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Household final energy footprints in Nepal, Vietnam and Zambia: composition, inequality and links to well-being

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Abstract

The link between energy use, social and environmental well-being is at the root of critical synergies between clean and affordable energy (SDG7) and other Sustainable Development Goals (SDGs). Household-level quantitative energy analyses enable better understanding regarding interconnections between the level and composition of energy use, and SDG achievement. This study examines the household-level energy footprints in Nepal, Vietnam, and Zambia. We calculate the footprints using multi-regional input–output with energy extensions based on International Energy Agency data. We propose an original perspective on the links between household final energy use and well-being, measured through access to safe water, health, education, sustenance, and modern fuels. In all three countries, households with high well-being show much lower housing energy use, due to a transition from inefficient biomass-based traditional fuels to efficient modern fuels, such as gas and electricity. We find that households achieving well-being have 60%–80% lower energy footprint of residential fuel use compared to average across the countries. We observe that collective provisioning systems in form of access to health centers, public transport, markets, and garbage disposal and characteristics linked to having solid shelter, access to sanitation, and minimum floor area are more important for the attainment of well-being than changes in income or total energy consumption. This is an important finding, contradicting the narrative that basic well-being outcomes require increased income and individual consumption of energy. Substantial synergies exist between the achievement of well-being at a low level of energy use and other SDGs linked to poverty reduction (encompassed in SDG1), health (SDG3), sanitation (SDG6), gender equality (SDG5), climate action and reduced deforestation (SDG 13 and SDG15) and inequalities (SDG10).

1. Introduction

Considering the urgency of climate change mitigation, growing inequalities, loss of biodiversity, and environmental pollution, there is a need for fast and sustainable pathways to improve livelihoods of millions of people (Kriegler *et al* 2012, Fuso Nerini *et al* 2018, Eisenmenger *et al* 2020). The Sustainable Development Goals (SDGs) offer a set of targets to guide the implementation of such pathways (United Nations 2015). Due to the multidimensionality and wide scope of SDGs, more research is needed to understand the interconnections, trade-offs, and co-benefits of SDG targets at country level (Fuso Nerini *et al* 2018, Mainali *et al* 2018, Moyer and Bohl 2019, Eisenmenger *et al* 2020). Existing research has identified more synergies than trade-offs between the SDGs, especially with regard to SDG7 'affordable and clean energy' (Fuso Nerini *et al* 2018). Yet, more research is needed on these synergies at national and local levels.

We suggest that two inter-related questions are central to the interactions between clean energy and other SDGs. First, if energy is used for fostering well-being, what do we mean by living well? Second, how much energy is required to end multiple deprivations?

To date, research into energy and development has highlighted that quantity and access to energy are insufficient metrics to capture multidimensionality of energy poverty (Kaygusuz 2011, 2012, Pachauri and Spreng 2011, Nussbaumer *et al* 2012, Roy 2012, Pachauri *et al* 2013). In addition, research has indicated that replacing biomass-based fuels (e.g. firewood or charcoal) with 'modern' fuels such as gas, electricity or biofuels is associated with improved well-being (Oparaocha and Dutta 2011, Prasad 2011, Karekezi *et al* 2012, Rahut *et al* 2014, Rao and Pachauri 2017, Crentsil *et al* 2019). The energy source is also particularly important for equal participation of women and children in improved living, including education and income-earning opportunities (Pachauri *et al* 2004, Kaygusuz 2011, Sovacool 2012, Rao and Pachauri 2017). Furthermore, there is a strong association between burning inefficient traditional fuels and respiratory infections, which disproportionally affect women and children (Smith *et al* 2004, 2014, Mannucci and Franchini 2017, Balmes 2019). Burning traditional fuels also produces black carbon emissions, which exacerbate global warming (Ramanathan and Carmichael 2008).

A few studies shed light on the distributional aspects of energy use and well-being. In particular, there is a gap in research on the relationship between final energy use and multiple deprivations (or need-satisfaction) at the household level. There is also a need to better understand how the level and composition of energy use changes with the social and physical infrastructure available to households.

Most studies of household energy footprints have focused on the Global North (Reinders *et al* 2003, Lenzen *et al* 2004, Bin and Dowlatabadi 2005, Cohen *et al* 2005, Büchs and Schnepf 2013). They have mostly consisted of analyses of energy consumption and its variation across socio-economic characteristics such as income, expenditure, household structure and regional setting (Herendeen and Tanaka 1976, Herendeen 1978, Lenzen *et al* 2006, Weber and Matthews 2008, Räty and Carlsson-Kanyama 2010, Büchs and Schnepf 2013, Ala-Mantila *et al* 2014). Only a few conceptual studies examine the links between energy and well-being (Pachauri and Spreng 2002, Nussbaumer *et al* 2012, Day *et al* 2016). But recently Rao estimated the links between national energy use and decent living standards (Rao and Pachauri 2017, Rao *et al* 2019a). To our knowledge, nobody has conducted this kind of analysis at a household level in developing countries. In addition, too few studies have examined the association between energy footprints and achievement of SDGs.

We seek to contribute to filling this gap by examining household energy footprints in Nepal, Vietnam, and Zambia. The sample of three countries covers different levels of development and access to modern energy in varying geopolitical contexts. In Nepal and Zambia, the majority of households rely on biomass for energy needs due to lack of access to modern fuels, while Vietnam offers better access to modern energy particularly in urban areas. Vietnam has higher Human Development Index of 0.66 compared to 0.53 and 0.54 for Nepal and Zambia (in 2011, the year of our study) and its GDP per capita is significantly larger that of Zambia and Nepal (4500$ compared to 2000$ and 3300$ in Nepal and Zambia in 2011 (World Bank 2011)).

We examine the composition and inequalities related to household energy footprints and associations between energy use and well-being. We explore 'basic well-being' defined as the achievement of access to clean water and food, education, and access to alternative modern fuels. We use the terms 'improved well-being' and 'decent living standards' when referring to other well-being outcomes not included in the analysis. These standards relate to improved living seen via the SDGs lens. A third and distinct concept is that of 'improved standards of living', which is understood to mean increased ownership of consumer goods. We further discuss interactions between basic well-being outcomes, energy and SDG targets.

2. Data and methods

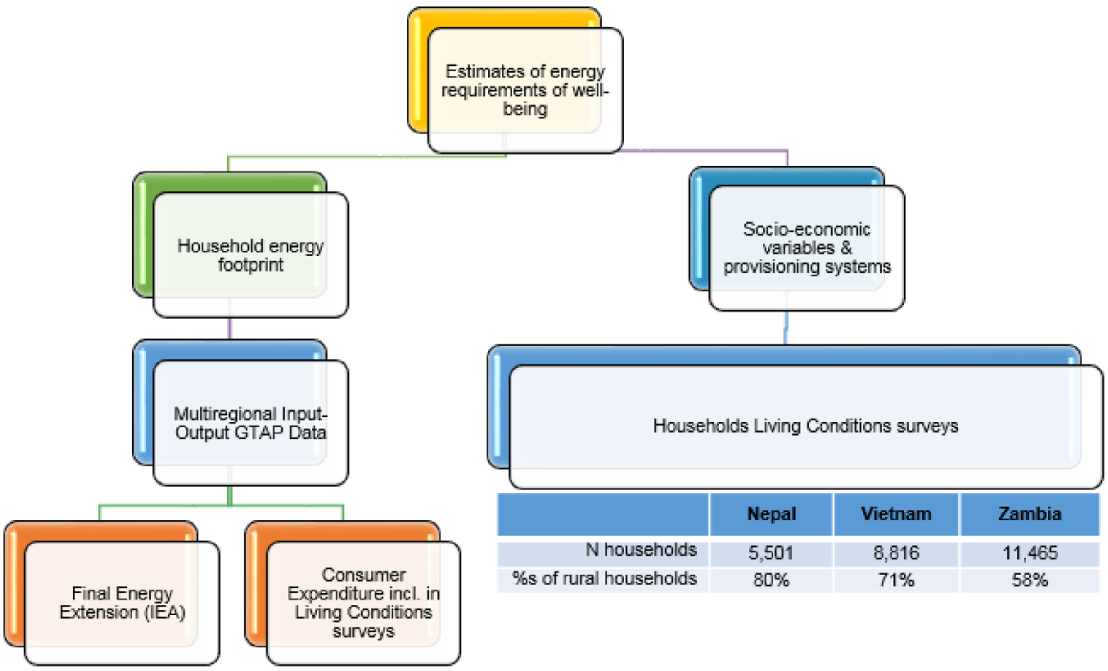
2.1. Energy model

We calculate household energy footprints using a method described in detail in our previous study by Baltruszewicz *et al* focusing on the case of Zambia (2020). Below we outline changes to that energy model and data used in this article.

To calculate energy footprints, we created an energy model built on consumption-based accounting using multi-regional input–output (MRIO) tables with a final energy extension using International Energy Agency (IEA) data (figure 1). The Global Trade Analysis Project (GTAP) version 9 (see Peters *et al* (2011) for methodology) with 2011 as a reference year is the basis of our MRIO model. To disaggregate household final demand in GTAP, we obtained household expenditure from nationally representative household surveys (figure 1). For Zambia, this was Living Conditions Survey of 2015 (Central Statistical Office (Zambia) and World Bank 2015) and for Nepal and Vietnam, household Living Standard Surveys conducted between 2010 and 2011 (General Statistics Office 2010, National Planning Commission Secretariat 2011).

2.2. Energy footprint dictionary

We focus on final energy consumption, as opposed to primary energy or greenhouse gas emissions, because of its significance to well-being in developing countries (Kaygusuz 2012, Fuso Nerini *et al* 2018) and



	Nepal	Vietnam	Zambia
N households	5,501	8,816	11,465
%s of rural households	80%	71%	58%

Figure 1. Framework for estimating household energy footprints and energy requirements of well-being outcomes. The final stage of the analysis in yellow. Below the 'household Living Conditions Surveys' box survey sample size and share of rural households in each country.

because we conceptualize energy use as a key for need-satisfaction (Rao and Baer 2012, Day *et al* 2016, Brand-Correa and Steinberger 2017). We distinguish between direct and indirect energy use (figure 2). Indirect energy use includes energy embodied in goods and services such as appliances, restaurants meals and food. Direct energy use refers to the use of residential and vehicle fuels such as cooking fuels and petrol and electricity used by households. These fuels have an indirect component due to the energy embedded in the supply chain, for example, energy used in coal mining to produce electricity.

We further differentiate between traditional, transitional and modern fuels. Traditional fuels include inefficient, biomass-based sources of energy such as firewood, charcoal, or dung while transitional fuels include kerosene and diesel for home usage (mostly for generators), which have improved efficiency, yet adverse effects on health (Lam *et al* 2012). Modern fuels include energy-efficient and non-biomass-based fuels such as gas and electricity. The rationale for the distinction is the environmental (e.g. deforestation) and health (e.g. indoor pollution) damage caused by traditional and transitional fuels (Riahi *et al* 2012). Grieshop *et al* also suggest that fossil fuels such as liquefied petroleum gas (LPG) for cooking may be the best option for both health and climate change (2011).

2.3. Well-being outcomes

We also investigated the association between energy use and achievement of well-being outcomes whilst controlling for household socio-economic characteristics. We build on the theory of human needs like in our previous study (supplementary materials (available online at stacks.iop.org/ERL/16/025011/mmedia)) to choose variables for analysis (Doyal and Gough 1991). We reviewed variables available from all three countries and chose four to represent the most basic well-being outcomes: (a) access to modern cooking fuels; (b) access to clean water close to home; (c) basic or higher education, and; (d) nutrition. Definitions of these variables, corresponding questions and linked SDG goals are indicated in table 1.

These well-being indicators measure the attainment of minimum requirements for the fulfillment of basic needs. Nutrition and clean water are satisfiers of a basic human need for physical health. Access to modern cooking fuels is important due to the adverse effects of traditional and transitional fuels on health. We consider that a household fulfills basic education if not only the household head, which in the majority of the cases is male, but also his spouse has nine or more years of education. This is to account for gender equality and the importance of women's education for children's heath (Hobcraft 1993, Adhikari and Sawangdee 2011, Carlson *et al* 2015).

2.4. Non-monetary consumption

Calculating household energy footprints for developing countries poses a challenge because households often self-provide food, and only partially rely on the market for cooking fuels (see supplementary materials). For Nepal, we used physical units to

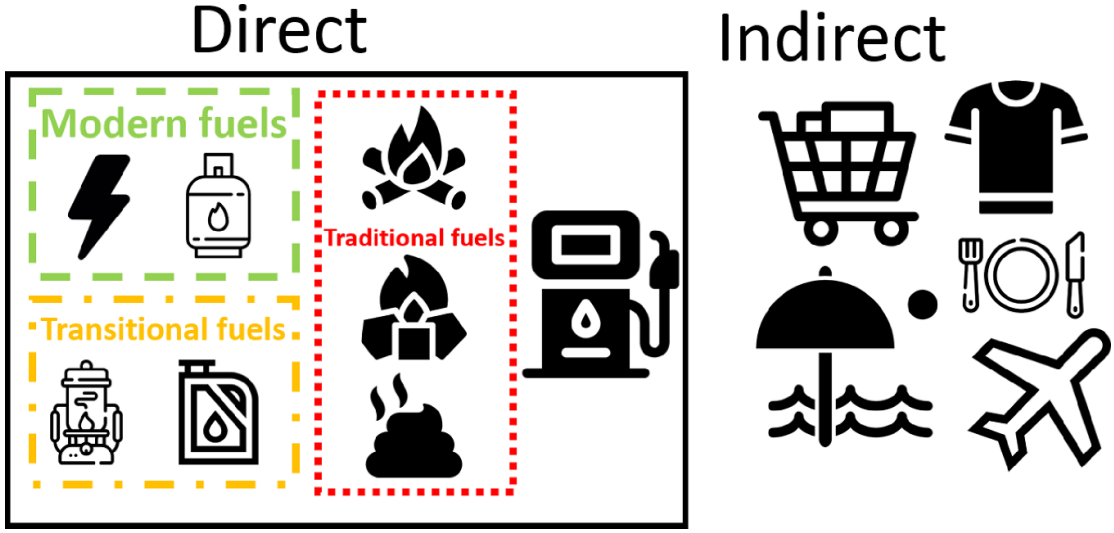


Figure 2. Energy footprint dictionary: direct, indirect, modern, transitional and traditional fuels categorization. Icons made by Freepik from www.flaticon.com.

calculate an average price per kilogram of collected firewood and charcoal. For self-produced biogas, we adjusted expenditure using LPG spend. For Zambia, we created an 'expenditure equivalent' based on income, the number of meals per day consumed, location (district level), and type of cooking device to calculate per capita spend on collected firewood and produced charcoal (see supplementary materials).

2.5. Statistical analysis

We report direct and indirect energy footprints in GJ cap^{-1} yr^{-1}. The final household demand in GTAP represents the whole population, hence the energy footprints are also weighted and representative. We group household energy footprints using income deciles, which are calculated using household yearly income based on the Organisation for Economic Co-operation and Development (OECD) equivalence scale, which assumes different weighting for adults and children. Individual weights available in household surveys are used to reflect the whole population. We excluded outlier households with expenditures on items higher than nine standard deviations. This resulted in excluding 4.8%, 5%, and 1.4% of the population in Nepal, Vietnam, and Zambia, respectively. These outliers are spread throughout all income groups.

2.6. Inequalities

We used Gini coefficients, which employ the frequency distribution of e.g. levels of expenditure or income in the whole population to account for inequalities (Steinberger *et al* 2010).

We explored the association between household socio-economic characteristics and well-being outcomes with logistic regression analysis. Importantly, we move modern fuels from the dependent variable related to achieving basic well-being outcomes to the side with independent variables. This enables a clear division between energy-related independent variables and non-energy well-being outcomes, which helps avoid the endogeneity problem and makes the interpretation of results easier. To reduce the number of variables, we conducted factor analysis, which results in the reduction of the original seven variables into three factors linked to collective provisioning context and protection (table 2). All results of the logistic regressions are reported using odds ratios for simplicity. The odds ratios express the ratio of the probability that the household will have all well-being outcomes met to the probability that the household will not have these outcomes met given the achievement of the independent variable.

2.7. Limitations

The data provided by the IEA does not cover all sectors in developing regions. In the IEA data, eight out of 23 final energy consumption sectors do not have any values for Nepal, 11 in Zambia, and 12 in Vietnam. This may lead to lower estimates of energy footprints of certain products such as food. A way to resolve this is to use additional energy-intensity estimates. Rao proposed energy intensities for main cereals in India, which could be applied also for Nepal (Rao *et al* 2019b). However, due to cultural and technological differences in food production in the countries we examine and to be able to compare energy footprints we chose not to use additional data, and acknowledge a possible underestimation of energy use for specific products.

Secondly, the lack of monetary value for cooking fuels and the use of averages to estimate them may have resulted in under- or overestimated footprints of residential fuels for some households in Nepal and Zambia.

Table 1. Well-being outcomes used for the analysis: definitions, corresponding survey questions, and related SDGs.

Well-being outcome	Related SDGs	Definition	The corresponding question in the survey
Access to modern cooking fuels	SDG7 'affordable and clean energy' SDG13 'climate action' SDG15 'life on land'	Based on the definition of modern fuels (see figure 2). Household meets the outcome if using 50% or more modern fuels.	
Access to clean water in close vicinity from home	SDG6 'clean water and sanitation' SDG3 'good health and well-being'	According to the United Nations water report (World Health Organization and UN-Water 2012), 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.	Nepal: Where does your drinking water come from? Vietnam: Which is the main drinking water supply of your household? Zambia: How far is this source of water from this house? What is the main source of drinking water for this household?
Basic or higher education	SDG4 'quality education' SDG5 'gender equality' SDG10 'reduced inequalities'	Household head and his/her spouse have 9 years or more of schooling. Nine years are in the majority of countries' lower limit of what is considered a basic education and it is in line with SD4 'Education' (UNESCO 2015).	
Nutrition in the form of having an adequate amount of food	SDG2 'zero hunger' SDG1 'no poverty'	Nepal: an adequate amount of food (adequate if answered *It was just* (or more than) *adequate for your family's needs*).	Nepal: Concerning your family's food consumption over the past month, which of the following is true?
		Vietnam: insufficient if it meets one of three criteria: household used food aid, stated to have an insufficient amount of food and foodstuff, or stated to have an insufficient amount of food while still having enough of foodstuff.	Vietnam: In 2009–2010, has your household benefit from the Food aid? Has the consumption of food and foodstuff by your household been sufficient to meet needs over the last 30 days?
		Zambia: adequate food if a household has three or more meals per day.	Zambia: How many meals excluding snacks do you normally have in a day?

Thirdly, we chose only four variables to represent well-being outcomes, because, with each additional outcome, the sample of households fulfilling all outcomes decreases, leading to samples too small for meaningful statistical analysis. Household surveys used in the analysis also consist of different sets of questions, which limits the number of common variables in comparative analysis.

Fourthly, incomes can be under- or over-reported. For example, Vietnamese dataset does not report whether the incomes are before or after-tax, whereas the majority of Nepalese households reported net income and the Zambian survey asked for gross income.

Some consumption categories were also covered in more or less detail. Public transportation is an example: Nepal provided detailed information about mileage, time use, vehicle type, and type of travel whereas Vietnam and Zambia only offered a distinction between public and private transportation.

3. Results

3.1. Total energy footprints

Energy footprints in Nepal, Vietnam, and Zambia are less than half of the global average in per capita terms (figure 3, International Energy Agency 2011). The composition of footprints indicates 'housing' and 'transport' are major users of energy in all three countries (figure 3). They mostly involve direct energy use of residential and vehicle fuels. The indirect energy embedded in rents, house maintenance, public transport, and car maintenance contributes only about 1%–2% of 'housing' energy footprint. But about 20% of Vietnam's and Zambia's and over half of Nepalese footprint for 'transport' was indirect. Indirect energy thus constitutes a minor portion of overall footprints, around one seventh in Nepal and Zambia, but in Vietnam, it is a significant portion of one-third of the total energy footprint (EF).

Table 2. Percentage of population in Nepal, Vietnam, and Zambia achieving basic well-being outcomes, DSLs and selected socio-economic characteristics.

	Nepal			Vietnam			Zambia		
	Whole pop.	Achvd	Not achvd	Whole pop.	Achvd	Not achvd	Whole pop.	Achvd	Not achvd
Total *N* of households in sample	5501	410	5091	8816	2420	6396	11 465	917	10 548
(a) Basic well-being outcomes:									
Adequate food	84%	100%	83%	92%	100%	88%	55%	100%	52%
Safe water	83%	100%	82%	90%	100%	86%	64%	100%	62%
Education ($\geqslant$9 years)	10%	100%	5%	65%	100%	49%	29%	100%	25%
Modern fuels	15%	100%	11%	42%	100%	17%	8%	100%	3%
HHs with all basic well-being outcomes	5%	100%	0%	30%	100%	0%	6%	100%	0%
(b) Socio-economic characteristics for DSL:									
*Solid shelter [P]	29%	84%	27%	87%	97%	83%	29%	86%	26%
*Min floor space [P]	48%	54%	48%	82%	86%	80%	66%	92%	65%
*Safe toilet [P]	54%	99%	52%	69%	93%	58%	30%	89%	27%
Clean cooking device	23%	98%	20%	81%	97%	75%	15%	90%	10%
Refrigerator	8%	44%	6%	41%	72%	28%	11%	59%	9%
*Phone	62%	98%	60%	79%	93%	73%	61%	91%	59%
*Television	44%	85%	42%	89%	95%	87%	37%	94%	34%
*Electricity access	69%	100%	68%	97%	100%	96%	30%	99%	26%
% households with all DSL	2%	29%	0.3%	24%	58%	9%	4%	38%	2%
N households	139	124	15	1916	1384	532	687	351	336
% DSL and basic well-being outcomes (1 and 2)	1%	29%	N.A.	18%	58%	N.A.	2%	38%	N.A.
N HHs with DSL and well-being outcomes (1 and 2)	124	124	N.A.	1348	1348	N.A.	1348	351	N.A.
(c) Additional characteristics:									
*Rural	80%	24%	83%	71%	46%	83%	58%	8%	61%
*Not poor	50%	77%	49%	89%	99%	85%	59%	95%	57%
*Access to market w/n 5 km [CP]	97%	100%	97%	91%	96%	89%	63%	92%	62%
*Access to public transport w/n 5 km [CP]	76%	100%	75%	89%	95%	87%	57%	77%	56%
*Access to healthcare center [CP]	90%	99%	89%	100%	100%	100%	63%	79%	62%
*Sewage [P]	8%	46%	6%	48%	81%	34%	15%	77%	11%
*Garbage disposal [CP]	56%	67%	56%	41%	68%	29%	6%	27%	5%
*Motor cycle	9%	42%	7%	76%	91%	69%	1%	0.3%	1%
*Household size	5 (2)	4 (2)	5 (2)	4 (2)	4 (1)	4 (2)	5 (2)	5 (2)	5 (2)
*Share of modern fuels (%)	17 (34)	96 (11)	13 (29)	49 (43)	97 (10)	28 (33)	11 (27)	95 (13)	6 (17)
*Residential fuels (GJ cap^{-1} yr^{-1})	15 (16)	3 (2)	16 (16)	9 (10)	5 (3)	11 (12)	13 (12)	8 (11)	13 (12)
*Total EF (GJ cap^{-1} yr^{-1})	18 (16)	12 (10)	18 (17)	20 (14)	22 (14)	19 (13)	16 (15)	19 (22)	16 (14)

Note: Achvd—corresponds to households that achieved four well-being outcomes listed in the first four rows; not achvd—corresponds to households without well-being outcomes listed in the first four rows; pop. stands for population; *N* households corresponds to number in the household survey; HH corresponds to households; min floor space corresponds to having a minimum of 10 m^2 per person; safe toilet means shielded from external environment and with safe waste storage and/or treatment; solid shelter includes durable walls and floor and living with a minimum of 10 m^2 of floor area per person; % DSL and basic well-being outcomes corresponds to shares of households that achieve four basic well-being outcomes and decent standards of living (DSLs); * variables used in the logistic regressions (see also table S9), [P] variable used to construct the protection factor, [CP] variable used to construct the collective provisioning factor (see table S8 in the supplementary materials); standard deviations in parenthesis.

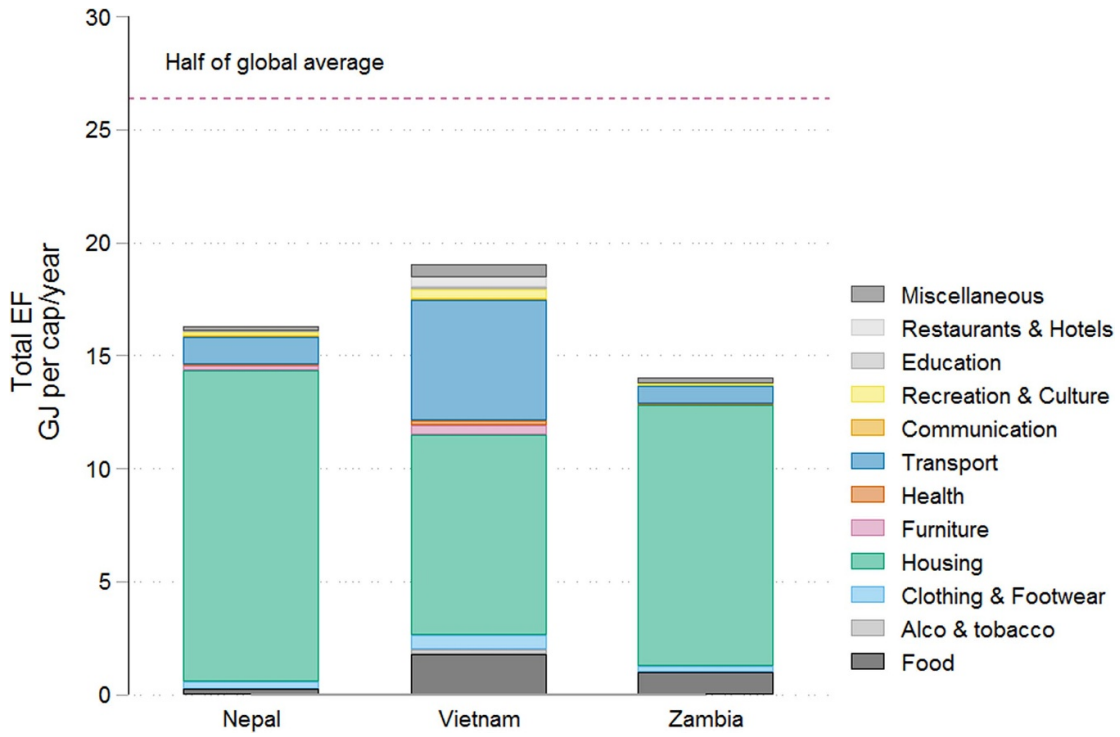


Figure 3. Total energy footprints in Nepal, Vietnam, and Zambia by consumption categories (GJ cap^{-1} yr^{-1}).

3.2. Energy footprints by income deciles

When comparing household energy use by income deciles (figure 4(a)), Vietnam and Nepal have comparable consumption for the lower half of the population, between 14 and 17 GJ cap^{-1}, while in Zambia, the EF of the first five decile is closer to 10 GJ cap^{-1}, only 40% of the EF of the highest decile. In Nepal, energy use is about the same for most income groups, although the type of energy use varies. Whilst 'housing' EF decreases by more than one-third between the first and the last decile, an eightfold increase of transport EF occurs. The 'transport' EF is prominent only in Vietnam, where it constitutes 40% of the total EF of the top income decile. Lower income levels and affordability and undeveloped road networks in Nepal and Zambia contribute to their lower vehicle fuel consumption.

3.3. Indirect energy footprints

Indirect energy footprints (dark gray bars in figure 4(b)) of the poorest half of the Vietnamese population increase by a mean 0.6 GJ cap^{-1} whereas in Nepal and Zambia the rise is more modest of 0.05 GJ cap^{-1} and 0.1 GJ cap^{-1}, respectively.

In Zambia, indirect energy use starts to increase in the higher income half of the population. In Nepal, it stays at the level of about 2.5 GJ for the first 80% of the population, sharply increasing only for the top two deciles (figure 4(b)).

Without access to different provisioning systems, the energy levels stay stable regardless of economic improvements. Prior studies show that energy use on leisure and luxury items is generally highly elastic (Oswald *et al* 2020). Yet, in Nepal the bottom half of the households use similar levels of energy on communication, recreation, culture, and clothing in the absence of alternatives.

3.4. Direct energy footprints—residential fuels

Further analysis of the direct EF of residential fuels indicates that in Zambia and Nepal only high-income households afford modern fuels (figure 5). In Vietnam, there is a rapid transition to modern fuel use in higher income deciles (figure 5). In Nepal, residential fuel use decreases by almost one-third in higher income deciles due to increased LPG usage (figure 5). This highlights the importance of access to and affordability of modern, efficient fuels in reducing household energy footprints. Indeed, the useful energy, or energy services, which higher income households enjoy, can be expected to be larger than those of poorer households. The point here is that high quality energy services, depending on modern fuels and efficient appliance, can very often be delivered at a fraction of the final energy of traditional and inefficient fuels.

Zambia offers an example of what can happen with limited access to modern fuels: more affluent households replace firewood with charcoal (figure 5). Both energy sources are inefficient and cause indoor air pollution, but only charcoal is consumed by higher income households. The income level of about 1000$ cap^{-1} is associated with only about 10%

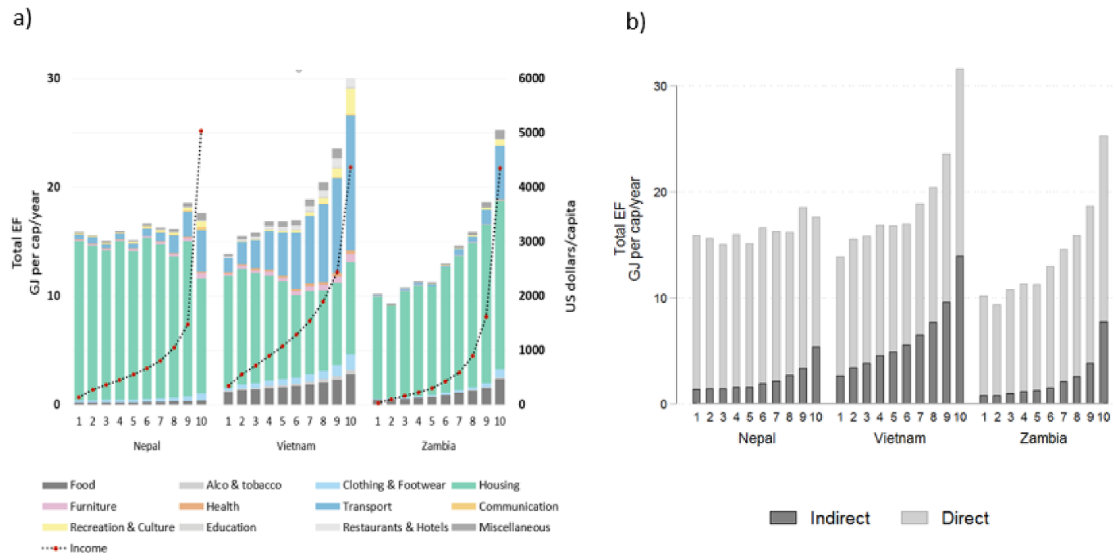


Figure 4. Household energy footprints by income deciles for Nepal, Vietnam, and Zambia for (a) 12 consumption groups. The *y*-axis represents average income per capita using the equalized OECD scale. (b) Total direct and indirect energy use.

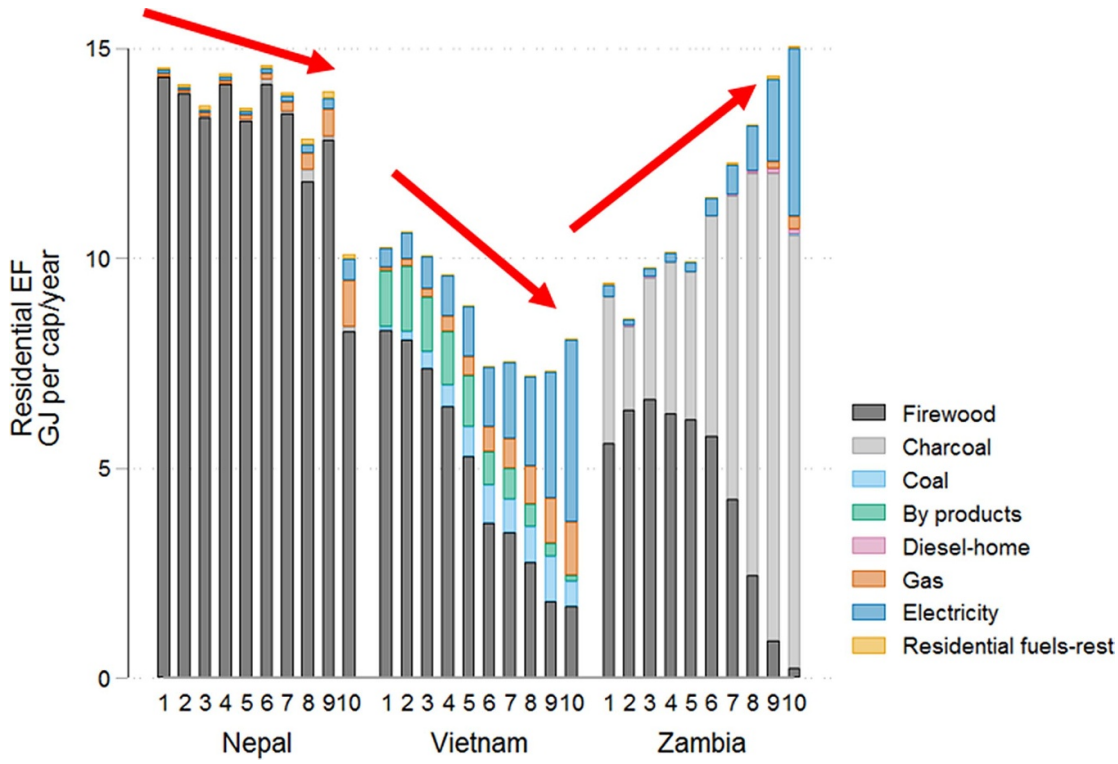


Figure 5. Per capita energy footprints by income deciles categorized by residential fuels in Nepal, Vietnam and Zambia.

modern fuel share in Nepal and Zambia, while in Vietnam it is roughly 15%. Only the two top deciles of Vietnamese households have a 50% modern fuel share in their energy portfolio. In Nepal, modern fuels only account for 25%, and in Zambia 33%, of the top defile's energy portfolio. The lack of access to modern and efficient fuels and particularly electricity clearly leads to even the most well-off households relying on traditional cooking fuels.

The results highlight that in developing countries fuel transition follows the energy stacking behavior. Households accumulate energy options when their income increases or access and affordability eases. Households are adopting modern, more efficient fuels but continue to use traditional fuels due to cultural and economic reasons, and to handle the stresses and shocks that affect income, access or affordability of energy.

3.5. Inequalities

Modern energy use is highly unequal in all countries (figure 6). In Nepal and Zambia, the top decile are responsible for over two-thirds of the modern fuels EF. In Zambia, 70% of the population does not use modern fuels at all. In Vietnam, the top decile uses six times more modern fuels per capita than the bottom three deciles and twice the national average.

Income has a larger inequality than total EF—but modern fuels are even more unequally distributed. The top decile in Nepal and Zambia earns almost half of the income whereas in Vietnam it is just one-third. The top decile uses a third of the energy in Nepal and Zambia and a fourth in Vietnam. These results suggest that the inequalities relate to the types of energy used, rather than just to amounts of energy used.

3.6. Energy profiles and well-being outcomes

We now turn to the link between the household energy profiles and the achievement of well-being outcomes. Rao and Min (2017), Millward-Hopkins *et al* (2020) have recently specified the physical requirements for decent standards of living (DSL), identifying household and collective characteristics needed to live in a healthy and safe environment. We examine what percentage of the population in each country attain the basic well-being outcomes of interest to us and how many achieve additional characteristics for DSL (table 2). In Nepal and Zambia, the absolute minimum requirements of having basic education, sufficient food, safe water and modern fuels are achieved by just around 5%–6% of the population. This decreases to below 2% in both countries when considering wider DSL outcomes. In Vietnam, around 30% attain the basic well-being outcomes and around 18% attain both basic and the DSL outcomes. The majority of the Vietnamese have access to electricity, safe water, and food. However, the minority uses modern fuels and refrigerates their food.

The overall energy footprints of the households who achieved basic well-being outcomes vary between 11 and 19 GJ cap^{-1}. This is 60%–80% lower than the global per capita average EF in 2011 (52 GJ) (figure 7).

We find that the Nepalese households achieving basic well-being outcomes use similar levels of energy compared to those estimated by Rao, Min, and Mastrucci for India (Rao *et al* 2019a). In Vietnam this is closer to Brazil, and Zambia compares to South Africa.[1] These studies (see figure 7) serve only the context for our results, as we recognize that there are substantial geographical, technical, infrastructural differences between them and our study.

The composition of the footprints differs from the observed national averages (figure 8(a)). Housing EF *decreases* for households that attain the four basic well-being outcomes in the three countries, while transport EF and categories linked to indirect energy *increased* in all countries.

3.7. Energy, well-being and income

When we distinguish the households with achieved basic well-being outcomes by their income level, we obtain three important results (figure 8(a)). Firstly, the lower income households (25th quartile) achieve their well-being outcomes with 30%–60% lower total EF and 60%–80% lower residential fuels energy use than the national average in each country. Secondly, although the 'transport' EF increases across income deciles, this is compensated by decreasing 'housing' EF. Finally, basic well-being outcomes can be achieved with strikingly low energy levels. But depending on physical and societal structures and created dependencies for need-satisfaction, an increase in income opens possibilities for further energy consumption linked to transportation, recreation, and culture. This is evident when considering indirect energy footprints.

Further analysis reveals that switching from energy-intensive firewood and charcoal to modern fuels explains why we observe decreased energy use (figure 8(b)). Nepal exhibits the most dramatic change—households with well-being outcomes use only a fraction of residential energy. For the 25th quartile, Vietnam and Nepal have the same level of residential fuel use. However, whereas in Nepal households mostly use gas, in Vietnam it is electricity. The Vietnamese households achieving basic well-being outcomes use less than one-third of the national average on residential fuel energy use (figure 8(b)). These results strongly suggest that basic well-being outcomes can be achieved with lower than average energy use per household in developing countries.

3.8. Logistic regression—factors that increase chances for well-being

In the end, we address the association between socio-economic characteristics and well-being by using logistic regressions (table 3). As noted in section 2, to avoid the endogeneity problem, we include modern fuels together with independent variables. This means the dependent variable 'achieved' includes having safe water, basic education and sufficient food. The sign of coefficient and odds ratio relates to the direction of change. One indicates no effect, positive effects are greater than one, and negative effects are between zero and one.

Households that have sufficient food, access to clean water, and secondary education have three (Zambia) to five (Vietnam) times higher odds of having solid shelter, toilet, and sewage. Increased total energy use, even though significant, does not contribute to increased odds of achieving well-being

[1] Although, these energy footprints could differ due to the discrepancies linked to IEA data, especially about food energy intensities in Nepal.

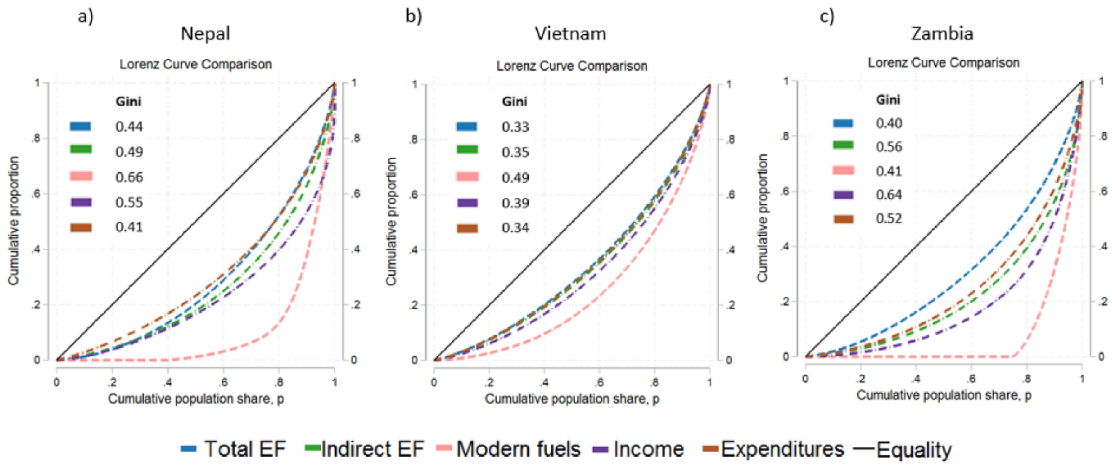


Figure 6. Lorenz curves and Gini coefficients for energy footprints, income and expenditures in (a) Nepal, (b) Vietnam, (c) Zambia.

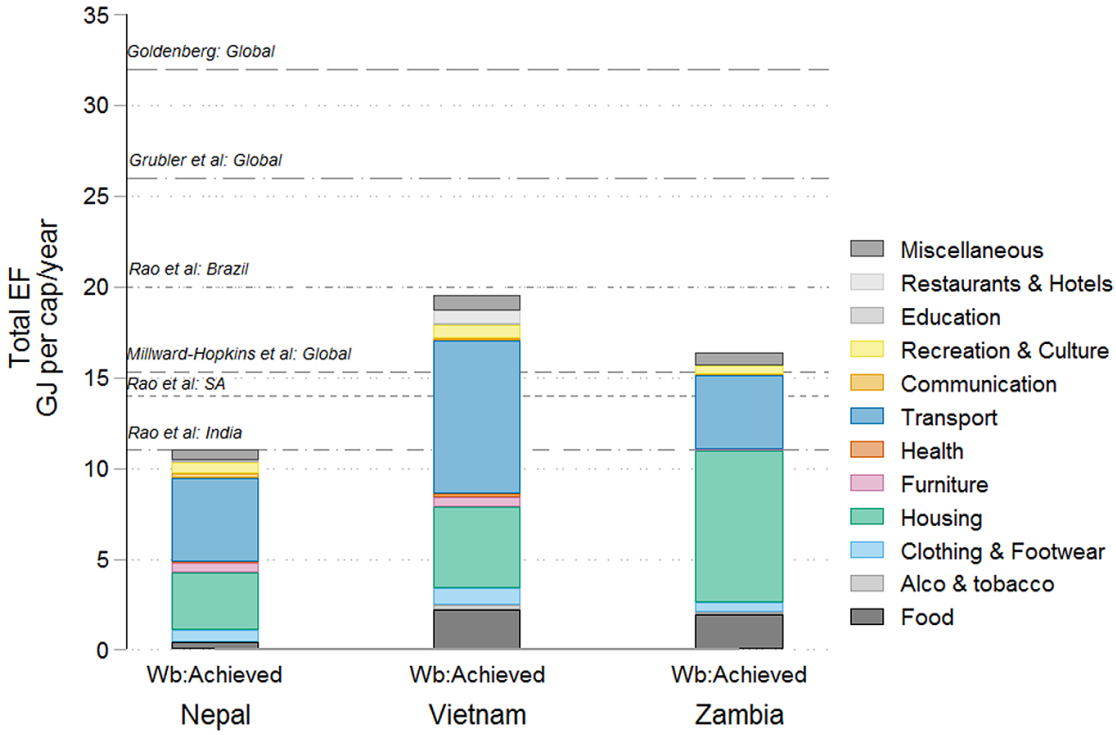


Figure 7. Comparison of total energy footprints for households that achieve well-being outcomes (including sufficient food, secondary education, safe water and more than 50% of modern fuels) in Nepal, Vietnam, and Zambia and reported estimates for decent living at a regional (Rao *et al* 2019a) and global level (Goldemberg *et al* 1985, Grubler *et al* 2018, Millward-Hopkins *et al* 2020). Based on Millward-Hopkins *et al* (2020).

outcomes. How the energy is delivered is more important than the amount of energy used. Access to collective provisionings and related devices (sewage, toilet, electricity, phone, public transport) which are part of DSLs (Rao *et al* 2019a) have important effects in our analysis: households with basic well-being outcomes tend to have higher odds of having the other DSLs irrespective of how much more energy they use.

To understand the role of the country context in achieving well-being outcomes, we used margin plots to analyze changes in probabilities of achieving well-being (sufficient food, safe water, basic education) depending on low or high levels of (a) households having modern fuels; (b) households with protection; and (c) households with collective provisioning systems[2] (figure 9).

[2]To the contrary of what might be assumed, these factors and the variables included in them are not directly linked to well-being outcomes. For example, having indoor flush toilet does not automatically mean that the household has access to safe water, nor having solid shelter and minimum floor area equals having basic education (see table S10–12 in the supplementary materials).

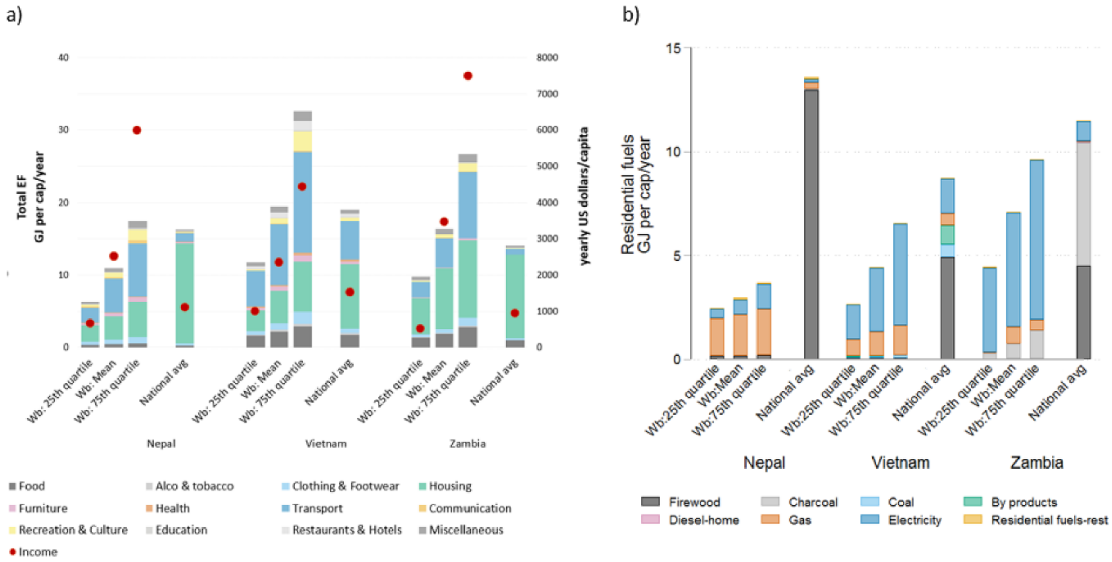


Figure 8. Households with basic well-being outcomes (sufficient food, safe water, basic education, and >50% modern fuels) and split by income quartiles and national average for (a) total EF, (b) residential fuels EF.

Table 3. Logistic regression models presenting the odds ratio for achieving basic well-being (here omitting the modern fuels variable) in Nepal, Vietnam, and Zambia.

	Nepal		Vietnam		Zambia	
F: protection	4.217***	(6.95)	4.638***	(21.85)	3.413***	(8.36)
F: collective provisioning Nepal	3.867**	(2.81)	—	—	—	—
F: collective provisioning Zambia	—	—	—	—	1.448*	(2.40)
Rural	0.711*	(−2.36)	—	—	—	—
Household size	0.840***	(−4.66)	0.855***	(−6.74)	—	—
Not poor	1.735***	(4.19)	—	—	3.988***	(10.11)
Minimum floor area	—	—	—	—	1.800***	(4.91)
Electricity access	—	—	—	—	1.729***	(3.49)
Residential fuels (GJ cap^{-1})	0.947***	(−5.31)	0.960***	(−6.07)		
Total EF (GJ cap^{-1})	1.042***	(4.95)	1.036***	(6.79)	1.011**	(3.12)
Share of modern fuels	1.010***	(4.59)	1.002*	(2.04)	1.015***	(8.07)
Access to market w/n 5 km	—	—	1.910***	(6.41)	—	—
Phone	—	—	2.140***	(10.06)	1.680***	(3.72)
Television	—	—	—	—	2.010***	(5.06)
Motor cycle	—	—	1.654***	(6.51)	—	—
_cons	0.0207***	(−6.78)	0.112***	(−14.39)	0.00517***	(−28.55)
N	5501	—	8816	—	11 465	—
Pseudo R^2	0.227	—	0.190	—	0.393	—
Chi2	786.8	—	1380.6	—	1283.8	—

Exponentiated coefficients; *z* statistics in parentheses.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.
Note: The dependent variable is a product of three binary variables: sufficient food, safe water, and basic education (see table S9). The dependent variable is coded 1 if all three binary variables equal to 1. Resulting factor analysis (see table S8), following factors are included (starting from the top of the table): factor: 'protection' which includes having solid shelter, sewage, and safe toilet; factor: 'collective provisioning Nepal', which refers to access to health canter, public transport and market within 5 km from home; factor: 'collective provisioning Zambia', which refers to garbage disposal and access to health centre, public transport and market within 5 km from home. Reading odds ratio: one indicates no effect, positive effects are greater than one, and negative effects are between zero and one.

At the national average level of 15 GJ, we observe significant differences in adjusted probabilities of achieving basic well-being outcomes between investigated countries (figure 9). In Nepal a high share of modern fuels increases the probability of achieving well-being outcomes by 10%. In Zambia the probability is twice as high, 20% at the level of 15 GJ. Zambian households with high levels of protection and collective provisioning are also more likely, compared to Nepal, to achieve well-being outcomes

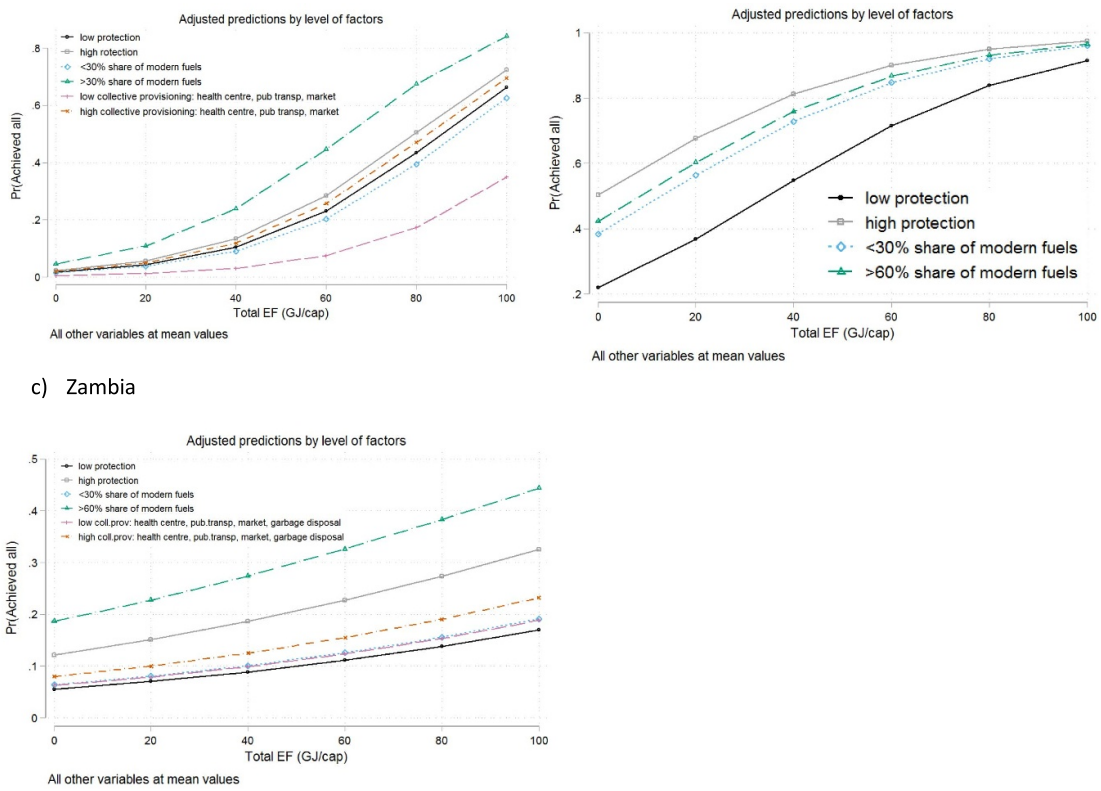


Figure 9. Adjusted predictions for the likelihood of achieved well-being by levels of factors and energy use. Note: low corresponds to factor level below or equal to 0.6. High corresponds to factor level higher than 0.6. *x*-axis presents the total energy footprint per capita in a given country. Probabilities are denoted on the *y*-axis with zero minimum and one corresponding to the maximum probability (multiply by 100 to interpret in %s).

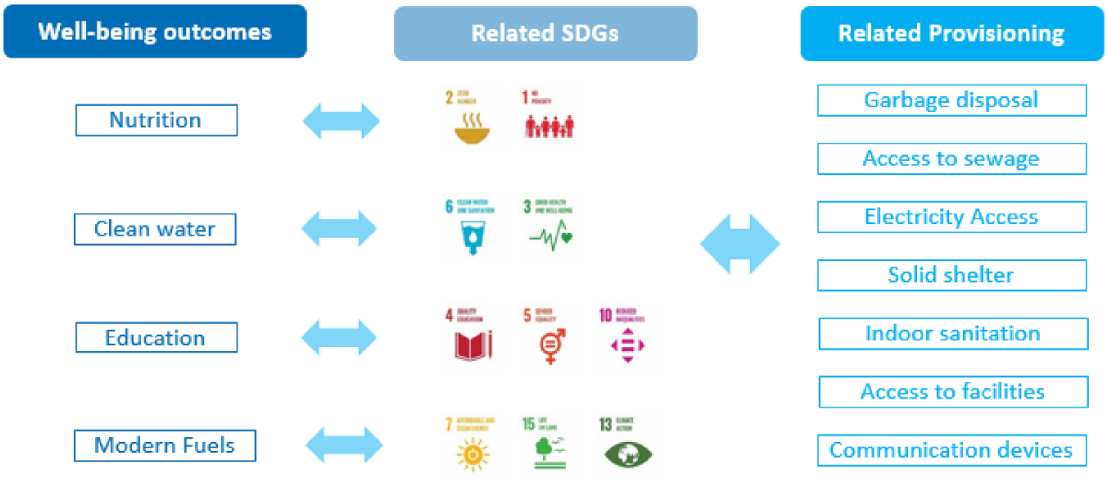


Figure 10. Translating provisioning variables and well-being outcomes to SDGs goals and possible synergies.

(13% and 9% respectively at the level of 15 GJ). In Vietnam, the general starting point of households is much better than in the other two countries. Households at the level of 15 GJ, which is lower than their national average energy use, already have a high probability of achieving basic outcomes—60% for high levels of protection and 50% when considering modern fuel usage.

The spread between adjusted probabilities lines (figure 9) shows how difficult it is to have basic outcomes met when access to protection, collective provisioning, and modern fuels are restricted according to our modeling. Nepalese households lacking collective provisioning have almost no real chance of achieving basic well-being outcomes. At the level of 30 GJ, which corresponds to the 10th income decile,

the adjusted probability is close to zero. In Zambia, the flat slope of probabilities linked to low levels of protection reflects the difficulties of having basic well-being outcomes without having access to indoor sanitation and solid shelter. In contrast, households with high levels of protection are twice as likely to achieve their basic well-being outcomes.

Overall, we observe that basic well-being outcomes are dependent on providing energy-efficient services that contribute directly or indirectly to improved well-being. This leads to the conclusion that, rather than overall levels of energy use, the more important determinants of well-being outcomes are the ways in which energy is provided and the energy services that households are able to obtain from such provision (Brand-Correa and Steinberger 2017).

4. Discussion and conclusions

We assessed households' direct and indirect energy footprints in three developing countries. We focused on the composition of these footprints, as well as related inequalities, and links to well-being. We found that the energy footprints are mainly due to residential fuel use, resonating with the results of (Oswald *et al* 2020) who also found that heat and electricity have high energy intensities in developing countries. Oswald *et al* (2020) also pointed out that inequalities in energy consumption are an important barrier for a just energy transition. We found that inequalities around modern energy sources matter more for well-being than inequalities linked to income.

Our findings suggest that, with increased income, energy stacking occurs. Households do not, on average, exceed two-thirds of modern fuels in their residential fuel use. But households who achieved well-being outcomes had a share of 90% of modern fuels. We consider that households are not likely to give up on traditional fuels for modern fuels when they are subject to reliability, accessibility and affordability considerations (Pachauri *et al* 2012, Lam *et al* 2017). Although often related (Pachauri *et al* 2004, Kaygusuz 2011, Sovacool and Drupady 2012, Smith *et al* 2013, Lelieveld *et al* 2015, Mannucci and Franchini 2017, Rao and Pachauri 2017), it is important to be cautious in assuming that access to modern fuels alone will resolve issues related to other types of poverty, or that it will benefit everyone in the same way. Socio-cultural processes, inequalities including gender issues can also impede the transition towards a just and equal decent living (Pachauri *et al* 2004, Oparaocha and Dutta 2011, Ryan 2014, Kumar 2018).

Most importantly, basic well-being outcomes of adequate food, safe water, secondary education and modern fuels can be achieved with significantly lower residential fuel energy use—between 60%–80% lower than the national averages. We find that the majority of these successful households have other decent living standards (DSL) provided for (table 2). Rao *et al* estimate similar levels—between 11 and 19 GJ cap^{-1} to be needed by 2030 for his DSL scenario while Grubler *et al* highlight the need for improving energy-service efficiency as a key to lowering energy demand in Global South[3] (2018). Whereas in the Global North we need to challenge the consumption-oriented lifestyles and bring sufficiency on agenda, for the Global South, the achievement of basic well-being outcomes mean efficiency gains and ensuring access to collective provisioning and protection that improve housing conditions, health, education, and communication. Indeed, our results demonstrate that the achievement of basic needs does not necessitate an increase in energy use, but rather (through improving energy services efficiency) improvements in the provisioning systems. This is an important finding, contradicting the narrative that achieving basic well-being outcomes require increased income or individual (rather than collective) consumption of energy. Rather than focusing on how much energy is used, we find more relevant the question of how and for which energy services.

The SDGs are the priority list to achieve a better and more sustainable life for all. Our analysis includes only a few outcomes listed in SDGs (figure 10), however, the majority of the investigated households lack even these basics. We recognize that achieving these outcomes will not solve all the other issues linked to poverty, gender equality, or a safe environment but we bring attention to the results that indicate that these basic and so desperately needed outcomes bring possible decreases in the total energy consumption (through energy-efficiency gains). It is difficult to predict how future energy consumption will change once these basic needs are satisfied. With higher incomes and consumption levels, we observe increases in energy use linked to private mobility and indirect energy use. However, these specific categories are not linked to basic well-being but lifestyle choices (outside of SDGs). Once the basic well-being outcomes are available to all and increases in income and consumption are more apparent, the political and institutional decisions will be crucial to control energy demand. Possible increases in the total energy consumption will depend on created dependencies for need-satisfaction. The danger of following in the footsteps Global North nations (including mimicking infrastructural and institutional lock-ins) will be essential when tackling issues around reductions in energy demand.

[3]Grubler *et al* estimated energy requirements in Global South needed to meet the 1.5° climate targets to be 32% lower. This is reduction corresponds to global scenario called low energy demand (LED) and refers to the total energy reduction between 2020 and 2050.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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References

Adhikari R and Sawangdee Y 2011 Influence of women's autonomy on infant mortality in Nepal *Reprod. Health* **8** 1–8
Ala-Mantila S, Heinonen J and Junnila S 2014 Relationship between urbanization, direct and indirect greenhouse gas emissions, and expenditures: a multivariate analysis *Ecol. Econ.* **104** 129–39
Balmes J R 2019 Household air pollution from domestic combustion of solid fuels and health *J. Allergy Clin. Immunol.* **143** 1979–87
Baltruszewicz M *et al* 2020 Energy footprints and well-being in Zambia: a household-level investigation *Review: Energy Research and Social Science*
Bin S and Dowlatabadi H 2005 Consumer lifestyle approach to US energy use and the related CO_2 emissions *Energy Policy* **33** 197–208
Brand-Correa L I and Steinberger J K 2017 A framework for decoupling human need satisfaction from energy use *Ecol. Econ.* **141** 43–52
Büchs M and Schnepf S V 2013 Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO2 emissions *Ecol. Econ.* **90** 114–23
Carlson G J, Kordas K and Murray-Kolb L E 2015 Associations between women's autonomy and child nutritional status: a review of the literature *Matern. Child Nutr.* **11** 452–82
Central Statistical Office (Zambia) and World Bank 2015 *Zambia Living Conditions Monitoring Survey 2015* (available at: http://zambia.opendataforafrica.org/ssvcmrd)
Cohen C, Lenzen M and Schaeffer R 2005 Energy requirements of households in Brazil *Energy Policy* **33** 555–62
Crentsil A O, Asuman D and Fenny A P 2019 Assessing the determinants and drivers of multidimensional energy poverty in Ghana *Energy Policy* **133** 110884
Day R, Walker G and Simcock N 2016 Conceptualising energy use and energy poverty using a capabilities framework *Energy Policy* **93** 255–64
Doyal L and Gough I 1991 *A Theory of Human Need* pp 113–28 (London: Macmillan Press)
Eisenmenger N *et al* 2020 The sustainable development goals prioritize economic growth over sustainable resource use: a critical reflection on the SDGs from a socio-ecological perspective *Sustain. Sci.* **15** 1101–1110
Fuso Nerini F *et al* 2018 Mapping synergies and trade-offs between energy and the sustainable development goals *Nat. Energy* **3** 10–15
General Statistics Office 2010 Viet Nam household living standards survey (VHLSS) General Statistics Office
Goldemberg J *et al* 1985 Basic needs and much more with one kilowatt *Energy* **14** 190–200 (https://www.jstor.org/stable/4313148)
Grieshop A P, Marshall J D and Kandlikar M 2011 Health and climate benefits of cookstove replacement options *Energy Policy* **39** 7530–42
Grubler A *et al* 2018 A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies *Nat. Energy* **3** 515–27
Herendeen R 1978 Total energy cost of household consumption in Norway, 1973 *Energy* **3** 615–30
Herendeen R and Tanaka J 1976 Energy cost of living *Energy* **1** 165–78
Hobcraft J 1993 Women' s education, child welfare and child survival: a review of the evidence *Health Transit. Rev.* **3** 159–75 https://www.jstor.org/stable/40652016
International Energy Agency 2011 *World Final Consumption (2011)* (available at: www.iea.org/sankey/#?c=World&s=Final_consumption)
Karekezi S *et al* 2012 *Global Energy Assessment - Toward a Sustainable Future* (www.iiasa.ac.at/web/home/research/Flagship-Projects/Global-Energy-Assessment/GEA_Chapter2_development_hires.pdf) GEA Writing Energy, Poverty and Development (Cambridge University Press and IIASA: Cambridge, New York, Laxenburg)
Kaygusuz K 2011 Energy services and energy poverty for sustainable rural development *Renew. Sustain. Energy Rev.* **15** 936–47
Kaygusuz K 2012 Energy for sustainable development: a case of developing countries *Renew. Sustain. Energy Rev.* **16** 1116–26
Kriegler E *et al* 2012 The need for and use of socio-economic scenarios for climate change analysis: a new approach based on shared socio-economic pathways *Glob. Environ. Change* **22** 807–22
Kumar A 2018 Justice and politics in energy access for education, livelihoods and health: how socio-cultural processes mediate the winners and losers *Energy Res. Soc. Sci.* **40** 3–13
Lam N L *et al* 2012 Kerosene: A review of household uses and their hazards in low- and middle-income countries *J. Toxicol. Environ.* **15** 396-432
Lam N L *et al* 2017 Seasonal fuel consumption, stoves, and end-uses in rural households of the far-western development region of Nepal *Environ. Res. Lett.* **12** 125011
Lelieveld J *et al* 2015 The contribution of outdoor air pollution sources to premature mortality on a global scale *Nature* **525** 367–71
Lenzen M *et al* 2006 A comparative multivariate analysis of household energy requirements in Australia, Brazil, Denmark, India and Japan *Energy* **31** 181–207

Lenzen M, Dey C and Foran B 2004 Energy requirements of Sydney households *Ecol. Econ.* **49** 375–99
Mainali B *et al* 2018 Evaluating synergies and trade-offs among Sustainable Development Goals (SDGs): explorative analyses of development paths in South Asia and Sub-Saharan Africa *Sustainability* **10** 3
Mannucci P M and Franchini M 2017 Health effects of ambient air pollution in developing countries *Int. J. Environ. Res. Public Health* **14** 1–8
Millward-Hopkins J *et al* 2020 Providing decent living with minimum energy: a global scenario *Glob. Environ. Change* **65** 1–19
Moyer J D and Bohl D K 2019 Alternative pathways to human development: assessing trade-offs and synergies in achieving the Sustainable Development Goals *Futures* **105** 199–210
National Planning Commission Secretariat 2011 *Nepal Living Standards Survey (NLSS III)* (Kathmandu: Central Bureau of Statistics)
Nussbaumer P, Bazilian M and Modi V 2012 Measuring energy poverty: focusing on what matters *Renew. Sustain. Energy Rev.* **16** 231–43
Oparaocha S and Dutta S 2011 Gender and energy for sustainable development *Curr. Opin. Environ. Sustain.* **3** 265–71
Oswald Y, Owen A and Steinberger J K 2020 Large inequality in international and intranational energy footprints between income groups and across consumption categories *Nat. Energy* **5** 231–9
Pachauri S *et al* 2004 On measuring energy poverty in Indian households *World Dev.* **32** 2083–104
Pachauri S *et al* 2012 Towards an integrativeframework for energy transitions of households in developing countries Tackling Long-Term Global Energy Problems ed D Spreng *et al* (Springer: London) **52** 73–96
Pachauri S *et al* 2013 Pathways to achieve universal household access to modern energy by 2030 *Environ. Res. Lett.* **8** 024015
Pachauri S and Spreng D 2002 Direct and indirect energy requirements of households in India *Energy Policy* **30** 511–23
Pachauri S and Spreng D 2011 Measuring and monitoring energy poverty *Energy Policy* **39** 7497–504
Peters G P, Andrew R and Lennox J 2011 Constructing an environmentally extended multi-regional input–output table using the GTAP database *Econ. Syst. Res.* **23** 131–52
Prasad G 2011 Improving access to energy in sub-Saharan Africa *Curr. Opin. Environ. Sustain.* **3** 248–53
Rahut D B *et al* 2014 Determinants of household energy use in Bhutan *Energy* **69** 661–72
Ramanathan V and Carmichael G 2008 Global and regional climate changes due to black carbon *Nat. Geosci.* **1** 221–7
Rao N D *et al* 2019b Spatial analysis of energy use and GHG emissions from cereal production in India *Sci. Total Environ.* **654** 841–9
Rao N D and Baer P 2012 'Decent living' emissions: a conceptual framework *Sustainability* **4** 656–81
Rao N D and Min J 2017 Decent living standards: material prerequisites for human wellbeing *Soc. Indicators Res.* **138** 1–20
Rao N D, Min J and Mastrucci A 2019a Energy requirements for decent living in India, Brazil and South Africa *Nat. Energy* **4** 1025–32
Rao N D and Pachauri S 2017 Energy access and living standards: some observations on recent trends *Environ. Res. Lett.* **12** 025011
Räty R and Carlsson-Kanyama A 2010 Energy consumption by gender in some European countries *Energy Policy* **38** 646–9
Reinders A H M E, Vringer K and Blok K 2003 The direct and indirect energy requirement of households in the European Union *Energy Policy* **31** 139–53
Riahi K *et al* 2012 Energy pathways for sustainable development GEA Writing (Cambridge, New York, Laxenburg: Cambridge University Press and IIASA) 1203–1306 (http://www.globalenergyassessment.org)
Roy J 2012 Lifestyles, well-being and energy Writing Team (Author) *Glob. Energy Assess.* (Cambridge University Press: Cambridge) 1527–48
Ryan S E 2014 Rethinking gender and identity in energy studies *Energy Res. Soc. Sci.* **1** 96–105
Smith K R *et al* 2013 Energy and human health *Annu. Rev. Public Health* **34** 159–88
Smith K R *et al* 2014 Millions dead: how do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution *Annu. Rev. Public Health* **35** 185–206
Smith K R, Mehta S and Maeusezahl-Feuz M 2004 Indoor air pollution from household use of solid fuels *Comparative Quantification of Health Risks. Global and Regional Burden of Disease Attributable to Selected Major Risk Factors* (Geneva: World Health Organization) p 1200
Sovacool B K 2012 The political economy of energy poverty: a review of key challenges *Energy Sustain. Dev.* **16** 272–82
Sovacool B K and Drupady I M 2012 *Energy Access and Development. The Governance of Small-Scale Renewable Energy in Developing Asia, the Handbook of Global Energy Policy* (Surrey: Ashgate) (http://sci-hub.tw/10.1002/9781118326275.ch14)
Steinberger J K, Krausmann F and Eisenmenger N 2010 Global patterns of materials use: a socioeconomic and geophysical analysis *Ecol. Econ.* **69** 1148–58
UNESCO 2015 Education 2030. Incheon declaration framework for action p 83 (available at: http://unesdoc.unesco.org/images/0024/002456/245656E.pdf)
United Nations 2015 Transforming our World: The 2030 Agenda for Sustainable Development (New York: United Nations) (http://sci-hub.tw/10.1201/b20466-7)
Weber C L and Matthews H S 2008 Quantifying the global and distributional aspects of American household carbon footprint *Ecol. Econ.* **66** 379–91
World Bank 2011 *World Development Indicators Database* (available at: https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD?end=2011&name_desc=false&start=1990&view=chart)
World Health Organization and UN-Water 2012 UN-water global analysis and assessment of sanitation and drinking-water (GLAAS) 2012 report p 101 (available at: www.un.org/waterforlifedecade/pdf/glaas_report_2012_eng.pdf)