Energy Research & Social Science 73 (2021) 101960

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Final energy footprints in Zambia: Investigating links between household consumption, collective provision, and well-being

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ARTICLE INFO

Keywords:
Well-being
Household energy footprint
Multiregional input–output analysis
Consumer expenditure surveys
Logistic regression
Developing countries

ABSTRACT

Substantial literature exists on household lifestyles and related energy use and emissions in the global north, but little is known for many countries the global south. We estimate household-level energy footprints for Zambia covering direct (traditional and modern energy carriers) and indirect energy use, and adopting energy extended multiregional input–output. We employ final energy consumption, as it is closer to energy services and thus the purpose of energy use than the total primary energy use. The inequality in energy footprints differs from the inequality in incomes: the poorest half of the households have similar energy footprints and only high-income urban households have significant indirect energy footprints, associated with spend on goods and services. We examine the association between energy footprints and basic well-being measured in terms of physical health, education, nutrition and access to clean water using logistic regression, for a sub-sample of households with children under the age of five. We find that access to provisioning systems is more important than income for need satisfaction. Rural households have limited access to modern energy and provisioning systems and as a result fewer of them attain desirable well-being outcomes. We conclude that access to collective provisioning systems such as education, electricity and indoor sanitation is more important for household need satisfaction than individual provisioning in the form of ownership of durables, or even income. Further research is needed to improve the understanding of the association between energy use and needs satisfaction as it is crucial for addressing decarbonisation and human development agendas.

1. Introduction

A considerable volume of literature has been published on household energy use in the global north. This literature has established that indirect energy use related to goods and services dominates over direct energy use and the associated use of dwelling heating and private transport [1–4]. These studies also suggest that income and expenditure are the best predictors of household resource use in the global north [5–12]. In addition, location is a strong predictor of direct energy use, due to the higher use of fuels for private transportation and heating in rural areas [1,13,14]. Non-income factors such as age, gender, household composition and size, population density, education and diet have been shown to have mixed effects on energy use that depend on the country context [1,10,15–21].

Despite extensive research on patterns of household consumption and its environmental impacts, only a few studies have examined household-level energy use in countries in the global south [22–25], and none in extractive and low-income African countries. In the most extensive research to date, Pachauri [26] examined the energy requirements of Indian households through the lens of expenditure, income and meeting human needs such as nutrition, education and health. Pachauri found that lack of access to an adequate amount of energy crucially contributes to poverty in India [26]. Her findings resonate with those of others that have linked access to electricity to improved health and education [27–30].

Researching energy use in developing regions is increasingly important, particularly at the household level [26]. Around 80% of humanity lives in developing countries, where people still strive for decent standards of living. In order to understand how energy contributes to well-being, we need to first understand how energy is used. Considering how culturally, socio-economically and historically different these countries are in comparison to developed countries, we cannot assume to find same patterns of lifestyles and drivers of resource use. Therefore, the objective of this study is to assess how access to energy and provisioning systems differs among households in relation to their energy use, as well as examine the relationship between energy use

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https://doi.org/10.1016/j.erss.2021.101960
Received 12 December 2019; Received in revised form 19 January 2021; Accepted 24 January 2021
Available online 3 February 2021

and basic well-being outcomes. For this endeavor, we chose final energy use as opposed to primary energy (see method section). This allows us to investigate the household's energy use closer to the purpose for which the energy is used in the first place.

We chose Zambia as our case-study country because of data availability and the characteristics of its economy and energy use. Zambian Gross National Income heavily depends on natural resource export, mainly that of copper. The dependence on natural resources in combination with meagre social and economic development is an example of the so-called Resource-Curse, which is shared by many African countries reliant on extractive industries [31]. Zambia is also a mostly rural country with energy use similar to many of its Sub-Saharan neighbours, which makes it a good case for cross-country comparative studies in the future.

In the following section we present our energy footprint estimation method, including the use of data that partially covers commodities outside of the monetary market. Next, we present household final Energy Footprints (EF) and how they depend on socio-economic characteristics of households. Location and access to provisioning systems are the two most important characteristics accounting for differences in energy use between households. Then, by employing logistic regression, we determine associations between energy use and basic well-being outcomes. We conclude this article with a discussion about the role of this type of household-level energy and well-being research into informing policies that aim at improving standards of living, while keeping lower energy use and carbon emissions.

2. Methods and data

Household energy footprints are best measured through consumption-based accounting using multi-regional input–output (MRIO) tables with an energy extension. This method enables the analyst to understand for what purpose regional or international level energy is used, due to whose demand (consumption-based-accounting), and with what impact stemming from the production side (production-side accounting). Using consumption-based accounting together with direct energy use (e.g. private transportation, fuel used for heating houses) led to the development of household carbon (or energy) footprints [32], which is today a well-established method for analysing patterns of household consumption. The description of a standard environmentally extended input–output computation is described in detail elsewhere (see for example [33–37]). We refer the reader to this literature, and focus here upon the data we used and specificities of our MRIO model.

2.1. Data

For this analysis, we chose an MRIO database constructed from the Global Trade Analysis Project (GTAP) version 9 (see [38] for construction methodology) with 2011 as a reference year. An advantage of GTAP, over other available MRIO databases, is that it has data for smaller economies such as Zambia, which in other databases are included under the umbrella of "Rest of the World" group [39]. Another advantage of GTAP is its high sectoral resolution (57 sectors of which 20 correspond to agriculture), which facilitates the mapping of external data such as Consumer Expenditure Surveys (CES) within the MRIO model. GTAP relies on voluntary data input and although GTAP has quality checks in place, we acknowledge the uncertainty related to self-reported data [40]. Moreover, each country has its limitations in constructing their national tables. For Zambia, some challenges are linked to mapping Zambian commodities to GTAP classification or reporting trade flows, which are compensated by information submitted by other countries [41].

For the energy-use extension (see [42,43] for method), we use International Energy Agency's (IEA) database for 2011. Here, energy balances are divided into three categories: 1) total primary energy supply; 2) statistical differences, transformation losses and energy industry own use; and 3) total final consumption. We use the latter category of data. Total final consumption covers all energy (e.g. electricity, heat coal) supplied to the end-use sectors (e.g. transport, residential, industry, other) for all energy uses (e.g. gasoline at the service station, electricity at the socket, or fuelwood in buildings) [44]. Using total final consumption is an innovative aspect of this study, as most previous research focuses on primary energy footprint. We employ final energy consumption in our analysis because it is closer to energy services [45], i.e. it better indicates the purpose of energy use than the total primary energy use. Moreover, it allows for better comparisons between different energy sources (i.e. renewables and fossil fuel based), and hence the consideration of final energy consumption facilitates the discussion on low carbon alternatives to fossil fuels [42].

Household expenditure data – collected by the 2015 Living Conditions Monitoring Survey (LCMS) is used for household final demand in the MRIO model [46]. LCMS is conducted every five years with technical and financial support from the World Bank. In 2015, a total of 12,250 households were interviewed on household demographic characteristics, migration, education, economic activities, health, household income and assets, household expenditure, community development issues, access to facilities, housing conditions, and poverty. The LCMS offers a high geographical resolution down to a constituency level where each individual household can be characterized within a geographical and socio-economic context. In addition, the survey contains demographic weights, which enable scaling up of expenditures to be representative of the whole population. However, these weights are an estimation based on a relatively small sample of the population. Therefore, caution is needed when interpreting the results at a whole population level.

2.2. Methods

Unlike other MRIO databases such as Exiobase and Eora, GTAP is not designed for MRIO. Additional steps must be taken, including the reallocation of international transport, before it can be used for MRIO analysis (explained in detail in [38]). Combining IEA with GTAP is done in several steps. First, the IEA data needs to be adjusted with values for marine and aviation bunkers, which are held separately from the rest of the IEA accounting. This is attributed by using the total output of each country in GTAP and calculating spending shares on shipping and aviation. Second, due to similar sectoral categorization, we were able to align of IEA end-use sectors and GTAP industries (see Table S1 in Supplementary materials). Third, we removed IEA sectors associated with households' direct energy use from the IEA-GTAP mapping, and added them to direct household energy use (which stands separate from the MRIO model). This includes IEA's residential and road sectors. Whereas the residential sector can be simply taken out and attributed to household direct energy use, the road sector includes private and commercial transportation. Hence, only the part corresponding to private transportation is included in the direct household energy use. Private transportation is further split into direct and indirect (i.e. embodied in transportation of products) energy use of households. Following Oswald et al. [47], we estimate the shares of energy use corresponding to the public, commercial and private road use assuming the commercial road energy use to be between 20% and 50% of the total road energy for 70% of the countries represented in GTAP. Fourth, after readjusting and mapping IEA to GTAP sectors, the proportions of GTAP industry spends can be used to identify energy values in IEA's broad industry sector. Following these four steps, we created an energy extension for each country in the MRIO model.

The Zambian household survey collects expenditures on 233 items and each of them is linked to one of the twelve categories in the Classification of Individual Consumption by Purpose (COICOP). This helped us to directly map Zambian expenditures to GTAP sectors (see Table S3). Although GTAP uses two different international product categorizations

(International Standard Industrial Classification, and Central Product Classification), they both map onto COICOP [48].

Despite international standardization, for several categories we observed differences in the description between GTAP and COICOP. To minimize misalignment problems, we use, with a few exceptions, Zambian products aggregated to twelve COICOP categories. Expenditures in the LCMS are reported in the purchaser prices, a price that consumers pay at the shop. GTAP uses market prices which are purchaser prices minus commodity taxes [38]. Because GTAP's household final demand was assumed to be the "true" vector, Zambian household expenditures, after converting from the local currency (Zambian Kwacha) to US dollars and adjusting for inflation, were matched to GTAP's. The difference between GTAP's final demand and LCMS spends was around 18%. This is a common observation [40], which does not influence the overall results.

We matched GTAP's final demand and Zambian household expenditures using the RAS balancing method [33], which uses row and column totals to balance inside of a matrix (here household expenditures). As a result, we obtained the final household demand and calculated energy intensities.

When calculating the energy intensities of Zambian products, we used additional information regarding the residential sector, available at the country level in the IEA database [49]. For example, instead of assigning one energy value to all house fuels, the supplementary IEA data enabled us to split it into specific house fuels like charcoal and firewood. In Zambia, 92% of the residential sector's energy use is biomass (biomass and charcoal) and waste, whereas only 7% is electricity. We used these percentages to split the total value of energy use in the Zambian residential sector and to redistribute it across households depending on their type of house-fuel.

Most MRIO models measure household consumption in monetary rather than physical units. This works well for the estimation of energy footprints in developed countries, but in developing countries households do not always rely on the market to obtain their house fuels. In Zambia, one-third of surveyed households reported using collected wood or self-produced charcoal for cooking. This creates a challenge for calculating household's direct energy footprint, which normally relies on expenditures as the input for household final demand. We overcome this difficulty creating an "expenditure equivalent" to fuel use per capita. We did this for four of the nine fuel products (firewood, charcoal, petrol/diesel, and electricity), constituting 97% of household's direct fuel use. We calculated expenditure equivalents for households that reported spending and assigned that spending to the households that had no expenditure reported based on income, number of meals per day consumed, location (district level) and type of cooking device (Fig. S1 in the supplementary materials). We justify the selection of these variables as follows: In Zambia the price of firewood or charcoal depends on the geographical location and accessibility to the forest [50]. Amount of wood purchased by a household varies depending on income and the number of meals per day consumed, as well as cooking device used [50]. Having access to this information in LCMS down to the district level enabled us to assign expenditure equivalents in a robust way. We confirmed this in our post-estimation analysis of direct EF and expenditure distributions.

We calculated household energy footprints for direct energy use (e.g. firewood and fuel for car usage) and for indirect energy use as embodied energy in the supply chains, due to purchases done by households (e.g. the energy embodies in goods and services bought by households). Capital formation and governmental spends are not the focus of the household energy analysis, hence they are omitted in our calculations [21].

All energy footprints are reported in GJ per household per year. Demographic weights are used to scale expenditures of individual households to the final demand representing the whole population [23,51], despite the limitation on sample size mentioned above. By using weighted households to scale up energy footprints to nationally representative levels, inequalities can be assessed by calculating Gini coefficients. The Gini coefficient takes frequency distribution (levels of energy or income) in the whole population and measures the inequality of this distribution [52].

2.3. Basic well-being outcomes

We used the theory of human needs (THN) proposed by Doyal and Gough [53] as a basis for quantitatively examining basic well-being outcomes. The THN provides a "eudaimonic" (as opposed to "hedonic") understanding of wellbeing [54]. In THN well-being is defined as a universal goal of 'participation in some form of life without serious arbitrary limitation' [55] which is valid regardless of place, culture or time.

The framework distinguishes between three aspects of well-being:

a. basic needs: physical health[1], critical autonomy, and autonomy of agency.
b. intermediate needs, which universally characterise basic needs: adequate nutritional food and water, protective housing, non-hazardous work, and physical environment, safe birth control and childbearing, appropriate healthcare, security in childhood, significant primary relationships, physical and economic security, and basic education.
c. need satisfiers: diverse, culturally depended needs satisfiers.

This conceptualization of human needs, and in particular of intermediate needs (b), served as a compass for reviewing variables from LCMS. For example, a mobile phone may be a vital device to fulfil the human need of significant primary relationships. However, it is one of many possible need satisfiers (c), and not a basic (a) or intermediate (b) need itself. We chose four variables of key intermediate needs from the LCMS[2]:

- health (malnutrition) status of *children* under age of five (H)
- access to clean *water* in close vicinity from home (W)
- basic or higher *education* obtained by household's head and his/her spouse (E)
- and nutrition in form of having three or more *meals* per day (N).

For simplicity, we further refer to those variables as basic well-being outcomes.

2.4. Logistic regression analysis

Logistic regression analysis was used to explore the association between household socio-economic characteristics and basic well-being outcomes. We considered only a sub-sample of households with children under the age of five (4755 households), as they included information about malnutrition status. To exclude outliers, which might distort analysis, we omitted the 1% of the households with the highest and lowest income, firewood usage and total energy footprint (altogether 258 excluded observations) as well as households with expenditures on items higher than nine standard deviations (72 observations). To be able to compare the same sample of households using different models, we further excluded 226 households due to missing values for some of the variables. This results in 4264 observations in the logistic regression analysis. When conducting regressions, we used the four binary dependent variables already mentioned above and referred to as

[1] Achieving basic need of health is very much related to addressing everyone's health requirements (rather than achieving a certain level of health) that in turn enables people to participate in society.

[2] *Lack of information in the LCMS made it impossible to assign an indicator to all types of needs.*

basic well-being outcomes. Based on the wellbeing literature mentioned above and knowledge about the country's context, we chose socio-economic, demographic, and spatial variables as explanatory variables in the analysis (Table 1). We report McFadden's pseudo R^2 and McKelvey and Zavoina's pseudo R^2 as measure fit. Caution needs to be taken when assessing the model fit with these scalars, as they only provide a rough index of whether a model is adequate [56]. All results of the logistic regressions are reported using odd ratios, as we believe they are simpler to understand than coefficients.

In the following section, we use the average marginal effects (AME) to examine the probability that the given well-being outcome will occur (dependent variable) while considering each of the independent variables separately and holding all the other independent variables at their observed values.

3. Results

3.1. Household expenditure and final energy footprints

Zambia's per capita total final energy demand is similar to many of its neighbours [59]. But an average Zambian uses only 12% of the energy that a citizen of the United States uses, and about 20% of the average final energy demand of a German.

Zambian households spend most of their money on food and their energy footprint is dominated by house-fuels used to cook it (see Fig. 1). Whilst less than one-fifth of the average energy footprint relates to indirect energy (linked to the consumption of food, clothing, recreation, etc.), indirect energy accounts for almost the entire household budget (Fig. 1).

Energy intensities and energy efficiency are important factor in explaining the proportional differences between expenditure and energy footprints observed in Fig. 1. We find high energy intensities for cooking fuels of firewood and charcoal (Table 2). Zambia is reliant on inefficient biomass, which come free (as collected firewood) or are inexpensive compared to other consumer products (charcoal). Furthermore, cooking devices in Zambia are of low efficiency. For example, to cook a kg of food requires <1 MJ of electricity but four times more using a charcoal fed mbaula[3] cooking stove, or six times more when cooking on open fire [60,61].

3.2. Inequalities

To better understand the differences between households' energy footprints, we calculate Gini coefficients - a common measure of inequality. Perfect equality corresponds to a Gini coefficient of zero and maximal inequality is expressed by a Gini coefficient of one. In our sample of households, income inequality is very high (Gini coefficient of 0.62), whereas the Gini coefficient for total EF is much lower (0.39). While households in the highest income quintile own more than two-thirds of all assets, they only use about half of all energy. The poorer half of the households owns just 10 percent of income but uses a quarter of all energy. The distribution of total EF and direct EF are similar, which might indicate easy accessibility to house-fuels, regardless of the household's income and expenditure.

Transport EF is highly unequal, with a Gini coefficient of 0.89 (Table 2). Because of limited road network and poor road conditions (9.1 km of roads per 100 km^2 and 9% of roads being paved [62,63]), private transportation is almost non-existent in rural areas. Transportation is only available to affluent urban households, as half of the households in the highest income decile own a car and live in cities. Only 1% of rural households own a car while their urban counterparts are

[3] A small, round stove consisting of three sheets of tin metal fabricated together. This traditional cooking stove is commonly used in whole of Zambia and is usually fabricated by local tinsmiths [69].

Table 1
Variables chosen for the logistic regression analysis.

Variable	Type	Definition
Achieved all	d	HHs with all four basic well-being outcomes achieved (healthy child, safe water, adequate food and basic education)
Healthy child	d	HHs with child that is not underweighted. Underweighting is a condition of low weight in relation to age. It is based on a composite index of weight-for-height (wasting) and height-for-age (stunting) [57].
Safe water	d	HHs with access to safe water within one km from home. According to the United Nations water report [58], improved drinking water supply supplies include sources that, by the nature of their construction or through active intervention, are protected from outside contamination, particularly fecal matter. These include piped water in a dwelling, plot or yard, and other improved sources, including public taps or standpipes, tube-wells or boreholes, protected dug wells, protected springs, and rainwater collection.
Adequate food	d	HHs with three or more meals per day.
Basic education	d	HH head and spouse with basic (7 years) education.
Province	n	Corresponds to ten Zambian provinces: 1. Central, 2. Copperbelt, 3.Eastern, 4.Luapula, 5. Lusaka, 6. Munchinga, 7.Northern, 8.North Western, 9. Southern, 10. Western
% rural households w/n district	n	Share of rural households within district (total number of districts = 74). Shares are divided into four categories: <25, 26–50, 51–75, 76–100.
Household size	c	Number of people living in the hh.
Female-headed household	d	HHs where female stated in the questionnaire to be the head of the household.
Household head's age	c	Age of hh's head
Number of children age > 5	c	Number of children above age of five living in the hh.
Number of children	c	Number of children living in the hh.
Not poor	d	HHs self-assessing their poverty status (positive for non-poor and moderately poor). Reference question in the hh survey: 'Do you consider your household to be non-poor, moderately poor or very poor?'
Income ($/OECD cap)	c	Income in USD dollars per person using OECD equivalence scale
Access to market w/n 5 km	d	HHs with access to the market within 5 km from home.
Public transp. w/n 5 km	d	HHs with access to public transport within 5 km from home.
Secondary school w/n 5 km	d	Access to a secondary school within 5 km from home.
Health facility w/n 5 km	d	Access to a health facility within 5 km from home.
% electrified households w/n district	n	Share of electrified households within 74 districts. Shares are divided into four categories: <20, 21–40, 41–70, 71+
Detached house	d	HH living in a detached house.
Flush toilet	d	HH has an indoor or outdoor flush toilet.
Phone	d	Ownership of at least one mobile or landline phone.
Car	d	Ownership of car.
EF Misc. goods & services (GJ/cap)	c	Energy footprint of miscellaneous goods and services
Indirect EF (GJ/cap)	c	Indirect Energy footprint
Maternal education (children < 5 yr.)	n	Reference to mothers of children under the age of five. Education divided into five categories: no education, primary (0–7), Junior secondary (8–9), Senior Secondary (10–12), Tertiary (12 +).

Note: 'd' corresponds to dichotomous, and 'c' to continuous variable type. HH – households. The positive effect (e.g. household with sufficient food, or female-headed household, or ownership of a car) is coded 1 and the negative effect is coded 0.

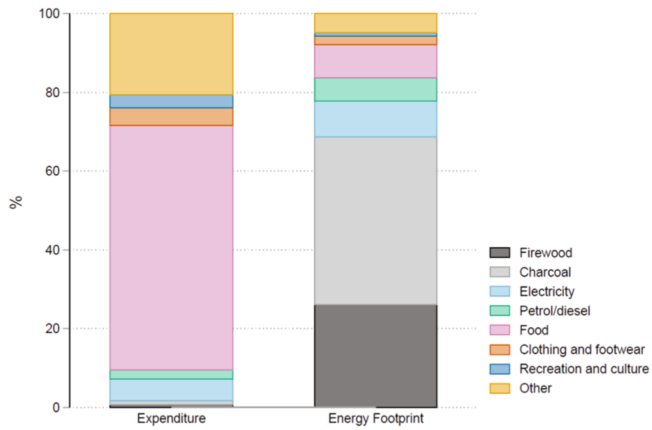

Fig. 1. Yearly expenditures and energy footprints per capita (% of final energy consumption).

Table 2
Energy intensities of products and product groups.

Consumption category	MJ/$
Indirect energy	
Food	3
Other	8
Clothing and footwear	11
Recreation and culture	7
Direct energy	
Firewood	1071
Charcoal	965
Electricity	40
Petrol/diesel	57

fourteen times more likely to own a car (Tables 3 and 4).

Table 3
Overview of income and final energy footprints inequalities across rural/urban areas..

	Gini coefficient				
n = 12249 Number of weighted population (M)	Total (15.5)	Rural (9)	Urban (6.5)	Top 20% share	Bottom 50% share
Total EF	0.39	0.35	0.37	45%	24%
Housing EF	0.40	0.37	0.39	45%	23%
Direct EF	0.41	0.37	0.39	45%	23%
Food EF	0.47	0.44	0.41	51%	19%
Expenditure	0.52	0.45	0.45	56%	16%
Indirect EF	0.51	0.44	0.45	56%	16%
Income	0.62	0.55	0.53	66%	10%
Transport EF	0.89	0.87	0.87	98%	0.013%
Detailed energy sources:					
Charcoal	0.38	0.40	0.36	69%	3.5%
Firewood	0.34	0.34	0.45	63%	5%
Electricity	0.37	0.37	0.37	95%	0%
Petrol	0.50	0.50	0.46	100%	0%

Note: The reference year is 2011 for energy and 2015 for income distribution.

Having described average household EF and expenditures on one hand, and inequalities of EF and income on the other, we now explore household energy footprints in more detail. For this analysis we consider two variables: income and location (i.e. urban/rural divide).

3.3. Location and income differences

As expected, households in higher-income equivalised deciles[4] have higher energy footprints. However, a surprising result is that the lowest 5 deciles, the poorer half of the sample, all have very similar direct EF (Fig. 2). Their energy footprint is made up almost entirely (90%) of cooking fuels. It is also important to highlight that households in the top income deciles use less charcoal and firewood than other income groups. High electricity connectivity and the use of electric cooking stoves among these households explain this result. Poorer households in turn have the lowest rates of electrification and they use significantly more biomass (Fig. 2). Moreover, only the households in highest income deciles use more substantial amounts of petrol, and its consumption by other income groups is negligible.

When considering differences in household EF profiles based on location (Fig. 3), we split the equivalised income deciles presented in Fig. 2 between rural and urban areas. This leaves an unequal number of households into each urban and rural part of a decile, but in both parts households have the same level of income. As expected, urban households have above average EF while almost all rural households use less than the national average. Wood fuel dominates the direct EF among rural households, whereas in urban areas charcoal use dominates. For rural households, firewood also constitutes an income source, as they produce charcoal from firewood and sell it to urban households. That is, affordability shapes access to and use of energy resources differently in urban and rural areas.

Turning now to indirect EF, among the poorer half of households it is just one-tenth (9%) of their total EF. In comparison, indirect EF accounts for one third of the total EF among the households in the most affluent decile (Fig. 2). Urban households use two and half times more indirect energy than their rural counterparts (Table 4), which reflects income differences across the urban–rural divide. For example, rural households have 74% lower disposable income, and, after fulfilling their basic needs, cannot afford much more (Table 4). Because of better access to markets, schools, and transportation, affluent urban households can in turn spend on education, clothing, and recreation and culture. As a result, urban households are responsible for two-thirds of the overall indirect EF in Zambia.

Interestingly, urban households with access to electricity have three times higher indirect EF on average than their non-electrified urban counterparts (Table 4). The urban electrified households also earn on average three times more, have on average three more years of education, have smaller number of unhealthy children and eat more regularly three or more meals per day than the non-electrified urban households. These results suggest that physical infrastructure (e.g. electricity) is available to a few affluent households who can spend their higher incomes on durables and services which need that physical infrastructure in the first place.

3.4. Final energy footprints and basic well-being outcomes

We now turn to households' energy use in relation to their basic well-being outcomes in terms of education (E), childrens' health (H), nutrition in form of meals per day (N), and access to clean water (W). Below households which have achieved an outcome have an upper case letter associated with it (H, E, N, or W) and households that did not attain an outcome have a lower case letter (h, e, n or w). The results reported in this and the next section (including regression analysis) consider only

[4] Equivalised income refers to the total income of a household divided by the number of household members, which are equalised according to their age. This operation is done using OECD equivalence scale. This is a widely used technique by, for example, Eurostat and OECD. As a result, equivalised income per capita has the capability to reflect reality as it does not assume that income should be equally divided between adults and children.

Table 4
Household characteristics across rural and urban regions in Zambia.

		Rural			Urban		
	Zambia	Total	Not Electrified	Electrified	Total	Not Electrified	Electrified
Share of population living in		58%	56%	3%	42%	14%	28%
Income (US$ per household)							
Income	2424	1103	959	4268	4174	1729	5362
Energy Footprint (GJ per household)							
Direct EF	68	57	57	68	82	64	91
Indirect EF	10	6	5	16	16	7	20
Access to							
Electricity	31%	4%			67%		
Clean water at home	58%	42%	40%	86%	79%	63%	87%
Accessibility (within 5 km)							
Food market	64%	41%	40%	64%	94%	93%	95%
Health facility	63%	48%	48%	66%	83%	81%	84%
Public transport	58%	42%	41%	67%	78%	74%	80%
Secondary school	33%	13%	12%	36%	58%	55%	60%
Mobility							
Car ownership	7%	1%	1%	13%	14%	1%	20%
Bicycle	35%	46%	46%	46%	20%	27%	17%
Motorbike	1%	1%	1%	5%	1%	0%	1%
Appliances							
Mobile phone	61%	46%	44%	87%	81%	68%	88%
Refrigerator	12%	1%	0%	27%	26%	2%	38%
Indoor toilet	16%	2%	0%	31%	34%	3%	49%
Education (household head)							
Number of finished grades	8	6	6	11	10	8	11
Health							
Chronically malnourished children (stunted)	49%	50%	50%	47%	47%	50%	45%
Diet							
3 + meals (incl. snacks) per day	55%	43%	41%	82%	71%	48%	83%

Note: Based on the Zambian LCMS 2015 household survey (data representative for the whole population - values calculated using demographic weights).

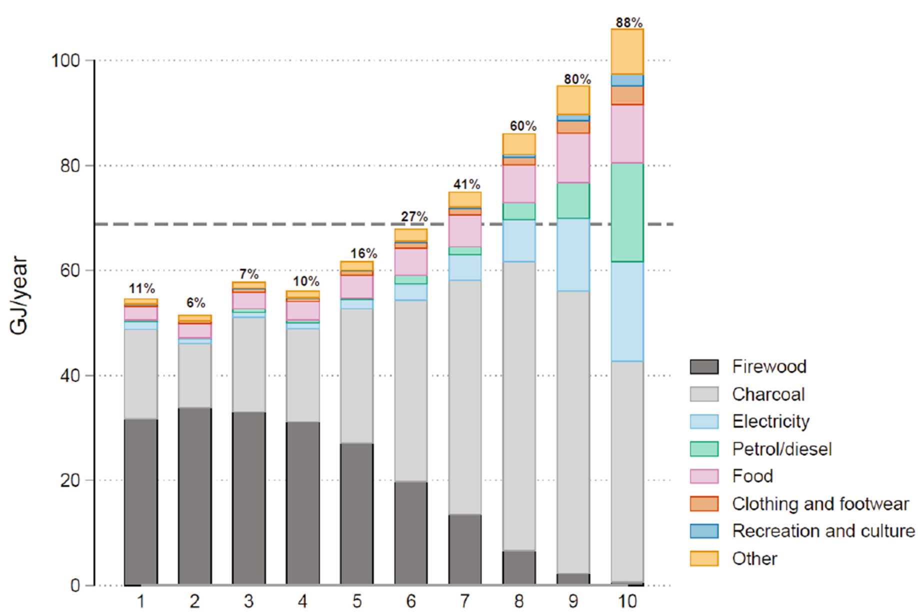

Fig. 2. Households' final energy footprints by income deciles, GJ/ household per year. Percentage above each bar indicate a share of households connected to electricity. The dashed line indicates a national average. Values calculated using the 2015 household survey data and demographic weights.

households with children under the age of five.

The households with children that attain all four well-being outcomes (HENW) are mostly urban (74%), earn almost two times more than the average Zambian household and are connected to electricity (Table 5). Facilities like food-market, health centres, public transport, and secondary school are typically within walking distance. HENW households are more likely to own durables such as mobile phones, fridges and cars. Both the head of the household and the spouse have 11 years of education on average. In contrast, increased levels of deprivation are associated with each basic well-being outcome not attained. For example, households missing two of the outcomes have three times lower electricity connection rates than households that only failed to

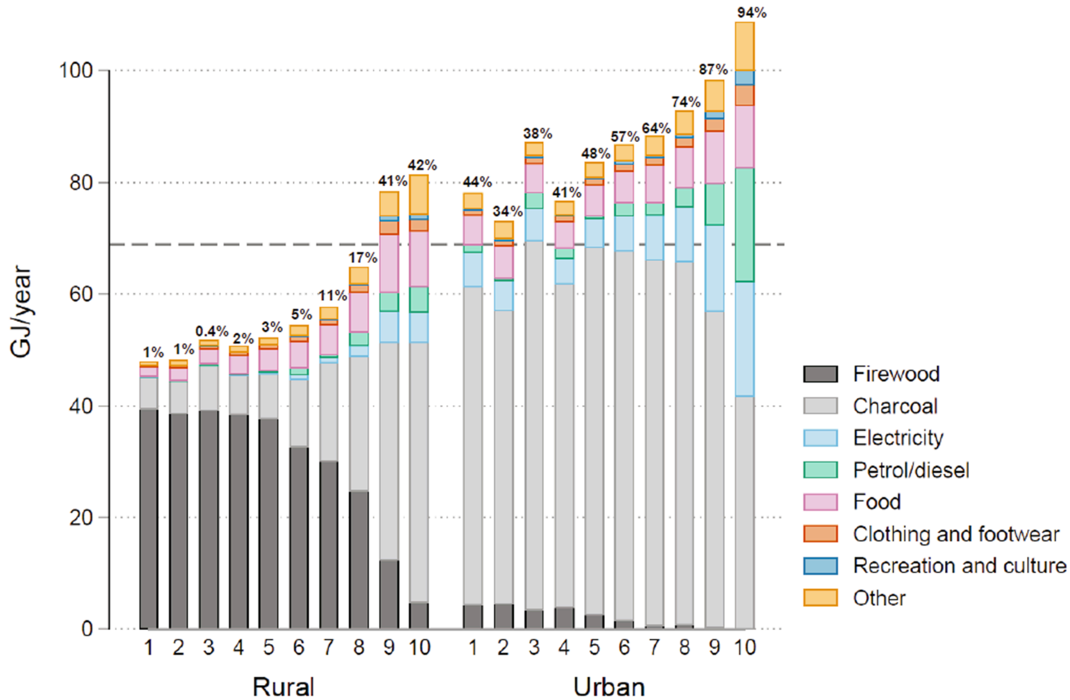

Fig. 3. Households final energy footprint across rural/urban areas by income deciles, GJ/household per year. Percentage above each bar indicate a share of households connected to electricity. The dashed line indicates the national average. Each decile corresponds to the same level of income as in Fig. 2.

attain one outcome. Walking distance to clean water and food markets also increases with each additional missing well-being outcome. That is, lack of infrastructure and lack of access to facilities impede attainment of basic well-being outcomes (Table 5).

Urban HENW households use a third more energy than their rural counter partners (Fig. 4). Among the rural households, only HENW households have higher than the national average EF. The reason for the difference in EF between rural households is the much higher indirect EF among the rural HENW households.

Attainment of basic well-being outcomes is clearly associated with additional energy inputs or changes in the quality of the energy sources. For example, in the rural context, having basic education in addition to having a healthy child (difference between HEnw and Henw) is associated with 13% higher EF, mostly because of higher use of cooking fuel (charcoal). However, having three or more meals per day (HeNw) in addition to only having a healthy child (Henw) is associated with a switch of a cooking fuel from firewood to charcoal rather than with an increase in the direct EF, which interestingly is lower for rural HeNw than for Henw.

Energy profiles of urban households are substantially different from those of rural households. In urban areas households missing one well-being outcome (e.g. hENW - healthy child, HEnW-meals per day and HeNW - education) have similar energy use but the same is not true for rural households. These three urban household types significantly differ in terms of their direct EF although their total EF are similar. Households with healthy children (HEnW) or having three meals per day (HeNW) use significantly more charcoal in comparison to households without a healthy child (hENW). Interestingly, households only lacking access to clean water at home (urban HENw) also have higher use of charcoal for cooking. This might be related to a need of using more energy to boil water before it is safe to drink.

Urban households, as already mentioned, use more of indirect energy than rural households. Yet, in both rural and urban areas, HENW households use three times more indirect energy than their other regional counter partners. This could be a result of a better access to provisioning systems such as electricity, road infrastructure and food markets by these households. This could be the case especially in urban areas, where indirect energy use is higher anyway. However, it might simply be a result of income disparities within urban areas (urban HENW households have on average 56% higher income than the rest of urban households).

Differences in access to physical provisioning systems may also contribute to the ability of urban households to satisfy their needs with lower energy intensity products (e.g. firewood *vs* charcoal and electricity) than rural households (Table 2). Access to secondary schools and sewage systems also varies between urban and rural households: a smaller number of urban households miss basic well-being outcomes related to them than rural households (compare sample size for urban and rural HeNW and HENw households in Table 5).

3.5. *Logistic regression*

In what follows, we consider how socioeconomic factors and energy footprints are associated with basic well-being outcomes by conducting logistic regression on a sub-sample of households with children under the age of five. Here we present the key results, whilst the details of the logistic regression models are provided in the supplementary materials (Tables S6 and S7). Table 6 indicates significant average marginal effects (AME) for access to clean water, education, healthy child and meals per day. We provide the probability increase that all or each of the well-being outcomes will occur while considering each of the independent variables in turn and holding all other independent variables at their observed values.

We discover that the highest probability of having all four basic well-being outcomes are linked to location (17% increase for Southern province *vs* Northern) and access to collective provisioning in the form of electricity (16% probability increase) and indoor sanitation (14% increase). In contrast, characteristics linked to individual consumption and durables, although significant, have a weak effect (6% increase in probability for mobile phone and 3% for income).

Moving on to consider each of the basic well-being outcomes, in turn, we observe that increased probability of having basic education is linked to electrification. Households situated in electrified districts have a 30% higher probability of having basic education than in districts with lower

Table 5
Household characteristics across sub-sample of households with children categorized by achieved or not basic well-being outcomes.

	Achieved all outcomes	Achieved three outcomes				Achieved two outcomes				Achieved one outcome		No outcomes achieved
	HENW	hENW	HEnW	HeNW	HENw	HeNw	heNW hEnW hENw	HenW	HEnw	Henw	hEnw heNw henW	henw
Sample size												
Total	1252	90	319	374	386	357	146	415	312	591	159	97
Rural	293	30	145	244	262	299	95	326	237	531	135	87
Urban	959	60	174	130	124	58	51	89	75	60	24	10
Location & electrification (%)												
Urban share	74	73	54	33	36	18	34	17	21	8	19	8
Electrified	66.9	50.8	32.6	23.2	24.2	11.4	21.3	4.0	4.5	0.3	7.5	0.6
Education (head and spouse)												
Number of finished grades	11	9	9	5	9	5	7	4	8	4	5	4
Income & Expenditure												
Average income decile	7	6	5	5	5	4	5	3	4	3	4	3
Income (US $ per equiv.cap)	1557	904	718	477	717	448	537	259	395	228	312	294
Income (US$ per household)	4424	2643	2063	1399	2000	1361	1564	743	998	655	941	848
Expenditure direct per cap	72.8	41.3	29.5	19.3	18.5	10.2	19.8	9.5	11.2	6.6	10.1	8.1
Expenditure indirect per cap	669	438	356	323	364	254	299	173	223	156	191	162
Energy Footprint per cap												
EF-direct	13.4	10.8	10.7	11.0	10.0	8.6	10.2	8.1	9.5	8.6	8.7	7.6
EF-indirect	3.8	2.3	1.6	1.4	1.9	1.0	1.4	0.8	1.1	0.7	0.9	0.7
Appliances and durables (%)												
Mobile phone	86.1	74.8	68.2	64.4	74.0	48.0	65.5	42.1	46.4	34.8	46.4	27.4
Refrigerator	27.2	10.4	7.3	2.1	6.7	3.9	8.5	1.3	0.9	0.0	0.1	0.0
Bicycle	27.2	25.9	37.8	50.2	45.7	53.0	46.6	44.4	43.4	40.1	48.0	36.9
Car	17.2	4.8	2.0	0.5	2.9	2.5	0.5	0.1	0.5	0.0	0.1	0.0
Indoor toilet	37.1	23.1	14.5	4.4	4.2	1.4	2.9	0.4	1.1	0.0	0.0	0.0
Accessibility (% within 5 km)												
Food market	85.6	84.4	73.4	57.7	59.6	45.0	69.6	56.5	46.2	33.5	54.7	40.7
Health facility	79.5	75.3	74.9	62.1	62.4	51.8	64.2	63.4	50.1	43.5	58.5	49.6
Public transport	77.2	62.9	67.1	57.6	62.6	44.0	65.8	53.0	43.4	36.0	56.4	37.0
Secondary school	53.5	38.7	45.2	26.0	26.7	17.3	35.8	24.5	18.5	10.7	25.5	16.1

Note: Based on the Zambian LCMS 2015 household survey and IEA energy data for 2011 values calculated using demographic weights).

connectivity. Probability of having safe water increases for households living in urban areas and for those who have a flush toilet. The best predictors for adequate food are location and indirect EF. Households in Southern province have >40% probability to have adequate food than those in Northern or Luapula provinces.

The predictions for having a healthy child are not at all as clear-cut. In Zambia, half the children under the age of 5 are chronically malnourished (50% of rural and 47% of urban children, see Table 4). Child malnutrition affects all groups in the society, which results in an overall small explained variation in the sub-sample (see McKelvey and Zavoina pseudo R2 in Table S6). Within our sub-sample, we observe that the maternal education, location, and, not surprisingly, the number of children have the biggest effect on the increase in the probability of having a healthy child. This is a similar result to the previous reporting on the issues of malnutrition in Zambia [57,64].

To conclude, collective provisioning plays a significant role in the attainment of the basic well-being outcomes in Zambia: access to electricity, schools, and sanitation are better predictors of positive societal outcomes than the level of income, the ownership of durables or the level of energy footprints.

4. Discussion and conclusion

Ours is the first study to quantify household-level consumption-based direct and indirect energy footprints (EF) in an African country. Previous studies employing MRIO has mostly focused on carbon footprints (as opposed to energy) when investigating households in the Global South (e.g. [8,65,66]). In addition, it is often a practice in MRIO studies to examine developing countries at the national level and extrapolate results using a representative country as a blueprint for the whole region (or continent) [67]. Our study is also a rare example among household foot-printing studies because we examine *energy* footprints in relation to basic well-being outcomes.

As explained in the methods, we were limited in our study by uncertainties related to the use of diverse datasets including self-reported data that might have been over- or under-estimated; misalignment of datasets; and the use of demographic weights. In spite of these limitations, the results add to our understanding of the size and distribution of energy footprints in Zambia and their relationships with basic well-being outcomes.

Our results indicate that Zambia is a highly unequal society in

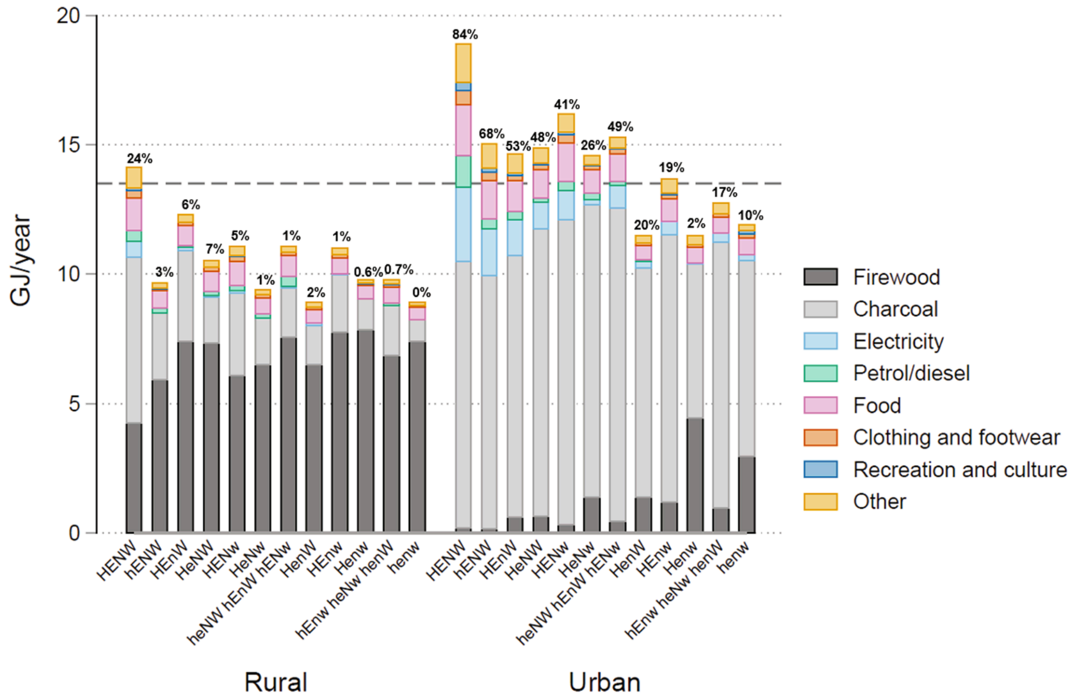

Fig. 4. Per capita final energy footprint across sub-sample of households with children under the age of five. Values above each bar indicate the share of households having access to electricity. The dashed line indicates the national average per capita. Values calculated using the 2015 household survey data and demographic weights.

income terms, and one where affluent households have privileged access to clean sources of energy. Although more than half of the population is rural, most of the energy is used by urban households. Cooking fuels constitute the majority of households' EF, even for the high-income households, whilst it constitutes a relatively small share of their spending.

Reliance on biomass such as firewood collected for free and inexpensive charcoal contributes to Zambia's infamously high deforestation rate, the highest in Africa [68,69]. It is difficult to counteract, due to the prevalence of poverty and the failure of the government to provide alternative sources of energy. Achieving Sustainable Development Goal 7 (universal affordable and clean energy by 2030) is challenging in a country where only 31% of the households have access to electricity. Currently in Zambia, electricity provision is prioritized to regions with mining industry and for high-income urban households living in them [62]. The rest of the people are confined to reliance on energy-intensive and dirty fuels which makes access to clean energy sources a social justice issue.

In line with previous studies (e.g. [3,4,21]), our results demonstrate a positive association between income and indirect EF, particularly for clothing, transport and recreation and culture. However, indirect EF is negligible for the lower income half of the population. Indirect EF could increase with upward social mobility, development of rural and urban areas and improved provision of infrastructure and electrification as households with more disposable income might follow the steps of the affluent households. We find that the distribution of energy footprint associated with transport is highly unequal as only a few high-income households own a car. Surprisingly, although previous studies have identified motorbikes as an intermediary mode of transport between bicycle and car [70,71], they are not common in Zambia: only 1% of households have a motorbike. This means that if and when incomes increase, households are likely to adopt private vehicle transportation unless public transportation services improve.

Rather than focusing on the quantity of energy used, we also studied the purpose of energy. We based our analysis on final energy consumption, which, in contrast to primary energy, is closer to the services that energy provides. Final energy enables us to discuss resource use in terms of its function and efficiency. Furthermore, by analysing well-being we can understand the role of different energy uses in facilitating the achievement of the well-being outcomes. Further research could adopt the conceptualization and method presented in this study to investigate other countries. This can be done with the use of Living Standards Measurement Studies (LSMS) conducted with help from the World Bank that are available for many understudied countries in the Global South.

Along these lines, our analysis of a sub-sample of households with children under the age of five confirms earlier findings that material and social infrastructure (such as, for example, maternal education, electricity access, and indoor sanitation), are associated with attaining basic well-being outcomes [72–74]. A weaker relationship is found between well-being outcomes and individual consumption related to income, as well as ownership of appliances. Although basic well-being outcomes in our sub-sample are achieved with higher levels of EF in urban areas, the energy intensities of consumption items are lower for the households that have attained all four well-being outcomes (HENW). Overall, contrary to the prevailing narrative that we need increased incomes and individual consumption to end poverty and related lack of basic standards and malnutrition, we observe the importance of access to services and goods through collective provision [75,76]. This result is relevant to development planning, particularly when considering the interrelation of SDG7 on energy access, with other Sustainable Development Goals, for instance. The importance of collective material and social infrastructure cannot be neglected here.

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.

Table 6
Average marginal effects.

	All outcome N = 4264 Change	Healthy child N = 4264 Change	Basic education N = 4264 Change	Safe water N = 4264 Change	Adequate food N = 4264 Change
Province:					
Northern vs Central	**−0.16*****		−0.09*	**−0.22*****	**−0.24*****
Northern vs Copperbelt	−0.06*			**−0.19*****	
Northern vs Eastern	−0.05*		**0.14*****	**−0.35*****	**−0.23*****
Northern vs Luapula				**−0.26*****	
Northern vs Lusaka	**−0.13*****			**−0.33*****	**−0.34*****
Northern vs Muchinga				**−0.1***	**−0.13*****
North Western vs Northern	0.06*	−0.09*		**0.17*****	**0.12****
Western vs Northern	0.09***		**0.1****	**0.1***	**0.15*****
Southern vs Central					**0.22*****
Southern vs Copperbelt	**0.11*****			**0.1***	**0.41*****
Southern vs Eastern	**0.12*****		**0.17*****		**0.22*****
Southern vs Luapula	**0.12*****	0.06*			**0.44*****
Southern vs Lusaka					**0.11***
Southern vs Muchinga	**0.13*****			**0.19*****	**0.33*****
Southern vs North Western	**0.1*****	**0.1****		**0.12****	**0.33*****
Western vs Southern	−0.07*			**−0.2*****	**−0.3*****
Southern vs Northern	**0.17*****			**0.29*****	**0.45*****
Household size (+1 person)			0.02***	0.03***	
Number of children age > 5 (+1 child)		0.05***			
Number of children (SD = 1.65)	−0.04*	**−0.16*****	−0.07*		
Not poor	0.09***	0.04*	0.08***		**0.11*****
Income ($/OECD cap) (SD = 1040)	0.03*		**0.12*****		
EF Miscellaneous (Marginal change)		**0.12***			
Indirect EF (GJ/cap) (SD = 1.70)	0.07**		**0.11*****		**0.21*****
Car	**0.12*****	0.06**			**0.18***
Mobile phone	0.06***		0.08***		0.04*
Secondary school w/n 5 km	0.04*		0.06**	0.04*	
Food market w/n 5 km	0.04*	−0.04**		0.06**	
Detached house	0.05***			0.09***	0.08***
Flush toilet	**0.14*****		**0.23*****	**0.23*****	
% rural households w/n district					
26–50 vs 0–25				**−0.16*****	
51–75 vs 0–25	0.08**		**0.12****		
51–75 vs 26–50	0.09***		0.08*	**0.17*****	**0.1****
76–100 vs 26–50	0.07*			**0.11****	
76–100 vs 51–75				−0.06***	
% electrified households w/n district					
21–40 vs 0–20	0.05*		0.09***	0.08***	
41–70 vs 0–20	**0.1*****		**0.12*****	**0.11***	
71 + vs 0–20	**0.16***		**0.3*****		
71 + vs 21–40			**0.22*****		
71 + vs 41–70			**0.18*****		
Maternal education (children < 5 yr.)					
Junior sec. vs primary		0.04*			
Senior sec.vs primary		0.05*			
Tertiary vs primary		0.09***			
Average Predictions Pr(y∣base)	**No** **Yes**	**No** **Yes**	**No** **Yes**	**No** **Yes**	**No** **Yes**
	0.77 0.23	0.12 0.88	0.50 0.50	0.37 0.63	0.43 0.57

Note* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; N – subsample size: households with children under age of five. Insignificant margins are omitted in the table. Bolded AME values on the level of 10 percentage points. The AME for the other independent variables used in the analysis can be found in Supplementary materials Table S8. AME for the remaining pairs of provinces are in the supplementary materials **(S8)**. Here we present pairs with Northern and Southern provinces – the two regions with the highest and lowest odds ratio of having sufficient food and all outcomes met. Key: Yes/No in average predictions show that in the sample the average predicted probability of, for example, having all outcomes met is 23%. Holding other variables at their observed values, increasing Indirect EF by one standard deviation, 1.70 GJ/cap, increases the probability of having adequate food on average by 21%. Households in districts where between 26 and 50% of households are rural decreases the probability of having safe water by 16% in comparison to households in districts where 0–25% are living in rural areas. Both effects are significant at the 0.001 level.

Acknowledgements

This work is an output of the Living Well within Limits (LiLi) project, financed by the Leverhulme Research Leadership Award (RL-2016-048). We thank everyone involved in the LiLi project group for their comments and feedback, especially Milena Büchs, Diana Ivanova, Jefim Vogel and Yannick Oswald. We are very grateful to Stembile Nana, Mwitwa Shamputa from the Zambian Statistical Agency, without whom this analysis would not be possible.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2021.101960.

References

[1] M. LENZEN, Energy and greenhouse gas cost of living for Australia during 1993/94, Energy 23 (6) (1998) 497–516, https://doi.org/10.1016/S0360-5442(98)00020-6.

[2] C. Cohen, M. Lenzen, R. Schaeffer, Energy requirements of households in Brazil, Energy Policy 33 (4) (2005) 555–562, https://doi.org/10.1016/j.enpol.2003.08.021.

[3] A.H.M.E. Reinders, K. Vringer, K. Blok, The direct and indirect energy requirement of households in the European Union, Energy Policy 31 (2) (2003) 139–153, https://doi.org/10.1016/S0301-4215(02)00019-8.

[4] S. Bin, H. Dowlatabadi, Consumer lifestyle approach to US energy use and the related CO2 emissions, Energy Policy 33 (2) (2005) 197–208, https://doi.org/10.1016/S0301-4215(03)00210-6.

[5] X. Zhang, L. Luo, M. Skitmore, Household carbon emission research: an analytical review of measurement, influencing factors and mitigation prospects, J. Cleaner Prod. 103 (2015) 873–883, https://doi.org/10.1016/j.jclepro.2015.04.024.
[6] D. Wiedenhofer, B. Smetschka, L. Akenji, M. Jalas, H. Haberl, Household time use, carbon footprints, and urban form: a review of the potential contributions of everyday living to the 1.5 °C climate target, Curr. Opin. Environ. Sustain. 30 (2018) 7–17, https://doi.org/10.1016/j.cosust.2018.02.007.
[7] M. Büchs, S.V. Schnepf, Who emits most ? Associations between socio-economic factors and UK households ' home energy, transport, indirect and total CO2 emissions, Ecol. Econ. 90 (2013) 114–123, https://doi.org/10.1016/j.ecolecon.2013.03.007.
[8] D. Wiedenhofer, D. Guan, Z. Liu, J. Meng, N. Zhang, Y.-M. Wei, Unequal household carbon footprints in China, Nat. Clim Change 7 (1) (2017) 75–80, https://doi.org/10.1038/nclimate3165.
[9] K. Hubacek, G. Baiocchi, K. Feng, R. Muñoz Castillo, L. Sun, J. Xue, Global carbon inequality, Energ. Ecol. Environ. 2 (6) (2017) 361–369, https://doi.org/10.1007/s40974-017-0072-9.
[10] M. Lenzen, M. Wier, C. Cohen, H. Hayami, S. Pachauri, R. Schaeffer, A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan, Energy 31 (2-3) (2006) 181–207, https://doi.org/10.1016/j.energy.2005.01.009.
[11] R. Herendeen, J. Tanaka, Energy cost of living, Energy 1 (2) (1976) 165–178, https://doi.org/10.1016/0360-5442(76)90015-3.
[12] C.L. Weber, H.S. Matthews, Quantifying the global and distributional aspects of American household carbon footprint, Ecol. Econ. 66 (2-3) (2008) 379–391, https://doi.org/10.1016/j.ecolecon.2007.09.021.
[13] R. Herendeen, Total energy cost of household consumption in Norway, 1973, Energy 3 (5) (1978) 615–630, https://doi.org/10.1016/0360-5442(78)90077-4.
[14] J. Munksgaard, M. Wier, M. Lenzen, C. Dey, Using Input-Output Analysis to Measure the Environmental Pressure of Consumption at Different Spatial Levels, J. Ind. Ecol. 9 (2008) 169–185. doi:10.1162/1088198054084699.
[15] M. Ornetzeder, E.G. Hertwich, K. Hubacek, K. Korytarova, W. Haas, The environmental effect of car-free housing: a case in Vienna, Ecol. Econ. 65 (3) (2008) 516–530, https://doi.org/10.1016/j.ecolecon.2007.07.022.
[16] R. Räty, A. Carlsson-Kanyama, Energy consumption by gender in some European countries, Energy Policy 38 (1) (2010) 646–649, https://doi.org/10.1016/j.enpol.2009.08.010.
[17] S. Ala-Mantila, J. Heinonen, S. Junnila, Relationship between urbanization, direct and indirect greenhouse gas emissions, and expenditures: a multivariate analysis, Ecol. Econ. 104 (2014) 129–139, https://doi.org/10.1016/j.ecolecon.2014.04.019.
[18] J. Minx, G. Baiocchi, T. Wiedmann, J. Barrett, F. Creutzig, K. Feng, M. Förster, P.-P. Pichler, H. Weisz, K. Hubacek, Carbon footprints of cities and other human settlements in the UK, Environ. Res. Lett. 8 (3) (2013) 035039, https://doi.org/10.1088/1748-9326/8/3/035039.
[19] A. Tukker, M.J. Cohen, K. Hubacek, O. Mont, The impacts of household consumption and options for change, J. Ind. Ecol. 14 (2010) 13–30. doi:10.1111/j.1530-9290.2009.00208.x.
[20] M. Wier, M. Lenzen, J. Munksgaard, S. Smed, Effects of household consumption patterns on CO2 requirements, Econ. Syst. Res. 13 (2001) 259–274. doi:10.1080/09537320120070149.
[21] D. Ivanova, K. Stadler, K. Steen-Olsen, R. Wood, G. Vita, A. Tukker, E.G. Hertwich, Environmental impact assessment of household consumption, J. Ind. Ecol. 20 (3) (2015) 526–536, https://doi.org/10.1111/jiec.12371.
[22] S. Pachauri, D. Spreng, Direct and indirect energy requirements of households in India, Energy Policy 30 (6) (2002) 511–523, https://doi.org/10.1016/S0301-4215(01)00119-7.
[23] S. Pachauri, An analysis of cross-sectional variations in total household energy requirements in India using micro survey data, Energy Policy 32 (15) (2004) 1723–1735, https://doi.org/10.1016/S0301-4215(03)00162-9.
[24] N.D. Rao, W.J. Min, A. Mastrucci, S. Pachauri, Decent Living Energy : How much energy do we ' need ' to provide minimum living standards to all ? Energy Requirements for Decent Living in India, IIASA Institutional Evaluation (2017) Retrieved from http://pure.iiasa.ac.at/id/eprint/14428/.
[25] N.D. Rao, J. Min, A. Mastrucci, Energy requirements for decent living in India, Brazil and South Africa, Nat. Energy 4 (12) (2019) 1025–1032, https://doi.org/10.1038/s41560-019-0497-9.
[26] S. Pachauri, An energy Analysis of Household Consumption, Springer, Netherlands 2007.
[27] F. Riva, H. Ahlborg, E. Hartvigsson, S. Pachauri, E. Colombo, Electricity access and rural development: Review of complex socio-economic dynamics and causal diagrams for more appropriate energy modelling, Energy Sustain. Dev. 43 (2018) 203–223, https://doi.org/10.1016/j.esd.2018.02.003.
[28] P. Nussbaumer, M. Bazilian, V. Modi, Measuring energy poverty: focusing on what matters, Renew. Sustain. Energy Rev. 16 (1) (2012) 231–243, https://doi.org/10.1016/j.rser.2011.07.150.
[29] K. Kaygusuz, Energy services and energy poverty for sustainable rural development, Renew. Sustain. Energy Rev. 15 (2) (2011) 936–947, https://doi.org/10.1016/j.rser.2010.11.003.
[30] S. Karekezi, S. McDade, B. Boardman, J. Kimani, Energy, Poverty, and Development, Glob. Energy Assess. (2012) 151–190. http://www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter2_development_hires.pdf.
[31] A. Boos, K. Holm-Müller, The Zambian Resource Curse and its influence on Genuine Savings as an indicator for "weak" sustainable development, Environ. Dev. Sustain. 18 (3) (2016) 881–919, https://doi.org/10.1007/s10668-015-9667-5.
[32] T. Wiedmann, J. Minx, A Definition of "Carbon Footprint," in: C.C. Pertsova (Ed.), Ecol. Econ. Res. Trends, Nova Science Publishers, Hauppauge, NY, USA, 2008: pp. 1–11. Retrieved from http://www.censa.org.uk/docs/ISA-UK_Report_07-01_carbon_footprint.pdf.
[33] R. Miller, P. Blair, Input-Output analysis: Foundations and extensions, Cambridge University Press, Cambridge, 2009.
[34] S. Suh, Handbook of Input-Output Economics in Industrial Ecology, Springer, Netherlands, 2009.
[35] M. Lenzen, L.L. Pade, J. Munksgaard, CO2 multipliers in multi-region input-output models, Econ. Syst. Res. 16 (2004) 389–412. doi:10.1080/0953531042000304272.
[36] K. Turner, M. Lenzen, T. Wiedmann, J. Barrett, Examining the global environmental impact of regional consumption activities — Part 1: a technical note on combining input–output and ecological footprint analysis, Ecol. Econ. 62 (1) (2007) 37–44, https://doi.org/10.1016/j.ecolecon.2006.12.002.
[37] G.P. Peters, E.G. Hertwich, The Application of Multi-Regional Input-Output Analysis to Industrial Ecology: Evaluating Trans-boundary Environmental Impacts, in: S. Suh (Ed.), Handb. Input-Output Econ. Ind. Ecol. Ser. Eco-Efficiency Ind. Sci., Springer, 2009: pp. 847–863. Retrieved from http://www.springer.com/earth+sciences/geostatistics/book/978-1-4020-4083-2?detailsPage=toc.
[38] G.P. Peters, R. Andrew, J. Lennox, Constructing an environmentally-extended multi-regional input–output table using the gtap database, Econ. Syst. Res. 23 (2) (2011) 131–152, https://doi.org/10.1080/09535314.2011.563234.
[39] S. Inomata, A. Owen, Comparative evaluation of mrio databases, Econ. Syst. Res. 26 (3) (2014) 239–244, https://doi.org/10.1080/09535314.2014.940856.
[40] K. Steen-Olsen, R. Wood, E.G. Hertwich, The carbon footprint of norwegian household consumption 1999-2012: carbon footprint of norwegian households 1999-2012, J. Ind. Ecol. 20 (3) (2016) 582–592, https://doi.org/10.1111/jiec.12405.
[41] M. Horridge, GTAP 5 Data Base Documentation - Chapter 11.P: Southern Africa (Botswana, Malawi, Mozambique, South Africa, Tanzania, Zambia, Zimbabwe), Africa Yearb. 9 (2013) 427–437. doi:10.7312/orth14675-014.
[42] A. Owen, P. Brockway, L. Brand-Correa, L. Bunse, M. Sakai, J. Barrett, Energy consumption-based accounts: a comparison of results using different energy extension vectors, Appl. Energy 190 (2017) 464–473, https://doi.org/10.1016/j.apenergy.2016.12.089.
[43] H. Wieland, S. Giljum, N. Eisenmenger, D. Wiedenhofer, M. Bruckner, A. Schaffartzik, A. Owen, Supply versus use designs of environmental extensions in input–output analysis: Conceptual and empirical implications for the case of energy, J. Ind. Ecol. 24 (3) (2020) 548–563, https://doi.org/10.1111/jiec.12975.
[44] IEA, Energy Statistics Manual, 2010. doi:10.1787/9789264033986-en.
[45] G. Kalt, D. Wiedenhofer, C. Görg, H. Haberl, Conceptualizing energy services: a review of energy and well-being along the Energy Service Cascade, Energy Res. Social Sci. 53 (2019) 47–58, https://doi.org/10.1016/j.erss.2019.02.026.
[46] Central Statistical Office (Zambia), World Bank, Zambia Living Conditions Monitoring Survey 2015, (2015). Retrieved from http://zambia.opendataforafrica.org/ssvcmrd.
[47] Y. Oswald, A. Owen, J. Steinberger, Large inequality in international and intranational energy footprints between income groups and across consumption categories, Nat. Energy. 5 (2020) 231–239. doi:10.1038/s41560-020-0579-8.
[48] United Nations Statistic Division, Classifications on economic statistics, (2019). Retrieved from https://unstats.un.org/unsd/classifications/econ/.
[49] IEA, Zambia balance, (2016). Retrieved from https://www.iea.org/sankey/#?c=Zambia&s=Balance.
[50] J. Mulombwa, Woodfuel review and assessment in Zambia, Food and Agriculture Organization of the United Nations, (1998). Retrieved from http://www.fao.org/publications/card/en/c/b715a0fc-d4c9-559b-ab59-daf6a27ea750/.
[51] C.L. Weber, H.S. Matthews, Quantifying the global and distributional aspects of American household carbon footprint, Ecol. Econ. 66 (2008) 379–391, https://doi.org/10.1016/j.ecolecon.2007.09.021.
[52] J.K. Steinberger, F. Krausmann, N. Eisenmenger, Global patterns of materials use: a socioeconomic and geophysical analysis, Ecol. Econ. 69 (2010) 1148–1158, https://doi.org/10.1016/j.ecolecon.2009.12.009.
[53] L. Doyal, I. Gough, A Theory of Human Need, Macmillan Education, Basingstoke, 1991.
[54] L.I. Brand-Correa, J.K. Steinberger, A Framework for Decoupling Human Need Satisfaction From Energy Use, Ecol. Econ. 141 (2017) 43–52. doi:10.1016/j.ecolecon.2017.05.019.
[55] I. Gough, Climate change and sustainable welfare: The centrality of human needs, Cambridge J. Econ. 39 (2015) 1191–1214. doi:10.1093/cje/bev039.
[56] J. Scott Long, J. Freese. Regression Models for Categorical dependent variables using Stata, Third, Stata Press, 2014.
[57] Zambia Central Statistical Office, Central Statistical Office, 2015 Living Conditions Monitoring Survey Report, 2016. Retrieved from http://www.zamstats.gov.zm/report/Lcms/2006-2010 LCMS Report Final Output.pdf.
[58] World Health Organization, UN-Water, UN-Water Global Analysis and Assessment of Sanitatioin and Drinking-Water (GLAAS) 2012 report., (2012) 101. Retrieved from http://www.un.org/waterforlifedecade/pdf/glaas_report_2012_eng.pdf.
[59] IEA, IEA Atlas of Energy, (2019). Retrieved from http://energyatlas.iea.org/#!/tellmap/-1002896040.
[60] N.H. Ravindranath, J. Ramakrishna, Energy options for cooking in India, Energy Policy 25 (1997) 63–75, https://doi.org/10.1016/S0301-4215(96)00105-X.

[61] J. Kaoma, G.B. Kasali, A. Ellegaard, Efficiency and emissions of charcoal use in the improved Mbaula cookstove, Stockholm, 1994. Retrieved from https://inis.iaea.org/search/search.aspx?orig_q=RN:26044747.
[62] The World Bank, Zambia: Improved Rural Connectivity Project, 2017. Retrieved from http://documents.worldbank.org/curated/en/984161494122524501/pdf/PAD2002-REPLACEMENT-Zambia-Connectivity-PAD-2.pdf.
[63] OECD/AfDB, African Economic Outlook 2006, OECD Publishing, Paris. https://doi.org/10.1787/aeo-2006-en.
[64] F. Masiye, C. Chama, B. Chitah, D. Jonsson, Determinants of child nutritional status in Zambia: an analysis of a national survey, Zambia Soc. Sci. J. 1 (2010) 4.
[65] M.I. Irfany, S. Klasen, Inequality in emissions: evidence from Indonesian household, Environ. Econ. Policy Stud. 18 (2016) 459–483, https://doi.org/10.1007/s10018-015-0119-0.
[66] M.N.V. Seriño, S. Klasen, Estimation and determinants of the Philippines' household carbon footprint, Dev. Econ. 53 (2015) 44–62, https://doi.org/10.1111/deve.12065.
[67] K. Kaygusuz, Energy for sustainable development: a case of developing countries, Renew. Sustain. Energy Rev. 16 (2012) 1116–1126, https://doi.org/10.1016/j.rser.2011.11.013.
[68] A. Chileshe, FOSA Country Report: Nigeria. Forestry Outlook Studies in Africa (FOSA), (2001). Retrieved from http://www.fao.org/docrep/004/AB592E/AB592E00.htm#TOC.
[69] M. Saket, Southern Africa, in: FAO (Ed.), Glob. For. Resour. Assess. 2000, 2000. Retrieved from http://www.fao.org/3/y1997e/y1997e00.htm#Contents.
[70] K. Gwilliam, Urban transport in developing countries, Transp. Rev. 23 (2003) 197–216, https://doi.org/10.1080/01441640309893.
[71] S.B. Nugroho, E. Zusman, R. Nakano, K. Takahashi, R.L. Kaswanto, H.S. Arifin, N. Arifin, A. Munandar, M. Muchtar, K. Gomi, T. Fujita, Exploring influential factors on transition process of vehicle ownership in developing Asian city, A case study in Bogor city Indonesia, IEEE Conf. Intell. Transp. Syst. Proceedings, ITSC. 2018-March (2018) 674–679. doi:10.1109/ITSC.2017.8317966.
[72] N.D. Rao, J. Min, Decent living standards: material prerequisites for human wellbeing, Soc. Indic. Res. (2017) 1–20, https://doi.org/10.1007/s11205-017-1650-0.
[73] N.S. Ouedraogo, Energy consumption and human development: Evidence from a panel cointegration and error correction model, Energy. 63 (2013) 28–41, https://doi.org/10.1016/j.energy.2013.09.067.
[74] K. Kaygusuz, Energy services and energy poverty for sustainable rural development, Renew. Sustain. Energy Rev. 15 (2011) 936–947, https://doi.org/10.1016/j.rser.2010.11.003.
[75] K. Hubacek, G. Baiocchi, K. Feng, A. Patwardhan, Poverty eradication in a carbon constrained world, Nat. Commun. 8 (2017) 1–8, https://doi.org/10.1038/s41467-017-00919-4.
[76] J. Millward-Hopkins, J. Steinberger, N.D. Rao, Y. Oswald, Providing decent living with minimum energy: a global scenario, Global Environ. Change 65 (2020), https://doi.org/10.1016/j.gloenvcha.2020.102168.