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RESEARCH ARTICLE

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Climatic shocks and multidimensional energy poverty in Ugandan households: does women empowerment play a moderating role?

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ABSTRACT

This study examines the effect of climatic shock and women empowerment on multidimensional energy poverty using panel data from Uganda National Panel Surveys from 2013/14–2019/20, complemented by the World Bank African Rainfall Climatology version 2 (ARC2) database. We find that climatic shocks increase energy poverty. However, there is great potential in energy poverty alleviation when women are more empowered in relation to men, but it is even greater when both genders are empowered in the same household amidst climatic shocks. Combating the impacts of drought, floods, landslides, and irregular rainfall while enhancing women's economic empowerment avenues should be a priority on the policy agenda for multidimensional energy poverty alleviation in Uganda.Highlights

- Energy poverty is assessed using a multidimensional approach.
- Four waves of the Uganda National panel survey and weather data were used
- Climatic shocks increase energy poverty.
- Women empowerment reduces energy poverty amidst climatic shocks, more so when both genders are empowered in the same household.

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Multidimensional; energy poverty; climatic shocks; women empowerment; Uganda

1. Introduction

Energy poverty alleviation is a key policy concern in developed and developing economies (Rodriguez-Alvarez, Llorca, and Jamasb 2021; Zhao et al. 2022). In Africa, modern energy is considered a pillar of socioeconomic growth (IEA 2022) as it provides essential capabilities that allow individuals to satisfy their fundamental energy needs (Churchill and Smyth 2020). However, inadequate access to modern energy coupled with the inability to use modern energy services in a convenient, affordable, reliable, and sustainable manner impairs human welfare, resulting in energy poverty. Energy poverty, defined as a 'situation of inability to realise basic energy needs due to lack of essential capabilities or insufficient choices in accessing and using modern energy services in a reasonable manner' (Day, Walker, and Simcock 2016), deprives people of the necessary capabilities to achieve valued functionings and undermines sustainable development in many ways (Lee et al. 2020; Nussbaumer, Bazilian, and Modi 2012; Ssennono et al. 2021).

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Thus, reducing energy poverty is a top priority on the agenda of many governments and international organisations, including the International Energy Agency (IEA), United Nations (UN), World Bank, among others (Sy and Mokaddem 2022).

Although extant literature considers socioeconomic explanations for energy poverty problem (see, e.g. Ampofo and Mabefam 2021; Churchill and Smyth 2020; Dogan, Madaleno, and Taskin 2021; Koomson and Danquah 2021; Du, Song, and Xie 2022; Rodriguez-Alvarez, Llorca, and Jamasb 2021; Munro and Bartlett 2019; Crentsil, Asuman, and Fenny 2019), the role of climatic shocks and women empowerment in explaining energy poverty has not been extensively examined – notably, the moderating role of women empowerment in the climatic shocks-energy poverty nexus at micro-level. Climatic shocks are unexpected weather events that outstrip the capacity of households to cope with them (De la Fuente 2007). They manifest in terms of prolonged drought, floods, and irregular rainfall and trigger adverse effects on microeconomic systems, environment, and livelihoods, ultimately impacting human wellbeing (Thakur and Bajagain 2019). On the other hand, women empowerment has been defined in many ways (Tandon 2016). However, in this study, it refers to the ability of women to access and manage material and social resources as well as influence issues that affect them (Friedman 1992; Kabeer 1999).

The motivation to investigate the association between climatic shocks, women empowerment and energy poverty stems from earlier research which shows that climatic shocks influence energy poverty (Feeny, Trinh, and Zhu 2021; Nawaz 2021; Li, Smyth, and Yao 2022; Churchill, Smyth, and Trinh 2022); especially among socially vulnerable groups including women (Asfaw and Maggio 2018). Theoretically, Sen (1999) posits that empowering such individuals enhances their capacities to withstand adversities and attain valued functionings such as access to and use modern energy services. As such, the present paper analyzes the effect of climatic shocks and women empowerment on multidimensional energy poverty using panel data for Uganda.

The energy poverty situation in Uganda reflects that of many low-income economies in Africa, making it an ideal context for this study. As is the case in many countries in Africa, the government of Uganda, through Sustainable Energy for All (SE4ALL) agenda, National Development Plans (NDP) II & III, and revised Energy Policy, is committed to ending energy poverty by 2040 (National Planning Authority 2020; MEMD 2019). To reaffirm the commitment, the country has embraced numerous policy initiatives to address energy poverty, including the ambitious rural electrification agenda, free electricity connection policy, and grid line intensification (MEMD 2019). However, despite these endeavors, more than 60% and 90% of the population lack access to electricity services and clean cooking solutions respectively (Ssennono et al. 2021; UBOS 2020). Consequently, many households have resorted to catastrophic coping mechanisms such as illicit electrical connections (electricity theft), the use of suboptimal fuels and technologies, skipping meals, and the use of life-threatening substances (such as paracetamol) to speed up cooking in order to conserve fuel (Wesonga 2020; Miller and Ulfstjerne 2020). Besides, rural women and children spend productive time (between 2 and 7 hours daily) collecting firewood and then inhaling dangerous fumes from indoor biomass stoves while cooking (Bamwesigye et al. 2020; WHO 2018). Such actions are manifestations of energy poverty and adversely affect human health, the environment, and other socioeconomic outcomes. For instance, around a fifth of Ugandan women and children die prematurely each year from inhaling toxins from indoor biomass stoves (WHO 2018). Moreso, recent evidence indicates that over 66% of Uganda's population is trapped in multidimensional energy poverty (Ssennono et al. 2021). Relatedly, a report by World Bank ranks Uganda as one of the top 20 countries with high incidences of energy poverty in sub-Saharan Africa (IEA, IRENA, UNSD, World Bank and WHO 2020). The country also has rich panel survey data, the Uganda National Panel data from World Bank's Living Standards and Measurement Study. The dataset provides information on women empowerment, energy access, cooking solutions, modern energy appliances, incidences of climatic shocks, coping strategies, and several socioeconomic characteristics; hence it supports the detailed analysis of the study variables.

This study is novel for Uganda and contributes to energy poverty literature by analyzing the effect of climatic shocks and women empowerment on energy poverty. Specifically, it complements prior studies that examine the impact of temperature shocks on energy poverty in different contexts (Churchill, Smyth, and Trinh 2022; Feeny, Trinh, and Zhu 2021; Li, Smyth, and Yao 2022) by analyzing climatic shocks in terms of self-reported indicators like drought, irregular rainfall, and floods. Unlike prior studies that look at temperature shocks as an exogenous variable (in terms of percent deviation in rainfall days), this study uses both self-reported shocks and percent deviation in rainfall days to ensure that the results are robust to alternative measures. More importantly, the study also explores the moderating effect of women empowerment on climatic shocks and energy poverty, as prior literature shows that climatic shocks increase energy poverty, especially among socially disadvantaged groups in Africa, including women (Listo 2018; Konte and Tirivayi 2019). Subsequently, other studies (e.g. Chaudhry and Shafiullah 2021) suggest the need for gendered policies to address the energy poverty problem in developing countries. Thus, this study provides evidence of the effect of women empowerment on energy poverty amidst adversities of climatic shocks.

The rest of this paper is structured as follows; section 2 summarises relevant literature; section 3 describes the data, variables, and methods; section 4 details the results and discussion; and section 5 concludes and provides policy implications.

2. Review of relevant literature

2.1 Measurement of energy poverty

There are scholarly discussions over what energy poverty is and how it should be measured. Many researchers and international organisations have attempted to define the concept in developing countries however, there is no universally accepted definition to date (Sy and Mokaddem 2022). The definition employed in the current study is based on Sen's capabilities framework (Sen 1999), which views Poverty as a state of deprivation in various capabilities useful in achieving valued functionings – a set of 'doings and beings.' Accordingly, energy poverty (a typical dimension of Poverty) refers to the 'inability to realise basic energy needs or functionings due to lack of essential capabilities in accessing and using modern energy services in a reasonable manner' (Day, Walker, and Simcock 2016).

Three methodological approaches are widely used in the energy poverty assessment: these include, unidimensional, dashboard, and multidimensional. The unidimensional measure uses objective or single indicators to measure and report energy poverty (Pachauri et al. 2004). This assessment method uses two approaches that is, (a) the engineering approach, which estimates the minimum energy requirement for essential energy services demanded by the household; and (b) the economic approach, which focuses on household income and energy expenditure to calculate the energy poverty line (see a review by Sy and Mokaddem 2022). The energy expenditure-income approach argues that households with relatively higher shares of energy related expenditure in their budget are considered energy poor (Boardman 1991). Although the approach is objective, it is more suitable for assessing energy poverty in the context of developed countries where appropriate data is available than in developing countries (Rafi, Naseef, and Prasad 2021). While poverty studies have widely used the Boardman method, this measure is limited in what it captures (affordability concerns) and sensitive to the choice of method applied to capture the rate of energy poverty incidence (Churchill and Smyth 2020; Herrero 2017).

The subjective approach measures relative energy poverty using qualitative tools (Gordon et al. 2000). This measurement approach underscores the value of self-reported indicators, primarily because they capture the material deprivation that results in households being unable to heat their houses in the winter (Thomson, Bouzarovski, and Snell 2017). Since each family defines thermal comfort differently, subjective self-reported metrics can strongly capture respondents' perceptions (feelings) of energy poverty. This approach helps to overcome the problem of purely using the objective measure suggested under the expenditure-based approach, especially in cases where the intended energy spending is higher than the actual expenditure. However, the main limitation to using subjective indicators to capture energy poverty is that it may bias estimates, mainly if not supported with quantitative evidence. In addition, the indicators may be prone to exclusion error due to the cultural sensitivities to energy poverty, especially where poor households are unwilling to reveal their incapacity to afford modern energy services (Churchill and Smyth 2021).

The multidimensional approach views energy poverty as deprivation (Day, Walker, Simcock 2016). This method uses two thresholds or 'cut-offs' to identify the multidimensional energy poor – one indicator specific and the other related to the number of indicators. A deprivation value or score (ranging between 0 and 1) is assigned to a household or an individual in relation to the weighted total of other deprivations. This approach is extensively applied to assess energy poverty in developing countries (Qurat-ul-Ann and Mirza 2020). The measure offers composite and aggregate level indicators that facilitate easy analysis and worldwide comparison (Nussbaumer, Bazilian, and Modi 2012; Ssennono et al. 2021). In addition, the method permits the integration of objective and subjective indicators by categorising them into dimensions (Churchill and Smyth 2020). Moreover, the technique is adaptable and thorough, making it appropriate for capturing the complex nature of energy poverty in the populace (Day, Walker, and Simcock 2016). The problem, however, is that no indicators, deprivation scores, or cut-offs have been internationally agreed upon (Pelz, Pachauri, and Groh 2018; Sokołowski et al. 2020). Notwithstanding, certain methods for determining cut-off points and deprivation scores/weights have been advanced in the literature. Therefore, the current study uses the Multidimensional Energy Poverty Index for Uganda (MEPI-U) (Ssennono et al. 2021). This is because the metric integrates both the demand and supply sides of energy deprivations.

2.2 Climatic shocks and energy poverty

Climatic shocks are major natural hazards that threaten modern energy transition and family subsistence in developing nations (Endalew and Sen 2021). Climatic shocks such as drought, irregular rainfall, and floods are significant externalities that negatively impact on the microeconomic systems (Endalew and Sen 2021). According to Dercon, Hoddinott, Woldehanna (1999), shocks are unfavorable occurrences that cause drop in consumption, loss of productive assets, loss of livelihood (Akwango et al. 2017), income (Rafi, Naseef, and Prasad 2021), and rural livelihoods (Endalew and Sen 2021). In sub-Saharan Africa (SA), climatic shocks have been found to increase energy poverty, partly because agriculture – the region's major income source – depends on rainfall and other climatic factors (Hallegatte, Fay, and Barbier 2018; Nsubuga et al. 2021). Floods, droughts, and erratic rainfall are examples of climatic shocks that thwart agricultural productivity, food security (Akwango et al. 2017), income (Rafi, Naseef, and Prasad 2021), and rural livelihoods (Endalew and Sen 2021).

Existing literature identifies multiple ways in which climatic shocks exacerbate energy poverty. For instance, using data from the Household Living Standards Survey (2010–2016) and forecasts from the European Centre for Medium-Range Weather Forecasts, Feeny, Trinh, and Zhu (2021) analyzed how temperature shocks affect energy poverty in Vietnam. They found that a multidimensional energy poverty measure rises after temperature shocks. Their research indicates that temperature shocks affect energy poverty by lowering agricultural revenue and productivity. Another study by Endalew and Sen (2021) also reveals that drought negatively influences household life and raises the demand for water, energy, and other social services in Ethiopia.

In Vietnam again, Que et al. (2022) investigated the effects of temperature shocks on energy poverty, and the findings reveal that short-term temperature changes have a considerable effect on energy poverty. They found that shocks lower agricultural output, followed by a rise in energy poverty. The findings further show that income moderates climatic shocks (Que et al. 2022). These results suggest that rising temperatures intensify fuel hardships independent of income or labor productivity; for example, by upsetting microeconomic systems. Likewise, Li, Smyth, and Yao (2022) examined the casual effect of warmer temperatures on energy poverty among Chinese using household survey data. The findings show that hotter weather worsens energy poverty on both extended and intense edges. The study found that higher temperatures reduce household income, decreasing the amount of money available for energy expenditures. Awaworyi Churchill, Smyth, and Trinh (2022) used Australian longitudinal data to analyze how an increase in temperature affects energy poverty and how it replicates the consequences of global warming. The authors conclude that lower temperatures reduce the likelihood of facing energy poverty.

Generally, the preceding studies suggest that climatic shocks in terms of temperature variations affect many socioeconomic indicators, including energy poverty. Unlike in extant literature, where temperature variations have mainly been measured using percent deviations in rainfall days, the current study utilises self-reported climatic and exogenous shocks (percentage deviation in rainfall days) to estimate energy poverty from a low-income economy perspective.

2.3 Women empowerment and energy poverty

The international development policy has given priority to empowerment, particularly for women, due to its role in driving the attainment of sustainable development (Rao, Min, and Mastrucci 2019). The concept of power relations, which relates to obtaining either more or less authority amongst actors, is fundamental to empowerment. According to Sen (1999), empowerment is a form of human capability that enhances one's ability to control the resources at their disposal and to transform those resources into desired results. This implies that it is a positively valued capability that allows individuals to attain their desired functionings, including averting energy poverty situations (González-Eguino 2015). Similarly, empowerment is defined by Kabeer (1999) as the confluence of resources, agency, and accomplishments that come from exercising power. Along those lines of argument, women empowerment is considered a unique type of empowerment since it encompasses decisions made in the family and home (Doepke and Tertilt 2019; Yasmin and Grundmann 2020).

Existing literature on women empowerment emphasises women's authority, control over resources and the capacity to make decisions about their lives, such as women's status, autonomy, and gender equality (Yasmin and Grundmann 2020). For instance, Malhotra and Schuler (2005) indicate that women empowerment comprises the ability of women to manage their resources and the power to make life decisions. Relatedly, Kabeer (1999) views women empowerment as 'women's ability to make strategic life choices where that ability had been previously denied them.' In other words, women empowerment entails the financial, social, human, and political resources that can increase a woman's ability to exercise power over her life choices. Such resources include education attainment, employment, social capital, networks, property ownership, and productive activities (Kabeer 1999). Following the various ways that women empowerment has been conceptualised, it has many dimensions, yet no direct measure exists in the literature. In other words, the women empowerment construct encompasses all facets of women's agency, rights, and resource ownership, making it multifaceted or multidimensional (Malapit et al. 2019; Sharaunga, Mudhara, and Bogale 2019).

A number of prior studies have attempted to investigate the connection between women empowerment and the different aspects of energy poverty but available evidence is limited to a few dimensions of energy poverty. For instance, Yasmin and Grundmann (2020) studied the effect of women empowerment on the decision to acquire clean cooking technology using individual-level household survey data from Pakistan. They discovered that financially independent women with greater agency and control over their resources are more likely to purchase or use biogas technology in their homes. The results also show that a woman's assets (such as agricultural land or home), education level, and employment status significantly influence her capacity to participate in household fuel choices. Another study in Indonesia covering 351 agricultural households revealed that involving a spouse in decision-making increases the likelihood of using modern cooking options, such as biogas technology (Putra, Liu, and Lund 2017). In addition, a study in India found that women tend to have higher preferences for clean fuels and technologies than men do, especially when there is financial means or positive benefits are expected (Puzzolo et al. 2016). Similarly, Mohapatra and Simon (2017) and Pachauri and Rao (2013) contend that a woman's intra-household bargaining power considerably enhances a household's decision to use contemporary cooking fuels and technologies.

Opoku, Kufuor, and Manu (2021) investigate the effect of women's participation in politics on access to modern energy in 36 African nations. The results demonstrate that having more women in parliament typically results in more people having access to electricity, including using sustainable energy sources. In the context of this study, involvement of women in political and in decision-making positions is just one way of exhibiting women empowerment. Implying that, a woman who is politically empowered is likely to enhance electricity access in their communities they represent while at the same time contributing to household consumption. To further support this assertion, Gafa and Egbendewe (2021) assessed the determinants of energy poverty in rural Senegal and Togo. The study indicates that women generally devote more energy resources than men. In addition, the study findings reveal that where the head of the household and the spouse jointly decide on energy usage, the household tends to use clean energy than when the choice is made solely. This finding emphasises the necessity of enhancing women's empowerment to enable them to engage in income generating activities since it could reduce energy poverty, particularly in rural Togo.

Furthermore, Choudhuri and Desai (2020) indicate that households that use clean fuels are often those where a woman has a high level of bargaining power over household choices. More recently, Murshed (2022) found that women's empowerment is key to the transition to clean cooking fuels in Sub-Saharan African nations. Implying that, where women are given the tools, they need to engage in economic activity, generate their own money, and manage it, they may be able to invest in modern energy services (de Groot et al. 2017).

Given that, energy poverty has a woman face in many developing countries (Amigo-Jorquera et al. 2019; Nguyen and Su 2021; Moniruzzaman and Day 2020; Ssennono et al. 2021), it's also important to understand the implications of women empowerment on energy poverty from a perspective of a low-income country. Prior literature suggests that women empowerment is essential in fighting the energy poverty problem (Putra, Liu, and Lund 2017; Mohapatra and Simon 2017; Pachauri and Rao 2013; Yasmin and Grundmann 2020). However, all these studies have dwelt on only one dimension of energy poverty, improving cooking solutions. This paper examines the role of women empowerment, a multidimensional construct in alleviating multidimensional energy poverty. Moreover, this study also analyses the moderating effect of women empowerment on climatic shocks and energy poverty.

3. Data and empirical methodology

3.1 Data

This study utilised four waves of the Uganda National Panel Survey (UNPS) data collected in 2014, 2016, 2019 and 2020 by Uganda Bureau of statistics with technical and financial support from the World Bank. The data used in the current study can be accessed on World Bank's website (www.worldbank.org). The UNPS data is unique because it comprises detailed and consistent data on several socioeconomic variables at individual and household levels over a horizon of 15 years, spread over eight rounds of data collected within 322 enumeration areas linked across time and that cover Uganda entirely. Each survey round covered a cross-section of a nationally representative sample of households surveyed over twelve months. Initially, the UNPS of 2009/10 had a total sample of 3123 households tracked up to 2011/12. However, due to attrition, a total of 2082 households had complete information between 2013/14 and 2019/20. Accordingly, this study analysed 2082 households tracked across the four waves. Of those, 2031 had at least a household member aged 14–64 years which is the working age according to the national employment policy of Uganda (MGLSD 2011). Previous studies like Sunday et al. (2022) used six waves of the same data – the Uganda panel dataset and they investigated the effect of attrition bias using attrition probits (Fitzgerald, Gottschalk, and Moffitt 1998). Their study findings revealed no statistical differences in the demographic characteristics of the households that transited from the earlier waves and those that did not. Therefore, the current study assumes that attrition bias is less likely to affect the results of the remaining sample.

The UNPS data was preferred because it offers detailed information on power access, use, cost, affordability, dependability, capacity, cooking technology, cooking fuels, cooking time and firewood collection time, and outages. Furthermore, the survey contains compressive information on shocks and coping strategies of households. Households were asked whether they experienced listed shocks (drought, irregular rainfall, floods, and landslides inclusive) in the twelve months before the survey. This information was used to derive self-reported incidences of climatic shocks (droughts, floods, Irregular Rains) alongside rain deviations using remote sensing data from African Rainfall Climatology version 2 (ARC2). According to Michler et al. (2020), the ARC2 is presumed to be a reliable weather data source, which is appropriate for Uganda. The analysis is based on 8124 observations.

3.2 Key variables

3.2.1 Multidimensional energy poverty (MEPI)

The current multidimensional energy poverty measure used in the current is computed following the Alkire-Foster method (see Ssennono et al. 2021). The measure employs equal weights for dimensions (energy access, cooking solutions, electrical services, and appliances) and nested weights for respective indicators as shown in Table 1. Each household's deprivation score is based on the deprivations they face in each of the eight indicators. The maximum deprivation score of each dimension is 1/3 of 100% or 33.3%. Electricity energy supply (access) and services and appliances dimensions each have three indications with each indicator weighted as 1/9 [1/3*1/3]. On the other hand, each cooking solutions indication is weighted as 1/6 [1/3*1/2]. Summating deprivation scores helps to identify multidimensionally energy deprived households. Literature uses a 30% cut-off to separate poor and non-poor individuals (Nussbaumer, Bazilian, and Modi 2012; Lozano and Taboada 2020) so that if the household's deprivation score is 30% or greater, it is multidimensionally energy poor (see detailed discussion in Ssennono et al. 2021).

Energy poverty is multidimensionally calculated as follows:

(a) *The Headcount Ratio (H):* This is the proportion of the multidimensionally energy-poor households in the population:

$$H = \frac{q}{n} \tag{1}$$

From Equation 1, q is the number of multidimensionally energy-poor households, and n is the total number of households.

(b) *The Intensity of Poverty (A):* This is the average proportion of the weighted component indicators in which multidimensionally energy-poor households are deprived. For multidimensionally energy-poor households only (those with deprivation scores greater than or equal to 30%), the deprivation scores are summed and divided by the total number of the

Table 1. Dimensions, indicators and deprivation cut-offs for multidimensional energy poverty.

Dimension(i)s	Indicator(j)	Variable	Deprivation cut-off (energy poor if) (1/0)	Weight
Electricity Energy supply (energy access)	Capacity	Power capacity ratings	Household has a power capacity rating of less than 500 kWh per day, uses a solar lantern, or has no access to electricity.	1/9
(1/3)	Quality	Quality of power	Household experiences low voltage of electricity, damage to appliances or uses a solar system that cannot power large devices or households use devices such as candles, dry cell batteries, kerosene lamps, etc., due to lack of access.	1/9
	Affordability	Affordability of power	Household spends >5% of total income on energy or household cannot afford to pay connection fee, and even if they are waived, they cannot afford the electricity bills.	1/9
Cooking solutions	Cooking exposure	Cooking exposure	Household uses a three-stone/open-fire stove or an unimproved cooking stove with traditional fuels in a poorly ventilated area.	1/6
(1/3)	Affordability	Expenditure on cooking fuel	Household's expenditure on cooking fuel is more than 5% of the total income or cannot afford an Improved Cooking Stove (ICS).	1/6
Electricity service and appliance	Information, communication, and entertainment	Information, communication, and entertainment appliance ownership	Household neither has a radio, mobile phone, phone charger, TV nor VCD/DVD.	1/9
(1/3)	Housing	Roofing type	Household members live in a dwelling with a grass thatched roof.	1/9
	Access to community services	Existence of at least one enterprise powered with electricity in the community	Community has no milk collection centre, grain/saw/oil mill, mobile phone charging/repairing services, restaurant/tea or coffee shop powered by electricity.	1/9

Based on the Alkire – Foster (AF) approach (Alkire, Kanagaratnam, and Suppa 2020) and Ssennono et al. (2021).

multidimensionally energy-poor households:

$$A = \frac{\sum_{i=1}^{q} c_i}{q} \tag{2}$$

where c_i is the deprivation score that the ith multidimensionally energy-poor household experiences. The deprivation score c_i can be expressed as the sum of the weights associated with each indicator j (j = 1, 2, … , 8) in which household i is deprived.

$$c_i = c_{i1} + c_{i2} + \ldots + c_{i8} \tag{3}$$

(c) MEPI-U: This is the product of multidimensional poverty headcount ratio (H) and the intensity of Poverty (A). Thus, the contribution of dimension d to multidimensional Poverty can be expressed as:

$$contrib_d = \frac{\sum_{j\in d}\sum_{1}^{q} c_{ij}}{n} / MEPI - U \tag{4}$$

From equation 4, d denotes electricity energy supply (energy access), cooking solutions, electricity services, and appliances. Alternatively, MEPI can be expressed as the weighted sum of the censored headcount rates h_j of each indicator, j. The censored headcount rate of indicator j refers to the proportion of households who are multidimensionally energy poor and deprived in this indicator:

$$MEPI = \sum_{j=1}^{8} c_j h_j \tag{5}$$

where c_j is the weight associated with indicator j (either 1/6 or 1/9) and the sum of the weight equal to 1.

3.2.2 Women empowerment

Women empowerment is a multidimensional construct (Alkire et al. 2013; Diiro et al. 2018; Rodríguez Guerrero, Nimeh, and Franco Correa 2021). In this study, empowerment comprises five domains broken down into different indicators. These domains include production, resources, control of use of income, leadership and time allocation. Table 2 below shows a summary of Women empowerment domains, indicators, level of adequacy in each indicator and corresponding weights.

3.2.3 Methodology for constructing women empowerment index

The study used the Alkire-Foster counting approach to compute the women's empowerment index (Alkire et al. 2013). Other studies (see e.g. Rodríguez Guerrero, Nimeh, and Franco Correa 2021) have used a similar approach to develop a measure for Women's empowerment. The approach evaluates empowerment on multiple dimensions while also capturing the concept of disempowerment. The degree of disempowerment is determined by the amount of empowerment inadequacies a woman may encounter. Using a dual cut-off counting approach, the first cut-off indicates whether a woman lacks in a certain dimension, and the second cut-off defines the proportion of weighted inadequacies a woman must have to be disempowered (Alkire et al. 2013). The methodology

Table 2. Indicators for constructing the women empowerment index.

Domains	Indicator	Definition of adequacy	Source	Weight
Production	Input in productive decisions	=1 if the respondent owns an income generating activity (either agricultural or non-agriculture or both) individually and jointly	Malapit et al. (2019), Diiro et al. (2018)	1/5
Resource	Ownership of assets	=1 if the respondent solely or jointly owns land, buildings, cattle or goats	Malapit et al. (2019)	1/10
	Access and decisions on financial services	′ = 1 if the respondent has access to and participates in decision-making concerning credit or individually or jointly operates an account in a financial institution	Malapit et al. (2019), Diiro et al. (2018), Boender, Malhorta, and Schuler (2002), Alkire et al. (2013), Sen (1999)	1/10
Income	Control over the use of income	=1 if the respondent decides on the use of income from all income generating activities	Malapit et al. (2019); Iqbal et al. (2015)	1/10
	Autonomy in income	=1 if a female is employed in a managerial position	Malapit et al. (2019)	1/10
Time	Workload	=1 if the respondent worked less than 10.5 hours in the previous 24 h	Malapit et al. (2019), Diiro et al. (2018)	1/10
	Leisure	=1if the respondent participated in leisure activities like visiting neighbors, watching TV, listening to the radio, seeing movies or doing sports	Malapit et al. (2019), Diiro et al. (2018)	1/10
Leadership	Group membership	=1 if the respondent is an active member in at least one economic or social group	Alkire et al. (2013), Malapit et al. (2019)	1/10
	Membership in influential groups	=1 if the respondent is an active member of the local council committee or actively participates in the local council committee	Malapit et al. (2019)	1/10

Source: Author's construction (2022) based on the ideas of Malapit et al. (2019), Alkire et al. (2013), Diiro et al. (2018).

provides a clear and visible headline that reflects the multidimensionality of the internal structure of empowerment and has the possibility of being decomposed into different indicators.

3.3 Computing the index

The index is constructed across the dimensions of disempowerment denoted M_0, and the final index of empowerment is computed as 1-M_0. The notation used for constructing the index focuses on the percentage of disempowered women and the percentage of the indicators in which they lack adequate achievements (Alkire et al. 2013). The steps taken to obtain the multidimensional measurement of empowerment are categorized in terms of identification and aggregation as shown in Figure 1.

Source: Author's computation based on literature.

From Figure 1, the women empowerment index is calculated using the following steps (Alkire et al. 2013):

In Step 1, nine weighted indicators from five dimensions were identified based on a nested uniform weighting scheme. All the dimensions have equal weight, and each indicator has equal weight within each dimension, as shown in Figure 1. Each individual is assigned an inadequacy score according to individual inadequacies in each of the nine indicators.

In Step 2, the maximum inadequacy score for each equally weighted dimension is 1, implying that each dimension's maximum inadequacy score is 1/5 (0.25). From Figure 1, four dimension including Resource, income, time and leadership have two indicators each, as such each indicator is weighted as 1/10 [1/5*1/2]. While the Production dimension has one indicator, so the indicator is weighted as 1/5.

In **Step 3,** the inadequacy scores for all indicators are summed to obtain the individual inadequacy score. Using a cut-off of 20 percent [k], a woman is considered disempowered if her inadequacy score is greater than 20 percent.

In **Step 4**, the study censored the inadequacies of women considered disempowered based on a cut-off of 20 percent [k]. Thus, women whose total inadequacy score is less or equal to

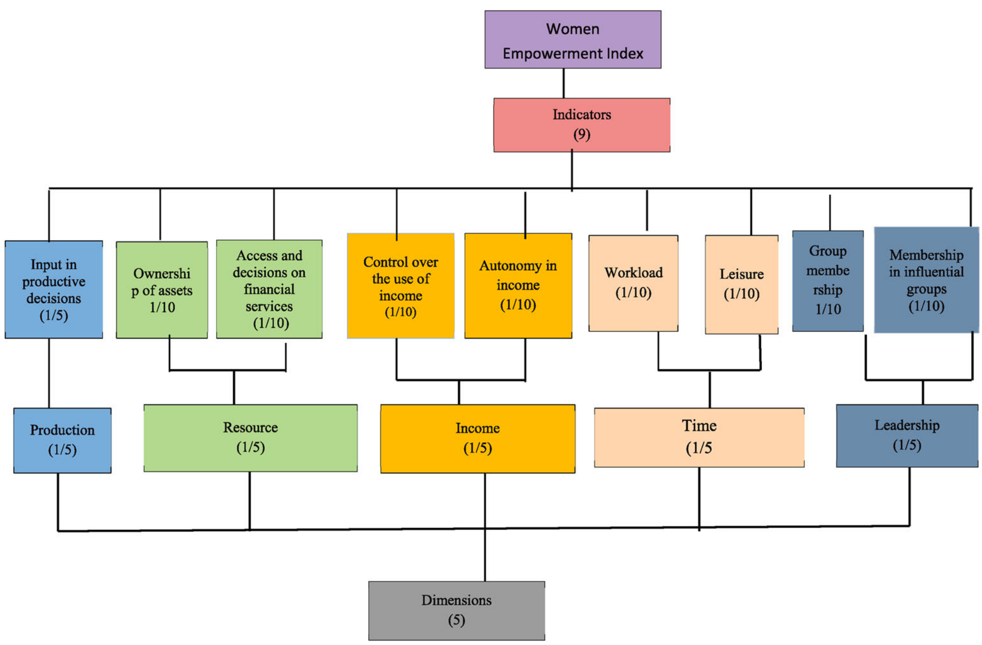

Figure 1. Composition of women empowerment index.

the cut-off (k) are replaced by zero implying that they are not disempowered. This is denoted by ci (k).

In **Step 5,** *we compute the disempowerment index (M_0)* following Alkire and Foster (2011), where (M_0) is a product of incidence and intensity of inadequacies. Incidence is the proportion of individuals whose share of weighted inadequacy is greater than 20 percent, while Intensity is the average proportion of weighted inadequacies they experience. Therefore,

(a) the disempowered headcount ratio (H_p) is given by:

$$H_p = \frac{q}{n} \tag{6}$$

where q is the number of disempowered women, and n is the total population.

(b) the intensity of disempowerment (A_p), is given by:

$$A_p = \frac{\sum_{i=1}^{n} W_i(k)}{q} \tag{7}$$

where $w_i(k)$ is the censored inadequacy of woman, and q is the number of disempowered women

(c) the disempowerment index (M_0) is given by

$$M_0 = H_p * A_p \tag{8}$$

Finally, the *Women empowerment index* (WEP) is given as:

$$(1 - M_0) \tag{9}$$

3.3.1 Climatic shocks (CS)

Extant literature identifies different types and measures of climatic shocks (Feeny, Trinh, and Zhu 2021; Nsubuga et al. 2021; Günther and Harttgen 2009). However, the current study focuses on the covariate shocks, which were identified using self-reported instances of drought, floods, landslides, and variable rainfall. To capture it, households were asked whether they had experienced any covariate shocks in the twelve months preceding the survey. In line with literature (Feeny, Trinh, and Zhu 2021), a dummy variable equal to one was created if a household reported experiencing a shock in the previous 12 months and zero otherwise.

For robustness, the study used exogenous shocks (percent rainfall deviations) from the World Bank's rainfall remote sensing data to check the consistency of self-reported household shocks to climatology data on energy poverty.

3.3.2 Covariates

For the control variables, the selection was based on extant literature on the determinants of energy poverty (e.g. Churchill and Smyth 2020; Crentsil, Asuman, and Fenny 2019; Koomson, Afoakwah, and Ampofo 2022) and available data. The study controlled for age, educational attainment, employment status, number of children and share of women in employment. Age is a significant covariate that can show how long the household has existed. The age and gender of the household head are also important socioeconomic determinants of multidimensional energy poverty. Education attainment is associated with cognitive development, which can influence household energy choices. Existing studies on the education-energy poverty nexus though limited in number (Apergis, Polemis, and Soursou 2022; Kose 2019; Acharya and Sadath 2019; Crentsil, Asuman, and Fenny 2019; Koomson and Danquah 2021) unravel a negative and statistically significant direct channel between educational attainment and energy poverty (Crentsil, Asuman, and Fenny 2019;

Sharma, Han, and Sharma 2019). Employment status is controlled for because it directly affects household income and consumption expenditure and has been reported to affect energy poverty (Bienvenido-Huertas 2021; Kose 2019; Romero, Linares, and López 2018). Also, family size or number of children has been associated with energy poverty, especially in developing countries, as it is considered a source of labour to collect firewood.

3.4 Econometric model and methodology

Research shows that the status of women empowerment and multidimensional energy poverty may be influenced by the same factors and can be endogenously determined. In order to estimate the effect of women empowerment on multidimensional household energy poverty, the study employs the instrumental variables method using ivreg2h function in STATA 17 to address potential endogeneity concerns (Chaudhry and Shafiullah 2021).

The model is specified as follows:

$$E_{i,t} = \beta_0 + \beta_1 I_{i,t} + \delta_{i,t} + \epsilon_{\beta,t} \tag{10}$$

$$MEP_{i,t} = \theta_i + \theta_1 E_{i,t} + \theta_2 X_{i,j,t} + \tau_{\theta,t} + \epsilon_{\theta,t} \tag{11}$$

In equation (10), the vector $I_{i,t}$ contains the variables used as instruments for women empowerment and subscript i indicates households in a given year (t). Given the limitation of identifying the external instruments correlated with women empowerment and multidimensional energy poverty, Lewbel (2012) heteroskedasticity identified the endogenous variable regression model in equation (10) using solely internal instruments. The approach with only internal instruments performs as good as endogenous variable regression estimators with external instruments. Notably, the Lewbel (2012) estimator has been utilised in energy poverty (Churchill and Smyth 2021; Farrell and Fry 2021) and renewable energy technology adoption literature (Aarakit et al. 2022).

In equation (11), $MEP_{i,t}$ is the multidimensional energy poverty indicator. A household is considered MEP if:

$$MEP_i = 1;\ c_i \geq 0.3$$

$$else,$$

$$MEP_i = 0;\ c_i < 0.3$$

$E_{i,t}$ indicates the women empowerment index, $X_{i,j,t}$ is a vector of control variables containing head and household characteristics, $\tau_{i,t}$ is household fixed effect; and $\epsilon_{\theta,t}$ and $\epsilon_{\beta,t}$ are the household error term. The above model is calculated using household fixed effect and region-level robust standard errors and is estimated using the random probit regression panel model.

The study also used Propensity Score Matching (PSM) method to address endogeneity (Churchill and Smyth 2020). PSM measures average treatment impact and its utilised to generate causal inferences regarding the influence of climatic shocks and women empowerment on multidimensional energy poverty.

4. Results and discussion

4.1 Descriptive statistics

The empirical analysis of this study is based on households with working persons aged 14–64 and at least one female household member. The age of working persons is defined according to the Uganda national employment policy (MGLSD 2011). Results in Table A1 show that, on average, the multidimensional energy poverty index for Uganda is 0.237 for households observed for a period between 2013 and 2020. This means that on average, 23.7% of households are energy poor and

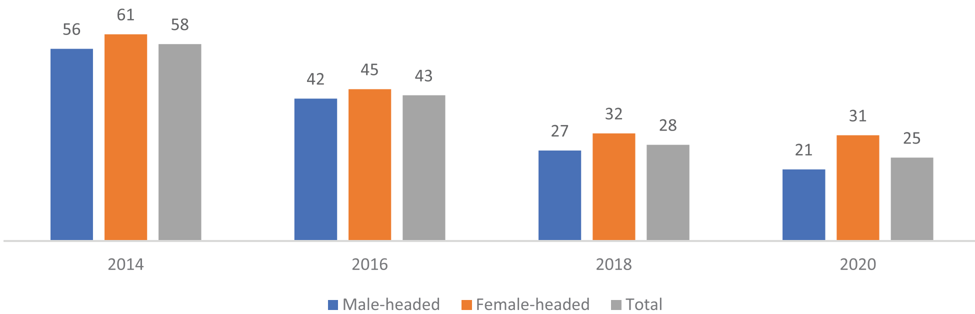

Figure 2. Incidence of multidimensional energy poverty in Uganda. *Source:* Authors' own developed based on 2014, 2016, 2019 and 2020 UNPS data.

deprived in at least two indicators. Table A.1 also indicates that on average 18% suffer climatic shocks, with drought accounting for 11.8%, floods accounting for 2.6% and erratic rains accounting for 5%. The results also indicate that on average, 28.7% of women are empowered, compared to 42.6% of males (Table A.1). Also, 44% of households have both female and male empowerment whereas 28% do not. Concerning employment, 44% of the respondents are farmers. Such a finding reflects the nature of Uganda's economy, which is predominantly agrarian.

Figure 2 below shows Uganda's energy poverty trend disaggregated by sex of the head. Over all, energy poverty has declined from 58% in 2014 to 25% in 2020. The figure further shows the gender disparities in multidimensional energy poverty in Uganda, with the female headed households having the highest proportion of persons who are energy poor. Concerning employment status, the results show that most respondents are employed on the farm. The high number of people working on the farm is because Uganda is predominantly an agrarian economy.

4.2 Effect of climatic shocks on energy poverty

Table 3 presents the results of the causal link between energy poverty and climatic shocks using Uganda's national panel data from 2013 to 2020. Column 1 shows the bivariate regression results between climatic shocks and multidimensional energy poverty and Column 2 shows the causal effect of climatic shocks on energy poverty after controlling for individual and household characteristics.

The results above show that climatic shocks positively and significantly affect energy poverty. Specifically, Column 1 indicates that a unit increase in climatic shocks increases the likelihood of a household being multidimensional energy poor by 8.7 percent at 1% significance level. This means that households that experience climatic shocks are 8.7 percent more likely to become energy-poor without controlling for household income, age, education and employment status of household head among other variables in the model. The results suggest that exposure to floods, droughts and irregular rainfall increases the likelihood of households failing to afford modern energy services.

The results in Column 2 show that climatic shocks positively and significantly affect energy poverty after introducing covariates. The estimates indicate that climatic shocks increase the probability of multidimensional Poverty by 5.4% at a 1% level of significance, which means that households that experience climatic shocks are 5.4% more likely to become multidimensional energy poor. This implies that households that experience droughts and irregular rainfall are less likely to use modern energy services.

Regarding control variables, the estimates in Column 2 reveal that energy poverty increases by 22.8% if the household is income poor. This means households with low income levels are less likely to afford modern energy services. The results for employment status of the household head, on the

Table 3. Climatic shocks and multidimensional energy poverty – Marginal effects from random effects probit.

	Column 1		Column 2 (4)	
Variables	Marginal effects	Se	Marginal effects	Se
Climatic shocks	0.087***	(0.01)	0.054***	(0.011)
Age			−0.006***	(0.002)
Age squared			0.004**	(0.002)
Education of head [No schooling]				
Primary			−0.117***	(0.017)
Secondary			−0.241***	(0.021)
Post-secondary			−0.424***	(0.029)
Employment status of HH head [Nonfarm Wage]				
Farm wage employment			0.122***	(0.028)
Nonfarm self-employment			0.044**	(0.017)
On-farm employment			0.100***	(0.018)
Unemployed			0.136***	(0.025)
Poor household [non-Poor]			0.228***	(0.015)
Number of child members			0.018***	(0.003)
Share of women in employment			−0.042**	(0.019)
Year of the survey [2014]				
2016			−0.116***	(0.013)
2018			−0.277***	(0.012)
2020			−0.296***	(0.011)
Household fixed effect			Yes	
Ecological zones fixed effect			Yes	
Observations			8124	

Notes: the reference category for education is no schooling, for employment status is nonfarm wage, for poor households is non-poor household and the year of the survey is 2014. Robust standard errors in parentheses.
Standardized coefficients in brackets. Level of sig. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

other hand, reveal that multidimensional energy poverty increases by 13.6% if the household head is unemployed, 10% if the household head is employed on a farm, and 12.2% if the household head earns farm wage. Therefore, households whose main occupation is farming are more likely to be energy poor. However, the results show that attaining primary-level education reduces the probability of a household being multidimensional energy poor by 11.7%, and secondary level education decreases the probability of a household being energy poor by 24.1%. Post-secondary education reduces the probability of a household being energy poor by 42.4%. This demonstrates that an increase in the education attainment of household heads reduces the likelihood of energy poverty. This is in line with literature (Crentsil, Asuman, and Fenny 2019; Churchill and Smyth 2020; Khundi-Mkomba, Saha, and Wali 2021), which suggests age, education, income and employment status affect energy poverty. Furthermore, the results show that the unobservable characteristics of households do vary over the years.

In short, regardless of the estimation technique and cut-off point of energy poverty used, the findings suggest that climatic shocks increase energy poverty in Uganda. This means that drought, floods and irregular rainfall increase energy poverty. The findings support earlier studies that suggest a strong positive association between climate-related shocks and energy poverty (Feeny, Trinh, and Zhu 2021; Churchill, Smyth, and Trinh 2022; Li, Smyth, and Yao 2022). Feeny, Trinh, and Zhu (2021) found that temperature shocks increase energy poverty among Vietnamese. Li, Smyth, and Yao (2022) also report an increase in energy poverty due to warmer temperatures in China. The implication is that climatic shocks generally aggravate energy poverty irrespective of the type of shock.

However, the findings of this study contradict that of Churchill, Smyth, and Trinh (2022) who find that global warming results in a modest decrease in the extent of energy poverty in Australia. The probable explanation is that many households in Uganda rely on agricultural income to meet their expenditure on basic needs, including modern energy services. This study's descriptive statistics show that most Ugandans are farmers and agricultural income predominantly contributes to their consumption expenditure. In addition, biomass – particularly firewood, crop residues and charcoal – contribute most to the primary energy consumed (Ssennono et al. 2021). Therefore, increased exposure to climatic shocks such as drought increases the availability of fuel wood resources which motivates households to use free wood for cooking. More so, climatic shocks affect agricultural yield (Trinh 2018) and income (Rafi, Naseef, and Prasad 2021), thereby reducing household expenditure on, for instance, modern energy services. Thus, climatic shocks increase energy poverty directly or indirectly through various pathways such as income.

Table 4 shows the regression analysis for the three reported climatic shocks to further check for the robustness of the dimensions on energy poverty. The results in Table 4 suggest that exposure to erratic rainfall followed by drought increases the probability of households becoming energy poor. Specifically, an increase in irregular rainfall by one percent point results in approximately 7.7 percent increase in energy poverty. Also, an increase in drought by one percent point results in a roughly 4.9 percent increase in energy poverty. At the same time, a percentage point increase in floods is weakly associated with an increase in multidimensional energy poverty. These findings suggest that irregular rainfall and drought are critical drivers of household multidimensional energy poverty. This is in line with previous studies that show that warmer temperatures increase the likelihood of energy poverty (Thomson et al. 2019; Feeny, Trinh, and Zhu 2021).

4.3 Moderating effect of women empowerment on climatic shocks and energy poverty

To examine the moderating effect of women empowerment on the relationship between climatic shocks and energy poverty, households with women aged 14–64 were considered regardless of whether the household had a male member or not. The results are shown in Table 5 below.

The results in Table 5 show that women empowerment reduces energy poverty by 6.4%. This implies that a unit percent increase in women empowerment results into a 6.4 percent reduction in energy poverty. However, the interaction of women empowerment on the effect of climatic shocks further dampens energy poverty by 8.7%. The implication is that households with empowered women are more likely to withstand the adversities of climatic shocks and sustain use of modern energy services.

These findings suggest that women empowerment is important in reducing multidimensional energy poverty. This is probably because empowered women have access to and control over both material and social resources, including information on the dangers of energy poverty, which enhances their ability to afford and use modern energy services. In addition, women empowerment is associated with having the power to make decisions regarding aspects that directly affect women (Kabeer 1999; Sharaunga, Mudhara, and Bogale 2019). Thus, empowered women are more

Table 4. Robustness check (energy poverty by type of climatic Shock).

VARIABLES	Marginal effects
Flood	0.062*
	(0.037)
Drought	0.049***
	(0.018)
Irregular rainfall	0.077***
	(0.027)
Control variables	Yes
Year fixed effects	Yes
Household fixed effects	Yes
Cluster fixed effects	Yes
Observations	
Observations	8124

Robust standard errors in parentheses.
*** p<0.01, ** p<0.05, * p<0.1.

Table 5. Moderating effect of women empowerment on climatic shocks and energy poverty.

Variables	Marginal effects	Se
Climatic shocks	0.038***	(0.018)
Female is empowered	−0.064***	(0.018)
Shock* Female is empowered	−0.087***	(0.033)
Covariates	Yes	
Year Fixed Effect	Yes	
Cluster fixed effect	Yes	
Household fixed effects	Yes	
Observations	8124	

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

likely to choose aspects that improve their wellbeing, such as using modern and sustainable clean cooking solutions that reduce energy poverty. This finding is supported by the descriptive statistics which show that household wealth reduces the likelihood of a household becoming energy poor. Also, the findings align with earlier studies that show that women empowerment increases the probability of households investing in modern energy services (Gafa and Egbendewe 2021).

Therefore, the results of this study confirm that empowering women enhances their ability to withstand multiple adversities, which is vital in addressing several socioeconomic challenges like energy poverty (Rao, Min, and Mastrucci 2019). This is because households with empowered women are more resilient and are less vulnerable to climatic shocks.

This study also examined gender differences in empowerment in relation to climatic shocks and energy poverty. To understand the moderating effect of gender differences in empowerment on climatic shocks and energy poverty, households with women and men aged 14–64 were considered. Table 6 below shows the results.

The results in model1 show that energy poverty reduces in households where only a female or male is empowered by 8.1% and 6.2% respectively. However, in households where both female and

Table 6. Moderating effect of women empowerment on climatic shocks and multidimensional energy poverty.

Variables	Model (1) Marginal	Model (2) Marginal
Climatic Shocks	0.053***	0.050**
	(0.017)	(0.023)
Empowerment Category (neither Male nor Female is empowered)		
Only female is empowered	−0.081***	−0.081***
	(0.018)	(0.020)
Only male is empowered	−0.062***	−0.059**
	(0.022)	(0.025)
Both males and females are empowered	−0.113***	−0.110***
	(0.026)	(0.030)
Shock* Only male is empowered		−0.001
		(0.038)
Shock* Only female is empowered		−0.010
		(0.045)
Shock*Both Males and females are empowered		−0.081***
		(0.013)
Covariates	Yes	Yes
Year Fixed Effect	Yes	Yes
Cluster fixed effect	Yes	Yes
Household fixed effects	Yes	Yes
Observations	8124	8124

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

male are empowered, energy poverty significantly reduces by 11.3%. Further analysis in model 2 reveals that the effect of empowerment on energy poverty is insignificant amidst climatic shocks in households where only female or male is empowered. As for households where both male and female are empowered, the effect of climatic shocks on energy poverty dampens by 8.1%, implying that empowering both women and men strongly diminishes the positive effect of climatic shocks on energy poverty. These results indicate that women empowerment reduces energy poverty more when both females and males are empowered compared to when only female or male is empowered. This means that during adversity like drought, households where both women and men are employed are more likely to afford modern energy services than those where only the man or woman is empowered. This could also imply that in times of difficulty such as floods, households where both women and men take part in decision making are more likely to access and use electricity. Therefore, the results suggest that during climatic shocks, empowerment of both female and male is crucial in dampening the accompanying energy poverty problem. As such, joint ownership and access to resources such as income, physical possessions and decision-making powers enhance a household's ability to mitigate energy poverty, especially in climatic adversities.

These findings corroborate those of previous studies (e.g. Gafa and Egbendewe 2021) that indicate that joint decision-making between the head and spouse on energy use issues is more beneficial for addressing energy poverty than when the decisions are unilateral. Thus, since women are traditionally in charge of cooking food and fuel management activities (World Bank 2004) while men often dominate the decision-making space, increasing female intra-household bargaining power and participation in decision-making enhances the ability of women to fight the vulnerabilities associated with shocks and energy poverty.

4.4 Robustness checks

To ensure robustness of the study findings, three different tests were conducted. First, the Lewbel (2012) 2SLS approach was used to examine the endogeneity problem in the main results (Table 7).

Given that the existing external instruments for women empowerment correlate with energy poverty, literature suggests that using internally generated instruments is sufficient to address endogeneity problem (Lewbel 2012). Based on this argument, the study used internal instruments (covariates) to control for endogeneity and to re-estimate the main model.

For the Lewbel approach, the precondition for identification is the presence of heteroscedasticity. In line with the arguments presented by Chaudhry and Shafiullah (2021), the Lewbel (2012) heteroskedasticity identified endogenous variable regression model was utilised and only internal

Table 7. Women empowerment and multidimensional energy poverty (Lewbel 2SLS Regression).

Variables	(1) Internal Instruments
Women empowerment	−0.118**
	(0.047)
HH head x-tics	
Household variables	Yes
Year fixed effects	Yes
Regional fixed effects	Yes
F-statistic	69.63
J-*p* value	.0344
Constant	0.330***
	(0.015)
Observations	8124
R-squared	0.109

All regressions include relevant covariates consistent with Table 3.
Standard errors are in parentheses.
****p* < 0.01, ***p* < 0.05, **p* < 0.1.

instruments for estimating the effect of women empowerment on energy poverty were incorporated. This technique has been used widely in energy poverty studies to address endogeneity problem (see Farrell and Fry 2021; Munyanyi, Mintah, and Baako 2021).

The results in Table 7 show that women empowerment positively and significantly affects multidimensional energy poverty even after controlling for endogeneity. The estimates indicate that women empowerment reduces the likelihood of a household being energy poor. In addition, the Hansen J-statistics satisfy the Lewbel (2012) assumption for validity of internal instruments; thus, the null hypotheses of valid instruments are not rejected. Similarly, the Breusch and Pagan (1979) test for heteroskedasticity is highly significant; hence the data satisfies the heteroskedasticity assumption. Further, the Lewbel 2SLS estimates are relatively higher than the forecast in the primary model (in Table 4), suggesting a downward bias in the baseline results. Since the results of the Lewbel 2SLS estimator, in terms of direction and significance, are consistent with those in the main model (Table 5), it confirms that the findings are robust.

Secondly, the study used Propensity Score Matching (PSM) analytical approach to further check the robustness of the main findings. PSM approach is often used to address endogeneity problems in non-experimental data (see Churchill and Smyth 2020; Aarakit et al. 2022). The treatment is for households who live in areas where climatic shocks are homogenous across neighborhoods, as the main results suggest that climatic shocks are associated with higher levels of energy poverty. Table 8 shows the results for PSM analytical approach.

Column 1 show that the average treatment effect on the treated (ATT) for climatic shocks and energy poverty is positive and significant across the different matching methods for households with at least one woman. These results are consistent with the main findings, confirming that climatic shocks increase the likelihood of a household being energy poor. The results in Column 2 indicate that the average treatment effect on the treated (ATT) for women empowerment and energy poverty is negative and significant across the different matching methods. This is congruent with the results in the primary model; hence, upholding the main finding that women empowerment reduces energy poverty in households with at least one woman. Therefore, the results affirm that women empowerment mitigates the adverse effect of climatic shocks on energy poverty.

Thirdly, the study used the percent deviation in rainfall days as an alternative measure of climatic shocks to further check for the robustness of the main results as shown in Table 9.

These results show that the percent deviation in rainfall days positively and significantly affects multidimensional energy poverty. This means that even on using percent deviation in rainfall days (exogeneous) as an alternative measure of climatic shocks on energy poverty, the direction and significance of the results are the same. Thus, the study concludes that the results in the main model are robust.

Table 8. PSM results with different matching methods.

Matching Method	Column 1 (Climatic Shocks ATT)	Column 2 (Women Empowerment ATT)
1 – Nearest Neighbor (one-to-one)	0.096***	−0.078***
	(0.027)	(0.025)
5 – Nearest Neighbor	0.080***	−0.082***
	(0.023)	(0.018)
Radius	0.125***	−0.124***
	(0.019)	(0.017)
Kernel	0.090***	−0.083***
	(0.017)	(0.015)
Local liner regression	0.080***	−0.090***
	(0.018)	(0.015)
Observations	8124	8124

Robust standard errors in parentheses; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.
The number of Bootstrap for all estimates is 50.

Table 9. The effect of percent deviation in rainfall days on multidimensional energy poverty.

VARIABLES	Marginal effects	Se
Percent deviation in rainfall days	0.476***	(0.065)
Year of survey fixed effects	Yes	
Household fixed effect	Yes	
Ecological zones fixed effect	Yes	
Observations	8124	

Robust standard errors in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Table 10. Estimated marginal effects on climatic shocks, women empowerment and multidimensional energy poverty using sub-sample analysis.

	Column (1) 75% sample	Column (2) 50% sample	Column (3) 25% sample
Variables	Marginal effect	Marginal effect	Marginal effect
Climatic shocks	0.061***	0.064***	0.059***
	(0.019)	(0.024)	(0.013)
Women empowerment	−0.069***	−0.124***	−0.081**
	(0.019)	(0.024)	(0.034)
Covariates	Yes	Yes	Yes
Year fixed effect	Yes	Yes	Yes
Cluster fixed effect	Yes	Yes	Yes
Household fixed effects	Yes	Yes	Yes
Observations	6093	4062	2031

Robust standard errors in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

4.5 Sensitivity tests

Various tests were conducted to check the sensitivity of the main results. First, the sensitivity of the main results concerning the different alternative sample sizes was tested (Table 10). To do this, the primary model was re-estimated using 75%, 50% and 25% of the total sampled households to estimate the effect of climatic shocks and women empowerment on energy poverty.

In line with the results in the main model, it is found that climatic shocks consistently increase the likelihood of households being multidimensionally energy poor regardless of the sample size. Conversely, the women empowerment index always reduces the probability of households being energy poor across different sample sizes. Thus, these results confirm that the main models are stable even with smaller samples.

Table 11. Robustness checks (Alternatives cut-offs for energy poverty).

VARIABLES	(1) 25% cut-off	(2) 40% cut-off
Climatic shocks	0.123***	0.069***
	(0.018)	(0.015)
Women empowerment	−0.048***	−0.054***
	(0.017)	(0.015)
Control variables	Yes	Yes
Year fixed effects	Yes	Yes
Household fixed effects	Yes	Yes
Cluster fixed effects	Yes	Yes
Observations	10,940	10,940

Standard errors in parentheses.
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Secondly, the sensitivity of the main results was examined using alternative cut-off points (Table 11). The main model used a cut-off point of 30%: however, some studies suggest that 30% cut-off point may be too high, while others argue that it may be too low (Munyanyi and Churchill 2022). A lower cut-off of 25% and an upper cut-off of 40% were used to ensure the results were robust. These results are consistent with those in the main model, implying that the results of this study are not influenced by the cut-off points used to construct the multidimensional energy poverty index.

5. Conclusion and policy recommendations

This study examined the effect of climatic shocks and women empowerment on multidimensional energy poverty, using four waves of Uganda National Panel Survey and the African Rainfall Climatology version 2 (ARC2) information on environmental and climatic events developed using remote sensing. Climatic shocks were measured using self-reported indicators such as drought, floods and irregular rainfall. Women empowerment was quantified using an aggregate index based on the Women Empowerment in Agriculture Index (WEAI) methodology (Alkire et al. 2013) while energy poverty was assessed using the multidimensional energy poverty index for Uganda (Ssennono et al. 2021). The study used random probit regression panel model for estimation and the Lewbel 2SLS instrumental variable and propensity score matching (PSM) analytical techniques for robustness of results.

Considering endogeneity, the study findings show that climatic shocks positively affect energy poverty, implying that climatic shocks increase the probability of households becoming energy poor. The findings further reveal that among the indicators of climatic shocks, irregular rainfall and drought significantly increase energy poverty. In addition, findings indicate that women empowerment reduces multidimensional energy poverty amidst climatic shocks, but it reduces further in households where both genders are empowered. These findings suggest that, (a) mitigating climatic shocks is crucial for multidimensional energy poverty alleviation among households in Uganda (b) Women empowerment dampens multidimensional energy poverty amidst shocks, (c) more interestingly, the reduction in multidimensional energy poverty is greater when both genders are empowered in the same household.

From a policy perspective, the study suggests that existing policies and initiatives (such as Rural electrification program) aimed at reducing multidimensional energy poverty should prioritise measures that mitigate the consequences of drought and unpredictable rainfall, which significantly impact contemporary energy production and distribution systems and people's lives in general. In other words, there is need to incorporate disaster management strategies in initiatives to mitigate energy poverty. In addition, the finding stress that women empowerment is essential in reducing household energy poverty more so amidst climatic shocks. Therefore, the present initiatives and policy attempts in developing countries to empower women are in the right direction. Nonetheless, the study findings suggest the need to expand the current empowerment policy programs to target both genders. This could go a long way in addressing multidimensional energy poverty among households especially when they are faced with climatic shocks. It would also aid in closing the gendered power disparity that persists in many low-income countries.

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Credit authorship contribution statement

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Appendix A1

Table A1. Descriptive statistics.

Variable	Description	Mean	SD
MEPI	1 = if household energy poor based on the multidimensional energy poverty cuff-off 30%	0.237	0.425
WEATHER	1 = if the household experienced climatic shocks drought, irregular rains, floods, erosions, or landslides in the last 12 months	0.181	0.385
FLOOD	1 = if the household experienced floods in the last 12 months	0.026	0.16
DROUGHT	1 = if the household experienced droughts in the last 12 months	0.118	0.323
IRRAIN	1 = if the household experienced irregular rains in the last 12 months	0.05	0.218
RAINFALL DAYS	The number of days with at least 1 mm of rain for the year	.457	1.79
EMPOWERED_F	1 = if Female is empowered	0.287	0.452
EMPOWERED_M	1 = if male is empowered	0.426	0.495
EMPOWERED_1	1 = if both females and males are not empowered in the household	0.282	0.45
EMPOWERED_2	1 = if only males are empowered in the household	0.138	0.345
EMPOWERED_3	1 = if only females are empowered in the household	0.139	0.346
EMPOWERED_4	1 = if both females and males are empowered in the household	0.44	0.496
AGEHEAD	Age of household head	45.362	14.123
NOEDUC	1 = if the household head has no formal education	0.091	0.287
PRIMARY	1 = if household head's highest education level achieved is primary education	0.528	0.499
SECONDARY	1 = if household head's highest education level achieved is secondary education	0.25	0.433
TERTIARY	1 = if household head's highest education level achieved is a Diploma or bachelor's and above	0.132	0.338
POOR	1 = if household is below the income poverty line for their region	0.113	0.316
HHCHILDREN	Number of children in the household aged 0–18 years	2.167	1.731
FLABORSHARE	Female share of working population in the households	0.519	0.273
RURAL	1 = if household resides in urban areas	0.688	0.463
URBAN	1 = if household resides in rural areas	0.312	0.463
CENTRAL	1 = if household resides in the central region	0.325	0.468
EASTERN	1 = if household resides in the Eastern region	0.223	0.416
NORTHERN	1 = if household resides in the Northern region	0.189	0.391
WESTERN	1 = if household resides in the western region	0.264	0.441
NONFARM WAGE	1 = if the household head has a nonfarm wage job	0.203	0.402
FARM WAGE EMPLOYMENT	1 = if the household head has a farm wage job	0.052	0.222
NONFARM SELF-EMPLOYMENT	1 = if the household head has a nonfarm self-employed job	0.221	0.415
ON FARM EMPLOYMENT	1 = if the household head has on farm employment job	0.441	0.496
UNEMPLOYED	1 = if the household head is unemployed./ not in the labour force	0.041	0.198