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Shedding light on vulnerability: Intersectional energy planning for development

Alycia Leonard [a,*], Kuthea Nguti [b], Micaela Flores Lanza [c], Stephanie Hirmer [a]

[a] *Department of Engineering Science, University of Oxford, Parks Road, OX1 3PJ, UK*
[b] *Strathmore University Business School, Karen Ole Sangale Rd, Nairobi, Kenya*
[c] *Aurora Energy Research, Calle José Abascal, 38, 1° Dcha, 28003, Madrid, Spain*

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ABSTRACT

To plan equitable sustainable development interventions, the needs of the most vulnerable in society must be assessed. However, in technical development spaces such as energy systems planning, intersectional needs assessment is often seen as impossible due to a lack of practical methods which use quantitative and categorical data. This study therefore develops a framework for intersectional needs assessment to inform development interventions and applies it in the context of energy planning. It operationalises Collins' matrix of domination to illuminate the intensity of energy and development needs across vulnerable groups. The framework synthesises acute and chronic vulnerability factors relevant to developing contexts, taking inspiration from both pressure-and-release and social ecology models. It is illustrated through a case study application to a dataset of needs and demographics collected in Siaya County, Kenya. Salient findings in the case study context include: a high prioritisation of solar PV systems by low-trust widowed people; a high prioritisation of money amongst disabled people, who may struggle with energy affordability; and a high prioritisation of motorcycles amongst those with no occupation, pointing towards a need for financial inclusion in the e-mobility transition. Energy-enabled water technologies (e.g., irrigation) are also found to be more highly prioritised during climate shocks than in daily life. The case study results illustrate how the framework can illuminate differences in needs both across and within vulnerable groups.

1. Introduction

This study explores how energy and development needs vary across intersectional vulnerable groups. To do this, it develops a vulnerability framework and intersectional needs assessment methodology which is demonstrated using a case study dataset from Siaya county, Kenya.

Communities in low- and middle-income countries (LMICs) contain diverse social identity groups with differing roles and levels of power [1]. Immediately, it must be recognised that this "colonial matrix of power" is frequently not an indigenous social structure, but has rather been violently imposed [2] (p. xi); nevertheless, such hegemony is near universal in the neocolonial world. As a result, when provided with the same development intervention, people from different groups do not benefit equally [3]: the most powerful or dominant groups tend to receive greater benefit [4], which can widen social inequity. It is therefore important to design development interventions which are aware of existing inequities and which work to counteract them where possible [5,6]. In practice, this involves accounting for the needs of the most vulnerable groups within the development agenda.

Energy is a critical enabler of development [7], including in sectors critical to vulnerable groups, such as health, economic growth, and education [8]. As such, energy systems must be designed to account for intra-community inequities: "careful design and targeting" is needed to ensure equitable benefit [9] (p. vi). This must be accounted for during needs assessment and demand estimation, as vulnerable groups often require energy services that differ from the population average [10]. The "usability of supply" for vulnerable groups must also be considered, including the availability, accessibility, affordability, and safety of energy [11] (p. 2). Furthermore, as climate change hits vulnerable groups the hardest [12] and energy is often needed to adapt to climate change [13], needs assessments must also determine how to build resilience to climate shocks. Energy systems must protect vulnerable groups from the effects of climate-shock-induced disruptions [14] and damage [15]; they must prepare for, absorb, recover from, and adapt to shocks to protect the aforementioned usability of energy [16]. In attempting to avoid further climate harms, prioritising the needs of vulnerable groups is critical to "the praxis of the just

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* Corresponding author.

E-mail address: alycia.leonard@eng.ox.ac.uk (A. Leonard).

Nomenclature	
LGBTQ+	Lesbian, gay, bisexual, transgender, queer, and others.
LMICs	Low- and middle-income countries
PV	Photovoltaics
UK	United Kingdom

transition" [17] (p. 133), as sustainable or green energy systems are not always inclusive [18].

At present, the needs of vulnerable groups do not always inform energy system design. Needs assessments for energy systems infrequently account for intra-community vulnerabilities beyond attempts to ensure representative consultation. For instance, while the United States Agency for International Development guide for community engagement around power projects in Kenya commendably states that "communities are not homogenous" and lists practical engagement tips, it notably focuses only on *accessing* those who are most marginalised within communities, not on methods to effectively *elicit and synthesise* their needs [19]. Similarly, the United States National Renewable Energy Laboratory guidelines explain types of justice and modes of community engagement, but offer little advice on evaluating needs across vulnerable groups, focusing their discussion of power instead on the differential between staff and community members [20]. They furthermore recommend that staff "leverage the power and knowledge that community members hold" despite the potential for this to perpetuate existing intra-community power dynamics. Neglecting to analyse needs in a way which accounts for power dynamics and vulnerabilities can cause harm, as seen in exclusion and land ownership issues resulting from the Lake Turkana wind power plant in Kenya [21–24].

To conduct vulnerability-aware energy needs assessment, it is fundamental to remember that the most vulnerable in society are frequently marginalised in multiple ways. People are complex and multifaceted: when they are vulnerable in multiple ways, their experience of marginalisation is not simply summative [25]. Rather, their vulnerabilities mutually constitute and reinforce each other [26]. This is the experience of *intersectionality*, as initially elaborated by Crenshaw to describe the experience of Black women in the United States [25]. Intersectionality has been applied beyond Black feminist scholarship to various multiply-vulnerable groups, such as racialised mentally-ill people in Europe [27] or refugee women in Africa [28]. By understanding oppression through an interlocking rather than additive model [29], lived experiences of oppression which operate beyond any single mathematical metaphor [30] can be better understood. It is therefore important to assess needs intersectionally and not only along single-axis identities.

While the need for intersectional assessment is recognised academically, it is seen as difficult to translate into practice, as "research practice [in intersectionality] mirrors the complexity of social life, calling up unique methodological demands" [31] (p. 1772). This complexity leads to the oft-lamented lack of intersectional methods in the literature [32–35]. There are few practical tools to assess intersectional needs quantitatively in the energy and development contexts. The United Nations intersectionality toolkit gives no advice on how to analyse existing quantitative data intersectionally, instead outlining qualitative intersectionality enablers [36]. Indeed, the study of vulnerability is generally seen to be not easily quantifiable [37]. This is problematic, as decision-makers often rely on quantitative indicators which structure complex information [38]. This is exacerbated by the development sector's focus on "short term, measurable results" [39], which favours pinpointed interventions aiming to alleviate a single vulnerability instead of systemic intersectional approaches. While recognising the value of qualitative needs assessment, it is critical to develop intersectional quantitative needs assessment approaches.

In the literature, methods for quantitative intersectionality analysis often require uncommon data types and ergo cannot be replicated at scale. For instance, Hancock's fuzzy-set-logic method proposes capturing identity markers using a scale from 0 to 1 instead of a binary yes or no; for instance, a person could racially identify as black at a value of 0.1, 0.5, or 0.9 depending on their heritage and perception of belonging [40]. While interesting, such data are not prevalent, and they are certainly not normally collected in large-scale surveys in LMICs (e.g., censuses, Multiple-Indicator Cluster Surveys, Demographic and Health Surveys). Focusing on energy and climate change, studies on intersectionality in climate adaptation focus on high-income countries (e.g., [41]), while those on energy meanwhile either focus on intersectional impacts of low-carbon energy systems [18] or hone-in on a specific axis of marginalisation [42] with no discussion of needs assessment. There is a gap for intersectional methods to map needs against vulnerabilities in energy and development.

To address this gap, this study develops a practical framework to map energy and development needs along intersectional vulnerable identity groups. It demonstrates this framework in the context of energy planning using a case study dataset from Siaya County, Kenya. This is the first practical toolkit to the authors' knowledge which undertakes explicitly intersectional quantitative analysis for energy systems planning in a development context. The novel contributions are:

- A novel generalised vulnerability framework is developed through synthesis of the literature.
- A novel analysis approach is developed for intersectional analysis of survey data.
- Novel insights about energy and development needs across vulnerable intersectional groups are developed through an application of these tools to a case study dataset from Siaya County, Kenya.

Through these contributions, this work provides routes to intersectional energy and development planning underpinned by common categorical and quantitative data types suitable for application in LMICs. The developed methods are made open access: https://github.com/alycialeonard/MOI.

To present this work, the study proceeds as follows. Section 2 synthesises the literature on vulnerability assessment to develop a generalised framework. Then, Section 3 develops intersectional analysis methods. The framework and methods are applied in Section 4 to the case study dataset and key results are presented. Section 5 discusses the results and their relevance in energy planning, and Section 6 concludes.

2. Framework development

To analyse energy and development needs across vulnerable groups, it is first necessary to identify who is vulnerable. To this end, a generalised framework of vulnerabilities is developed through a review of the literature.

Defining vulnerability is an unresolved problem [43] as it is a dynamic concept in continuous flux [37] which is highly dependent on context. This study adopts Adger's fluid definition of vulnerability, as a "state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" [37] (p. 268). This definition highlights three key components of vulnerability: relative exposure, sensitivity, and adaptive capacity. These components can be affected within different spheres, sectors, and geographies of life; as highlighted by Otto, vulnerability can be "internal, person-specific and external, socioeconomic and locational" [44] (p. 1652). This speaks to a complex political ecology of vulnerability [45], wherein vulnerability is not only caused by hazards but by the systems which fail to equip certain groups of people to handle them [46]. Conceptually, de Sousa Santos illuminates this type of vulnerability as the denial of "options" to those with particular "roots" within the construction of their identity [47] (p. 76). Vulnerability also

varies temporally: it may be transient or chronic [37], resulting from a short-term shock or a prolonged stress [48], and therefore causing states of vulnerability with different durations. As such, some argue that vulnerability must be defined within the context of the situation in which it is measured (e.g., before and after disaster [49]). In the case of systematically disadvantaged communities in LMICs, multi-hazard vulnerability [50] is generally chronic, though it can be exacerbated by additional short-term vulnerability (e.g., in the case of climate events, conflict, or indeed their vicious cycle [51]). This framework therefore attempts to encapsulate influencing both chronic and acute vulnerability.

Conceptual frameworks for vulnerability analysis include risk-hazard [52,53]. pressure-and-release [54], and social ecology [55,56]. While risk-hazard centres a specific risk and exposure to its acute effects, pressure-and-release centres the "social conditions and root causes of exposure" [57] (p. 71). Meanwhile, social ecology focuses on the linkages between human and environmental systems that affect vulnerability and risk, and which can create feedback loops. This work follows primarily a pressure-and-release model by prioritising analysis of the social conditions of exposure over analysis of particular hazards. It also borrows from social ecology by considering these conditions and their root causes systemically and accounting for place-based nuances, particularly in setting thresholds of harm [55].

Cutter's work on social vulnerability is taken as a foundation for framework development [58,59]. Vulnerability factors considered in their work include: socioeconomic status, gender, race and ethnicity, age, commercial and industrial development, employment loss, rural/urban designation, residential property, infrastructure and lifelines, renting, occupation, family structure, education, population growth, medical services, social dependence, and special needs populations. Many of these factors align with early Intergovernmental Panel on Climate Change definitions of vulnerability, which focused on physical dimensions such as health, safety, and food security [60]. However, social dimensions, such as race and ethnicity, have also been proven critical to the understanding of vulnerability including in disaster response [61]. As Cutter's factors were identified in studies using data from the United States, not all apply globally, and specifically not within LMICs. As such, they are cross-checked to verify their broader applicability. Cardona's work on determinants of risk lists similar factors but adds wealth, religion, caste, and disability to those already mentioned [57]. Otto [44] adds health status, discusses socioeconomic class instead of status, broadens the type of housing and assets considered, and explicitly lists access to social networks, cultural knowledge, and political power. More recent work adds queerness as a potential factor [62], as LGBTQ+ communities are vulnerable in the face of disasters [63].

Synthesising these factors, Table 1 presents a framework of potential markers of vulnerability applicable in LMICs. While vulnerability assessment inherently requires normative judgements [64], these factors are generalised to be applicable across contexts insofar as possible. They are grouped into categories which merge Otto's levels of vulnerability (i.e., individual and internal/external, socioeconomic, locational [44]) with Collins' perception of the levels at which people resist oppression: "the level of personal biography; the group or community level of the cultural context created by race, class, and gender; and the systemic level of social institutions" [29] (p. 545).

It is important to note that assessing vulnerability requires both identifying contributing factors and setting appropriate thresholds. These "thresholds of harm" [45] (p. 372) are often discussed with regards to the stresses or shocks impacting vulnerable people (e.g., [44, 101]). However, this work also refers to thresholds in defining vulnerability. Such thresholds may be numeric (e.g., having an age above a defined numeric threshold for elderly) or categorical (e.g., belonging to the categorical group of women). These thresholds are necessarily context-specific: what makes a person vulnerable in one context may not make them vulnerable in another, depending on locational and cultural specificities. The way these thresholds are set in this study is detailed in Section 3.
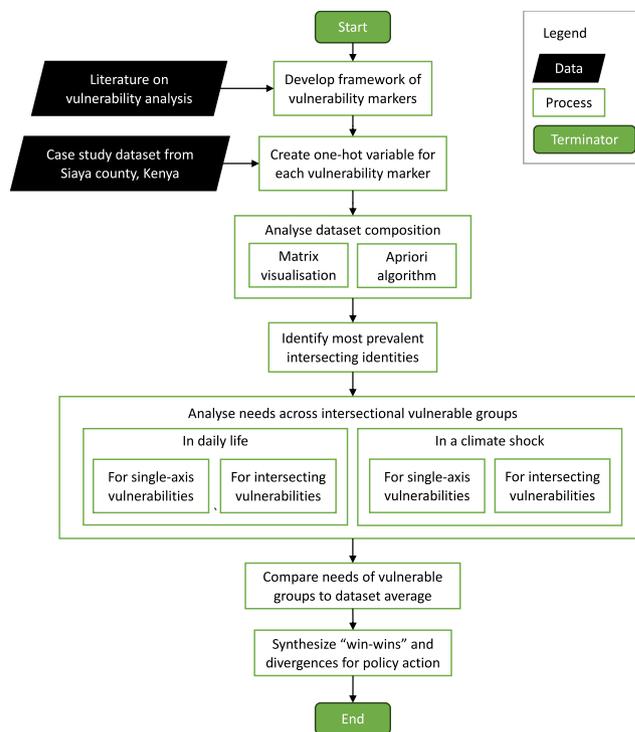

Fig. 1. Flowchart illustrating the steps of the study method.

3. Methods

In this section, methods are developed to apply the vulnerability framework intersectionally to quantitative and categorical survey data. These methods operationalise Collins' matrix of domination [29] as a practical needs assessment tool, in which each cell defines a unique position in a multi-dimensional power hierarchy. This aligns with Weldon's intersectionality-plus concept by enabling the analysis of vulnerabilities individually or in combination, and by accepting that social structures (and the vulnerabilities they induce) vary spatially [102]. The steps of the method are illustrated in Fig. 1.

3.1. Data preparation and framework application

First, data is prepared and processed using the vulnerability framework. These methods are designed for typical needs assessment survey data, wherein each data record contains respondent demographics as well as expressed needs which hold some rank or prioritisation. Here, a case study dataset of 300 survey records from Siaya County, Kenya is used. This was collected as part of a collaboration between the authors and CLASP Kenya. Siaya, a rural county in Western Kenya (Fig. 2), is facing high levels of poverty and food insecurity alongside increasing droughts [103] and floods [104]. Furthermore, its economy is dominated by agriculture and fishing, industries with high climate risk. An understanding of its urgent needs is therefore critical for adaptation [105].

The case study dataset was collected using the user-perceived value approach [106], which captures (1) demographic and socioeconomic information; (2) the priorities of respondents as selected from a contextually-specific set of 45 *items* (listed in Table 2); and (3) the *values* that underpin their priorities. During data collection, items were presented to respondents as a set of illustrated visual prompts. Respondents selected the items which were most important to them in descending priority order. All items were presented at the same time. Respondents' priorities were captured under two circumstances: (1) top five items

Table 1

Generalised framework of potential vulnerability factors applicable in LMICs following a pressure-and-release model informed by social ecology, as synthesised from the literature [37,43–46,48–61,63,64] and supplemented with additional factor-specific sources.

Level	Vulnerability factor	Explanation
Individual	Race	Individuals who are racialised based on context-specific physical characteristics may experience increased social and/or physical vulnerability (e.g., in health outcomes [65], pollution exposure [66]).
	Ethnicity	People belonging to minority ethnic groups are frequently more vulnerable than those in the ethnic majority (e.g., due to segregation, discrimination [61], and access differences [67]).
	Language	Those who do not speak the most common language(s) in an area are generally more socially vulnerable than those who do [58].
	Age	Both children [68] and elderly people [69] are typically physically vulnerable, and they may also be socially vulnerable depending on context.
	Gender	Women [70,71] and other minority gender groups (e.g., transgender [72] or non-binary [73] individuals) are typically more vulnerable than men.[a]
	Orientation	People of queer sexual and romantic orientations (e.g., gay, lesbian, bisexual) are typically more vulnerable than heterosexual people [63].[a]
	Religion	In societies with a strong and culturally important religious majority, individuals who practice less common religions may be marginalised.
	Disability	Disabled people are more likely to be physically vulnerable (e.g., limited mobility, difficulty seeing or hearing) and/or socially vulnerable (i.e., stigmatisation, learning difficulties) [74,75].
	Health status	Similarly to disability, those who experience chronic physical or mental health conditions (e.g., AIDS, schizophrenia) are often physically or socially vulnerable.
	Immigration status	Refugees and migrants experience increased social precarity and vulnerability compared to citizens (e.g., due to detention/incarceration [76], unfounded stigma of criminality [77,78], poor healthcare [79]).
	Marital status	In societies where marriage affords social and economic power, unmarried (i.e., single, separated, divorced, or widowed) people may be vulnerable [80,81]. Polygamy may also increase vulnerability [82,83].
	Occupation	Those who are unemployed [84] or do not hold a stable occupation are often vulnerable. Informal labour [85] and low-paid service labour [58] are generally more vulnerable than other types of employment.
	Class and caste	In societies with rigid social hierarchies, those who are perceived to be of a lower class [61] or caste [86] are likely to be more vulnerable than those of a higher class or caste.
	Education	People who have received less education are generally more vulnerable than those who are educated, who develop more coping strategies [87] which promote long-term resilience [88].
	Social connectivity	Individuals with weaker social bonds [89] and less trusting and cohesive social networks [90] are often more socially vulnerable.
	Political power	Those with less access to political information or less ability to participate in democratic processes (e.g., living in less democratic societies [91]) are often more vulnerable.
	Attitudes and expectations	Those with lower satisfaction in their living conditions are typically more vulnerable than those who are satisfied.
Household	Housing	Poor housing conditions or unstable housing tenure (i.e., renting [92]) can make a household more vulnerable [58].
	Assets	Lacking certain assets [93] can make a household more physically vulnerable (i.e., to lung disease in the case of cooking [94]) or socially vulnerable (i.e., based on class perceptions).
	Wealth	Lacking wealth can make a household more physically or socially vulnerable, as they do not have the resources to build long-term resilience [58].
	Income	Similar to wealth, income can make a household more physically or socially vulnerable, as they do not have the resources to purchase assets to meet their needs in the shorter term.
	Household composition	The size of a household (i.e., number of children [81]), the gender of the household head, and other demographic factors can make a household more vulnerable in context-specific ways.
	Access to infrastructure	Households without access to basic infrastructure (e.g., water [95], electricity, transport) are generally more vulnerable than those who have access.
	Access to services	Households without access to services (e.g., healthcare [96]) are generally more vulnerable than those who have access.
Community	Density	Extremely dense urban communities tend to be more vulnerable than others, including due to informal housing and inadequate infrastructure [97,98].
	Conflict and stability	Communities experiencing geopolitical conflict or instability are generally more vulnerable than those experience relative peace and stability [51].
	Industrial proximity	Communities located near heavy industrial developments may be more physically vulnerable (i.e., due to industrial waste exposure) [99,100].

[a] Note that the patriarchy and heteronormativity underlying these vulnerabilities have often historically been imposed through colonial influence.
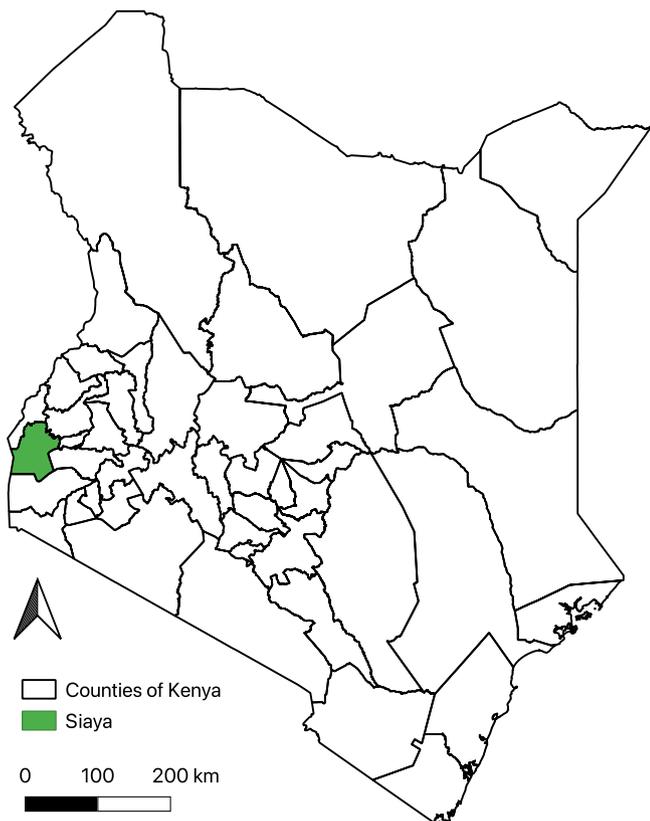
in daily life (hereafter "general" priorities); and (2) top three items in the case of a climate shock (hereafter "climate" priorities). Each time a respondent selected an item, they were asked why this item was important to them, and their responses were recorded verbatim. The sampling strategy aimed for representation across social classes, equal gender representation, and 5% or greater disability representation. The data was collected in local languages by local enumerators, and subsequently translated into English. It was then annotated with the underlying values motivating each response. For further details on the case study dataset, please refer to the data descriptor [105].

Table 2

Items used in the case study user-perceived value data collection. Note that while the items are grouped thematically here for clarity, all were presented to respondents at the same time via illustrated prompts during data collection.
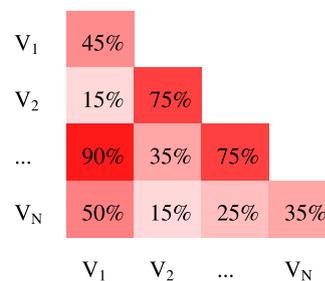
Theme	Items
Energy and appliances	Solar PV System, Electricity, Battery, Generator, Mobile phone, Grain mill, Light bulb, Torch, Computer, Fridge, Grinder, Stove, Wood Stove, Gas Stove, Kerosene Lantern
Transport of people and goods	Motorcycle, Boat, Car, Bike, Donkey and Cart, Wheelbarrow, Road
Water and sanitation	Borehole, Rainwater Harvesting System, River, Overhead Water Tank, Water, Watering Can, Jerrycan, Water Pump, Irrigation, Toilet (Squat), Toilet (Flush), Disposable Sanitary Pad
Health	Doctor, Hospital, Medicine
Other	Bible, Clothes, Furniture, House, Money, School, Vegetables, Corrugated Iron Sheet

Fig. 2. Location of Siaya County, Kenya, from where the case study data set originates.

Fig. 3. Intersectional matrix visualisation setup. The axes are labelled with each vulnerable category from V_1 to V_N. The intensity of the colour in each cell indicates either (a) the relative proportion of the dataset in that identity group when analysing dataset composition, or (b) the intensity of the need amongst those in that intersectional identity group when conducting needs analysis.

To prepare the data for analysis, vulnerability factors from Table 1 are first identified within the dataset. Then, context-specific vulnerability thresholds are defined (i.e., what constitutes a vulnerable person on each axis). These are determined through review of the literature and/or indigenous knowledge of the study context. One-hot encoding is then undertaken to assign a binary variable to each data record to indicate whether it belongs to each vulnerable group using the defined thresholds.

For the case study dataset, thresholds are determined through both literature review and lived experience of the Kenyan author. The case-study-specific factors and thresholds are shown in Table 3. Factors from the main framework which are excluded here were either (a) not collected in the survey data, or (b) uniform across the surveyed sample. For instance, individual and household factors are the focus,

as community-level vulnerabilities are not captured. Note that the frequency of accessing information includes radio, TV, newspaper, and internet (i.e., the answer to access rate for all four has to be either "Never" or "Occasionally" to be considered low information access). Frequency of information access is taken as an indicator of political power, as information access has been identified as a critical determinant of public participation, including at county governance level in Kenya [107]. The definition of youth aged 18–35 as vulnerable is based on the youth bulge in Kenya and the unemployment and precarity that young people face as a result [108]. Elders are not included; while elders are more physically vulnerable on average, this study focuses on social vulnerability, and culturally in Kenya, elders are socially and politically powerful [109]. The low income threshold is defined at the World Bank's 2023 rural poverty line for Kenya (i.e., 3252 KES per month per adult person [110]). This is used very conservatively as the threshold for the whole household irrespective of the number of adults therein. Household size is not included – while studies demonstrate the correlation between household size and food insecurity in some contexts [111], it has also been shown that large family sizes are often culturally desirable [112]. This divergence requires further investigation; given the lack of agreement in the literature, it is omitted at present. As the mobile phone is the most frequently owned asset across the dataset, it is assumed that those who do not own a mobile phone are disadvantaged by the lack of this communication technology.

3.2. Composition analysis

The composition of the dataset is analysed to determine which vulnerabilities are most common throughout the sample, and which most frequently co-occur. Using the one-hot variables associated with each record, a matrix is generated which shows the co-occurrence of each vulnerability marker with each other vulnerability marker, as illustrated in Fig. 3. Both axes of the matrix list all vulnerability markers, and each cell shows the proportion of the dataset at the doubly-vulnerable intersectional identity. This is denoted as a percentage in the cell and visualised using colour intensity. As this matrix is necessarily symmetric due to the use of the same axes, only the lower triangular portion is used. The diagonal of this matrix (i.e., where each vulnerability intersects with itself) shows the prevalence of each single-axis vulnerability. In the analysis of the case study dataset, vulnerabilities which are found to be very rare in this step are excluded from subsequent analysis to prevent spurious results.

While this approach visualises Collins' matrix of domination in two dimensions, there can also be higher dimensional intersectional vulnerability. That is, three or more vulnerabilities could co-occur and compound. To account for this, patterns of higher dimensional co-occurrence are mined from the dataset using the apriori algorithm [113] as implemented in the Python mlxtend package [114]. Combinations of vulnerabilities which co-occur in more than 10% of

Table 3

Specific vulnerability factors and thresholds used in the case study.

Vulnerability factor	Definition of vulnerability	Variable name
Age	Age ≤ 35	Youth
Gender	Gender = "Female"	Female
Disability	Disability = "Yes"	Disabled
Marital status	Marital status = "Single"	Single
	Marital status = "Divorced"	Divorced
	Marital status = "Widowed"	Widowed
Occupation	Occupation = "Unemployed"	No occupation
Education	Highest level of education = "Primary"	Low education
	Highest level of education = "No education"	No education
Social connectivity	Connection in community = "Not connected at all"	Low social connectivity
	Trust in others = "You can't trust anyone"	Low trust in others
	Group membership = "None"	No social support groups
Political power	Frequency of accessing information ∈ ["Never", "Occasionally"]	Low information access
Housing	Satisfaction with home quality = "No"	Low satisfaction with housing
	Previous flood or fire in home = "Yes"	Previous flood or fire in home
Assets	Assets ∌ ["Mobile phone"]	No mobile phone
Income	Income < KES 3,252/month	Low income
Household composition	Household head ∈ ["Grandma", "Mother", "Sister", "Wife"],	Female-headed household
Access to infrastructure	Electricity source ∈ ["Dry cell battery/torch", "Phone touch light", "None"]	No electricity access
Access to services	Difficulty of accessing at least one service = "Very hard"	Perceived difficulty accessing services

the dataset are thus identified. However, to enable two-dimensional visualisation, only dual-vulnerability intersectional groups are carried forward into the needs analysis.

3.3. Needs analysis

To analyse needs from the case study dataset, the frequency of item prioritisation is used as a proxy for the intensity of need for that item and the service it provides. Energy items are centred in the analysis, while non-energy items are analysed to contextualise energy needs.

Survey records belonging to each vulnerable group are first isolated as data sub-sets. This is accomplished using the one-hot variables assigned in Section 3.1. Needs are ranked for each data sub-set – that is, the frequency of item selection is evaluated across each sub-set, and ranked in descending order. The ranking of needs is then compared across sub-sets to identify similarities and divergences in prioritisation across vulnerable groups.

This analysis is undertaken both for single- and dual-vulnerability groups. In the single-vulnerability case, each data sub-set contains all respondents holding a single vulnerability (i.e., where a single one-hot variable is true). In the dual-vulnerability analysis, each data sub-set contains respondents holding both vulnerabilities in question (i.e., where two one-hot variables are true).

Heat-map matrices are used to visualise the intensity of needs across different vulnerable groups. For the single-vulnerability analysis, needs are listed along one axis and vulnerable groups are listed along the other. The cells of the matrix denote the proportion of each single-axis vulnerable group which prioritise each item as a percentage, and visualise this using colour intensity. For the dual-vulnerability analysis, matrices similar to that illustrated in Fig. 3 are used. One matrix is constructed per item being evaluated, and each axis lists all vulnerable groups. The values in matrix cells correspond to the proportion of those who hold those intersecting vulnerable identities who also prioritised the item in question, shown as a percentage and visualised using colour intensity. Each matrix thus provides a snapshot of relative prioritisation of the item in question across different intersectional groups.

The needs of vulnerable groups are also compared to average needs across the dataset. By identifying overlaps between average needs and those of specific groups, interventions likely to be "win-wins" for both the broader population and vulnerable groups can be identified. Divergences, meanwhile, point to a need for targeted interventions

specific to certain groups.

Note that the values and verbatim data from the case study dataset are used here to enrich the discussion of the findings. Values related to item selections are presented as percentages (i.e., the percentage of all value annotations for the specific item or group which are the value being discussed). Verbatim data is presented in quotes and attributed anonymously to speakers with the notation [Gender, age]. While these qualitative data add richness, they are not necessary to undertake the core needs analysis. However, should similar qualitative insight be desired in studies conducted using quantitative or categorical datasets, the core needs analysis can be used to *target* follow-on qualitative work. Interesting divergences can be interrogated specifically, saving time and resources.

3.4. Scope and limitations

This methodology has a number of limitations, as enumerated and explained below.

- The method uses binary thresholds on each vulnerability axis. For instance, a cut-off is used to denote age-based vulnerability, despite the fact that vulnerability may vary continuously along this axis in practice. This is done to take a consistent approach is applied across all variables in the case study dataset, some of which are binary or recorded categorically.
- The method only represents needs at a snapshot in time when data was collected. While the same approach could be applied on temporal or longitudinal data, this is left as an avenue for future work, as discussed in Section 5.2.
- The method focuses on reacting to vulnerability rather than preventing vulnerability. Behavioural, cultural, and policy change required to address systemic roots causing vulnerability, and ergo prevent it, is beyond the scope of influence of most energy planning.
- The method primarily visualises two-dimensional vulnerability. While multi-dimensional vulnerability is analysed through the apriori algorithm, it is difficult to visualise these groupings on a two-dimensional plane. Visualisation is important for both academic publication and stakeholder engagement (e.g., in policy-making and planning). As such, this limitation is imposed for ease of communication.

3.5. Ethics and positionality

Prior to collection of the case study dataset, a risk and ethics assessment was undertaken and evaluated by the Medical Sciences Interdivisional Research Ethics Committee at the University of Oxford in accordance with the procedures laid down by the University for Ethical Approval for all research involving human participants. It was approved with Reference: R83092/RE001. Furthermore, a risks and ethics assessment was conducted and approved following Kenya's National Commission For Science, Technology and Innovation ethics board under license No: NACOSTI/P/22/21,652 in research involving human participants. As recommended in [115], interviewees were compensated for their time. All names were removed from data records to preserve anonymity.

The authors of this work identify as women of Canadian, Kenyan, Bolivian, and German origin respectively. While we have endeavoured to work in an unbiased way, our interpretations could be coloured by our positionalities. This work builds upon Black feminist intersectional scholarship originating from the United States. Three of our team do not identify as Black, and none of us originate from the United States. As such, though we have endeavoured to remain true to their scholarship, our application of intersectionality may deviate from the original authors' intentions. Additionally, much of the vulnerability literature informing this work was developed for high-income countries, whereas this study evaluates vulnerability within LMICs. Again, we have interpreted the original scholarship in this context while accounting for LMIC-specific complexities.

4. Results

This section illustrates the case study application of the framework and methods, and shows how they can be used in the context of energy planning. First, the intersectional composition of the case study dataset is studied. Then, energy-relevant needs expressed in the dataset are evaluated across vulnerable groups, and contextualised using results about broader development needs.

4.1. Dataset composition

Fig. 4 shows the prevalence of each vulnerable and intersectional identity in the dataset. There is significant vulnerability amongst respondents: 61% have low education (i.e., primary only or no education), 61% are female, 55% report low satisfaction with their housing, and 57% are low income. Note that as divorcees constitute only 1% of the dataset, this category is dropped from subsequent analysis.[1]

Vulnerabilities also frequently compound and intersect in the case study dataset. The five most common dual-vulnerability groups in the dataset are women with low-income (40%), women with low education (39%), low education and low income people (39%), women who have low satisfaction with their housing (35%), and women in female headed households (34%). Dual vulnerabilities constitute 54% of all sets of vulnerabilities which co-occur in more than 10% of the dataset, as identified using the apriori algorithm; 33% contain three vulnerabilities, 11% contain four vulnerabilities, and 1% contains five vulnerabilities. This supports the methodological choice to focus on two-dimensional intersectionality analysis. The top results for triple vulnerability are women with low education and low income (27%) and women in female-headed households with low income (24%). The top result for four co-occurring vulnerabilities is women in female-headed households with low income who are widowed (15%). The list of sets of vulnerabilities occurring in more than 10% of the dataset is provided in Table 4

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[1] The low occurrence of divorcees is likely due to complications surrounding divorce in the study context, including social stigma and patriarchal structures limiting women's property rights [116]. This makes women more likely to identify as "separated", which is not captured in the dataset.

Table 4
Combinations of three or more vulnerabilities which co-occur in ≥10% of the dataset.

Freq.	Vulnerabilities
27%	Female, Low education, Low income
24%	Female, Female-headed household, Low income
23%	Female, Low income, Low satisfaction with housing
22%	Female, Female-headed household, Widowed
21%	Female, Female-headed household, Low satisfaction with housing
21%	Female, Low education, Low satisfaction with housing
20%	Female, Female-headed household, Low education
19%	Low education, Low income, Low satisfaction with housing
16%	Female, Low income, Widowed
16%	Female-headed household, Low income, Low satisfaction with housing
15%	Female-headed household, Low income, Widowed
15%	Female, Female-headed household, Low income, Widowed
15%	Female, Low education, Widowed
15%	Female-headed household, Low education, Widowed
15%	Female, Female-headed household, Low income, Low satisfaction with housing
15%	Female-headed household, Low education, Low income
15%	Female, Female-headed household, Low education, Widowed
14%	Female, Female-headed household, Low education, Low income
13%	Female, Low satisfaction with housing, Widowed
13%	Female-headed household, Low satisfaction with housing, Widowed
13%	Female, Female-headed household, Low satisfaction with housing, Widowed
13%	Female, Low education, Low income, Low satisfaction with housing
13%	Female-headed household, Low education, Low satisfaction with housing
12%	Female, Female-headed household, Low education, Low satisfaction with housing
12%	Female, Low income, Low information access
11%	Female, Female-headed household, Low information access
11%	Low education, Low income, Widowed
11%	Low information access, Low income, Low satisfaction with housing
11%	Female, Low satisfaction with housing, Youth
11%	Female, Low education, Low income, Widowed
10%	Female, Low education, Previous flood or fire in home
10%	Female, Low information access, Low satisfaction with housing
10%	Low education, Low income, Previous flood or fire in home
10%	Female-headed household, Low education, Low income, Widowed
10%	Female, Female-headed household, Low education, Low income, Widowed
10%	Female, Low income, Youth
10%	Female, Low income, Low trust in others

4.2. General needs across single vulnerability axes

The percentage of each group which selected each item as one of their top five general priorities is shown in Fig. 5. The ten most prioritised items across the dataset are: House (72%), Vegetables (61%), Clothes (60%), Money (56%), Water (39%), Mobile Phone (35%), Bible (20%), Solar PV System (16%), Borehole (14%), and Hospital (11%). Only two of these items are explicit energy consumption or production technologies (i.e., Mobile Phone and Solar PV System); however, others are enabled by energy (e.g., a hospital requires medical technology and lighting, water may come from a pump). While there is general agreement on the most highly prioritised items, there is interesting variance across vulnerable groups. For instance, a house is selected as a priority much less frequently than average by those who have experienced a previous flood or fire (54% vs 72%); perhaps this caused them to value their home less.

The selection of clothing interestingly illustrates variance in prioritisation based on social vulnerability. Single people prioritise clothes far more frequently than average (77% vs 60%). One can hypothesise that they are focusing more on their appearance as they aim to attract a life partner. Their justifications for this priority relate highly to how they are perceived by others: "*embarrassment comes when you have no clothes and your nakedness is seen*" [Male, 35], "*clothes are important because we are protected from the sun and we don't seem insane or of unsound mind*" [Male, 25], and "*when you wear clothes on your body you look decent and you gain confidence*" [Female, 24]. This shows the link between their vulnerability (i.e., their unmarried status) and their material needs.

The variance in the prioritisation of money, meanwhile, seems to reflect physical vulnerability. People who self-identified as disabled prioritised money far more frequently than average (75% vs 56%). In
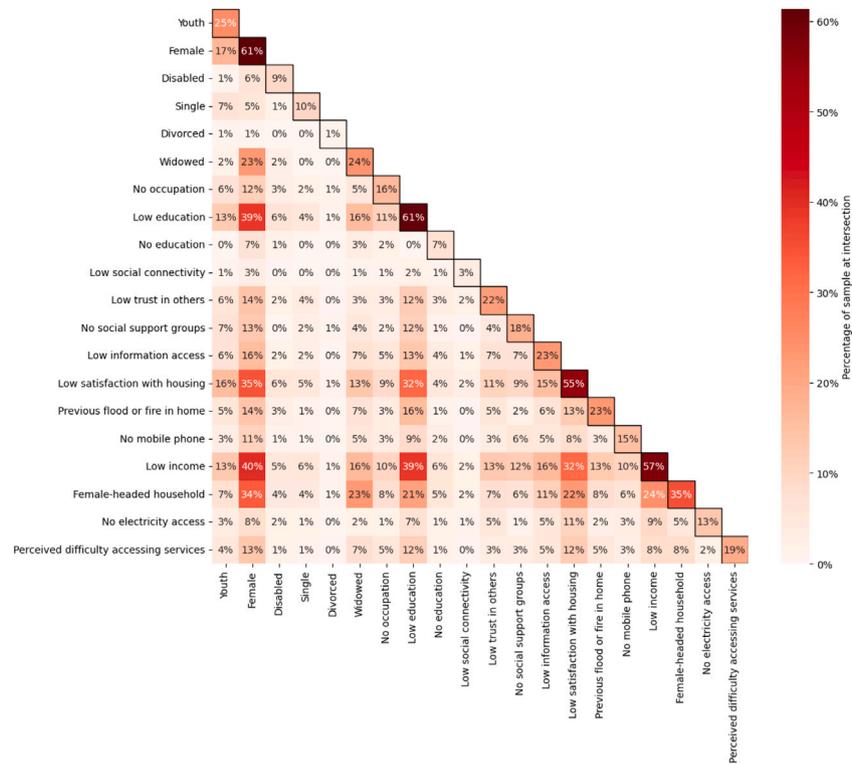
Fig. 4. Percentage of the case study dataset which falls at each vulnerable intersection (N=300). For instance, the number 40% at the intersection of "low income" and "female" means that 40% of the sample (i.e., 120 respondents) are women who are also low-income.
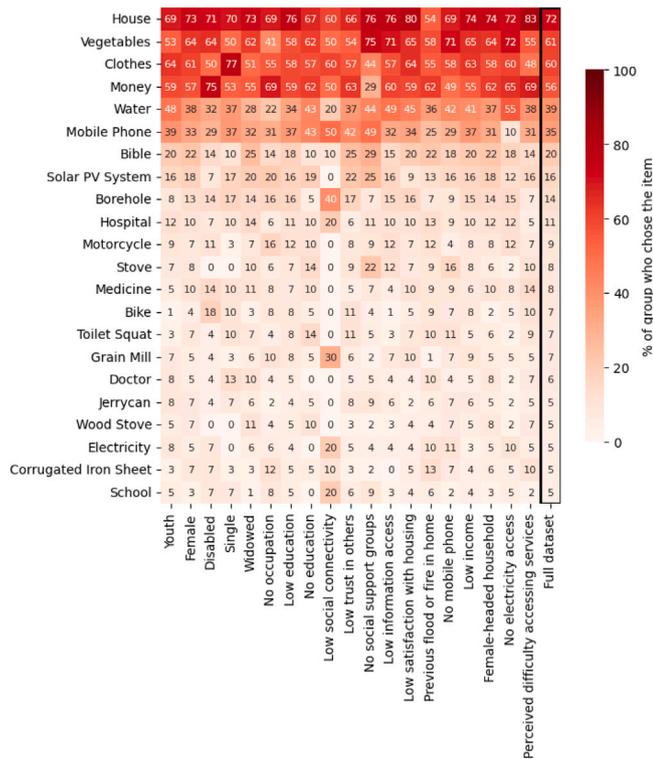

Fig. 5. Percentage of each single-axis vulnerable group who prioritised each item in the survey dataset. Only items which are selected by 5% or more of the full dataset are shown. Items are shown in descending order based on full dataset selection frequency.

their justification of this priority, they referred more often than average to caring and well-being. One respondent referred to money as a way

to procure water given her disability: "*I don't go to fetch water, so when I have money, I pay someone to overcome these problems. I had a stroke and so I lost one side of my body. So there is no way I can carry water.*" [Female, 52]. Another spoke about using money to get medical care and food: "*The money can help me to go and seek treatment in hospital so that I can get help. I can use the money to buy food when my legs can not walk.*" [Female, 76]. Again, this shows a link between their vulnerability (i.e., their disability) and a strengthened material need.

4.3. Comparison with climate-event needs

Priorities in general life are compared with those in the case of a climate shock in Fig. 6. Notably, there is less agreement about top priorities in the case of a climate event than in daily life. This is demonstrated by the relatively lower frequency of selection for the top item in each case (i.e., 56% in general vs 40% in climate). People therefore have more differing views about what is needed in the case of a climate shock than in daily life.

Money is prioritised most highly in a climate shock, whereas a house is prioritised most highly in daily life. It is largely prioritised during a climate shock in order to buy food; the value most frequently attributed to money is "Food Security" (20%). Generally, people think that "*if you have money, you will not see the hardship of drought*" [Female, 33]: they perceive that they will be able to buy all the things that the drought has taken away. As explained by another respondent, "*during a drought, everything will need money*" [Male, 50]. People also prioritised money to access healthcare and water: "*Money helps me to buy the medicine that I take. When there is drought, I can pay someone who has a donkey and a cart to bring for me water*" [Female, 67]. Despite the fact that droughts are proven to disrupt supply chains [117], there seems to be little consideration as to whether a climate event could disrupt supply chains in a way that makes money less useful.

Energy-enabled water-provision items, such as irrigation and water pumps, jump in priority in the climate case compared to the general case (i.e., increasing in rank by 20 and 31 respectively). This aligns
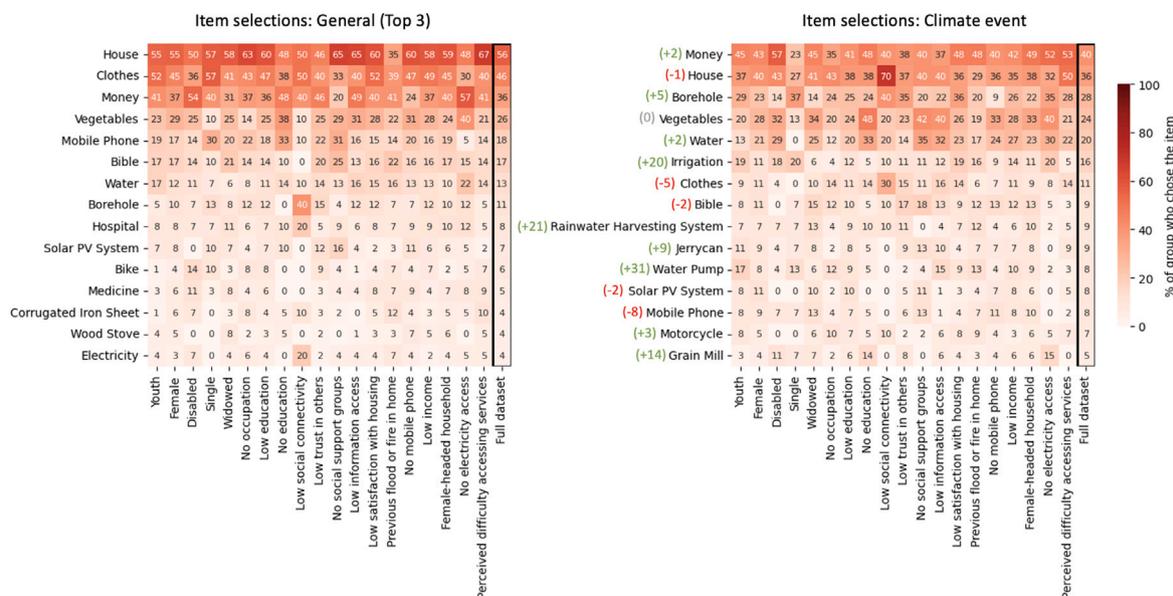
Fig. 6. Percentage of each single-axis vulnerable group who prioritised each item in daily life (right) and in the face of a climate event (left). The top fifteen items in each case are shown. As only three items could be selected in the face of a climate shock, only the top three items selected in daily life are included to make the percentages directly comparable. The relative change in ranking of the item in the climate event case vs daily life is shown in brackets next to the item. This is shown in green where the item became more highly prioritised and in red where the item decreased in priority.

with concerns about drought and heat, and shows the importance of agriculture to livelihoods in this context. Other water-related items, such as boreholes and rainwater harvesting systems, also jump in priority (i.e., increasing in rank by 5 and 21 respectively).

4.4. Intersectional analysis of energy-specific needs

Energy-specific needs are analysed across intersectional vulnerable groups. The energy-specific items in the dataset cover *electricity production* (i.e., solar PV system, electricity, battery, generator); *electricity use* (i.e., mobile phone, grain mill, irrigation, light bulb, torch, computer, fridge, grinder, water pump); *fuel-based appliances* (i.e., stove, wood stove, gas stove, kerosene lantern); and *transport* (i.e., motorcycle, boat, car). Results of interest for these items are presented in the sub-sections below.

4.4.1. Solar PV systems

The most frequently prioritised electricity production item in daily life was a solar PV system (16%). The values most frequently attributed to this priority are "Multipurpose" (16%), "Knowledge attainment (learning)" (15%), "Reliability" (14%), and "Accessibility to services" (11%).[2] Respondents discussed how solar PV "*helps the children to their studies*" [Male, 38]; it powers "*TV so that we can watch the news, so we are a bit updated on things*" [Male, 52]; its light makes it such that "*you can cook with ease as you see how you are cooking*" [Female, 18]; it provides income as "*when other people lack the solar PV system, they can come and give me ten shillings after charging their phones*" [Female, 67]; it promotes security, as "*when there is light in the house, you can walk around without fear*" [Female, 54]. People value the system for the diversity of functions and services it enables, aligning with views of energy as a development enabler [7]. This prioritisation of solar

PV based on all the services it can provide may explain the lower prioritisation of other basic electrical services (e.g., light bulbs were only selected as a priority by 2% of respondents and kerosene lanterns by 1% of respondents in the general case).

Solar PV systems were also prioritised over other electricity systems due to their zero operating cost. As one elderly respondent said, "*electricity is good but why use five poles for electricity to reach your home while there is free sunlight from God? You use the sun for free. You just have to buy the solar, otherwise, the light it uses is from God*" [Female, 75]. This is an important consideration for vulnerable groups who are cash-strapped. That said, the relative affordability of on- and off-grid solutions depends highly on context [118]. While solar PV has been found in Kenya to be relatively more affordable in areas with low demand and high connection costs [119], it should be interrogated whether the perception of solar as cheaper is rooted in good marketing or local economics.

The selection of solar PV across intersectional identities is visualised in Fig. 7a. Looking across vulnerabilities, disabled people prioritised a solar PV system notably less than average (7%). One can hypothesise that this is due to other pressing material needs. This would align with findings from high-income countries that disabled people and their households consume less energy than others and are more likely to face energy or fuel poverty [120,121]. A particular spike in prioritisation occurs for widowed people with low trust in others (50%). One can theorize that this could be due to an increased need for self-reliance, which a solar PV system can provide. Widowed people have also been seen previously to have a high incidence of energy poverty (e.g., in Uganda [122]) – perhaps they perceive this as avoidable via a solar PV system.

4.4.2. Mobile phones

Mobile phones were the most frequently prioritised electricity use item in daily life (35%). People with no electricity access prioritise it far less than average (10%). This is unsurprising, as it is more difficult to make use of a phone without an in-home way to charge it. The values underlying the prioritisation of a mobile phone are dominated

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[2] Recall that, as discussed in Section 3, this means that of all values discussed in relation to a solar PV system, 16% are "Multipurpose", 14% are "Reliability", and so on.
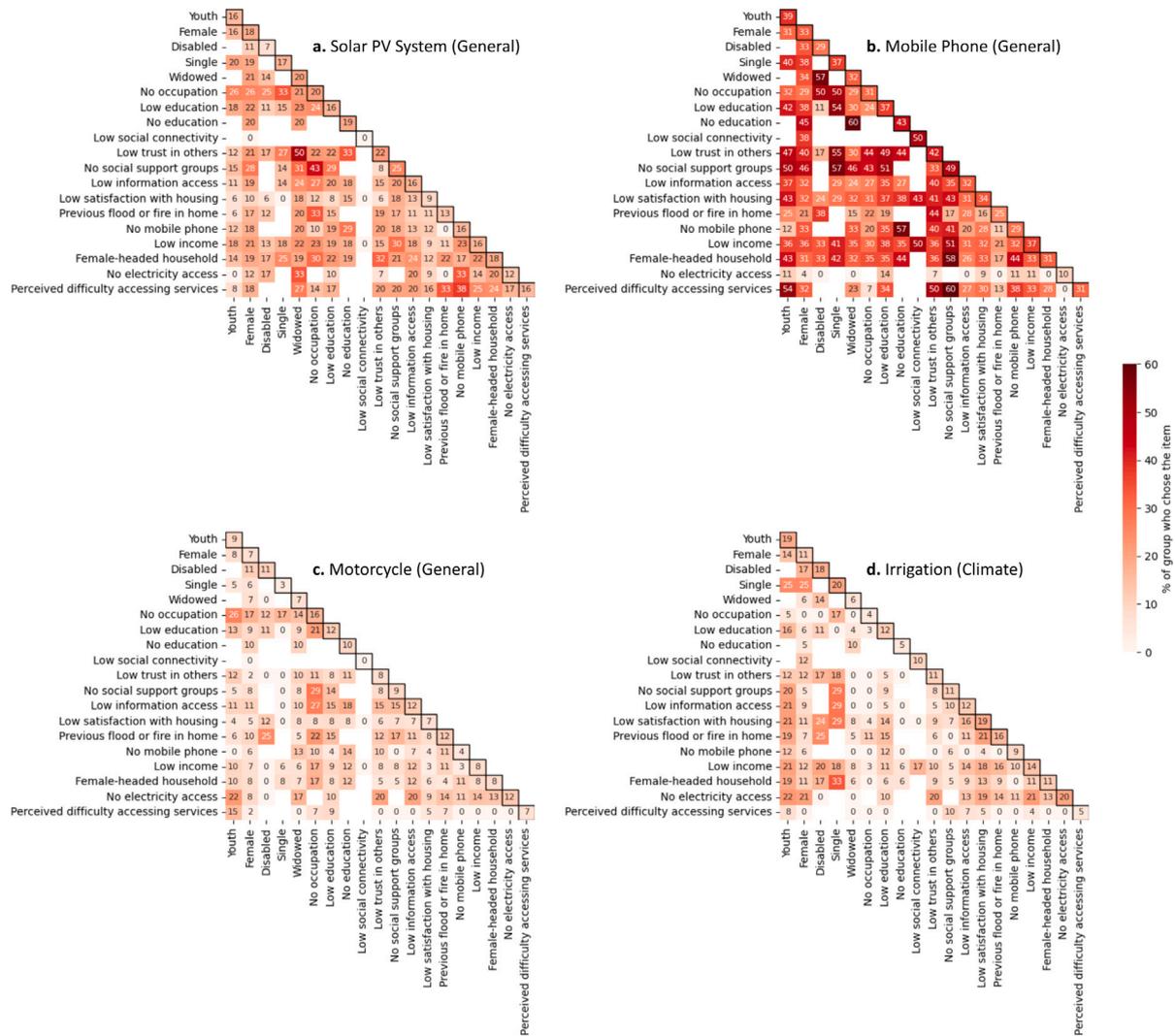
Fig. 7. Prioritisation of select energy items across intersectional vulnerable groups. Note that the colour bar is capped at the highest value in any cell (i.e., 60%).

by "Connection" (59%) followed by "Unburden" (17%). This could be linked to their frequent usage for market access and sales amongst farmers [123].

The prioritisation of the mobile phone across intersectional identities is visualised in Fig. 7b. This shows how pockets of heightened need can hide within already vulnerable groups: while 35% of all widowed people prioritised a mobile phone, 60% of widowed people who are disabled and 57% of widowed people with no education prioritised it. One can hypothesise that, due to their vulnerability, they value the social connectivity that the phone brings more highly, but deeper investigation would be needed to confirm or deny this. This aligns with the literature, specifically with regards to the importance of mobile phones for disabled people [124]. Similarly, there is a spike of prioritisation for those with difficulty access services and no social support groups (60%), which is notably higher than either group's prioritisation on average (31% and 49% respectively).

4.4.3. Motorcycles

Motorcycles were selected as a priority item by 9% of participants in daily life. People with no occupation value a motorcycle the most compared to the average (16%). The values attributed to the motorcycle relate to transportation and income generation, among other purposes. The view of a motorcycle as a money-making tool is evident across

respondents: "*a motorbike can enable me to start a motorbike transport business where I can get someone to ride it and get some money to sustain my needs*" [Female, 27], "*the advantage of a motorcycle is that I can employ these kids who have finished school, and, from that, I'll earn some money with which to feed my children*" [Female, 32].

The relative selection of a motorcycle across intersectional identity groups is shown in Fig. 7c. There are spikes in prioritisation amongst those who have no occupation and who either are in no social support groups (29%), have low information access (27%), or are youth (26%). This aligns with the literature on motorcycle-based boda-boda services in Kenya being a key source of youth employment [125]. One can theorize that these intersectional groups experience greater precarity in their unemployed state than others, and ergo place higher priority on this income-generating energy-enabled tool.

4.4.4. Irrigation

Irrigation was chosen as a priority item by 3% of all participants in daily life, but 16% of participants in the case of a climate shock. The relative selection of irrigation across intersectional identity groups during a climate shock is visualised in Fig. 7d. Single people (20%) and people with no electricity access (20%) selected irrigation the most frequently. There were several vulnerable intersections with single-ness which had higher prioritisation of this item, including the intersections

with female-headed households(33%), previous floods or fires (29%), low housing satisfaction (29%) and no social support groups (29%).

In justifying this priority during a climate shock, the most frequently expressed values were "Food security" (33%), "Water security" (29%) and "Yield" (13%). The verbatim text shows that people want irrigation in order to grow food in drought, as illustrated by the following quote: "*Irrigation is of great importance during drought period because we as humans require food on a day to day basis. Therefore during the drought periods we are forced to look for other options of getting food and irrigation is one of the solution that we require to make food*" [Male, 38]. The justifications of this priority also showed an awareness of climate change more broadly: "*Given the ensuing change in climatic conditions in our region, it is only through irrigation that one can manage to have predictable harvest and food security*" [Male, 57]. Irrigation is therefore seen as a key energy-enabled means to sustain agriculture and food security during a climate event. Some respondents even mentioned electrification of irrigation directly in their justifications: "*After I have dug for water I can connect this pipe to electricity that powers it such that it becomes like a jet so now it will pump water to my maize crops or vegetables*" [Female, 64]. It is important to note, however, that as climate change progresses, should irrigation uptake increase while water availability decreases, careful management and conservation will become necessary [126].

By contrast, in daily life, the main values justifying this priority were "Food security" (35%), "Income" (12%), and "Yield" (12%). "Water security" drops to 3%, and "Income" raises significantly in importance. In daily life, irrigation is seen more as a way to improve yields and make more money than as an essential: it is more about thriving than surviving. This aligns with recent experimental evidence from Kenya showing irrigation pump increase farm income by 13% [127]. Justifications for this priority discussed how irrigation enables people to pay for school fees: "*this is where I get money for my family like for school fees, for their food*" [Male, 42], "*when I get a good harvest and my child has been sent out of school I can talk to the teacher and give out even one sack of maize to clear the fees*" [Female, 58]. People also spoke about ease of use of irrigation versus analog watering methods considering age and mobility: "*the machine has benefits because if for example you plant vegetables, it is hard considering our old age, to take a bucket and irrigate a crop one at a time*" [Male, 59].

4.5. Contextualising energy results within non-energy needs

To contextualise the energy-specific results, general high-ranking priorities are revisited with an intersectional lens, as shown in Fig. 8.

The prioritisation of money (Fig. 8a) contextualises the affordability of energy services. As previously discussed, there is a higher prioritisation of money amongst disabled people than other groups. However, there are further doubly-vulnerable intersections related to both disability and unemployment which show even stronger need. Among disabled people, who already strongly prioritise money (75%), those who have previously experienced a flood or fire and those with low trust value money even more highly (88% and 83% respectively). Among those who have no occupation, who also valued money more highly than average (70%), the same two intersections show higher prioritisation (89% for both), as did the intersection with perceived difficulty accessing services (100%) and those who are widowed (86%). These intersections which highly prioritise money may have competing needs which draw their resources away from energy spending.

Meanwhile, the prioritisation of both vegetables (Fig. 8b) and water (Fig. 8c) can help contextualise the need for irrigation services. While people with no social support groups prioritise vegetables more highly than average (75%), those who also have low information access (90%) or no mobile phone (88%) prioritise them even more frequently. It can be hypothesised that these intersectional identities are more likely to rely on farming than others, and ergo to prioritise vegetables. As such, they may make be a good target group for the deployment of

irrigation services. Regarding water, those with no mobile phone and no electricity access prioritise water the most frequently (67%). As such, perhaps by offering electrical water-provision services, this group can receive two-birds-one-stone benefits. In both cases, programme delivery should clearly not rely on mobile phone communication only.

Finally, the prioritisation of a bible (Fig. 8d) provides interesting context into coping strategies, support systems, and self-reliance as they pertain to climate and energy. Those who have no social support groups (29%), have low trust in others (25%) or are widowed (25%) prioritise their bibles more than average. Within these groups, there are even higher pockets of prioritisation amongst those who have no social support groups and had a previous flood or fire (67%), those who are widowed with low trust in others (50%), and those with no social support groups and low trust in others (50%). These intersectional vulnerable identities stem from difficult experiences of lacking or unexpectedly losing something that many take for granted (i.e., a spouse, a home, and social support). One can hypothesise that these people place greater importance on their bibles and ergo their faith given the lack of these other safety nets. To reach these vulnerable groups during energy system planning, then, perhaps it will be most effective to reach out through faith leaders instead of conventional social structures, who can frame the benefits of energy within their faith-based priorities.

5. Discussion

"*In order to create the universal, you must pay very great attention to the specific. Universality, I think, emerges from the truthful identity of what is.*" [128] (p. 128)

By creating a framework and method to illuminate energy needs across intersectional vulnerable groups, this work opens avenues for more inclusive design of energy infrastructure. While acknowledging the power structures which create vulnerability to be colonial in origin [2], by analysing the needs of those oppressed by this structure, it attempts to reach across "the abyssal line" of epistemological cartography to understand those who are normally excluded [47] (p. 123). In doing so, it aims to provide the tools to create a fuller picture during needs assessment. To draw a metaphor, it provides a finer brush to render the scene in greater detail using the same palette of data, allowing elements previously omitted or overlooked to become visible.

This application of this method may bring more questions than answers. This is intentional. By unearthing specific intensities of need, the natural next step is to wonder why these pockets of need have emerged, and how they can best be addressed. The approach developed here does not assume to be able to answer all these questions; rather, it tries to paint a first-pass picture as a means to target deeper investigation.

The case study results show that needs in Siaya County vary both *across* and *within* demographics, validating the importance of intersectional needs assessment. As an example across demographics, consider the results for disabled people, who prioritise money more than average and solar PV systems less than average. They express multiple needs they fulfil with money related to their care and well-being, which may make them unlikely to uptake solar PV systems if this energy service is offered. Looking instead within demographics, widowed people who have low trust in others prioritise both a solar PV system and a bible much more frequently than average, or than their respectively single-axis identity groups (see Figs. 7a and 8d). This would be invisible in non-intersectional analysis, and points to a high need for energy services that promote self-reliance within this group.

Such results validate the premise that the needs of multiply-marginalised people are not simply additive, and the intensity of need at intersections cannot be discerned by only looking at single-axis vulnerabilities. This variance presents both in general life and in the case of climate shocks. Indeed, as previously discussed, there
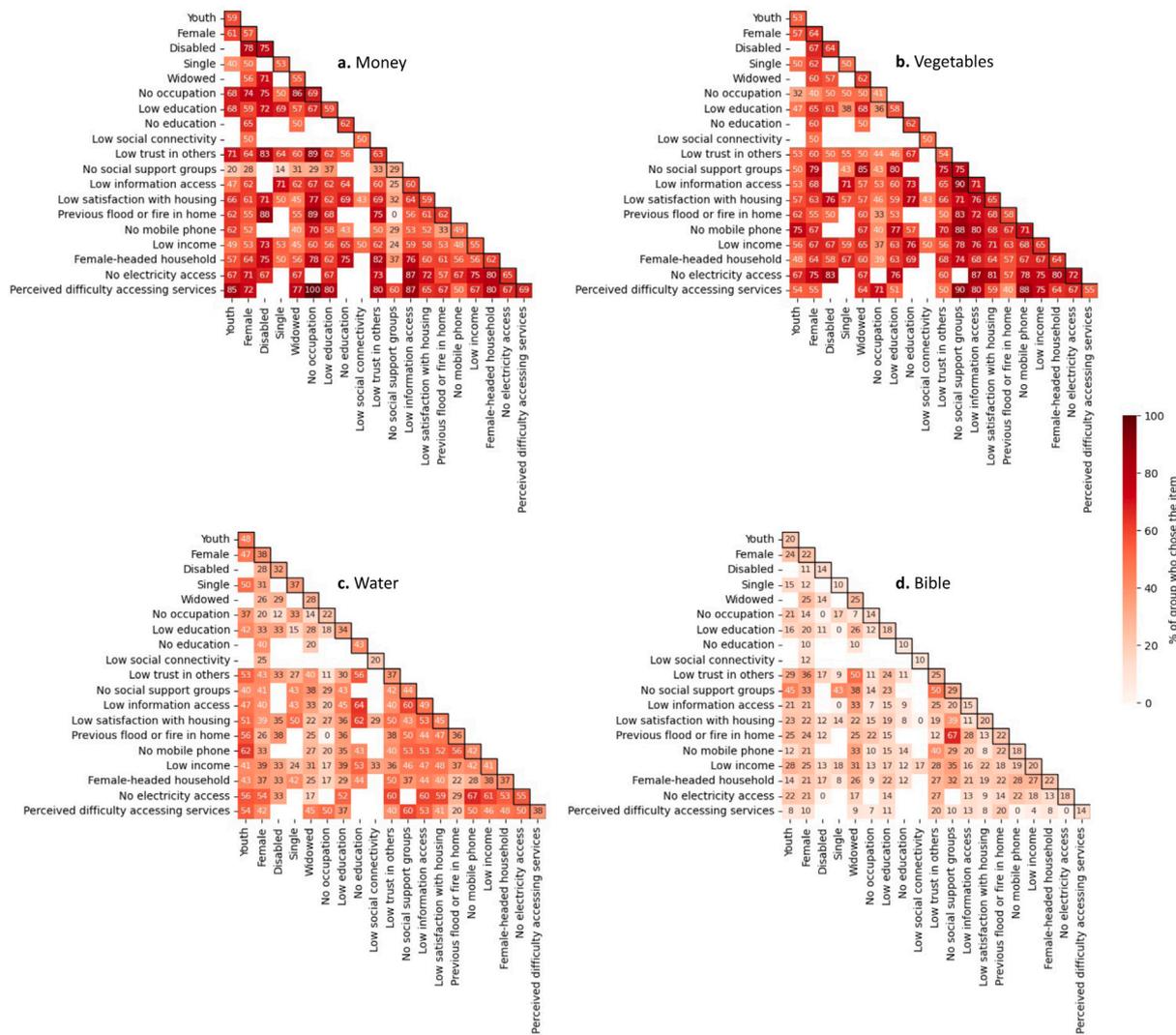
Fig. 8. Prioritisation of select contextualising items across intersectional vulnerable groups.

is less agreement across vulnerable groups about top priorities in a climate shock than in daily life. Justifications for these priorities often alluded to pushing through a shock rather than maintaining the pre-shock status quo, speaking dynamic to energy-enabled resilience rooted in tenacity rather than stability [16].

It is difficult to benchmark the case study results against existing research due to a lack of comparable studies. Most studies of climactic vulnerability in Kenya focus on overarching physical factors [129] and are neither specific to energy nor vulnerable demographics. Nevertheless, they point to the same risks that this work highlights including vulnerability to drought and flood [130] and high existing water scarcity [130], aligning with our key findings (e.g., on irrigation). Generally speaking, the literature denotes vulnerable groups in Kenya as having restricted access to capital, credit, and land, aligning with our findings on the importance of money to vulnerable groups during shocks [130]. Meanwhile, the literature also corroborates the ability of electricity access to reduce vulnerability [131].

There is even less literature which addresses Siaya County specifically. Be that as it may, one of the few relevant studies found that two of our vulnerability markers (e.g., age and education) influence climate variability knowledge, and discussed how adaptation measures

vary based on economic status [132], validating the need for inter-sectional approaches. Indeed, broader literature on Siaya indicates the influence of social structures of marginalisation on everything from food intake [133] to educational aspirations [134]. Despite the lack of energy-specific literature, these studies emphasise the importance of studying daily phenomena and needs in the county intersectionally.

5.1. Policy and planning insights

The case study results provide useful insights for vulnerability-aware energy planning in line with the Constitution of Kenya [135], the Energy Act of 2019 [136], and the upcoming Integrated National Energy Planning framework. Looking across demographics is critical to ensure the inclusion of cross-cutting themes such as gender and agriculture in energy planning, as stipulated in these policies.

The solar PV system was found to be the most popular electricity production technology in Siaya County. The verbatim data justifying this priority refer to the many services it enables (e.g., lighting, appliances) and the benefits those bring, aligning with energy as a development enabler. As discussed above, there is a particular pocket of need for this technology at the intersection of low trust and widowed

people, possibly due to their high need for self-reliance. In energy planning, this finding can be applied by prioritising this demographic for solar PV distribution. Specific subsidies or support programmes can be provided to enable this demographic to purchase the technology more easily.

While the mobile phone was found to be the highest priority electricity consumption item in Siaya County, the intensity of this priority varied across vulnerable groups. For instance, while widowed people prioritised a mobile phone close to the dataset average, those who are both widowed and either disabled or uneducated prioritised this far more frequently. To apply this finding in energy systems planning, it can be noted that it is critical not to interrupt the availability of mobile service to support these vulnerable groups. For instance, one can envision a scenario where a village has a mobile phone charging business serving these customers, and particularly those who are additionally intersectionally vulnerable by not having their own electricity connection. If a grid connection is offered in this community, perhaps the business will lose customers and close. However, this would disproportionately impact these vulnerable groups. As such, a method to bridge these people to new phone charging services (e.g., subsidised solar PV chargers) would be needed, or the charging business would require subsidy to continue providing the service.

Motorcycles were prioritised in Siaya County for multiple uses including transport and income generation. While these technologies are not yet electrified, they are among Kenya's priorities for electrification, as evidenced by their focus in President Ruto's e-mobility programme [137]. As motorcycles are prioritised more highly by unemployed people than average, likely for their potential as a money-making tool, the e-mobility transition must take care not to exclude these vulnerable people from the market.[3] Should fuel supply become disrupted, or the electric alternatives be priced too high for these people to afford, they may lose a vital income stream. Mechanisms to avoid broadening these social divides must be accounted for in energy planning. These could include subsidies to ensure that operating costs of e-mobility remain relatively consistent with conventional fuels, and staged closures of fuel stations to avoid sudden income disruption.

The results across non-energy items provide useful context on factors which may affect intersectional energy uptake in Siaya County. As previously discussed, the high prioritisation of money amongst disabled people shows that they may have multiple competing financial needs which limit their ability to pay for energy. The prioritisation of vegetables amongst those with no social support groups, low information access, and no mobile phone points to a potential customer base for irrigation systems, while the prioritisation of water by those with no electricity access and no mobile phone points to a potential opportunity for two-birds-one-stone intervention. In both cases, the energy service provider will need to plan for non-mobile-based communication as they deploy the energy service. This could include ensuring they conduct in-person community meetings with the relevant demographics. Finally, the high prioritisation of a bible amongst intersectional groups who have experienced loss and isolation, including those who have had a fire or flood, who are widowed, or who have no social support groups, may indicate a need for self-reliance and contact via faith leaders to create uptake. These are therefore critical stakeholders to engage during planning to ensure reach to vulnerable customers.

5.2. Future work

There are multiple avenues for future work arising from this research, as enumerated below.

First, future work could allow for continuous variability of vulnerability along axes. As discussed in Section 3.4, this work employs binary thresholds for vulnerability despite existence on a fuzzy and continuous spectrum in practice. Further work may wish to expand on the analysis by introducing methods which allow continuous variability of vulnerability along axes captured continuously (e.g., age, income).

Second, future work could compare vulnerable groups with relatively privileged groups. Intersectionality is not just a concept that applies to marginalised groups; it structures the lives of both the vulnerable and powerful [102]. To complement the comparison of results with the dataset average, the needs of vulnerable groups could be compared with those of relatively privileged groups. This would require the development of a parallel privilege, power, or resilience framework, and application of similar methods to those developed here.

Third, future work could pursue mathematical formalisation of intersectionality. While this work has shown that intersectional vulnerabilities result in pockets of need which are not additive, it makes no attempt to mathematically formalise these relationships. Following Weldon's intersectionality-plus framework [102], generalised expressions could be developed and tested for applicability beyond the study context. As the numeric results are the key focus for the planning purposes outlined here, this is left as an avenue for future work.

Fourth, future work could apply this method on temporal demand data. This framework could be applied to a dataset with both an item priority and an item usage (i.e., temporal) dimension. As Multi-Tier Framework or other similar survey data becomes increasingly available, this will be an exciting avenue for future work. However, it will be important to note the nuanced difference between existing usage, aspired usage, and priority of services in such analyses. Additionally, temporal clustering may be needed to reduce complexity.

Fifth, future work could undertake higher-dimensional visualisation. While this study restricted visualisation to the two-dimensional plane, and thus focused on dual-vulnerability analysis, non-traditional visualisations could be explored for higher-dimensional intersectional analysis. These could include physical three-dimensional representations or motion video. This would be an exciting area for future interdisciplinary collaboration, perhaps including visual art as a medium.

Sixth and finally, future work could explore demographic-based demand projection. With sufficient data to conduct robust machine-learning-based training of needs against vulnerability indicators, there could be a potential to project demand patterns in new communities based on relative distribution of key overlapping vulnerabilities which "explain" the most demand variance. This would require communities to be contextually similar in terms of these explanatory variables (i.e., such that they have similar thresholds and vulnerability effects).

6. Conclusions

This study has investigated energy needs across intersectional vulnerable groups by developing a vulnerability framework and analysis methods. The framework, constructed through synthesis of the literature on social vulnerability to environmental hazards, captures acute and chronic vulnerability at individual, family, and community levels. The methods draw upon Crenshaw's concept of intersectionality [25] to operationalise Collins' vision of a matrix of domination [29] and map intersectional needs. The implementation of the methods is made open access for reuse: https://github.com/alycialeonard/MOI.

The framework and method are demonstrated through application to a case study dataset of 300 user-perceived value surveys from Siaya County, Kenya, which include item priorities both in daily life and during a climate shock, and the values underpinning these. In this case study dataset, the most common intersectional vulnerable groups are women with low income, women with low education, and people with both low income and low education. While housing was found to be the top priority in daily life, in the case of a climate shock, money became the top priority, and energy-enabled water services

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[3] Notably, the status quo of the industry also increases vulnerability and perceived "disposability" of its workers [138] – this must also be addressed within the sector.

(e.g., irrigation) increased in importance. Looking at energy-specific results, solar PV systems were the most highly prioritised electricity generation technology due to their ability to fulfil multiple purposes in the home. They were particularly highly prioritised amongst widowed people with low trust in others, perhaps indicating a need for energy self-reliance. Mobile phones were the most frequently prioritised electricity use technology, with particular prioritisation amongst widowed people who are either disabled or have no education. Motorcycles were the most frequently selected energy-enabled transport technology, with spikes in prioritisation amongst unemployed people who are in no social support groups, have low information access, or who are youth – this must be accounted for in the e-mobility transition. Broader development needs contextualise these findings: for instance, disabled people have a higher need for money to meet their care needs, which may limit energy affordability. Given these results, the Siaya County Energy Plan could demographically targeted incentives or subsidies for: (1) the deployment of solar PV systems; (2) access to mobile phone charging services and reliable networks; (3) energy-enabled irrigation to assist during climate shocks; and (4) the e-mobility transition to avoid further marginalising boda-boda drivers.

By developing a method for intersectional energy needs assessment suitable for LMICs, this study aims to open the conversation as to how intersectionality can be practically operationalised in development needs assessment. It aims to illuminate how considering intersectional vulnerable groups need not be a fully qualitative and unscalable exercise. Rather, it shows how intersectional insight can be pulled typical large-scale survey data to inform energy and development interventions.

CRediT authorship contribution statement

Alycia Leonard: Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – original draft, Visualization, Project administration. **Kuthea Nguti:** Writing – review & editing, Validation. **Micaela Flores Lanza:** Conceptualization, Data curation, Writing – review & editing. **Stephanie Hirmer:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration.

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.

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Data availability

The data used in this work is available openly online [105]. Method implementations are available on GitHub: https://github.com/alycialeonard/MOI.

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