of accessing electricity are pursued, driven primarily by necessity and survival, and in response to specific service provision shortfalls or access challenges. Understanding the motivations behind the strategies used, can offer the utility and policymakers avenues to develop solutions that fill the energy provision gaps most felt by households. Despite the challenges encountered in securing electricity and the availability of alternative energy options, a considerable number of households have maintained their grid connection. Consequently, it is expected that future energy landscapes in slums will predominantly rely on the main grid as the primary energy source, supplemented by off-grid sources that offer the affordability,

flexibility, and reliability that the grid currently lacks. This can inform energy provision that is attuned to these expectations. The coping strategies point to the diverse energy needs, capabilities and aspirations of slum dwellers, and equally diverse solutions will be required to meet these needs and expectations. However, we also offer a cautionary tale: widespread adoption of coping strategies and misguided acceptance of this status quo by utilities and policymakers may further disenfranchise slums from safe, affordable, and reliable grid access. Uganda's energy system mirrors the 'modern infrastructure ideal', but most households in slums having to cope so diversely presents a case for decoupling electricity provision from this ideal and calls for hybridized energy solutions.

Insights from this work hold valuable lessons for curbing urban energy poverty, and a good understanding of poor people's coping strategies and the complexities inherent in them can inform effective policymaking and resilience building [2,5]. The extent of the coping strategies used can augment existing measures of energy access in slums; for instance, because many households limit their electricity usage or ration electricity, the true picture of energy demand and consumption can only be inferred when considered through the lens of coping strategies. Curbing energy poverty would then entail minimising households' need for coping strategies. The widespread usage of inefficient electrical appliances can be addressed through awareness campaigns combined with policies and avenues to ensure that efficient electrical appliances are affordable to low-income households [61]. Further, the micropolitics of electricity provision in slums needs to be unpacked, regarding actors and processes that engender certain coping strategies. The *kamyufu* and landlords impose some strategies, and these actors need to be more meaningfully engaged in electricity provision endeavours.

The wide-ranging strategies used to access electricity underscores the importance of electricity to slum communities and demonstrates that slum dwellers need and want electricity, to the extent that nearly all households go to great lengths to acquire electricity, despite the risks associated with some access options. With the imminent departure of Umeme, whose focus has been financial viability over the last two decades, there is an opportunity for the new public utility to put people first and consider electricity service offerings for all urban neighbourhoods, including slums which make up the bulk of Uganda's cities. Uganda's energy policies have mostly focused on grid extension, rural electrification and ramping up large generation. But to achieve universal electricity access and with this lift millions of people out of poverty will require consideration for versatile electricity provision models, many of which can be deduced from poor people's energy practices. In a country where 60 % of the urban population lives in slums, this approach would be responsive and demand-driven. This work focused on one slum settlement in Uganda's capital Kampala, and further work could explore coping strategies and electricity access heterogeneity in city neighbourhoods of different socio-economic demographics, and in other secondary cities. This would capture a wider perspective at city-level, and perhaps reveal differences or similarities between locales, that could inform equitable electricity provision and advance an equitable urbanization agenda.

Ethics statement

This research study received ethics approval from the Uganda National Council for Science and Technology, Ethics ID number: SS1036ES and University College London, Ethics ID number: 20673/001. The research study was conducted in accordance with the principles embodied in the Declaration of Helsinki and in accordance with local statutory requirements. All participants gave written or verbal informed consent to participate in the study.

CRediT authorship contribution statement

Penlope Yaguma: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Federico Caprotti:** Validation, Visualization, Writing – review & editing. **Muhamad Rosyid Jazuli:** Writing – review & editing. **Priti Parikh:** Methodology, Supervision, Writing – review & editing. **Yacob Mulugetta:** Funding acquisition, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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