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Sustainable energy for slums? Using the Sustainable Development Goals to guide energy access efforts in a Kenyan informal settlement

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ABSTRACT

Urban and *peri*-urban communities across the Global South face considerable energy access challenges with over one billion people living without adequate access to basic services such as energy, water, and healthcare. Lack of access to modern energy services has cascading effects on the United Nations 2030 Agenda and the achievement of the corresponding Sustainable Development Goals (SDGs). In this article we address this issue, using the SDGs as a framework to evaluate how policies and plans for local energy access can be coordinated with all SDG Targets. With a case study in Kibera, Kenya, we analyse how local energy access could enable or inhibit all local SDG Targets. Based on this knowledge, we propose a set of actions to achieve full modern energy access without compromising other local Sustainable Development Goals. We propose a new taxonomy to evaluate how actions affect the interlinkages between local energy access and the achievement of the SDGs. We find that the SDGs, applied as a framework to direct national policies and strategic projects, offer a holistic outlook, helping to unpack discrete thinking and support an integrated sustainable future for all.

1. Introduction

Energy access is recognised as an enabler for sustainable development, and its importance is acknowledged in the United Nations' 2030 Agenda. Sustainable Development Goal (SDG) 7 aims to "ensure access to affordable, reliable, sustainable, and modern energy for all" [1]. Yet still today 789 million people live without access to electricity and close to 2.8 billion people remain reliant on inefficient and polluting cooking fuels [2]. Lack of energy access is often framed as the plight of rural areas, but considerable challenges remain in urban communities within or on the outskirts of cities [3,4].

Today, an estimated fifty-five percent (55%) of the world's population, representing 4.3 billion people, live in urban spaces [5]. Approximately one in three urban inhabitants dwell in informal settlements and slum households, without access to basic services – potable water, appropriate housing, healthcare – and modern energy [2,5,6]. Target 11.1 of SDG 11 Sustainable Cities and Communities aims to improve the condition of these urban residences and "ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums" [1]. However progress to achieve this Target is largely offset by internal population growth and rural–urban migration [2] with seventy percent (70%) of the world's population projected to live in urban areas by 2050 [5]. Given the growing urbanisation across the developing world, the inaccessibility of modern energy services to these urban communities presents an urgent challenge [7].

Castán Broto et al. [8] highlighted the need for the inclusion of urban slums and informal settlements in the energy access agenda. Earlier studies have examined energy access in urban areas from the perspectives of energy poverty measurements [9]; barriers and enabling frameworks [7,10,11]; energy justice, sustainability assessments and transitions [12–14]; health [15–17]; and political economy [18,19]. However, to the best of our knowledge, no study has investigated energy access in urbans slums and informal settlements from the context of achieving the United Nations 2030 Agenda.

The SDGs are increasingly being used as a framework to analyse and understand such complex challenges and implications of projects and policies across a variety of sectors [20–26] including energy [27–29]. We adopt the SDGs as a framework for analysis to investigate energy access in urban slums and informal settlements from the context of achieving the United Nations 2030 Agenda. A high share of urban households in sub-Saharan Africa live in urban slums and informal settlements, and the region has the lowest rates of energy access in the

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world [6]. We put forth an in-depth case study of the informal settlement Kibera in Kenya. In Kenya, over fifty percent (50%) of urban households live in such areas [30], whilst national access rates to electricity and clean cooking fuels stand at fifty-six percent (56%) and thirteen percent (13%), respectively [31,32]. Although urban slums and informal settlements across the Global South share similarities in terms of their deprivations and barriers to services, they are not homogenous, and embedded in their historic, geographic and institutional contexts [33]. For this reason, we limit our study to a specific informal settlement to allow in-depth analysis and draw on a case study of electricity and liquefied petroleum gas (LPG) access in the informal settlement of Kibera, Kenya.

The paper is structured as follows. Section 2 introduces our case with a description of present-day electricity and LPG access in the informal settlement of Kibera. Section 3 describes the methodological steps in our application of the SDG framework. Section 4 discusses the results of our application. Section 5 presents the implications of our use of the SDG framework, including its potential use for policymaking and to shape in future research.

2. Case of electricity and LPG access in Kibera

We centre our study on Kibera, an informal settlement in Nairobi, Kenya, and examine the case of electricity and LPG access within the community. Kibera is believed to be the "largest slum in Africa" [34]. With an estimated population between 200,000 and 700,000 people, Kibera occupies a land area of approximately two square-kilometres [34–36]. As the land it occupies is formally considered government property, Kibera is classified as an informal settlement and thus residents are considered to be squatters, associated with insecurity of tenancy and high vulnerability [37–39].

Despite the ambitions of the Kenyan government to achieve universal energy access by 2030 [40] energy access challenges in the neighbourhood are considerable, with barriers of high supplier and consumer cost, unreliability of supply, lack of awareness, safety concerns, and a lack of leadership [41–43]. We limit our case to two energy options, electricity and LPG, considered to be modern and clean energy options [44]. Both are likely to be the dominant energy sources in urban areas, being heavily promoted by the government of Kenya [40,41].

2.1. Electricity access in Kibera

Kenya aims to achieve universal electricity access by 2022 [40]. Kibera, less than 10 km from Nairobi's city centre, is in close proximity to existing distribution lines – owned and operated by the state-corporation Kenya Power and Lighting PLC, who also own and operate transmission and distribution throughout Kenya [43,45,46]. Yet several barriers prevent the residents of Kibera from obtaining formal electricity access through the grid.

The connection cost to the grid is high and often required upfront at three-to-five times the average monthly income of Kibera's residents [43]. Once connected, households must further add the cost of tariffs, Value Added Tax (VAT), adjustment of fuel consumption and foreign exchange rate fluctuations and levy to support electrification to their electricity costs, making the energy source unaffordable for many [43]. Such expenses lead residents to obtaining informal access: via a neighbour or directly tapped into the grid through faulty connections, often through resellers who haven't the skills or knowledge to ensure a safe and reliable connection [41,47]. Informal resellers - often residents themselves - understand Kibera's energy needs, practices, and ability to pay and often offer flexible modes of paying at a lower price than that of Kenya Power and Lighting PLC, making such connections affordable [42,45]. However, informal connections impact the overall electricity supply, causing voltage drops and power shortages, meaning access is often unreliable [42].

Whilst the Kenyan government has subsidised households' first 50kWh of monthly electricity consumption through a lifeline tariff since the 1990s [41,48] only the Kenya Slum Electrification Programme has specifically focused on the electrification of households in slums and informal settlements across Kenya and aimed to gain customers in Kibera [49]. Nevertheless, tensions remain between informal electricity resellers and Kenya Power and Lighting PLC and their antagonism further prevents households gaining a formal connection as the utility refuses to enter the percieved hostile environment and risk the safety of their workers [41,45]. This exacerbates the problem, stigmatising residents as untrustworthy or criminal, with basic service utilities reluctant to improve access in Kibera, fearing it will be a commercial loss [41,42,45,47]. Yet informal connections are a cause of concern for many residents who report cases of electrically-induced fires and electrocutions leading to serious and fatal injuries [41]. Many seek a safer, more secure, formal connection but fear punishment for having obtained informal access to electricity [50].

2.2. LPG access in Kibera

The Kenyan government is aiming to achieve universal access to modern cooking by 2030, promoting the use of LPG as an alternative to kerosene and charcoal [51,52]. However, whilst LPG use has more than tripled in Kenya over the last two decades, it's uptake in residential cooking and heating has been concentrated in urban areas amongst higher-income households [53,54]. For lower-income households, several barriers constrain wider adoption.

LPG has a high retail cost relative to alternative lower quality biomass fuels and over the last five years the retail cost of LPG has fluctuated between US$1.4/kg to US$2.2/kg, having been deregulated since 1994 [54–57]. To improve the affordability of LPG the government removed value-added tax (VAT) on LPG in 2016, although a sixteen percent (16%) VAT and twenty-five percent (25%) import duty still remains on cooking appliances and accessories. In an attempt to standardise cylinders and promote competition, the government regulated the wholesale price of LPG in 2009, requiring all wholesalers to participate in a cylinder exchange pool [57,58]. This exchange pool was further strengthened in the 2019 Petroleum (LPG) Regulation, standardising LPG cylinder capacities and requiring that each must be fitted with unified valves to improve safety [59]. Nevertheless, reports of "unscrupulous" dealers selling half-filled cylinders as well as safety concerns for the explosion of cylinders due to LPG leakages contribute to residents' mistrust of the fuel [41,50].

Although there is evidence to suggest that LPG is generally recognised as a clean cooking fuel by residents of Kibera, reservations remain [50]. Due to LPG supply shortages, charcoal is often preferred, being not only affordable and available, but delivering the right taste and look to staple dishes prepared in the neighbourhood [50]. Residents typically purchase fuel in small quantities on a day-to-day basis [50,54,60]. Whilst this is possible for charcoal and kerosene, LPG is often only dispensed in discrete quantities dictated by cylinder size with 0.5, 1, 3, 6 and 13 kg available on the Kenya LPG market [59]. Smaller sized cylinders aim to promote affordable LPG access for lower-income houses, however, unlike kerosene and charcoal, where the unit price is typically fixed, LPG benefits from economies of scale: the cost per kg decreases per kg purchased [58]. Thus, buying in bulk offers households better value for money as well as savings for any cylinder management offered, but this is rarely possible for Kibera's residents.

3. Materials and methods

The SDGs capture the aspirations of the 2030 Agenda, from the eradication of poverty to the strengthening of worldwide partnerships [1]. These interconnected Goals and respective 169 Targets integrate all three components of sustainable development - social, economic, environmental - and can be applied as a framework to direct national policies and strategic projects with coherence and coordination. The SDG

framework has been used to analyse and understand several complex challenges: between Goals [22,61,62], infrastructure [23,24], energy [27–29], artificial intelligence [26], and climate change [25].

We apply the SDG framework to the case of electricity and LPG access in Kibera, following the methodology presented in Fig. 1 and described in Sections 3.1 to 3.3. First, mapping the impact of electricity and LPG access in Kibera, followed by the selection and application of actions to promote energy access and an assessment of their impact on the achievement of SDG Targets. Our mapping process was iterative, with actions re-evaluated and improved based on this analysis in order to maximise the number of Targets enabled.

3.1. Mapping the impact of electricity and LPG access in Kibera

The first step in our investigation was to map the impact of electricity and LPG access in Kibera. We adapted the methodology of Fuso Nerini et al. [27] in our approach. Fuso Nerini et al. [27] assessed global interlinkages between energy system and the 2030 Agenda and categorised them in terms of synergies and trade-offs. Through a search of published studies and grey literature, Fuso Nerini et al. [27] identified evidence of interactions between the achievement of each Target and the pursuit of SDG 7 and the synergies and trade-offs of these interactions were characterised using a consensus-based expert elicitation process.

In this study, we adapt this methodology to inform local decisions making on energy access. For each of the 169 Targets of the SDGs, we posed two questions: i. "Will the provision of electricity or LPG access in Kibera enable or inhibit the achievement of the Target?" and ii. "Will the achievement of the Target enable or inhibit the provision of electricity or LPG access in Kibera?" Evidence of an interlinkage that promoted either energy access or the achievement of Target was marked as an enabler, whilst those that prohibited energy access or the achievement of Target were marked as an inhibitor. In the absence of evidence, no interlinkages were marked, meaning the absence of published evidence, rather than the absence of an interlinkage. We chose to use the terms "enabler" and "inhibitor", rather than "synergies" and "trade-offs" as in previous literature [25,27] to mark the causality of the interlinkage. This first methodological step provided the baseline assessment of the impact of electricity and LPG access in Kibera, against which we evaluated the performance of selected actions (Section 3.2) to promote energy access within the SDGs (Section 3.3).

3.2. Determining actions to promote electricity and LPG access in Kibera

Actions to promote electricity and LPG access in Kibera were identified through a review of literature and considered known interventions and best practices for implementing basic services into slums and informal settlements around the world and applicable to existing policies, projects, and programmes in place in Kibera, and Kenya, today. The final selection of actions was based on positive response to inclusion criteria questions:

Has action been applied to overcome energy access barriers?
Has action been applied in context of urban slums and informal settlements?
Has action been implemented locally, nationally or regionally?

3.3. Promoting electricity and LPG access in Kibera to achieve the SDGs

The final step in our investigation assessed the impact of actions on each SDG Target, posing the question "How will actions to promote electricity and LPG access impact the achievement of the Target?" To categorise the impact of the action on the Target, we developed a classifications system to allow for systematic thinking beyond simply enablers and inhibitors [62]. The taxonomy, presented in Table 1, was based on the outcome of previous mapping (Section 3.1), i.e. a Target identified to be enabled by electricity and/or LPG access could be further strengthened through actions to further promote access. The SDG framework was applied to the case of Kibera and geographically centred on the informal settlement. However, we could not ignore the overall supply chains involved in the delivery of electricity and LPG. Thus, we mapped any interlinkage between Targets and upstream components of the supply chain that were recognised to affect the provision of energy access in Kibera. Where specific reference to Kibera was

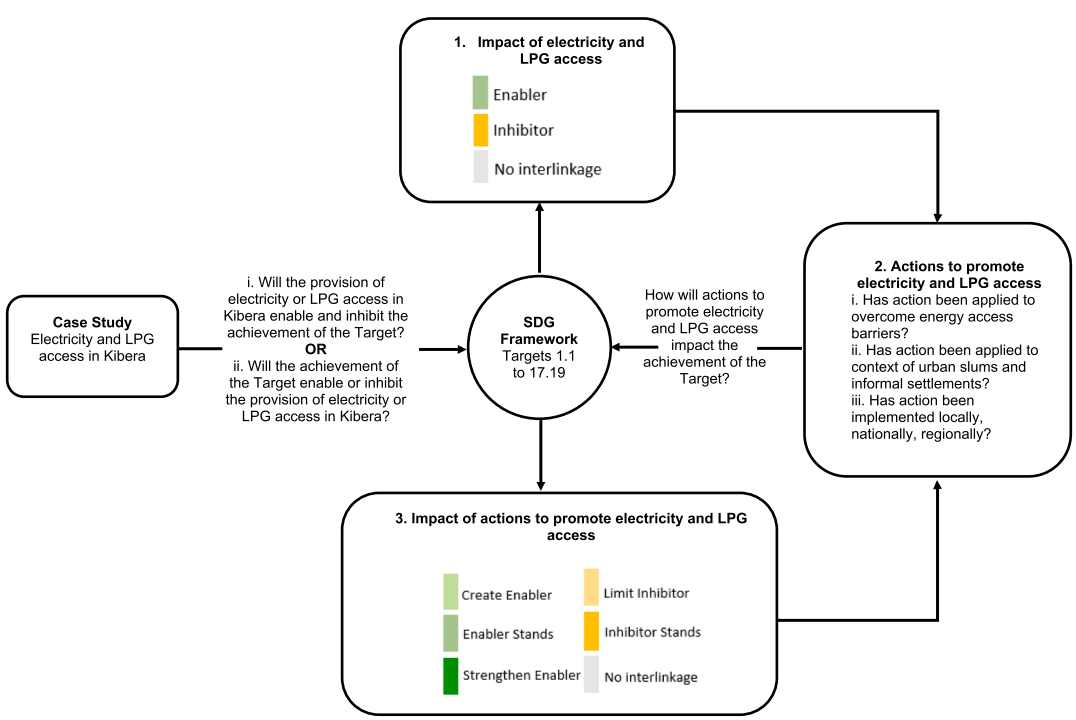

Fig. 1. Illustration of the methodology applying the SDG framework to the challenge of energy access in urban slums and informal settlements.

Table 1
Taxonomy to evaluate how actions affect interlinkage between actions to promote energy access and the SDG Targets.

CLASSIFICATION	EXPLANATION	EXAMPLE
Create Enabler	Enabler, not previously identified, created as a result of actions.	Political recognition means consideration and recognition of informal settlements in national policy and decision-making.
Strengthen Enabler	Enabler previously identified improved as a result of actions.	Programmes to raise awareness in the safe use of energy can be used as an educative platform.
Overcome Inhibitor	Inhibitor previously identified removed as a result of actions.	Financial incentives improve the affordability of energy for households.
Limit Inhibitor	Inhibitor previously identified lessened, but not eliminated, as a result of actions.	Strengthening supply chain improve security of LPG supply but does not influence the global oil price and Kenya remains dependent on imports.
Interlinkages Stand	Enablers, inhibitors, or no interlinkages stand as actions have no evidence of impact.	Actions do not impact Target

lacking, we widened our search, drawing on evidence from the national level and other informal settlements within Kenya, and from the regional level from neighbouring countries in sub-Saharan Africa.

4. Results and discussion

We investigated energy access in Kibera from the context of achieving the SDGs. First, we present the impact of electricity and LPG access on achieving SDG Targets within Kibera, and the converse, i.e., the impact of SDG Targets on achieving electricity and LPG access. Next, we present the impact of actions to promote electricity and LPG access on the achievement of SDG Targets. Full results can be found in Supplementary Material.

4.1. Mapping the impact of electricity and LPG access in Kibera

Fig. 2 presents the outcome of mapping, illustrating where access to electricity and LPG enables or inhibits the achievement of each SDG Target locally within Kibera.

Mapping the impact of electricity and LPG access in Kibera within the SDG framework, SDG Targets are enabled across all but one SDG. Access to modern and clean energy alleviates poverty and improves living conditions [63] enables Targets such as 1.1: By 2030, eradicate extreme poverty for all people everywhere and 11.1: By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums.

Enabling Targets of SDGs 8 and 10, energy access provides an opportunity for productive employment and growth of home-based small- and medium-sized enterprises (SMEs) [41]. For example, small-scale, home-based food vendors in Kibera using charcoal and kerosene fuels for cooking could, with the appropriate enabling conditions, transition to LPG [43]. As a cleaner fuel option, LPG has the added benefits of allowing for faster service, cost savings and increased earnings [43,64]. Similarly, electricity can power shops and restaurants, providing refrigeration for food storage and extending shelf-life, allowing for longer working hours with better luminescence or lighting, and improving customer service [43].

However, given the high upfront cost, electricity and LPG could be an expensive alternative to charcoal and kerosene which is typically purchased in small quantities on a day-to-day basis [50,65]. Increased daily costs could inhibit residents' ability to pay for other basic services [41]. This inhibits Targets such as 2.1: By 2030, end hunger and ensure access by all people, 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all, and 7.1: By 2030, ensure universal access to affordable, reliable and modern energy services, which specifically mentions the need for "affordable" energy access.

Targets within SDG 3 Good Health and Wellbeing can be enabled by modern energy access. Indoor air pollution (IAP) from the combustion of solid fuels and kerosene for cooking and lighting accounts for 3.8 million deaths each year [66] with pneumonia, as a consequence of IAP exposure, a leading cause of under-five mortality in informal settlements [67]. Women, usually responsible for cooking in the home, bear the brunt of the health impacts of IAP [68]. Access to electricity and LPG reduces indoor air pollution, for the benefit of health (Targets 3.1, 3.2, 3.4) when compared to the use of solid fuels and kerosene [69]. Moreover, use of LPG removes the risk of spillages or accidental poisonings from the use of kerosene whilst formal electricity connections minimises fatalities and injuries from faulty connections (SDGs 3.9, 6.3, 12.4) [70]. Access to electricity enables the use of information and communication technologies to support child education and adult learning with implications for health and global citizenship (Targets 3.1, 3.d, 17.8) [71].

Reliance on imports of LPG [57,72] inhibits the achievement of Targets within SDGs 11, 12 and 17 concerning economic resilience and sustainability. LPG supply is governed by the throughput international crude oil and natural gas production [58,64], meaning Kenya is vulnerable to supply shortage and variable import costs as dictated by global oil prices, inhibiting Targets 12.1, 12.2, 17.13 [73].

No Targets are enabled within SDG 14 Life Below Water, as the focus of our mapping is on household level energy access. However, both electricity and LPG access inhibit Target 14.3 which seeks to minimise ocean acidification. Electricity generated through the combustion of fossil-based sources and LPG, as a by-product of crude oil and natural gas production, contributes to anthropogenic greenhouse gas emissions, the known cause of ocean acidification inhibiting SDGs 13, 14, 15 [58,64,74,75]. Moreover, whilst over 60 percent of Kenya's generating capacity is from renewable sources [40], growing demand for electricity has led to the construction of Kenya's first coal power plant [40] inhibiting Targets 13.1 and 13.2, and grid expansion can negatively impact terrestrial ecosystems within Kenya (SDG 15) [76].

4.2. Determining actions to promote electricity and LPG access in Kibera

Identified actions, presented in Table 2, seek to provide energy access in informal settlements while reinforcing identified enablers and removing – to the extent possible – inhibitors with the SDGs Targets.

Affordability concerns are overcome through financial incentives to affect fuel costs [77]. A range of incentives are available, and subsidies are a common means of promoting energy access in informal settlements [70]. For electricity, connection costs can be lowered through subsidies and loans coordinated and implemented by the government. Monthly payments can be arranged through prepayment methods and covered by a lifeline tariff [49,76], whilst innovations for LPG, such as Pay-As-You-Go, offers residents flexibility to better reflect the income of households [78,79].

To improve availability, the supply chain involved in the delivery of energy to households must be strengthened. For electricity this involves the expansion of the grid - the transmission and distribution network to and within the neighbourhood - as well as national investment into renewable energy sources [40]. For LPG, increasing bulk storage facilities along the supply chain, at the port of Mombasa and in filling stations across the country, will improve supply security, whilst increasing the number of outlets within Kibera improves availability [57]

Community engagement, through participation and programmes, can raise awareness for electricity and LPG, gain the trust of residents and ensure the needs and practices of the neighbourhood are met [50,80].

Political recognition influences all other interventions as it covers all levels of agency and policymaking, bringing to light the otherwise

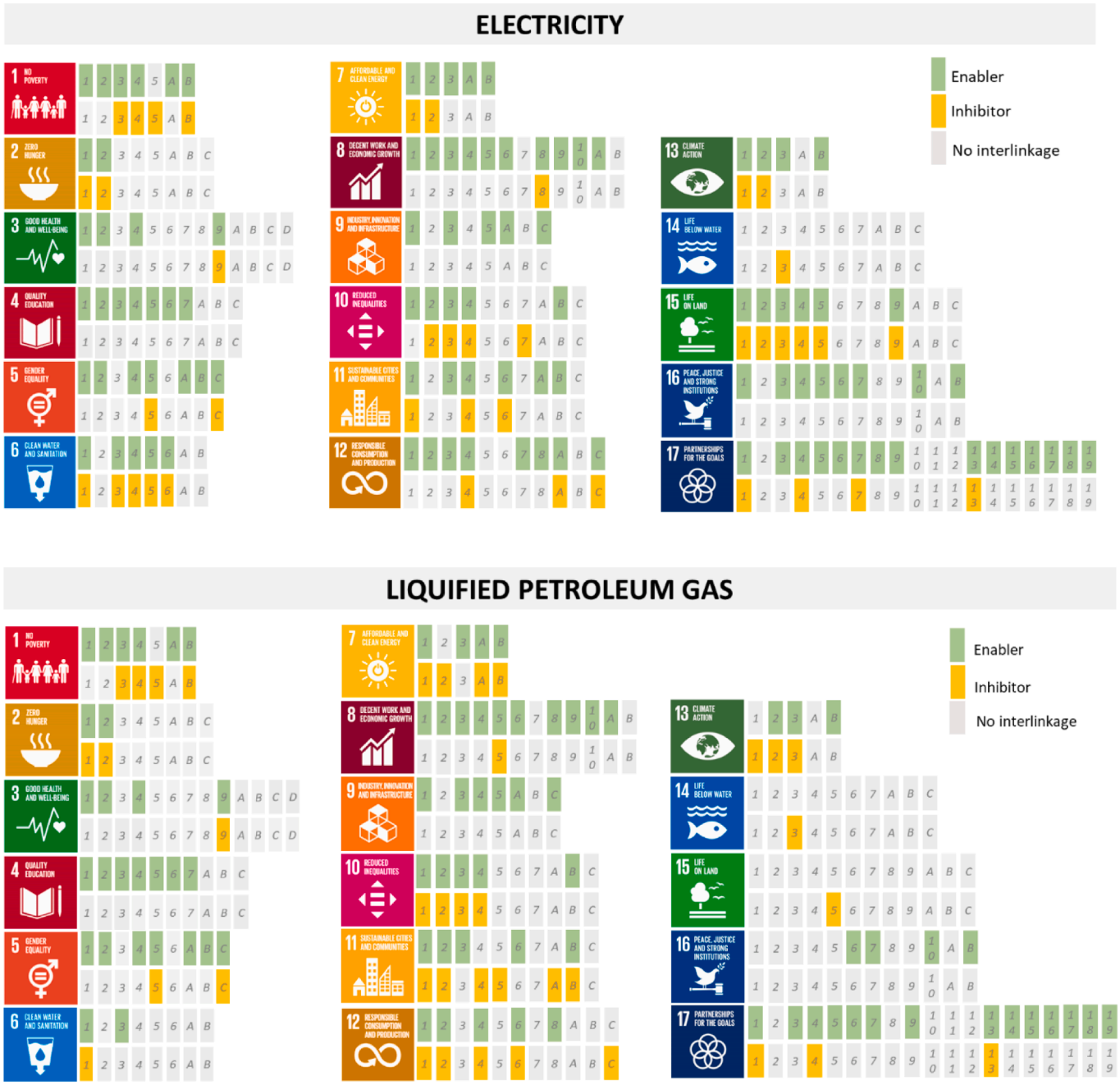

Fig. 2. Detailed assessment of the provision of electricity and LPG access on the SDGs. Evidence of interlinkages that promoted either energy access or Target was marked as an enabler, whilst those that prohibited energy access or Target were marked as an inhibitor from SDGs. In the absence of evidence, no interlinkages were marked, meaning only the absence of published evidence, not necessarily absence of impact. Full results can be found in Supplementary Material.

"invisible" challenges of informal settlements [4]. Ambivalence, misrecognition, or non-recognition has been reported to prevent residents from benefiting from policies, projects and programmes [41], and can be overcome through political recognition and the acknowledgement of the energy needs and practices of Kibera's residents.

4.3. Promoting electricity and LPG access in Kibera to achieve the SDGs

The impact of actions to promote energy access on each SDG Target was determined and categorised, illustrated in Fig. 3, from creating new enablers, strengthening those in existence, to limiting or overcome inhibitors as described in Section 3.3. Impacts can be seen across all 17 Goals with varying effects on Targets.

Financial incentives overcame the inhibitors of affordability for Targets 2.1, 6.1, 11.1, previously discussed, as well as reducing the household burden on women and creating opportunities for income-generating activities, strengthening enablers of SDGs 5 and 8 [81]. For some Targets, for example 1.3: Implement nationally appropriate social protection systems and measures for all, financial innovations only limit inhibitors. However, whilst subsidies and lifeline tariffs, prepayment and financial innovations are widely adopted policy tools to lower fuel costs and electricity, they must be ensured to reach their intended recipients [4]. For example, whilst Kenya's lifeline tariff aims to improve the affordability to electricity access, it is consumption based and applied to the first 50 kWh of consumption per month [42]. Provided households are already grid connected, this tariff is built on the

Table 2
Actions to promote energy access. Proposed actions aim to overcome identified barriers to electricity and LPG access whilst complementing their respective supply chains and existing policies, projects, and programmes in place in Kenya.

BARRIER TO ENERGY ACCESS	ACTIONS TO PROMOTE ENERGY ACCESS	EXAMPLE
Lack of affordability due to high upfront cost of electricity and LPG payments	Financial incentives	Subsidies, payment of energy services provided (rather than the cost of energy infrastructure), prepayment methods, lifeline tariffs
Reliability of supply leading to electricity and fuel shortages	Strengthening supply chains	Network expansion, standardisation, outlets
Lack of awareness for the benefits of modern and clean energy access and actions in place to support its promotion	Community engagement	Awareness programmes, community participation
Political ambivalence for the energy needs for slums and informal settlements	Political buy-in, recognition, and/or ownership	Public awareness, mainstreaming Sustainable Energy for All and SDG 7 at the various levels of governments at national and sub-national (regional, municipal, district) level

assumption that lower-income households, like those in Kibera, own fewer appliances and consume less. Whilst not illogical, it means middle- and higher-income households also benefit from the tariff, weakening the overall motivation of the incentive and failing to meet the energy needs of the poorest.

Strengthening the supply chains of LPG improves not only its availability, but also safety, affordability, and environmental sustainability [77]. Investments in bulk storage will improve the affordability of LPG, allowing economies of scale in imports as the port of Mombasa can handle large volumes of LPG , and reduce security of supply concerns as Kenya has buffer stocks that can be drawn upon in times of shortage or high prices [57]. This impacts those Targets whose indicators refer to the Sendai Framework for Disaster Risk Reduction (1.5, 11.b, 13.1), creating enablers and limiting inhibitors; although the country's reliance of import ultimately limits the energy sovereignty of Kenya, so inhibitors relating to imports will never be entirely overcome [58]. Strengthening infrastructure for electricity creates training and employment opportunities for residents. For example, job creation in the Last Mile Connectivity programme, aimed to expand Kenya's distribution grid, was a key performance indicator, tracking both the nature of employment (temporary/permanent) and the inclusion of gender [76], strengthening Targets 1.1, 1.2, 4.3, 4.4, 4.5, 4.7, 5.5, 5.c.

The safety of LPG is improved by standardising the cylinders, appliances and enforcing the national standards, laws, and regulations, affecting five Targets (3.9, 8.8, 12.4, 16.5, 16.6) and requiring cooperation between supply agencies and national government to ensure appropriate legislation and enforcement of the rules [77]. Such actions will prevent unscrupulous dealers selling half-filled cylinders and builds trust in the community as to the availability and safety of LPG [41].

Engaging the local community will have a widespread impact on the achievement of the SDGs [41]. Programmes to raise public awareness can highlight the benefits of electricity and LPG and educate users on the safe use and storage of cylinders. Such programmes can also be used as a platform for education, strengthening enablers for Targets of education and training (SDGs 3, 4 and 5). Community engagement involves the inclusion of residents in informal settlements and are often trusted sources of information and better positioned to understand the energy needs of Kibera [50,82]. Engaging women, either as individuals or in cooperatives, disseminates information quickly through the neighbourhood as residents respond to more personalised forms of advertising such as one-to-one marketing and public demonstrations [83]. Such participation strengthens enablers, such as 5.5: Ensure women's full and effective participation and equal opportunities for leadership and 10.2: By 2030, empower and promote the social, economic and political inclusion of all [81,84].

Political buy-in and recognition acknowledges the energy needs and practices of households in Kibera to overcome several inhibitors [41,70,85], ensuring actions to promote energy access reach those in need e.g. Target 1.3: By 2030, ensure that all men and women, in particular the poor and the vulnerable, have equal rights. By acknowledging Kibera's residents as active leaders, communities can be mobilised and empowered if supported by government strategies of growth, education, and vocational training [41,81,83] thus strengthening enablers to SDGs 4, 5, 11, 16. Recognition of the societal norms and social relationships between men and women allows the creation of policies and programmes that aim to achieve a more gender-equitable outcome, strengthening enablers of Targets of SDG 5 [81,82].

5. Conclusions

In this paper, we draw on a case study of the informal settlement of Kibera, Kenya, to identify the impact of electricity and liquefied petroleum gas (LPG) access on both local residents and the achievement of 2030 Agenda. By using the SDGs as a framework for analysis, we reveal the cross-sectoral implications of actions beyond energy, including co-benefits for health, water and sanitation, climate, and other SDGs. This structured knowledge of the distributional impacts that electricity and clean cooking via LPG has on the local achievement of the SDGs provides useful knowledge to motivate and structure policy and programmes to further energy access in Kibera. We propose that the design and implementation of actions to promote energy access can also maximise the local achievement of the SDGs.

Our methodology, applying a new taxonomy that classifies the impact of actions to promote energy access, highlights which Targets could be more easily achieved through interventions in the energy system and those that are beyond reach. For instance, we show the importance of community engagement, with benefits across the SDGs. Beyond raising awareness for the use of clean and modern energy, community engagement can also provide educational opportunities (SDG 4), promote gender equality (SDG 5), and allow local opportunities for leadership (SDG 10). Similarly, strengthening supply chains involved in the delivery of energy services not only increases the availability, quality and reliability of energy access but additionally provides employment opportunities (SDG 8), improves safety (SDG 3) and fosters trust in the community (SDG 16).

For policymakers in developing countries with limited resources, such analysis allows for effective prioritising of actions by revealing those with the most cross-benefits across development targets. The SDG framework, as applied here, can be a powerful tool for the evaluation of actions. By first capturing the cross-sectoral implications of energy decision, policies, and projects, actions can be refined and/or redesigned to increase their impact in both promoting energy access and the achievement of SDGs.

We must acknowledge, however, that the 2030 Agenda is a political compromise between the 193 member states of the United Nations, and thus may not capture the best interests of Kibera, an informal settlement in Nairobi, Kenya. Nevertheless, applied pragmatically - with consideration of political implications and complementary international goals and frameworks - the SDGs offer a holistic overview of the development priorities of today's world. The 17 Global Goals encompass the economic, social, technical, legal, and environmental perspectives that must be considered when tackling complex challenges. Nowhere is this more important than in slums and informal settlements that, with multiple deprivations, need coherent and coordinated action to achieve the 2030 Agenda.

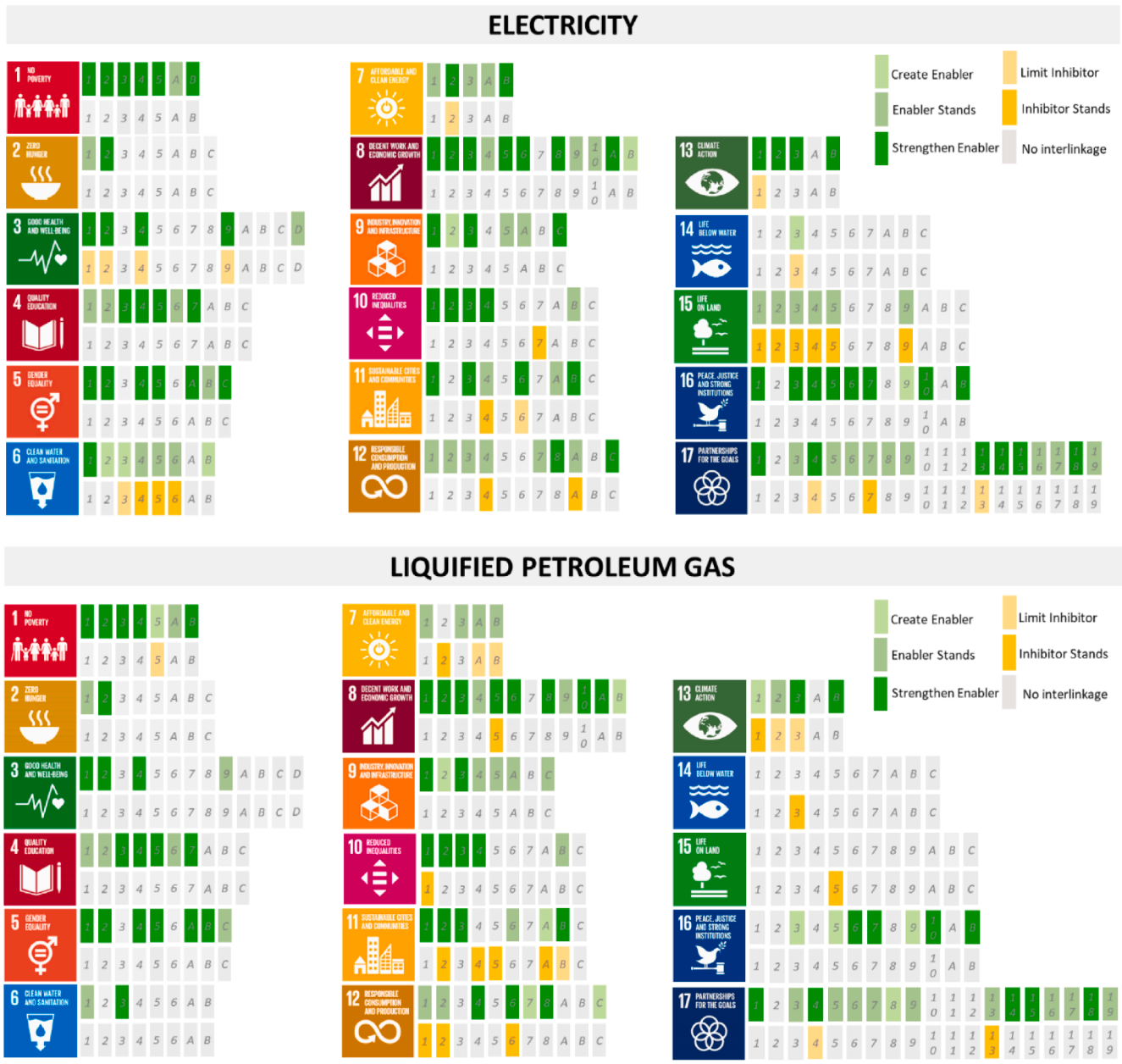

Fig. 3. Detailed assessment of the impact of interventions to promote electricity and LPG access on the SDGs. Evidence of the impact of interventions on Target was classified as follows: i) New enabler (achievement of Target created by intervention); ii) Strengthened enabler (achievement of Target improved by interventions); iii) Limited inhibitor (barrier(s) to achievement of Target lessened by intervention); iv) Overcame inhibitor (barrier(s) to achievement of Target removed by intervention). In the absence of evidence, no impacts of interventions were marked, meaning only the absence of published evidence, not necessarily absence of impact. Compared to previous mapping (Fig. 2) actions to promote electricity access strengthen 62 enablers, create a further 7 enablers, overcome 17 inhibitors and limit 11. Actions to promote LPG access strengthened 52 enablers and created a further 11, overcoming 17 inhibitors and limiting 7. Full results can be found in Supplementary Material.

5.1. Implications for future research

Following our demonstrated methodology, the SDG framework could be applied in other contexts, be it in other informal settlements, or to other challenges, such as the provision of water or sanitation. Applied as a framework to direct national policies and strategic projects, the SDGs offer a holistic outlook, helping to unpack discrete thinking and support an integrated sustainable future for all.

In our application of the SDG framework, we focused on the case of electricity and LPG access in Kibera. We do not provide a comprehensive review of energy access, focusing instead on two energy options considered to be clean and modern and promoted by the government of Kenya. Expanding to include incumbent fuels, such as kerosene and charcoal, would reflect the realities of energy access in Kibera, and indeed Kenya, in greater detail. Charcoal, particularly, is an important energy source in both urban and rural Kenya, and whilst our mapping captured the impact of LPG on the income of rural charcoal producers, further ramifications are likely. Moreover, actions to promote electricity and LPG access were selected based on known interventions and best practices for implementing basic services into slums and informal settlements. To evaluate actions, in order to design or refine them, a narrower scope of selected actions may provide deeper, more detailed analysis and targeted recommendations for policymaking.

CRediT authorship contribution statement

Emily Christley: Conceptualization, Methodology, Investigation, Writing - orginal draft, Writing - review & editing. **Hanna Ljungberg:** Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Emmanuel Ackom:** Conceptualization, Writing - review & editing. **Francesco Fuso Nerini:** Conceptualization, Methodology, Writing - review & editing, Supervision.

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.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2021.102176.

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