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Investigating the interplay between electricity access and food security: Insights from refugee settlements in Zambia, Malawi, and Uganda

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ABSTRACT

With increasing displacement trends, low energy access rates in refugee settlements, and the majority of forcibly displaced populations residing in countries experiencing acute food insecurity, the nexus between food security and energy access is increasingly relevant. While the pathways connecting energy access to the four dimensions of food security (availability, access, utilisation, and stability) are well established in the literature, only a few studies empirically provide evidence of the relationship between energy access and food security, particularly in the humanitarian context. Drawing from 926 household-level observations collected via in-person interviews in settlements in Uganda, Malawi, and Zambia, this study contributes new insights on the influence of electricity access on food security in protracted refugee situations. Within the sampled population, 65 % of households experience severe food insecurity while a substantial 76 % majority lacks access to a reliable electricity service. Through a logistic regression analysis, we detect a mitigating effect of electricity access on severe food insecurity, although weakly significant, while controlling for income, gender of the household head, household size, and settlement dummies. The odds of experiencing severe food insecurity are reduced by a factor of 0.7 for households with access to electricity compared to those without access. However, they increase for households located in the most economically disadvantaged settlement. The study highlights the importance of policies that support the right to work and empower female-headed households, as income-generating activities play a mitigating role; in turn, households headed by women are about 1.7 times more likely to experience severe food insecurity compared to those headed by men. More generally, in emphasising the role of reliable energy services in the consumption of safe and nutritious food, this work calls for an integrated humanitarian approach that addresses food security together with long-term, sustainable energy solutions.

Introduction

Ensuring access to affordable, reliable, and modern energy to forcibly displaced populations living in settlements is essential to running water, sanitation and hygiene (WASH) facilities and to powering communal and private spaces (schools, health centres, homes, and businesses) as it is part of the 'leave no-one behind' agenda cutting across all the Sustainable Development Goals (SDGs). In the longer run, it is also essential to support livelihood opportunities and self-reliance, together with mitigating land degradation and greenhouse gas emissions (Grafham, Lahn, & Haselip, 2022). For these reasons, a consensus has emerged on the urgent need to implement market-based and development-oriented energy solutions in refugee communities in line with SDG 7 - Affordable and Clean Energy (GPA, 2022; IEA et al., 2023; Rosenberg-Jansen, 2022).

Such a goal aligns also with the Global Compact on Refugees (GCR), which calls for actions to enhance refugee self-sufficiency and scale up capacity development for renewable energy (United Nations, 2018), and

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with the Global Strategy for Sustainable Energy of the United Nations High Commissioner for Refugees (UNHCR) (UNHCR, 2019). In fact, strengthened partnerships between development and humanitarian agencies, donors, host communities, their governments, and refugees are having an impact on improving access to sustainable, affordable and clean energy and addressing the energy needs of refugee households from the onset of emergencies. At the same time, refugees remain, by large, personally responsible for collecting or purchasing fuels, together with other energy technologies, such as cookstoves or solar panels, from local markets (GPA, 2022; IEA et al., 2023). Differently, the GCR also acknowledges that food and nutrition are priority basic needs, and humanitarian agencies, such as the World Food Program (WFP) and the Food and Agricultural Organisation (FAO), actively "facilitate access to sufficient, safe and nutritious food, and promote increased self-reliance in food security and nutrition" (United Nations, 2018, p. 31). Such support aligns with SDG 2 – Zero Hunger and relies on several means ranging from cash and food assistance to collaborating with hosting governments to create supporting environments for self-reliance.

Within this framework, a frequently overlooked but crucial issue emerges: the necessity of energy for food security. The significance of this issue is underscored by the fact that the consumption of safe, nutritious food hinges on stable energy services for food utilisation, conservation, production and processing (Caniato, Carliez, & Thulstrup, 2017). Generally speaking, energy access influences households' "dietary choices, cooking practices and water treatment, all of which can significantly affect […] food security and nutrition" (WFP, 2021, p.2). Specifically to the humanitarian context, the availability of fuel and appropriate cooking technologies can prevent a number of negative coping mechanisms, such as reducing the frequency and size of meals or selling food for fuel. When made possible by electricity access, food conservation can support dietary improvements in camp settings, and solar systems can be used in irrigation and other agricultural processes in contexts where displaced populations are engaged in farming activities (Thomas, Rosenberg-Jansen, & Jenks, 2021). In short, ensuring that food security and nutrition targets are achieved are challenges inherently linked to the supply of energy in the humanitarian domain, especially in the least served areas in low-income countries.

Within the United Nations (UN) system, there is awareness of the close relationship between energy and food security (e.g., WFP and UNHCR are Steering Group members of the Global Platform for Action on Sustainable Energy in Displacement Settings, GPA), but very few food security interventions (2 %) address food safety and energy access at the same time (Nisbet, Lestrat, & Vatanparast, 2022). Two recent country-level studies indeed show the supporting effect of electricity access on food security (Candelise, Saccone, & Vallino, 2021; Pondie, Engwali, Nkoa, & Domguia, 2023), but they do not include forcibly displaced populations.

To partially contribute to addressing this knowledge gap, this study focuses on six refugee communities in three countries in Sub-Saharan Africa (SSA): Zambia, Malawi, and Uganda. All settlements under observation qualify as situations of protracted displacement, defined by UNHCR as contexts "where more than 25,000 refugees from the same country of origin have been in exile in a given low- or middle-income host country for at least five consecutive years" (UNHCR, 2024, p. 22). Notably, of the 37.4 million people under the mandate of the UNHCR at the end of 2023 (refugees, refugee-like persons and other people in need of international protection), 66 % were living in protracted situations (UNHCR, 2024), and 1 in 5 of all refugees worldwide was hosted in SSA (UNHCR, 2023a). At the same time, GPA (2022) estimates that the vast majority of forcibly displaced populations living in camps do not have access to electricity (94 %) and rely on firewood and charcoal for cooking (81 %), while UNHCR indicates that at the end of 2018, 80 % of the world's displaced populations were residing in countries or territories experiencing acute food insecurity (UNHCR, 2020).

Focusing on this specific context – refugees living in settlements in protracted situations in Sub-Saharan countries – the present study asks whether access to electricity contributes to reducing the probability that a refugee household experiences severe food insecurity and explores what other economic and sociodemographic factors are relevant in the relationship between access and food security. These questions are addressed empirically using data pertaining to refugee households and collected from the field. Specifically, the analysis relies on a cross-sectional data set of 926 household observations extracted from a larger database of primary data from 1412 in-person interviews conducted in 2022 (Casati, Fumagalli, Baldi, & Moner-Girona, 2024). The empirical analysis carried out in this study comprises descriptive statistics and regression models.

Publicly available data on electricity access in protracted refugee settlements in SSA based on field data collections are extremely scarce, and only a few publications report them (e.g., Corbyn & Vianello, 2018; Okello, 2016; Practical Action, 2020; Van Hove & Johnson, 2021). In turn, analysis of surveys on food security and cooking fuels within refugee settlements in SSA are more often available within the grey literature (e.g., UNICEF Uganda et al., 2024),[1] and the original survey data is occasionally made available (upon motivated request) by UNHCR.[2] Finding both types of information, on energy (including electricity) access and on food security, in the same data set is quite rare. This speaks to a broader research agenda into various aspects of clean cooking in humanitarian settings, where gaps and needs have been identified by the GPA (Rosenberg-Jansen and Haselip, 2021). Hence, the first contribution of this work consists of novel evidence on current levels of food security and electricity access rates among the observed households.

The second contribution of this work, based on a selective literature review, is an analysis of the pathways connecting energy access and food security. This analysis compares research focused on national residents and studies focusing on forcibly displaced populations. Notably, both literature streams indicate that energy access is a driver of food security, yet they also underscore the scarcity of context-specific, empirical research supporting or contesting the relationship between energy access and food security, particularly within the humanitarian domain (Bounie et al., 2020; Bonan, Pareglio and Tavoni, 2017; Caniato et al., 2017; Sola, Ochieng, Yila, & Iiyama, 2016). Building on this, the third contribution of this study is to derive evidence from a logistic regression analysis of the role of electricity access, in combination with income and other sociodemographic and location-specific factors, in determining the probability of food insecurity for refugee households.

The rest of the paper is organised as follows. Section *Energy access and food security* reviews the literature and derives hypotheses for the regression analysis. Section *Data and descriptive statistics* introduces the empirical data and the descriptive statistics. Section *Methodology* presents the methods. Section *Results* reports the results and discusses the main findings and limitations of this study, and Section *Conclusions* concludes the paper.

Energy access and food security

The literature review focused on two types of scientific articles: those proposing a framework to explain how energy access impacts food security, and those focusing on providing empirical evidence of the relation between the two.[3] While our main focus is the interplay of energy access and food security in the humanitarian context (Annex A,

[1] This detailed information focusing on refugee settlements in Uganda was published in early 2024 when our empirical work was already concluded.

[2] https://microdata. unhcr.org/index.php/catalog/SENS/?page=1&region%5B%5D=6&ps=15&repo=SENS.

[3] For a comprehensive literature review on humanitarian energy, see Rosenberg-Jansen (2022); for a comprehensive literature review on food security in the humanitarian domain, see Nisbet et al. (2022).

Table A.1), we also consider work in the broader domain of resident nationals lacking access to energy (Annex A, Table A.2) due to the sparse availability of literature on the food security and energy access nexus in a humanitarian setting.

When considering studies focusing on the humanitarian context, the following emerges:

- A lack of access to modern energy is indirectly linked to food *availability,*[4] as the combined needs of displaced and host populations can pose a strain on the local environment via forest degradation and loss of agricultural livelihoods, which can also negatively impact the *stability* of food access and supply in the longer term (Caniato et al., 2017).
- The need to procure fuel can directly impact the amount of money that can be spent on food, affecting a household's purchasing power (the food *access* dimension). Also, due to the significant time required for fuel collection and food preparation for their families (traditionally a woman's task), lack of energy access can take time away from more productive or income-generating work and affect people's livelihoods. Consequently, 'time poverty' can further deteriorate the ability to access food for households with few income sources (Caniato et al., 2017; Thomas, Rosenberg-Jansen, & Jenks, 2021).
- Fuel shortage and limited energy efficiency of traditional stoves are often a major constraint to food preparation and may have a significant nutritional impact (the food *utilisation* dimension). Also, the lack of food preservation technologies (seldom found in humanitarian settings) is linked to higher losses of food available on the local market or produced through subsistence farming and small livestock rearing (Thomas, Rosenberg-Jansen, & Jenks, 2021).
- Abdalla and Goulao (2024) link *food insecurity* (in general) to a set of primary drivers (inadequate shelter, WASH, and access to healthcare) and a number of secondary ones, such as unemployment, low education, lack of access to electricity and cooking fuels/technologies, and inadequate integration into the host countries (adaptation to new food varieties and feeding practices). Importantly, the same authors identify restrictive/inadequate national policies and laws regarding refugees as the underlying root cause of all secondary and primary drivers.

When considering work focusing on resident nationals, we observe the following:

- Facing a lack of access to modern energy, households allocate more budget to securing fuel instead of food and more time to fuel procurement instead of engaging in income-generating activities, including the production of food via agricultural practices (or use of inferior forms of biomass energy like dung and agricultural residues, with negative consequences for agricultural productivity), thus compromising both the food *availability* and the food *access* dimension (Sola et al., 2016).
- The extended time devoted to fuel collection significantly affects food *utilisation* dimension, curtailing the time available for food preparation, and scarcity in fuelwood availability prompts households to modify their cooking methods, often leading to skipping or substituting specific energy-intensive foods to conserve cooking fuel (Brouwer, den Hartog, Kamwendo, & Heldens, 1996; Makungwa, Espulani, & Woodhouse, 2013; Sola et al., 2016).
- Electricity access is linked to food security by means of two routes. The direct route captures the positive impact of electricity access on food *availability* and *utilisation* by "fostering agriculture productivity, improving food production for subsistence as well as by increasing food quality and quantity due to improvements in efficiency of conversion, cooking and conservation" (Candelise et al., 2021, p. 5). The income-mediated route describes the impacts that occur because of improved *economic access* to food, enabled by increases in monetary income (or improvements in income distribution) to be utilised to purchase food. In fact, electricity access can bring improvements in education or gender balance and "promote the creation of small enterprises, boost production and efficiency of the existing ones and thus generate new employment and income" (Candelise et al., 2021, p. 2). In turn, increased income expands people's purchasing power, which can translate into improved food security.

In summary, these two streams of literature indicate that a lack of energy access impacts food security via three main pathways:

(i) the degradation of the local environment and the reduced agricultural productivity affect food *availability* and *stability,*
(ii) the reduction in income available for food affects the food economic *access* dimension (by limiting the opportunities for and the time that can be spent on productive and income-generating activities) and
(iii) the use of inefficient technologies in food preparation and conservation impacts the food *utilisation* dimension.

A few differences separate the two domains. With regard to food *availability* and *stability*, the literature focusing on the humanitarian context is comparatively more concerned with the strain that the lack of access to modern energy might put on the environment (the presence of both the host and the displaced population in the same location could impose an increased burden on the local resources). This issue has relevant climate implications as well (Bofa & Zewotir, 2024; WFP, 2021) and the diffusion of solar e-cooking among forcibly displaced populations and their host communities is the focus of the Solar-Electric Cooking Partnership for Displacement Contexts (SOLCO), a multistakeholder initiative launched at both the Global Refugee Forum in 2023 and at COP28 in Dubai (Last Mile Climate, n.d.; UNEP-CCC & WFP, 2024; UNEP, 2019). Indeed, the use of solid biomass, such as firewood and charcoal, is very widespread, while cooking fuels like ethanol, liquid petroleum gas (LPG) or biogas have limited diffusion in refugee settings located in remote, underserved areas (Njega et al., 2024). In turn, the literature on resident nationals emphasises another important aspect of the food availability dimension (Candelise et al., 2021): the role of energy access in enhancing productivity in formal and informal (subsistence) agricultural production. A similar focus seems to be lacking in the humanitarian domain.

With regard to *economic access* to food, the limited income and income-generating opportunities available to refugees understandably amplify concerns related to the impact of energy poverty on a family's purchasing power and its time poverty (Caniato et al., 2017; Thomas, Rosenberg-Jansen, & Jenks, 2021). In connection to this, another peculiarity of the humanitarian domain resides in the key role of national refugee policies governing the right to work and the freedom of movement in enabling access to income-generating activities and thus the economic access dimension of food security (Abdalla & Goulao, 2024). Echoing this literature, UNHCR (n.d.) indicates that refugees are highly vulnerable to food insecurity and undernutrition, particularly when sheltering in areas with limited work opportunities and restricted access to national support systems. In turn, while the broader-domain literature clearly highlights the income-mediated effect of electricity access (supporting income-generating activities) on food security (Candelise et al., 2021), this connection is not often discussed in the humanitarian literature. Similarly, while the broader literature highlights the potential positive impact of electricity access on income distribution (as studied by Candelise et al., 2021), this aspect is rarely addressed in the humanitarian context. Notably, the uneven distribution of income within

[4] The four dimensions of food security are defined in FAO et al. (2023).

settlements is often overlooked, even though it might play a role in shaping economic access to food security.

Finally, while the food *utilisation* dimension is not inherently different between the two domains (it is mostly a technological issue), it is rendered more complex in the humanitarian domain by a lack of coordination between agencies responsible for food, on the one hand, and non-food items on the other (technologies and fuels used in food preparation and conservation).[5] Furthermore, as noted by Abdalla and Goulao (2024), utilisation also has a socio-cultural dimension and for displaced populations, it might be difficult to adapt to local food and diet or to access nutritious food options (e.g., fresh food from the market).

In terms of empirical evidence of the impact of energy access on food security, several authors (e.g., Bonan et al., 2017; Sola et al., 2016) have noted that very few studies deliver conclusive support for this relationship, emphasising the need for more methodologically rigorous research in this area. Two country-level studies stand out in this regard. Using a panel of 54 developing countries (2000–2014), Candelise et al. (2021) empirically show that electricity access indeed positively impacts food availability and utilisation, as well as economic access to food, although the latter, indirect route is sensibly weaker than the former, direct one. Focusing on SSA, Pondie et al. (2023) take a similar approach and study a panel of 36 countries over the period 2000 to 2020. Their results confirm that access to electricity and clean cooking fuels positively influences food security, with the latter having a stronger effect than the former.

In addition, Candelise et al. (2021) note that the microeconomic literature is rich in empirical studies investigating how responsive food security is to income changes (e.g., (Brown, Ravallion, & van de Walle, 2019; Davis et al., 2010; Haddad, Pena, Nishida, Quisumbing, & Slack, 1996; Smith & Haddad, 2002; Smith, Rabbitt, Jensen, & C.-., 2017; Soriano & Garrido, 2016). The mixed results of this stream of studies point to a mediating role of households' characteristics, such as resource allocation within the household, the presence and role of women,[6] the number and type of income-generating activities (particularly, the effect of agricultural income sources), the level of education, the number and type of household members, and the presence of a social network. Similarly, the literature looking at the impact of electricity access on income (available for consumption, including food consumption) highlights the moderating effect of other factors, such as gender empowerment and education (e.g., Acheampong, Dzator, & Shahbaz, 2021; Bonan et al., 2017; Jeuland et al., 2021). Additional drivers of food security highlighted by the empirical literature include access to safe drinking water and healthcare (Monirul Alam, Alam, & Mushtaq, 2018).

In light of all of the above, this study aims to empirically explore the impact of electricity access on food security, focusing on settlements in SSA where refugees live in protracted situations and where climate change poses increasing risks of food and nutrition insecurity (Jennings et al., 2024). We expect that access to electricity positively impacts the level of food security experienced by refugees (via the food *utilisation* dimension). We also expect income to play a similar role (via the food *access* dimension) as improved food security is linked to higher income via increased purchasing power.[7] Furthermore, in light of the results from the microeconomic literature, we expect that sociodemographic traits might also play a role. Finally, while we lack field data to capture the food *availability* dimension for the observed refugee communities, we assume that this and other (unobserved) location-specific characteristics (e.g., health and WASH conditions, national refugee policies) might have a relevant impact on food security.

Data and descriptive statistics

The study uses data collected via in-person interviews conducted by Utrecht University and the European Commission- Joint Research Center, with the support of the Division of Resilience and Solutions of UNHCR. As detailed in Casati et al. (2024), the questionnaire designed for the interviews aimed at gathering data on the respondents' energy supply and demand. Additional questions completed the information set with selected socio-economic characteristics of the different respondents (households, businesses and communal loads, such as health posts or schools).

A total of 1412 interviews were conducted in 2022 in six refugee settlements in three Sub-Saharan African countries: Meheba in Zambia, Dzaleka in Malawi, and Nyumanzi, Pagirinya, Ayilo II, and Maaji II in the district of Adjumani, Uganda (Fig. 1). From these primary data, we extracted the household responses.[8] These 926 observations comprise three country-specific groups: 252 households located in Meheba (Zambia), 252 households in Dzaleka (Malawi), and 422 households in the four settlements in the Adjumani district (Uganda) – hereinafter the "Adjumani settlement". As summarised in Annex A, Table A.3, the three settlements differ along several contextual factors, including the level of food insecurity as measured by humanitarian agencies in recent years: moderate in Meheba and mild to severe in Dzaleka and Adjumani.

For each observed household, a subset of responses were selected, relevant to the present study and aimed at capturing:

- *Food insecurity:* from questions related to the Food Insecurity Experience Scale Survey;
- *Electricity access*: from questions on energy resources and appliances;
- *Income*: from questions on monthly income and income-generating activities;
- *Sociodemographic characteristics*: from questions regarding the household's composition.

From these data, we created the variables used in the empirical analysis. These are described below, detailing their construction and presenting their descriptive statistics.[9] The primary focus of the rest of this Section is on the variables capturing levels of food insecurity experienced by the observed households, as well as on electricity access. The variables capturing income and socio-demographic characteristics are more briefly described to avoid redundancy. In fact, they are taken from the dataset associated with the work by Casati et al. (2024), where their construction and descriptive statistics have also been illustrated.

[5] As for refugees residing in settlements, Thomas, Rosenberg-Jansen, and Jenks (2021) note that there is a disconnect between the responsibility to ensure food availability and utilisation, which is entrusted to the WFP and the FAO, and the responsibility to supply fuel and cookstoves, often entrusted to humanitarian actors providing shelter. Hence, although food is often provided, access to fuel and cooking technologies is often overlooked, together with energy and technologies for food preservation. In fact, UNHCR always advocates for alternatives to camp settings and, when this is not possible, for sites with a minimum of connectivity with services and infrastructures.

[6] While most evidence suggests that female-headed households are at a higher risk of experiencing poverty, hence food insecurity (Buvinić & Gupta, 1997), food insecurity vulnerability was recently found to be uniform across genders (Rudin-Rush, Michler, Josephson, & Bloem, 2022).

[7] In fact, access to modern energy creates time and improved opportunities for productive and income-generating activities, which are then connected to higher income. However, limitations in data availability prevent us from disentangling this income-mediated effect. Similarly, studying the dimension of food *stability* would require longitudinal data to which we have no access.

[8] Of the 1412 interviews, 926 were conducted with household respondents, 396 with business owners and 90 with energy managers of communal loads. Only the questionnaire used for the household interviews included questions related to food security.

[9] For transparency, the full dataset is available from the authors upon request.

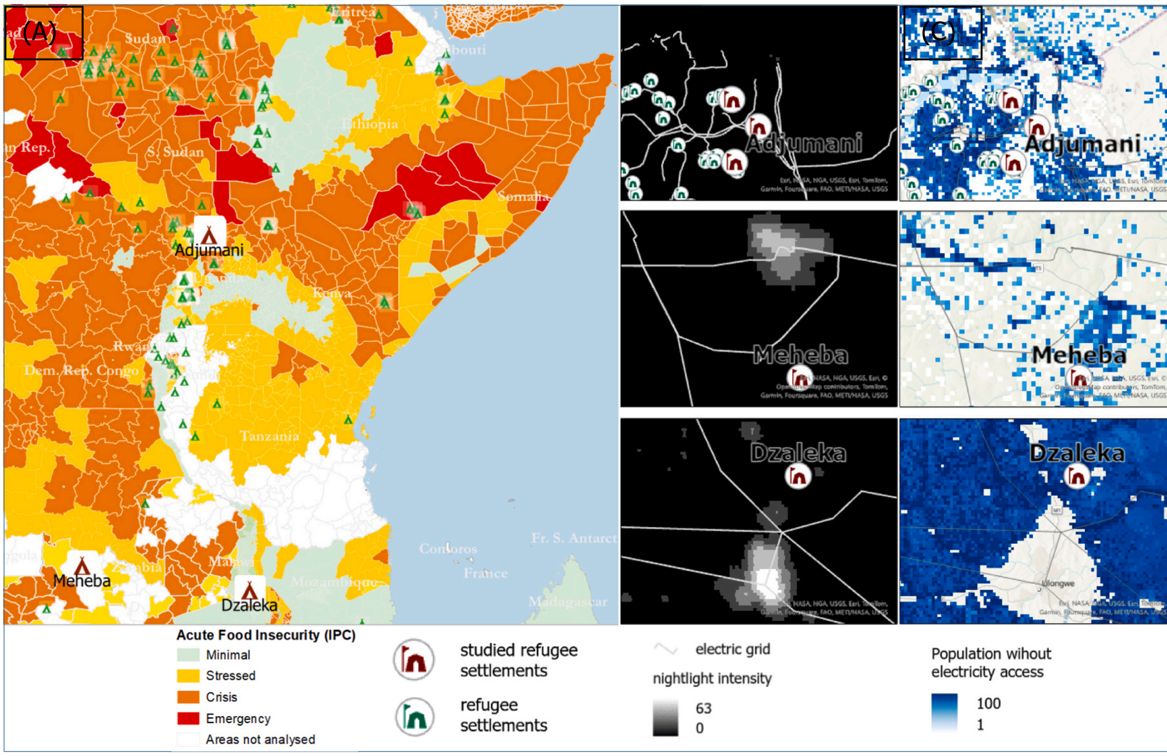

Fig. 1. (A) Refugee settlements locations and Acute Food Insecurity at the time of the data collection (2022). The IPC (Integrated Food Security Phase Classification) background is shown as food security contextual information for the regions of interest. (B) Existing electricity grid and night-time lights. (C) Percentage of population lacking access to electricity. Sources: IPC (https://fews.net/about/integrated-phase-classification); Clean Energy Access Tool (https://africa-knowledge-platform.ec.europa.eu/energy_tool); (Baldi, Moner-Girona, Fumagalli, & Fahl, 2022).

Food insecurity

According to FAO, a household or a person is food insecure "when they lack regular access to enough safe and nutritious food for normal growth and development and an active and healthy life. This may be due to unavailability of food and/or lack of resources to obtain food" (FAO, n.d.). In practice, food insecurity can be experienced at different levels of gravity, from mild to severe (FAO, 2016). A person who is severely food insecure most likely experiences physiological hunger (FAO, n.d.). Nevertheless, a person who has access to food to meet their energy requirements can be "uncertain that food will last, or they may be forced to reduce the quality and/or quantity of the food they eat in order to get by". This moderate level of food insecurity can still contribute to various forms of malnutrition and can have serious consequences for health and well-being (FAO, n.d.).

Table 1
FIES-SM questions and coding. The questions centre on self-reported food-related habits and experiences connected with increasing challenges arising from resource limitations. Source (FAO, 2016).

	Question: During the last 12 months, was there a time when, because of lack of money or other resources:	Levels of food insecurity
1	You were worried you would not have enough food to eat?	**Food security to mild food insecurity**: uncertainty regarding ability to obtain food
2	You were unable to eat healthy and nutritious food?	**Moderate food insecurity**: compromising on food quality and variety / reducing food quantity and skipping meals
3	You ate only a few kinds of foods?	
4	You had to skip a meal?	
5	You ate less than you thought you should?	
6	Your household ran out of food?	**Severe food insecurity**: no food for a day or more
7	You were hungry but did not eat?	
8	You went without eating for a whole day?	

The Food Insecurity Experience Scale (FIES), developed by FAO, is a statistical tool designed to evaluate the prevalence of food insecurity within a population. The associated Survey Module (SM) consists of eight dichotomous questions (yes/no) that gauge a spectrum of severity in food insecurity (Cafiero, Viviani, & Nord, 2018). As illustrated in Table 1, individuals or households are considered 'food secure to mildly food insecure' if they express uncertainty regarding their ability to obtain food (affirmative response to question 1 in the SM); they are categorised as 'moderately food insecure' when they need to compromise on food quality and variety (affirmative responses to questions 2 and 3) or if they have to reduce the quantity of food and skip a meal (affirmative responses to questions 4 and 5). The classification of 'severely food insecure' applies when individuals or households report going a whole day or more without eating (affirmative responses to questions 6 to 8).[10]

While our questionnaire was designed to capture a continuous scale of food insecurity based on the FIES, a methodological challenge emerged during data collection. Respondents who affirmed a given level of food insecurity (e.g., going a whole day without eating) were not consistently informed about the importance of answering all questions related to the less severe levels of food insecurity. Consequently, many affirmed only one question, hindering the application of the recommended Rasch model and classifications for experience-based food

[10] The Integrated Food Security Phase Classification (IPC) scale for Acute Food Insecurity in Figure 1 is not directly derived from the FIES-SM questions and coding. Instead, the IPC scale uses a range of information sources and indicators, including food consumption, livelihood change, nutritional status, and mortality, to determine the phase of food insecurity for a given population. Therefore, while both tools aim to assess food insecurity, they operate differently and are used for different purposes within food security analysis.

security measurement (Cafiero et al., 2018). To address this challenge, coding was adjusted to align closely with the FAO's definition of severe food insecurity, focusing on situations where individuals ran out of food or went without eating for a whole day. In practice, from the primary data, we derived the severe food insecurity binary variable, *sevfoodins*, taking a value of 1 when respondents answered yes to at least one of the last three questions in Table 1 and zero otherwise. The reference group (where the variable is 0) comprises respondents reporting mild to moderate food insecurity (around 30 % of the sample), as well as those who did not respond to any FIES-SM questions (approximately 4.5 %). In other words, this study emphasises self-reported food insecurity, distinct from objective measures like malnourishment. While this approach cannot thoroughly assess food and nutrition security, it still provides a nuanced understanding of the household's experienced food challenges.

In addition to the FIES-SM questions, respondents were queried about their regular access to fresh food and whether they had ways to keep the food fresh, with both inquiries requiring a yes or no response. These questions were aimed at further understanding the respondents' food security situation by assessing their ability to not only acquire but also maintain the quality of their food, which is crucial for ensuring a nutritious and balanced diet. Accordingly, we defined two additional dichotomous variables, taking a value of 1 when respondents answered yes to the questions on fresh food access and preservation (*ffresh_a* and *ffresh_p*, respectively) and zero otherwise. These two variables are reported for completeness of information only – they do not enter the empirical models.

Table 2 shows that the majority of the observed households experienced severe food insecurity in the year prior to the interview (65 % of the total sample). Also, while the majority had access to fresh food (59 % of the total sample), only a small fraction had the means to preserve it (8 % of the total sample). Disaggregating by refugee settlement unveils stark contrasts (Annex A, Table A.4). The situation is especially severe in Adjumani, where almost 88 % of the sampled households experience severe food insecurity – while the prevalence of severe food insecurity in Uganda in 2020–22 was 25 % (FAO et al., 2023). Access to fresh food was available to less than half (46 %) of the respondents, and only 5 % of them had the means to preserve fresh food. Dzaleka also records a prevalence of severe food insecurity (68 % – compared to the 52 % prevalence of severe food insecurity in Malawi). Access to fresh food is available to a relatively larger share (67 %) of the respondents, and a comparatively large portion of them (16 %) had means to preserve food. In turn, while severe food insecurity is less pervasive in Meheba (25 % – compared to the 32 % prevalence of severe food insecurity in Zambia), and the majority of the respondents (73 %) had access to fresh food, only 5 % reported to have the means to preserve it. According to Thomas, Rosenberg-Jansen, and Jenks (2021), energy and technologies for food preservation are the 'neglected pillars' of food security in the humanitarian domain.

Table 2
Descriptive statistics for household respondents.

Variable	Obs	Mean	Std. Dev.	Min	Max
Food insecurity					
sevfoodins [binary]	926	0.65	0.48	0	1
ffresh_a [binary]	917	0.59	0.49	0	1
ffresh_p [binary]	918	0.08	0.27	0	1
Electricity access					
access [binary]	926	0.24	0.43	0	1
Income and related variables					
income [$/month]	648	175.79	256.98	7.63	1562.50
housework [binary]	926	0.26	0.44	0	1
farming [binary]	926	0.48	0.50	0	1
secondary[binary]	926	0.46	0.50	0	1
Sociodemographic characteristics					
femhead [binary]	914	0.58	0.49	0	1
size [N.]	923	7.26	3.41	1	15

Electricity access

The main focus of this study is on the interplay of severe food insecurity and electricity access. The latter is measured by a dichotomous variable, *access*, taking on the value 1 if the household's energy supply included any of the following technologies: a Solar Home System (SHS), solar PV panels, a connection to a private or shared petrol or diesel generator, mini-grid, or to the national grid. Conversely, a value of 0 was assigned if the energy sources were limited to charcoal, firewood, gas (LPG), kerosene lamps or solar lamps. Solar lamps were specifically coded as 0, not 1, due to their inability to facilitate cooking or preserve food aligning with the paper's objective to examine the influence of functional electricity access on food security.

As reported in Table 2, the rate of electricity access over the observed sample is 24 % and, as expected, the variable *access* is negatively correlated with severe food insecurity (*sevfoodins*) – correlation matrix in Annex A, Table A.5. Also, considerable heterogeneities exist in the rate of electricity access across settlements: 14 % in Adjumani, 28 % in Dzaleka, and 37 % in Meheba.[11]Consistently, fuels and energy supply technologies used by the observed households also varied across settlements (Annex A, Table A.6).[12] For instance, some of the observed households in Dzaleka (13 %) are connected to the national grid, while some of the observed households in Meheba (4.4 %) have access to a diesel generator. By contrast, in a mostly rural setting such as Adjumani, neither of these two options (diesel generator and national grid) are available. The diffusion of home appliances directly related to food utilisation was very limited, with e-cooking devices and fridges at 1.3 % and 2.4 % of the total sample, respectively, compared to e.g., 33 % phone chargers (Annex A, Table A.6 – data also not employed in the empirical models but reported for completeness). Only about 3.2 % of the observed households in Dzaleka reported having e-cooking devices, and 2.8 % reported having fridges. Meheba had the highest diffusion of fridges (5.6 %) but only limited diffusion of e-cooking devices (1.2 %). The diffusion of food-related appliances was negligible in Adjumani.

Income and sociodemographic characteristics

Another important factor contributing to severe food insecurity is income. In this study, *income* is a continuous variable derived from direct questions regarding the minimum and maximum monthly household income. The maximum income, in contrast to the minimum income, is used due to the tendency of the respondents to understate the true value in fear of repercussions on aid reception in humanitarian settings. It is also important to note that the household income was initially reported in the individual's local currency. To achieve comparability across the

[11] Adjumani is a rural area where refugee settlements are relatively recent and present the lowest average income among the observed areas. Consistently, the measured (Tier 2) access rate (14 %) is below both the urban and rural access rates for Tier 1 in Uganda (respectively 72 % and 36 %). Dzaleka is, instead, a semi-urban settlement geographically close to the country's capital, and the national grid reaches one of the areas included in the field data collection. The measured (Tier 2) access rate of 28 % is, respectively, below and above the national access rate for Tier 1 in urban (54 %) and rural (6 %) areas in Malawi. Meheba is the oldest of the observed settlements and the one presenting a relatively large average household income: a (Tier 2) access rate of 37 % is below the urban but above the rural national averages for Tier 1 access in Zambia – respectively 87 % and 14.5 % (IEA et al., 2023).

[12] Analysing poor Sub-Saharan African households' willingness to pay for different types of electricity access, Sievert and Steinbucks (2020) show how income levels can influence households' preferences for off-grid solar technologies vs grid ones.

three different countries, the income amount was converted to international dollars using the World Bank's Purchasing Power Parity (PPP) conversion factor for private consumption (Annex A, Table A.7).

The average monthly income for the observed sample is about $176/month. In fact, the distribution of the *income* variable is left-skewed, with a significant share of respondents indicating a value below the mean (Annex A, Fig. A.1), and a negative correlation exists between *income* and *sevfoodins*. Notably, the average value of the variable *income* is about double in Dzaleka than in Adjumani and twice as large in Meheba than in Dzaleka ($304/month in Meheba, $160/month in Dzaleka and $79/month in Adjumani).

Furthermore, only 70 % of the observed households declared their monthly income. Hence, to include a larger portion of the sample in the empirical analysis, we built three additional income-related variables. Given the refugee status of the respondents, the dichotomous variable *housework* distinctly captures households where members cannot rely on income from work outside of the home. These are about 26 % of the respondents, and, as expected, the variable *housework* is positively correlated with *sevfoodins*. Notably, only a negligible percentage of the observed households in Meheba (2 %) are not engaged in any work outside of the house, compared to a relatively larger percentage in Dzaleka (23 %) and an even larger one in Adjumani (43 %).

The binary variable *farming* is equal to one if the main income-generating activity of the household is crop farming, livestock farming, or a combination of both. While the correlation between *farming* (the main economic activity for almost half of the observed households) and *sevfoodins* is negative, the relationship of this variable with severe food insecurity is conceptually ambiguous. On the one hand, it can signal an unstable (season-dependent) income, and on the other hand, it can mean increased food availability (hence, a negative correlation). The percentage of farming households in the observed sample is the highest in Meheba (71 %) and the lowest in Dzaleka (29 %), with about less than half of the respondents (46 %) engaging in farming in Adjumani.

The binary variable *secondary* captures whether the household can rely on a secondary economic activity to generate income (when this is true, the variable is equal to one). As expected, *secondary* is negatively correlated with food insecurity, and about 46 % of the respondents can count on a second economic activity. Specifically, 66 % of the families in Meheba have a secondary income source; in turn, only less than half of the households in Dzaleka (42 %) and Adjumani (36 %) do.

Finally, this study considers two sociodemographic characteristics of the household. The binary variable *femhead* takes the value 1 when the household head is a woman. More than half of the households in our sample (58 %) are female-headed households, and the variable is positively correlated with increased food insecurity. When considering each settlement separately, female-headed households are the majority only in Adjumani (82 %) but still a sizable percentage in Dzaleka (39 %) and Meheba (36 %).

The variable *size* captures the number of household members. The average size of the observed households is quite similar across settlements (the sample mean is 7.3), with about 6 members in Dzaleka and Meheba and around 8 members in Adjumani. In our sample, larger households are positively correlated with increased food insecurity.

Methodology

To explore the nexus between severe food insecurity and electricity access, we employ different specifications of a logistic regression model. This method is highly fitting for the aim of this study as it lets us assess the likelihood (P) of a household i being severely food insecure (*sevfoodins*) contingent on a collection of predictive factors ($\boldsymbol{X}$), i.e., factors that might affect the occurrence of the event. The conditional probability of the event occurring $(\mathrm{P}(sevfoodins_i) = 1|\boldsymbol{X}_i)$ is a dichotomous variable bounded between 0 and 1 and can be formulated as:

$$P(sevfoodins_i = 1|\boldsymbol{X}_i) = \frac{e^{\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots+\beta_n X_n}}{1+e^{\beta_0+\beta_1 X_1+\beta_2 X_2+\ldots+\beta_n X_n}} \quad (1)$$

Logistic regression models rely on the so-called logit transformation of the probability and estimate the natural logarithm transformation of the odds ($\frac{P}{1-P}$), i.e., of the ratio of the probability of the two outcomes, i.e., the probability of a household being severely food insecure divided by the probability of it *not* being severely food insecure (in this case, mildly or moderately food insecure). The latter is termed the logit function (Wooldridge, 2010) and is expressed as follows:

$$ln\left(\frac{P(sevfdins_i = 1)}{1-P(sevfdins_i = 1)}\right) = \beta_0+\beta_1 X_1+\beta_2 X_2+\ldots+\beta_n X_n \quad (2)$$

where the left-hand side of Eq. (2) are the log-odds (or logits) of being severely food insecure, and the right-hand side takes the form of a conventional linear regression where β_0 is the intercept, and $\beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n$ is the combination of the predictor variables $(X_1, X_2, \ldots, X_n)$ and their respective coefficients $(\beta_1, \beta_2, \ldots, \beta_n)$. Each coefficient represents the change in the log-odds of a household being severely food insecure corresponding to a one-unit change in its respective predictor variable X_i, holding all other variables constant. To estimate the parameter values of the logistic regression model, we employ the Maximum Likelihood Estimation (MLE) method (Wooldridge, 2010).

Specifically, to test the hypothesis of a mitigating effect of electricity access and income on severe food insecurity and to verify the mediating role of the households' sociodemographic characteristics, as well as the impact of other unobserved location-specific characteristics (see end of Section *Energy access and food security*), we estimate a set of three models with an increasing number of explanatory variables. We start with the first model (Model 1) capturing the relationship between the probability of a household being severely food insecure (the dependent variable) and the independent variable *access*; in the same model, we also include the sociodemographic characteristics of the households (variables *femhead* and *size*). Then, using the same dependent variable, we estimate a second model, Model 2, where the independent variables now include *access*, the household income, and the sociodemographic characteristics of the households (*femhead* and *size*).

The descriptive statistics of the data shed light on a pronounced heterogeneity across the settlements under study. Specifically, Meheba exhibits relatively better conditions, particularly with regard to electricity access rates, higher income, and reduced severity of food insecurity. In turn, Adjumani emerges as the most challenged settlement in nearly all dimensions. This variation underscores the complexities inherent in humanitarian settings, emphasising the intricacies associated with each specific settlement/country. While we have no strong reasons to assume that the drivers of severe food insecurity are different in different locations, there are location-specific characteristics that our dataset does not capture (Bofa & Zewotir, 2024). For instance, the scope of our data collection did not include information on food or water availability, which might differ across settlements; other examples of factors that could influence the level of food security for the entire settlement/country include the existence of food-related interventions or differences in national policies affecting refugees' freedom of movement and their right to work. For these reasons, the third model (Model 3 - with the same dependent variable as in the previous two), includes, as independent variables, electricity *access*, the household income, the sociodemographic characteristics of the households (*female* and *size*), and settlement dummies.

While individual variables like settlement age and location could be included in Model 3 in lieu of the settlement dummies, they risk introducing multicollinearity or reducing the degrees of freedom in our analysis, particularly given the limited sample size. Settlement dummies, by contrast, provide a parsimonious way to control for unobserved heterogeneity without overcomplicating the model: they

Table 3
Results of the logistic regression analysis – dependent variable: severe food insecurity.

	Model 1		Model 2a		Model 2b		Model 3a		Model 3b	
	Coeff.	Odds ratios	Coeff.	Odds ratios	Coeff.	Odds ratios	Coeff.	Odds ratios	Coeff.	Odds ratios
Intercept	−0.896*** (0.255)	0.408	1.764*** (0.481)	5.837	−0.846*** (0.283)	0.429	1.834*** (0.546)	6.256	0.641 (0.390)	1.898
access	−0.674*** (0.166)	0.510	−0.559*** (0.201)	0.572	−0.774*** (0.177)	0.461	−0.396* (0.225)	0.673	−0.283 (0.199)	0.754
income (log)			−0.458*** (0.082)	0.633			−0.112 (0.098)	0.894		
housework					1.275*** (0.255)	3.577			0.791*** (0.275)	2.204
farm					0.165 (0.185)	1.179			0.556** (0.220)	1.744
secondary					−0.518*** (0.182)	0.595			−0.353* (0.204)	0.703
femhead	0.946*** (0.148)	2.574	0.726*** (0.182)	2.067	0.821*** (0.155)	2.272	0.508** (0.209)	1.662	0.361** (0.182)	1.435
size (log)	0.654*** (0.132)	1.923	0.341** (0.156)	1.406	0.630*** (0.138)	1.878	0.011 (0.180)	1.011	0.337** (0.153)	1.400
meheba							−2.382*** (0.282)	0.092	−2.585*** (0.244)	0.075
dzaleka							−0.381 (0.279)	0.683	−0.666*** (0.236)	0.514
Obs.	911		639		911		639		911	
Pseudo R-squared	0.098		0.370		0.153		0.462		0.276	

Note: Standard errors are reported in parentheses. The symbols ***, ** and * indicate statistical significance at the 1 %, 5 %, and 10 % level respectively.

capture the composite effect of various settlement-level characteristics while allowing the focus to remain on household-level outcomes, which is central to our analysis. Note that to clarify the results obtained in Model 3 we also estimate Model 1 and Model 2 separately per each of the settlements.

Before presenting the results, a few practical remarks on the regression analysis are as follows. First, considering that about 30 % of the household respondents did not disclose their income (the number of observations for *income* is 648 – see Table 3), we always estimate two versions of Model 2 and Model 3: versions (a) capture household income using the variable *income* and versions (b) achieve the same goal using the income proxies: *housework*, *farming* and *secondary*. Second, following Sievert and Steinbuks (2020), we transformed all continuous variables into logarithms to control for outliers. Third, to diagnose potential multicollinearity between the selected variables, we applied the Variance Inflation Factor (VIF) to all empirical models. The multicollinearity diagnostics confirm that no pair exhibits concerning levels of correlation (all VIF values are well below the commonly used threshold of 10), ensuring the absence of strong multicollinearity among the independent variables and the robustness of the results. Fourth, to interpret the results, we refer to the regression coefficients and the odds ratios, i.e., the ratio of the probability of an event occurring over the probability of it not occurring. Odds ratios express a multiplicative effect (rather than the additive effects of the log-odds): odds ratios greater than 1 correspond to a positive effect (they increase the odds), and odds ratios between 0 and 1 correspond to negative effects (they decrease the odds).

Results

As shown in Table 3, the results from Model 1 and the two variations of Model 2 consistently depict a significative and negative coefficient for the variable *access*. This suggests that access to electricity is associated with a decreased probability of the household experiencing severe food insecurity, as results are consistent when controlling for household income and for sociodemographic factors. As for the latter, we observe a positive relationship between the probability of the household experiencing severe food insecurity and the household being female-headed and larger in size (variables *femhead* and *size*). As for the former, a significant and negative relationship is found in Model 2a between the probability of a household experiencing severe food insecurity and the variable *income*. Consistently, in Model 2b, the probability of a household experiencing severe food insecurity is lower among households having a secondary income-generating activity with respect to those without one (variable *secondary*) and higher for households without productive activities outside of the house with respect to those without (variable *housework)*, while the effect of the variable *farming* (households with farming as the main income- generating activity) is not significant.

In turn, the results of the two variations of the complete model (Model 3, where we also include the settlement dummies), indicate that some of the effects described so far are only weakly confirmed, while location-specific characteristics significantly matter in relation to the probability of a refugee household being severely food insecure. Specifically, Model 3a indicates that the odds of experiencing severe food insecurity decrease by a factor of 0.09 for households located in Meheba rather than in Adjumani (the reference location). In the same model, the variable *access* is statistically significant only at a 10 % level, although with the expected negative sign (the odds of being severely food insecure decreases by a factor of about 0.7 for households with access to electricity with respect to households without access), while the coefficient for *income* becomes insignificant. Of the two variables describing sociodemographic factors, only the gender of the household head is statistically significant (the odds of being severely food insecure are 1.7 times higher when the household head is a woman rather than a man).

When considering Model 3b, where income proxies replace *income*, the coefficients for *meheba* and *dzaleka* are both significant, indicating a decrease in the odds of being severely food insecure for households located in Meheba and Dzaleka compared to households in Adjumani. Also, reversing the findings of Model 3a, the variable *access* is not statistically significant, but the income proxies are. Households counting on a *secondary* income see their odds of being severely food insecure decreased by a factor of 0.7 with respect to those who do not, while the odds of being severely food insecure increase by a factor of 1.7 for households engaging in *farming* as their primary economic activity and are more than two times higher for households not engaged in productive activities outside of the house than for those who are (*housework*). Lastly, the odds of being food insecure are approximately 1.4 times higher in households led by women than in those led by men (*femhead*) and increase with additional households members (*size*).

In summary, settlement dummies capture critical structural differences, such as resource availability and policy environments, that impact food security and were unaccounted for in Model 1 and Model 2. The increase in explanatory power in Model 3 underscores the importance of accounting for these contextual factors when estimating the effects of the household-specific variables. When doing so, the effect of electricity access and income on the probability of the observed refugee household being severely food insecure is in the expected direction but not consistently significant in the two versions of the model. In turn, sociodemographic and location-specific effects exhibit a relatively higher statistical power. In other words, electricity access and income interact with local factors, shaping their impact on severe food insecurity. In Annex A, we report the results of Model 1 and (two versions of) Model 2 when estimated per settlement (Table A.8 – Dzaleka, Table A.9 – Adjumani, and Table A.10-Meheba). The expected mitigating effect of electricity access and income on the probability that a refugee household is severely food insecure can be empirically observed only in one of the three observed communities (Adjumani).[13]

Discussion

The logistic regression results indicate that our main hypotheses, i.e., households with access to electricity and higher income are less likely to experience severe food insecurity, are only partially verified. Conversely, they indicate that settlement-level conditions significantly determine the probability of a refugee household being severely food insecure. Lastly, they suggest that female-headed and larger households exhibit increased vulnerability to severe food insecurity.

As for electricity access, our results only partially support prior empirical evidence that access to electricity decreases the likelihood of severe food insecurity (Candelise et al., 2021; Pondie et al., 2023). While these results were obtained using longitudinal, country-level data, which did not include forcibly displaced populations, this study is based on household-level observations within the humanitarian domain (cross-section data for three settlement locations). Our analysis shows that the mitigating effect of electricity access is only weakly statistically significant in Model 3a and sensitive to local conditions, pointing to the need for further empirical evidence of the interplay between electricity access and food security within refugee settlements. At the same time, it calls for a deeper integrational approach as addressing only one of these domains rather than the common nexus they form, might be insufficient (Thomas, Rosenberg-Jansen, & Jenks, 2021), at least in certain locations (e.g., Adjumani).

Furthermore, our analysis highlights the need for settlement-level studies to identify local factors determining the interconnectedness of food security and energy access within humanitarian settings (Abdalla & Goulao, 2024;). As for the three settlements observed in this study, we can qualitatively note that a lower probability of food insecurity in Meheba aligns with it being an integrated settlement, meaning it can be included in the country's economic development plans. Refugees are free to undertake income-generating activities and live in an open, partly integrated way with the host communities. UNHCR still operates the settlement, but no other UN agency is present, and the budget allocated to Meheba is relatively small compared to the overall residual humanitarian needs. Strategic objectives focus, instead, on inclusion opportunities and local integration (UNHCR, 2021). In turn, the Malawian government has been historically more restrictive towards displaced people, limiting their movement and access to social services and restricting them from employment opportunities. However, the protracted and congested nature of Dzaleka means that only a small portion of the refugee population can meet their basic needs, hence the larger support provided by humanitarian agencies (UNHCR, 2023b). Differently, Uganda is one of the few countries in SSA to have adopted an integrated service delivery approach whereby refugees enjoy the right to work, move freely, own property, and have equal access to social services as nationals (The World Bank, 2021). At the same time, in the district of Adjumani, there are 18 different refugee settlements, and the ones observed in this study face significant gaps in critical sectors, including health, water, and food (Van Hove & Johnson, 2021). In sum, the role of contextual factors remains largely to be explored.

When considering the effect of income, our results resonate well with the findings of Smith et al. (2017) who emphasized the role of employment status (even if informal) in determining food security for resident nationals. The heightened vulnerability to severe food insecurity of households without external economic activities likely stems from their precarious financial circumstances and the absence of regular income streams. Indeed, households that can rely on a secondary source of income are shown to be less likely to experience severe food insecurity. In this regard, we note that irregular income is typical in humanitarian contexts, and numerous factors, including the national policies of host countries, can intensify its implications. Specifically, restrictions on refugees' rights to work can introduce additional layers of economic uncertainty.

Continuing to focus on income, we find that engaging in farming can increase the probability of being severely food insecure. While households engaged in farming are inevitably subject to seasonal fluctuations affecting income and food supply levels throughout the year, the cross-sectional nature of the data means these variations are not directly captured. Nonetheless, since the food insecurity variable encompasses experiences from the last 12 months, it may indirectly reflect the impact of such seasonality. Taking a different perspective, one could have assumed that engaging in farming would reduce the probability of being severely food insecure due to the informal food security net farming can create, as Davis et al. (2010) pointed out. Being involved in farming may generate a certain level of stability in the availability of food as the households could supply themselves with crops and livestock. Beyond being a source of sustenance, engaging in farming could also facilitate access to and collection of crop residues, which essentially could serve as an alternative energy source for cooking. This means that such households, irrespective of their access to electricity or reliance on conventional firewood collection, could possess an additional fuel source that bolsters their overall food security. In sum, the role of farming needs further investigation.

As for sociodemographic characteristics, Buvinić and Gupta (1997) underscored the greater vulnerability to experiencing poverty that female-headed households face, which consequently could put these households more at risk of experiencing food insecurity. This trend manifests in the observed humanitarian settings: our analysis highlights the heightened likelihood of female-headed households in terms of food insecurity. A possible interpretation goes back to the household income. A boxplot (Annex A, Fig. A.2) comparing the distribution of the variable *income* between female- and male-headed households reveals a discernible income disparity, with male-headed households demonstrating a higher median income, possibly explaining this result. While it is tempting to attribute this vulnerability to lower incomes and subsequently compromised access to food, the exact causative factors remain elusive. Potential sociocultural dynamics, including the reasons leading to female headship, need to be probed further before drawing any definitive conclusions, as stressed by Haddad et al. (1996).

The increased likelihood of severe food insecurity associated with larger household size intuitively aligns with the notion that as more members are added to a household, available resources must be spread across more individuals, potentially thinning out the per capita share (e.g., Sraboni, Malapit, Quisumbing, & Ahmed, 2014). Another possible interpretation derives, again, from examining the relationship between household size and the number of income contributors. Indeed, our data suggests that larger households have a higher average income; however, this relationship is not consistently linear (Annex A, Fig. A.3). It is

[13] We have also replicated Model 2a and Model 3a using an imputation approach for the missing income values. This analysis confirms the results of Table 3 for Model 2a and, as for Model 3a, that settlement dummies are significantly correlated with the probability of a household being food insecure – the variable *access* is not statistically significant.

possible that the largest refugee families may be generated by orphans, elderly and persons with disabilities that a head of household takes care of but who cannot produce an income. In sum, without data on individual income contributors within households, drawing definitive conclusions about this aspect remains challenging.

Limitations

As all refugee communities observed in this work fall within SSA, they share geographical, climatic, and potentially sociocultural parallels to a certain degree, and this common ground formed the basis for the aggregate analysis to identify common determinants relevant to food insecurity in humanitarian settlements. While results pointed to a relevant role for local locations, there are limitations to this research that warrant acknowledgement and require the results of our analysis to be interpreted as pertaining primarily to the respondents – their generalisation to the SSA region (or other world regions) should be considered with caution.

A key limitation of the research derives from the data. On the one hand, the questionnaire employed during the fieldwork was not designed to capture the full spectrum of socioeconomic and food security conditions experienced by refugee households at the time of the interviews. As a result, the information available to study food security was limited. Not only the variable capturing food insecurity is less accurately constructed than desirable, but our research was unable to control for additional characteristics known to be related to food insecurity, such as the level of education and labour skills of the household head or access to water and health care. Also, available data on cooking practices and fuels, or energy and food prices, were very limited. On the other hand, the sampling method employed for the collection of the field data lacked stratification. Instead, interviews were conducted by walking through the settlements and asking people if they wanted to be interviewed. While the number of interviews is statistically representative, the sample cannot be considered fully representative of the socioeconomic and demographic characteristics of the observed communities.

Furthermore, while electricity access is not uncommon among the observed households, the diffusion of electrical appliances relevant for food preparation and conservation is rare (see Table A.6). Further research investigating the effect of electricity access on food security should address this distinction – between access to electricity and access to food-related appliances – more carefully than we could do with the available data. Similarly, it should also include the impact of appliances linked to productive uses of electricity (for instance, farming) if they are present.

Finally, although the data collection is extensive compared to other publicly available datasets related to refugees in SSA, the relatively small sample sizes per settlement and the cross-sectional nature of the data imposed restrictions. For instance, only limited data for each settlement exists to shed light on the determinants of food insecurity within each settlement, and the absence of panel data prevents us from capturing, e.g., seasonality more efficiently. Also, causality cannot be inferred from the results, and we could not correct for the potential endogeneity of the determinants of food insecurity – income can have strong reverse causation with food security as improved food security can turn into higher productivity (Candelise et al., 2021). In sum, removing these limitations ultimately hinges on access to better-quality data.

Conclusions

This research explored the food-energy nexus within protracted refugee settlements in Sub-Saharan Africa. The data used for this purpose was collected in 2022 from Meheba (Zambia), Dzaleka (Malawi), and Adjumani (Uganda) via in-person interviews with 926 households. A statistical analysis of the responses revealed a rate of electricity access of 24 % over the entire sample, where this percentage captures households with SHSs, PV panels, or a connection to a diesel generator or to the national grid (thus excluding households with solar lanterns or similar technologies). At the same time, it revealed a prevalence of severe food insecurity (65 % of the sample) and indicated that while fresh food might be accessible to many (59 % of the sample), only a small fraction of the sampled households had ways to preserve it (8 %). Furthermore, 'across settlements' heterogeneity emerged, with Meheba presenting relatively higher electricity access rates and a lower prevalence of food insecurity but also higher income and Adjumani being the most challenged on all fronts.

Drawing from an extensive literature review (looking at studies on resident nationals and forcibly displaced populations), we hypothesised that access to electricity and income, together with selected sociodemographic factors and settlement-level characteristics, would play pivotal roles in determining food insecurity in such environments. Based on logistic regression models, the empirical investigation indicates that electricity access can be associated with a reduced likelihood of experiencing severe food insecurity. This result (connected to the food utilisation dimension) holds when controlling for economic access to food (via the variable *income* but not when controlling for income proxies), sociodemographic factors (household size and headship), and unobserved heterogeneity across settlements (settlement dummies), but present a weak statistical significance (at 10 % level). To reinforce the meaning of the latter remark, we observed that when splitting the sample per settlement, the expected mitigating effect of electricity access on food insecurity is empirically supported only in one location (Adjumani) out of three.

Capturing the mitigating effect of household income (linked to economic access to food) was also not straightforward. Nevertheless, the empirical analyses showed a potentially relevant role for the income proxies as well as for some sociodemographic factors. We observed that a secondary income-generating activity is associated with a lower probability of being food insecure, while not working outside of the house and engaging in farming as the primary economic activity are correlated with a higher one. The same occurs for the size of the household and the gender of the household head (the odds of being food insecure are approximately 1.7 times higher in households led by women than in those led by men).

Finally, we found that settlement-specific characteristics play a relevant role, reducing the probability that a household located in Meheba (or Dzaleka), compared to Adjumani, is severely food insecure. Such findings resonate with the description of the observed refugee communities and are potentially linked to food availability, the quality of other essential services (e.g., water and health), and to national refugee policies governing access to work and freedom of movement but would require an ad-hoc study to be investigated.

By partially extending results previously obtained in a different context (resident nationals) and at a different spatial scale (country level), this study makes an important contribution to the relatively scarce empirical literature on the relationship between electricity access and food security in protracted refugee situations in SSA. Also, it underscores several practical recommendations: *(i)* the need to enhance electricity access, also as a means to support food security, at least in some refugee communities; *(ii)* the need, for the same reason, to facilitate refugee access to work and income-generating activities; *(ii)* the need to include female-headed households in the design of support mechanisms addressing food security; *(iv)* the need to consider the potential benefits of a cohesive policy that simultaneously tackles food security issues and provides long-term energy solutions. In this regard, it is important to recall that the responsibility for national refugee policies lies with the host governments and humanitarian agencies can only advocate for more inclusive ones.

Interventions are urgent, particularly in SSA, where climate change and conflicts pose increasing risks of food and nutrition insecurity. In this context, a better understanding of the interplay between food security, energy, and displacement could support humanitarian agencies in formulating and prioritising sustainable strategies for forcibly displaced and host communities, advocating for more development action and favourable policies that promote the achievement of SDG 2 and SDG

7. Specifically, based on the findings of the present study, new research should look more carefully into:

- The direct and indirect routes that connect energy access and food security, via efficiency gains in the production and conversion of food in the agricultural sector, and via the use of modern technologies in the preparation and conservation of food;
- The role of income-related contextual factors, such as access to wage employment and national refugee policies facilitating freedom of movement and access to work, thus connecting with the advocacy work conducted by UNHCR;
- The role of economic and land-use contextual factors, such as local food availability (local markets and prices), the availability of land for farming (and the legal framework governing land use by refugees), as well as access to water (for drinking/cooking and for agricultural activities);
- And, last but not least, the technological transition to clean cooking fuels as a means to deliver food security and health benefits, and to contribute to the broader environmental and climate agenda – even the growth in electricity consumption, unless decoupled from carbon emissions, could further strain climate-induced challenges, thus amplifying food insecurity even further.

CRediT authorship contribution statement

Hedda Most: Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – original draft. **Magda Moner-Girona:** Visualization, Methodology, Investigation, Funding acquisition, Conceptualization, Writing – original draft. **Paola Casati:** Methodology, Formal analysis, Data curation. **Manuel Llorca:** Supervision. **James Haselip:** Supervision, Conceptualization. **Elena Fumagalli:** Supervision, Funding acquisition, Formal analysis, Data curation, Conceptualization, Writing – original draft.

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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Annex A

Table A.1
Overview of energy access and its impact on food security in the humanitarian domain. The frameworks proposed in the academic literature connect: (a) the barriers to energy access; (b) the lack of access to traditional and/or modern[a] energy (plus other aspects sometimes); (c) the actual impacts; and (d) the impacted food security dimension (although, not always).

Authors	Domain	(a)	(b)	(c)	(d)
Caniato, M., Carliez, D., & Thulstrup, A. (2017)	Humanitarian (in general)	Barriers to energy access: technological, economic, sociocultural, and political	Lack of access to traditional and modern energy	Negative impact via degradation of local environment in the long term	Stability
				Negative impact via degradation of local environment - including disrupted agricultural production - in the short term	Availability
				Negative impact on income available for food	Access
				Negative impact via time poverty due to time spent in fuelwood collection and food preparation instead of productive and income generating activities	
				Negative impact via inefficient technologies	Utilisation
Thomas, P. J. M., Rosenberg-Jansen, S., & Jenks, A. (2021)	Humanitarian (settlements in developing countries)	Lack of coordination between Shelter (responsible for cook stoves and cooking fuel) and WFP and FAO (responsible for food)	Lack of access to traditional and modern energy	Negative impact via lower productivity and inefficient conversion – mostly in agriculture	Availability
				Negative impact on income available for food	Access
				Negative impact via time poverty due to time spent in fuelwood collection and food preparation instead of productive and income generating activities	
				Negative impact via inefficient technologies for food preparation and conservation	Utilisation

(continued on next page)

Table A.1 (*continued*)

Authors	Domain	(a)		(b)	(c)	(d)
Abdalla, L., & Goulao, L. F. (2024)	Humanitarian (refugee camps in the European Union)	Inadequate national policies concerning refugees	Inadequate shelter, WASH, and healthcare	Poverty, unemployment, low education Lack of access to traditional and modern energy Inadequate integration	Not described in detail	Food and Nutrition Insecurity in general

[a] 'Modern' energy includes electricity and clean cooking fuels and technologies (e.g., LPG and solar cookers), while 'traditional' energy refers to fuelwood or solid fuels burnt on open fires or in inefficient stoves.

Table A.2
Overview of energy access and its impact on food security in the broader domain of resident nationals. The frameworks proposed in the academic literature connect: (a) the barriers to energy access; (b) the lack of access (or the access) to traditional and/or modern[a] energy; (c) the actual impacts; and (d) the impacted food security dimension.

Authors	Domain	(a)	(b)	(c)	(d)
Brouwer, I. D., den Hartog, A. P., Kamwendo, M. O. K., & Heldens, M. W. O. (1996) Makungwa, S. D., Epulani, F., & Woodhouse, I. H. (2013).	Resident nationals (Malawi)	Reduced forest stock (converted to crop fields)	Lack of access to fuelwood (traditional energy)	Negative impact via reduced time for food preparation (because of time spent in fuelwood collection) and omission (or substitution) of essential-energy demanding dishes	Utilisation
Sola, P., Ochieng, C., Yila, J., & Iiyama, M. (2016)	Resident nationals (Sub-Sharan Africa)	Not described in detail	Lack of access to fuelwood (traditional energy)	Negative impact via reduction in agricultural productivity (because crop residues and dung are used as energy forms instead of in agricultural practices)	Availability
				Negative impact via reduced time for food preparation (because of time spent in fuelwood collection) and omission of essential energy-demanding dishes	Utilisation
			Lack of access to modern energy	Negative impact via time poverty (allocation of household time to fuel procurement instead of food production and conversion in agriculture)	Availability
				Negative impact via time poverty (allocation of household time to fuel procurement instead of productive and income-generating activities) Negative impact on income available for food	Access
Candelise, C., Saccone, D., & Vallino, E. (2021)	Resident nationals (developing countries)	Not described in detail	Access to electricity	Positive direct impact (via increased productivity and efficient conversion - mostly in agriculture)	Availability
				Positive indirect impact (via income and income distribution)	Economic access
				Positive direct impact (via efficient storage and processing)	Utilisation

[a] 'Modern' energy includes electricity and clean cooking fuels and technologies (e.g., LPG and solar cookers), while 'traditional' energy refers to fuelwood or solid fuels burnt on open fires or in inefficient stoves. The older articles in this review focus on the lack of access to 'traditional' energy. The literature progresses to include 'modern' energy, until the most recent article is only concerned with electricity.

Table A.3
Main characteristics of the refugee settlements. Adapted from Casati et al. (2024).

Settlement	District (Country)	Established	Population (Number)	Urban/rural (Surface)	National refugee policy	Food security
Meheba	Kalumbila (Zambia)	1971	About 34,000	Mix of semi-urban and rural area (720 km^2)	Supportive (CRRF and GCR adopted)[a]	About 57 % of population surveyed via the Standardised Expanded Nutrition Survey (SENS) reduced the quantity and/or frequency of meals during the month before the survey (moderate food insecurity); no general food distribution (UNHCR et al., 2018).
Dzaleka	Dowa (Malawi)	1994	About 50,600	Urban to semi-urban area (2 km^2)	Restrictive (CFFR adopted, GCR planned but not implemented)[a]	Significant increase in food insecurity, rising from 68 % in 2020 to 87 % in 2023; all refugees receive cash-based food assistance that was reduce to 70 % of the caloric needs due to funding constraints since September 2020 (WFP, 2023).
Nyumanzi Pagirinya Ayilo I Maaji II	Adjumani (Uganda)	2014 2016 2014 2015	About 43,000 About 35,500 About 25,200 About 17,000	Rural area (3128 km^2 for the entire district)	Supportive and proactive (CRRF and GCR adopted)[a]	In 2023, the leading basic need that households cannot meet is food (80 %) – by contrast fuel for cooking is unmet in only 9 % of households; 93 % receive food assistance in kind or in cash; based on the Consolidated Approach for Reporting Indicators (CARI) of food security (combining the Food Expenditure Share, Food Consumption Score, and Livelihood Coping Strategies indicators) 15 % of households were severely food insecure and 60 % moderately food insecure (UNICEF Uganda et al., 2024).

[a] CRRF is the Comprehensive Refugee Response Framework, and GCR is the Global Compact on Refugees.

Table A.4
Descriptive statistics for household respondents per settlement.

Variable	Dzaleka (Malawi)					Adjumani (Uganda)					Meheba (Zambia)				
	Obs.	Mean	Std. Dev.	Min.	Max.	Obs.	Mean	Std. Dev.	Min.	Max.	Obs.	Mean	Std. Dev.	Min.	Max.
Food insecurity															
sevfoodins [binary]	252	0.68	0.47	0	1	422	0.88	0.33	0	1	252	0.25	0.44	0	1
ffresh_a [binary]	244	0.67	0.47	0	1	421	0.46	0.50	0	1	252	0.73	0.45	0	1
ffresh_p [binary]	244	0.16	0.37	0	1	422	0.05	0.22	0	1	252	0.05	0.21	0	1
Electricity access															
access [binary]	252	0.28	0.45	0	1	422	0.14	0.34	0	1	252	0.37	0.48	0	1
Income and related variables															
income [$/month]	169	160.48	136.00	16.01	960.58	261	78.99	105.62	7.63	572.26	218	303.54	375.99	15.63	1562.50
housework [binary]	252	0.23	0.42	0	1	422	0.43	0.50	0	1	252	0.02	0.15	0	1
farming [binary]	252	0.29	0.45	0	1	422	0.46	0.50	0	1	252	0.71	0.45	0	1
Secondary [binary]	252	0.42	0.49	0	1	422	0.36	0.48	0	1	252	0.66	0.47	0	1
Sociodemographic characteristics															
femhead [binary]	250	0.39	0.49	0	1	417	0.82	0.38	0	1	247	0.36	0.48	0	1
size [N.]	252	6.40	3.33	1	15	419	8.41	3.34	1	15	252	6.21	3.00	1	15

Table A.5
Correlation matrix.

	sevfoodins	*ffresh_a*	*ffresh_p*	*access*	*income*	*housework*	*farming*	*secondary*	*femhead*	*size*
sevfoodins	1									
ffresh_a	−0.103	1								
ffresh_p	0.075	0.176	1							
access	−0.166	0.071	0.032	1						
income	−0.267	0.143	0.206	0.219	1					
housework	0.266	−0.112	−0.017	−0.003	−0.207	1				
farming	−0.177	0.039	−0.026	−0.100	0.034	−0.538	1			
secondary	−0.257	−0.083	0.021	−0.076	0.207	−0.521	0.444	1		
femhead	0.261	−0.169	0.065	−0.115	−0.226	0.216	−0.032	−0.174	1	
size	0.130	−0.092	−0.027	0.010	0.043	0.121	−0.007	−0.017	0.133	1

Table A.6
Diffusion of energy sources and appliances among households per settlement (percentages on the total number of respondents – multiple answers were possible. Information was gathered during the field data collection by visually inspecting the technologies in use in each of the observed households.

	Appliances [%]		Energy technologies and fuels [%]						
	E-cooking	Fridge or freezer	None, torches, candles	Charcoal	Firewood	Solar lamps	Solar PV/SHS	Petrol/diesel generator	National grid
Dzaleka	3.2	2.8	9.1	57.1	40.5	13.9	15.5	0	13.1
Adjumani	0.2	0.2	2.1	39.1	82	3.6	13.7	0	0
Meheba	1.2	5.6	5.6	31	27.4	30.6	34.1	4.4	0

Table A.7
Purchasing Power Parity (PPP) conversion factors.

Country	Conversion factor[a]
Malawi [Malawian Kwacha/international $] - 2021 data	312.31
Uganda [Ugandan Shilling/international $] - 2021 data	1,310.6
Zambia [Zambian Kwacha/international $] - 2021 data	6.4

[a] Source: https://data.worldbank.org/indicator/PA.NUS.PPP - Accessed in Nov. 2022.

Table A.8
Dzaleka - Results of the logistic regression analysis – dependent variable: severe food insecurity.

Dzaleka	Model 1		Model 2a		Model 2b	
	Coeff.	Odds ratio	Coeff.	Odds ratio	Coeff.	Odds ratio
Intercept	0.054	1.056	1.578	4.849	−0.128	0.880
	(0.400)		(1.057)		(0.431)	
access	0.361	1.434	0.101	1.107	0.244	1.276
	(0.321)		(0.426)		(0.341)	
income (log)			0.096	1.101		
			(0.203)			
housework					1.744***	5.718
					(0.489)	
farm					0.370	1.448
					(0.348)	
secondary					0.033	1.033
					(0.336)	
femhead	0.180	1.198	0.222	1.248	0.188	1.207
	(0.283)		(0.366)		(0.294)	
size (log)	0.323	1.379	−0.638*	0.528	0.198	1.219
	(0.221)		(0.343)		(0.224)	
Obs.	250		168		250	
Pseudo R-squared	0.023		0.402		0.078	

Note: Standard errors are reported in parentheses. The symbols ***,** and * indicate statistical significance at the 1 %, 5 %, and 10 % level respectively.

Table A.9
Adjumani - Results of the logistic regression analysis – dependent variable: severe food insecurity.

Adjumani	Model 1		Model 2a		Model 2b	
	Coeff.	Odds ratio	Coeff.	Odds ratio	Coeff.	Odds ratio
Intercept	0.461	1.586	1.704*	5.495	0.689	1.993
	(0.655)		(0.949)		(0.777)	
access	−0.798**	0.450	−1.020**	0.361	−0.893**	0.409
	(0.378)		(0.425)		(0.406)	
income (log)			−0.279*	0.757		
			(0.154)			
housework					−0.129	0.879
					(0.521)	
farm					0.305	1.356
					(0.518)	
secondary					−0.712	0.491
					(0.466)	
femhead	0.932***	2.539	1.109***	3.031	0.953***	2.593
	(0.338)		(0.398)		(0.342)	
size (log)	0.481	1.617	0.279	1.322	0.460	1.583
	(0.314)		(0.371)		(0.318)	
Obs.	414		255		414	
Pseudo R-squared	0.069		0.375		0.077	

Note: Standard errors are reported in parentheses. The symbols ***,** and * indicate statistical significance at the 1 %, 5 %, and 10 % level respectively.

Table A.10
Meheba - Results of the logistic regression analysis – dependent variable: severe food insecurity.

Meheba	Model 1		Model 2a		Model 2b	
	Coeff.	Odds ratio	Coeff.	Odds ratio	Coeff.	Odds ratio
Intercept	−1.282***	0.277	-1.347	0.260	−1.455**	0.233
	(0.492)		(0.963)		(0.574)	
access	−0.472	0.624	−0.331	0.718	−0.466	0.628
	(0.323)		(0.346)		(0.326)	
income (log)			0.0133	1.013		
			(0.172)			
housework					0.676	1.967
					(0.955)	
farm					0.479	1.615
					(0.372)	
secondary					−0.448	0.639
					(0.329)	
femhead	0.209	1.233	0.368	1.445	0.162	1.176
	(0.307)		(0.329)		(0.311)	
size (log)	0.137	1.147	0.123	1.131	0.205	1.227
	(0.267)		(0.285)		(0.278)	
Obs.	247		216		247	
Pseudo R-squared	0.051		0.143		0.063	

Note: Standard errors are reported in parentheses. The symbols ***,** and * indicate statistical significance at the 1 %, 5 %, and 10 % level respectively.

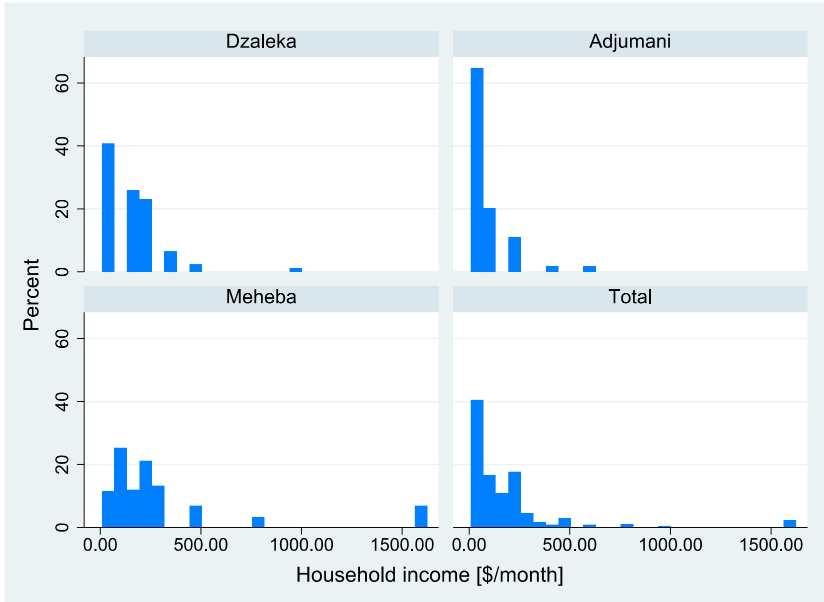

Fig. A.1. Distribution of monthly household income within settlements and over the total sample.

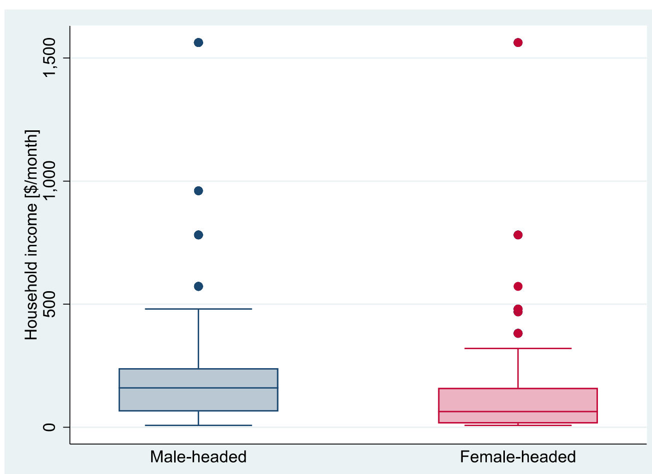

Fig. A.2. Box plot of the household monthly income per gender of the household head. The box captures values in the 25th to 75th percentile. The whiskers represent the highest and lowest data points, excluding outliers.

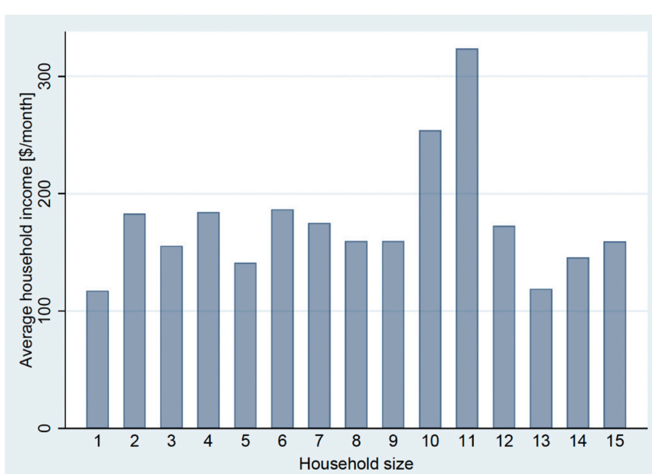

Fig. A.3. Average monthly income by household size.

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