Household Energy Footprints and Links to Well-Being

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

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Abstract

Energy is essential for satisfying human needs and, at the same time, energy production is the main contributor of the greenhouse gas emissions driving the climate crisis. There is thus a need to understand how to reduce energy use while achieving, or maintaining, high levels of well-being. Research so far focused on exploring this issue from top-down approaches and using aggregate data national level data. The aim of this thesis is to expand this research and provide more nuanced insights into the under-researched demand side of energy use and well-being on a household level. Applying concepts and frameworks from a range of literature, including ecological economics, industrial ecology, well-being, and poverty studies; this thesis explores household final energy demand and links it to well-being outcomes in three countries in Global South: Vietnam, Nepal, and Zambia, and one case-study country in the Global North: the United Kingdom.

My research finds that reducing poverty and achieving high levels of well-being can be done with low levels of energy demand. Based on examples in Global South, this thesis shows that changes in total energy consumption and incomes are less important for the achievement of well-being than access to modern fuels and collective services. Further, the high residential fuel use can also imply inefficient traditional fuel use. In this context, lower energy use on residential fuel can be indicative of better health, and access to modern and more efficient energy sources. Access to collective provisioning, in form of electricity, markets, health care, and public transport are vital and key to being able to achieve well-being. Overall, the delivery of collective services can help in achieving development goals and at the same time contribute to lowering footprints.

Findings from the Global North case study show that in the UK, private transportation in the form of car and air transport contributed the most to the total energy footprint of the rich and high-energy users. The study focuses on high inequalities in energy distribution and emphasizes the role of the top energy users with high well-being in driving excess energy use. A more detailed analysis of household types reveals that individuals with protected characteristics are especially vulnerable to energy poverty, while their contribution to overall energy demand is negligible.

Overall, focusing on well-being steers the attention towards questions of minima and maxima, as well as the context within which we satisfy needs. In this way, questions of efficiency can be discussed not only in the way of gains in energy reduction but in the light of gains for well-being.

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Abbreviations

AME	Average marginal effects
BN	Basic Needs
COICOP	Classification Of Individual Consumption by Purpose
DSL	Decent Standards of Living
GDP	Gross Domestic Product
GJ	Giga Joule
GTAP	Global Trade Analysis Project
HDI	Human Development Index
IEA	International Energy Agency
IN	Intermediate Needs
IO	Input-output
IPCC	Intergovernmental Panel on Climate Change
Kwh	kilowatt-hour
LCFS	Living Cost and Food Survey
LED	Low Energy Demand
LiLi	Living well within Limits
LSMS	Living Standards Measurement Survey
MEPI	Multidimensional Energy Poverty Index
MJ	Mega Joule
MRIO	Multiregional input-output
OECD	Organisation for Economic Co-operation and Development
SDGs	Sustainable Development Goals
SoP	System of Provision
THN	Theory of Human Need

UK	United Kingdom
USS	Understanding Society Survey
WHR	The World Happiness Report

Chapter 1
Introduction

1.1 Empirical context

Energy use is unequally distributed globally, within countries, and within households. There is a large chasm in levels and types of energy use between the Global North and South. For example, although Africa and OECD members have a similar population, OECD countries consume six times more final energy than African nations (Figure 1-1) (IEA 2021b). Access to modern fuels (e.g. renewables but also natural gas) is also unevenly distributed as most modern fuels are consumed by Global North (IEA 2021c). While in the Global South biofuels and waste are primary energy sources for the residential sector, the Global North depends on more efficient but dirty fuels like oil and natural gas (IEA 2021a).

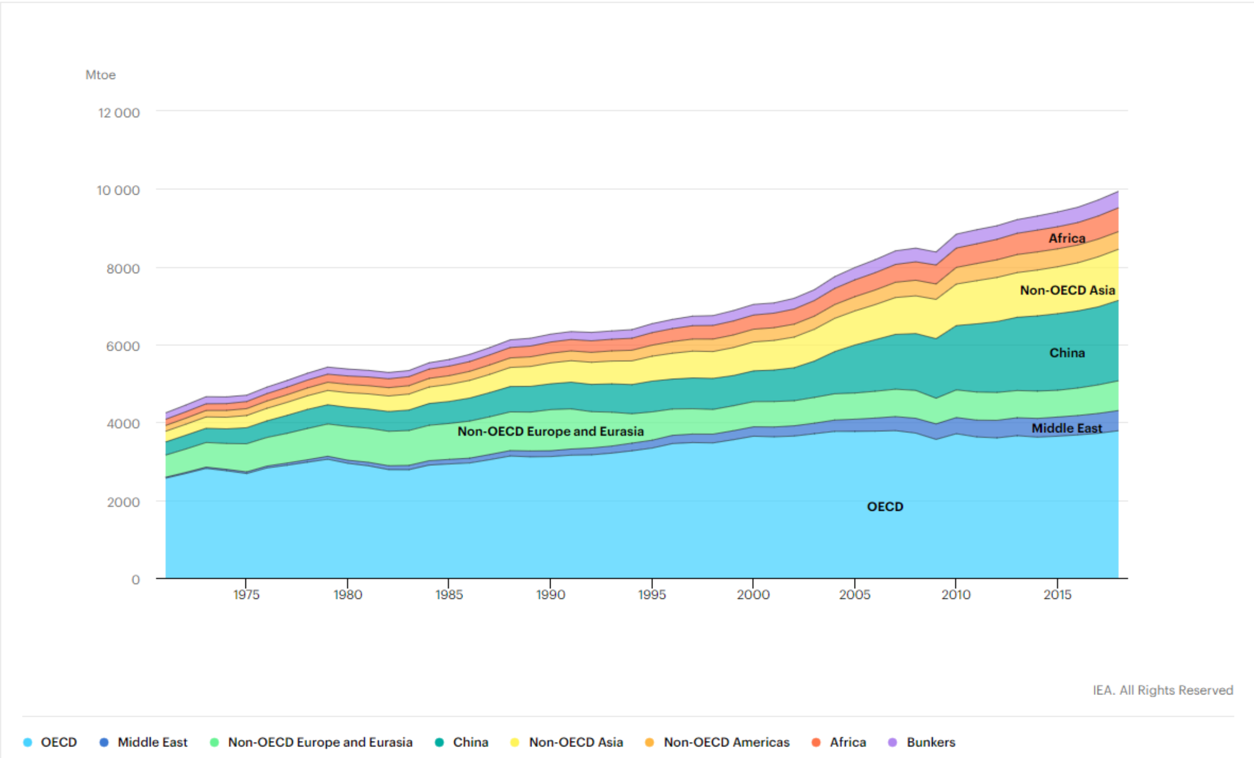

Figure 1-1 World total final consumption by region, 1971-2018
Note: Source (IEA 2020)

There is also inequality in energy use between and within countries. Electricity use per capita in Europe can be as high as 54.6 megawatt in Iceland, which is seven times more than in Germany – the largest producer of electricity in Europe. Considering inequalities within countries, it is often rich, urban households who have access to modern fuels, while the rural poor depend on less efficient traditional fuels (World Bank 2021).

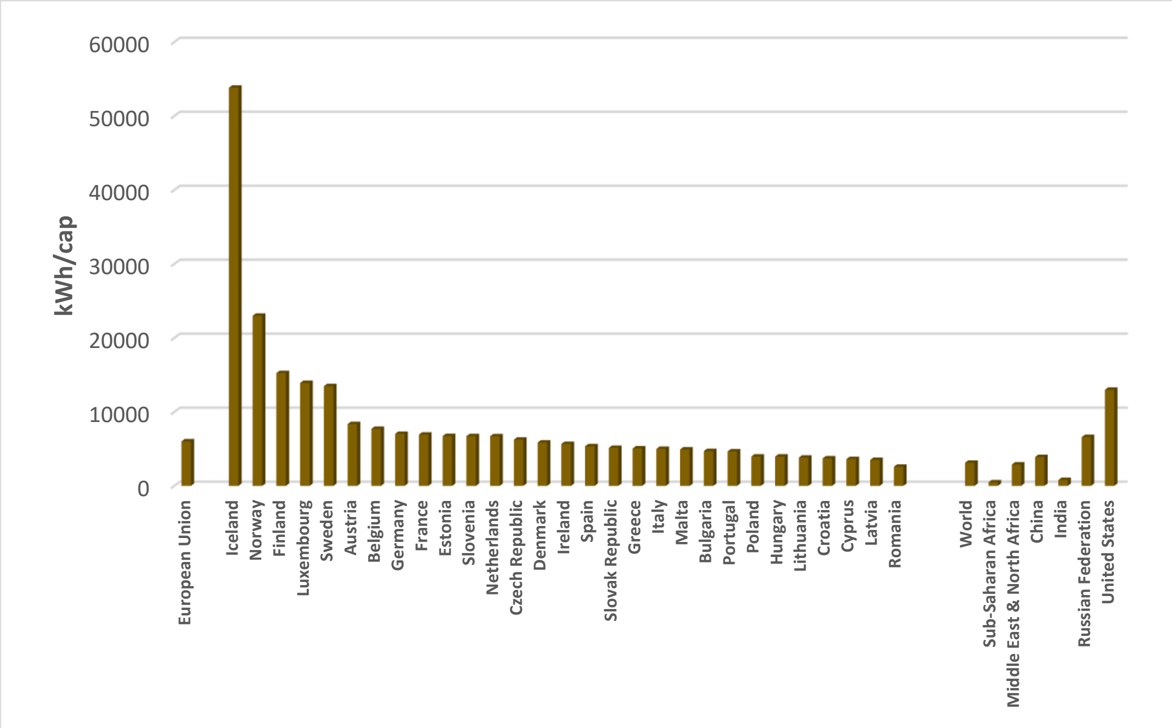

Figure 1-2 Electric power consumption (kWh per capita).
Note: Own figure, data from (OECD/IEA 2014)

Moreover, access to energy is also unevenly distributed within households, where women and children are disproportionally affected by the use of polluting fuels, and when non-polluting, modern fuels are available, women often are the last to benefit from them (Rao and Pachauri 2017, Kumar 2018, Oparaocha and Dutta 2011, Pachauri and Rao 2013).

Regardless of the huge disparity in energy access and distribution, we observe a constant growth of energy demand. Global total final consumption between 1990 and 2019 increased by 60% (IEA 2020). During that period transport sector, almost entirely based on fossil fuels, increased by 83% and final consumption in the residential sector grew by 39% (IEA 2020). But the increases in energy demand and energy access are not the same everywhere. Currently, the International Energy Agency (IEA) estimates that globally 770 million people are without electricity access and most of them are situated in Africa and developing countries in Asia (IEA 2022). Further, between 2019 and 2021 in sub-Saharan Africa energy access stalled, with an estimated 2% decrease in the number of people with access to electricity and clean cooking fuels (IEA 2021d). This decrease, mostly a result of the COVID pandemic, might have a longer than temporary effect, as mobilizing development for energy access progress is not guaranteed.

Uneven energy access leads to vast numbers of people experiencing dire living standards. Currently, cooking with traditional fuels, results in breathing polluted air, which leads to over 2.5 million premature deaths a year (IEA 2021d). It is estimated that over four billion people lack access to affordable, reliable and accessible methods of cooking, which in turn pushes many to continue to stack traditional, solid fuels (like firewood or charcoal) (World Bank 2020, Pelz *et al* 2021, Shankar *et al* 2020).

Given that energy use is essential for meeting human basic needs and it is coupled with fossil-fuel use, this leaves humanity at a crossroads: there is an urgent need for energy demand reduction, yet the majority lacks access to basic energy services (SE4All 2014, Minx *et al* 2017, Keyßer and Lenzen 2021, Brand-Correa and Steinberger 2017, Creutzig *et al* 2021). The urgency for resolving this challenge has been widely recognized by both the policy and research community (IPCC 2022).

Despite these dire statistics and the recognition of the importance of energy in facilitating well-being, there has been limited research into energy distribution at the household level linked with the achievement of well-being. This is the case in the Global North and especially the Global South. Consequently, at the household level of analysis, not much is known about total (direct and indirect) energy distribution and how to reduce energy use while keeping high levels of well-being. This thesis delves into this overlooked research by focusing on three case-study countries: three in the Global South (Vietnam, Nepal, and Zambia) and one in the Global North (UK).

1.2 Literature Review

The research presented in this thesis is interdisciplinary. It benefits from the fields of ecological economics, industrial ecology, and sociology. More specifically, it draws upon energy poverty studies, a system of provision approach, household footprinting research, inequalities studies, and well-being concepts. Below, I present the most important literature that helped me build a conceptual and methodological framework for this thesis. The literature presented here often exists in separate silos, therefore I connect it in section 1.4. followed by the research design.

1.2.1 Well-being - what it means to live well

Defining 'living well' has many answers and often depends on the political and economic agenda behind it. In academia, the well-being definition is rather blurry, where researchers depending on their background (e.g. neoclassical vs heterodox economics) often find themselves in opposing camps. In what follows I contrast different schools of thought around well-being and introduce the conceptualization of well-being chosen for this thesis.

In the 'neoliberal' model, development is defined as 'progress' measured with economic growth (Harvey 2005, Costanza *et al* 2014, Cobb, C., *et al* 1995, Schmelzer 2015). No matter if the context is extreme poverty or increasing standards of living, the prevalent strategy for "development" or "progress" is to grow the economic "pie" by increasing the production of goods and services and creating new markets for selling them. The logic is to reduce poverty (or increase living standards) by increasing the spending capacity of households and governments (Kallis *et al* 2018, Macekura 2020). On this assumption, gross domestic product (GDP) serves as a perfect indicator for measuring social progress. Thus when development is “diagnosed” by income, the “remedy” is economic growth.

However appealing, this narrative finds itself often too simple and does not reflect the reality faced by millions of people (Hickel and Kallis 2019, Raworth 2012, Steinberger *et al* 2020, Stiglitz 2009). Thus, it is those living in extreme poverty that have perhaps been most harmed by this narrative. Discourses that include the “trickling effect” of economic growth, or the “rising tide lifts all boats” analogy, are unlikely and contested, especially by academics focusing on inequalities (Piketty *et al* 2022).

Considering these criticisms, many alternative definitions of what means to live well and how to measure it have been suggested. Those measurements could be broadly categorized into hedonic and eudaimonic characteristics. Hedonic understanding of living well (or well-being) draws from a preference theory that focuses on maximizing pleasure (Dolan *et al* 2008), and well-being understood in a eudaimonic way implies having opportunities to meet ones potential considering the societal context (Nussbaum 2000, Sen 1993). The World Happiness Report (WHR) (Helliwell *et al* 2016) is an example of the hedonic approach while the Human Development Index (UNDP 2016), based on the capabilities approach, is a well-known example of the eudaimonic approach. While WHR focuses on self-assessment of contentment with living situation, it can hardly be used as a comparative tool, nor it can inform about living standards.

But defining well-being is also an assessment of lack of it –poverty. Alkire’s multidimensional poverty measurement offers to look beyond only income, or subjective happiness when considering poverty and points to multiple deprivations that poverty involves (Alkire 2002, Alkire *et al* 2015). In this way, people are poor not because they have fewer dollars per day to spend than a certain poverty threshold, but because they cannot access goods and services that provide sanitation, education, or health. Often, these cannot be accessed even with increased incomes or even though a person might feel happy about their situation.

Currently, in the development perspective, well-being is often characterized by accessibility, for example having or not access to electricity, modern fuels, clean water, or education. The Sustainable Development Goals (SDG) and their indicators measure exactly that (UN 2017). Similar to other eudaimonic characteristics of well-being, specific SDGs measure distribution effects related to health, education, sanitation, or gender equality but they often fail to inform about quality aspects of those characteristics. Overall, the potential of the SDGs for development in the Global South and mitigation potentials of the Global North are yet to be seen.

In this thesis, I use the eudaimonic perspective and employ the theory of human need (THN) proposed by Doyal and Gough to conceptualize and operationalize well-being. In THN well-being is defined as a universal goal of ’participation in some form of life without serious arbitrary limitation’ (Gough 2015, p 1197) which is valid regardless of the place, culture or time. According to Doyal and Gough, this universal goal of minimally impaired social participation can be achieved by fulfilling the basic needs of physical health[1], critical autonomy, and autonomy of agency, the latter being subdivided into mental health, cognitive understanding, and opportunities to participate (Figure 1-3). If one is not able to fulfill these basic needs, the goal of minimally impaired social participation (well-being) cannot be fulfilled.

Doyal and Gough further proposed eleven prerequisites that are necessary to fulfill those 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. They called these “universal characteristics of need satisfiers” or “intermediate needs”, and consider them universal, non-substitutable, non-hierarchical, and satiable (Figure 1-3). For example, it is not possible to substitute one need for another: one cannot fulfill the need for adequate nutritional food and water with more education, or vice versa. The fulfillment of all intermediate needs (IN) is required for well-being: it is not possible to achieve minimally impaired social participation by only providing for some needs, say adequate nutritional food and water, and protective housing: the fulfillment of other needs linked to health, education and security are also necessary. Doyal and Gough further specified to which basic needs (BN) each of the IN corresponds (the first six IN listed above are linked to physical health and the last five to autonomy) (Doyal and Gough 1991, Gough 2015).

Further, Doyal and Gough make a clear distinction between universal intermediate needs, required by everyone everywhere, and the culturally specific ‘satisfiers’ that are used to fulfill those needs (Figure 1-3. For instance, protective housing can be satisfied with a house built from mud or bricks; economic security can be fulfilled with various types of work or social safety net systems, and so on. The decision of which satisfiers are chosen to achieve needs is embedded within the context of social and physical provisioning systems.

As mentioned at the beginning of this section, eudaimonic approaches refer to a multi-dimensional understanding of human need and they contrast with hedonic approaches, which focus on the individual feelings and wants (happiness, pleasure) and one-dimensional indicators (e.g. individual purchasing power). Making a distinction between wants and needs is central to addressing ways to

[1] *Achieving basic need of health is related to addressing to a large extent everyone’s health requirements (than achieving a certain level of health) that in turn enables people to participate in society.*

achieve well-being in a resource-constrained world. Within a hedonic understanding of well-being, 'wants' play a central role. They are characterized by being potentially insatiable and infinite while disregarding the notion of finite resources and the needs of others. For instance, wanting a faster car or highly processed food are wants that might contribute to one's subjective happiness, but not necessarily to eudaimonic well-being. Gough and Doyal address this issue within the THN framework by highlighting that 'need is a threshold concept' (Gough 2015, p 1202). This indicates that there is a minimum threshold required for fulfilling our basic needs: above this threshold, the need can be considered satisfied. The empirical evidence for such a threshold can be seen in the 'saturation' effect observed between human development indicators and energy use (Steinberger and Roberts 2010). Moreover, in some cases, over-consumption far beyond the threshold can be expected to result in adverse effects on the satisfaction of human needs and well-being, to which Max Need refers as negative satisfiers (Max-Neef 1995, 1991).

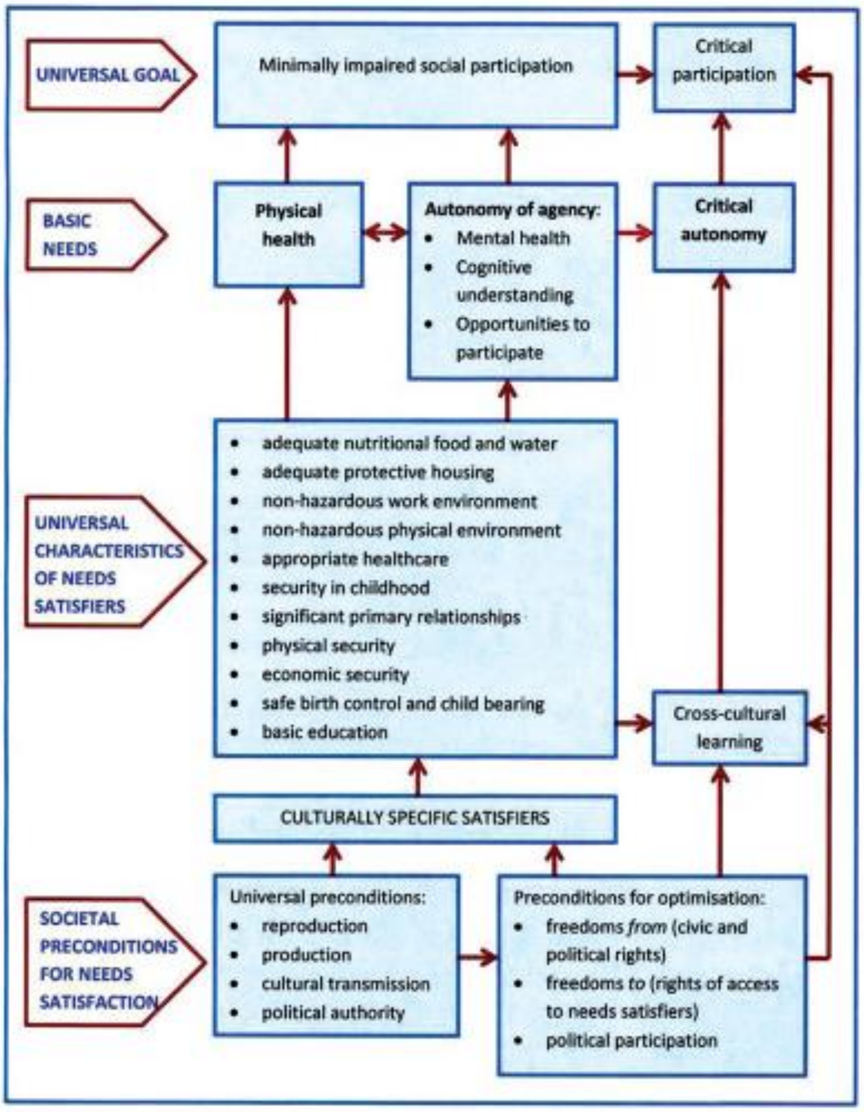

Figure 1-3 Theory of Human Need Framework. Source: (Doyal and Gough 1991, Gough 2015)

The thresholds only describe the bare minimum (social and technical) needed to meet the goal of achieving basic needs for everyone. This is contained within the description of IN by using terms like 'appropriate' and 'adequate'. According to Doyal 'In principle, (need) satisfaction is adequate when using a minimum amount of appropriate resources, it optimises the potential of each individual to sustain their participation in those constitutive activities important for furthering their critical interests' (Doyal and Doyal 2013, p 14). In practice, thresholds for minimum well-being depend on what is 'possible in countries with the best physical cognitive, emotional, environmental and political indicators' (Doyal and Doyal 2013, p 14).

In a resource-limited world, THN can be useful when considering what should be a baseline, or in other words, a 'constrained optimum' threshold, in which we and future generations can thrive. As basic needs are independent of time and were the same for our grandparents as they will be for our grandchildren, navigating with a universal needs framework can help to specify what is required for living within planetary boundaries – or in Raworth's words, living within 'a safe and just place' (Raworth 2012). To meet the universal goal of social participation, people always did and will need the same preconditions: to be physically and mentally healthy and to have critical autonomy. Thus, we can be certain that in the future people will require a minimum level of IN like water and nutrition, adequate shelter, security in childhood, health care, etc. What we do not know and cannot predict is how those needs will be satisfied. This uncertainty does not remove the responsibility for living our lives within biophysical planetary boundaries, so future generations can also benefit from a stable environment and the availability of resources as did their parents. This thought was highlighted in the Brundtland Report and referred to as ''living within a doughnut'' of sustainability by Raworth (Raworth 2017, Brundtland, G.H 1987). For building sustainable targets, THN provides a baseline that could be used while considering depletion of resource use and what is just and right from an intergenerational perspective.

Overall, in comparison to other eudaimonic approaches, I find the human need approach the best suited for the research presented in this thesis. There are two distinct camps within the eudaimonic school of thought: the first one is nested in capabilities approaches (Sen 1993, Nussbaum 2000, Robeyns 2006) and the second is based on human need approaches (Doyal and Gough 1991, Max-Neef 1991). THN and capabilities approaches are highly complementary and both could be used for research presented in this thesis, however, I chose THN, for several reasons. THN is better suited for operationalization than what Sen provides in his moral framework (Sen 1993). Following, Martha Nussbaum proposed primary and secondary capabilities (Nussbaum 2000), however, her list remains challenging for translation for a quantitative study. I found THN easier to work with, as the universal characteristics of human need provide direct links to physical provision (e.g. protective shelter). In their book, Doyal and Gough propose a set of indicators to measure basic and intermediate needs

(Doyal and Gough 1991). Moreover, the distinction between human needs and diverse need satisfiers enables studying the decoupling of energy use from human need.

As already mentioned above, THN is a threshold concept, which allows considering sufficiency perspectives. This is important, as it helps to establish that human needs can be satisfied and beyond this satisfaction, the gains could diminish. Moreover, past a certain level of resource use/human need satisfaction, the excess might lead to negative effects on well-being (e.g. via environmental or societal degradation).

Others started to use human need approaches to conceptualize and operationalize well-being. Lamb and Steinberger offer deficit–oriented eudaimonic approaches, that seek to identify barriers to achievement of well-being, as perhaps simpler to operationalize and possible to apply in mitigation studies (Lamb and Steinberger 2017). Rao and colleagues used THN language and Nussbaum's central capabilities to define well-being, for which they developed prerequisites in form of decent living standards (Nussbaum 2000, Rao and Baer 2012, Rao and Min 2017, Doyal and Gough 1991). Finally, Brand-Correa and Steinberger build on THN and Max-Neef's fundamental human needs to conceptually link energy, energy services, provisioning systems, and well-being (Brand-Correa and Steinberger 2017, Max-Neef 1991, Doyal and Gough 1991). A similar approach to theirs was presented by Day et al., but from a capabilities perspective (Day *et al* 2016).

1.2.2 Provisioning systems

The eudaimonic understanding of well-being considers the importance of social and physical context available to individuals within which they fulfill their needs. There are a number of approaches to describe and analyze these conditions within which needs are satisfied. Here I specify the most relevant to this thesis, which include systems of provision, practice theory and life cycle approaches.

"Provisioning systems" is an umbrella term for the production, distribution, and consumption of goods and services. It goes beyond the "supply chains" usually considered in energy studies, life cycle assessment, and sustainable consumption and production in several important ways. First, it explicitly acknowledges the networked, intertwined aspect of production and consumption. Secondly, through its use in heterodox economic analysis, it has a clear emphasis on the social aspects of production: institutions, actors, structures, relations (as outlined in Ben Fine's approach (Fine 1998, Fine and Leopold 2002, Bayliss and Fine 2020, Fanning *et al* 2020), The importance of provisioning systems in the context of research on energy and well-being is that it enables the joint analysis of governance/institutional arrangements (around distribution and access, for instance) alongside more traditional aspects (energy vectors, efficiency of use).

In the literature, questions around the physical and social aspects of provisioning systems were mostly addressed by using conceptual methods based on social sciences, heterodox economics, and sociology. In their study of social aspects of provisioning systems, Fine and Leopold coined the term "Systems of Provision" (SoP) and chose the commodity as a starting point for analysing and explaining shifting changes in patterns of consumption (Fine and Leopold 2002). By addressing issues beyond an economic perspective, like consumption norms, culture, or people's ethics, SoP helps to understand how commodities are provisioned, in what type of context, and how this could be changed (Fine *et al* 2018). Initially, SoP was mostly applied to study goods and services linked to food and fashion (Fine 1998, Fine and Leopold 2002), however, recently the application broaden to study water, energy, (Bayliss *et al* 2020) car dependence (Mattioli *et al* 2020), and broader consumption (Fine *et al* 2018).

Another strand of work that aims to understand how we chose specific 'satisfiers' for human need are theories of practice. Practice theory is a sociologically-based approach to study sustainable consumption, and thus combines social and physical aspects within its study. It also considers decision-making beyond market choice and focuses on studying sets of practices that we in our societies produce, transform and reproduce every day (Røpke 2009, Schatzki 1996, Shove and Walker 2014). Recently, practice theory came to the forefront in energy-oriented research on consumption. Examples can be found in studies investigating shower practices, dwelling retrofit, biking, food, or mobile phone usage (Bartiaux *et al* 2014, Dalpian *et al* 2015, DellaValle *et al* 2018, Hansen 2017, Horta *et al* 2016, Shove and Walker 2010, Wilhite 2014, Hebrok and Heidenstrøm 2019, Anantharaman 2017). Together with SoP, practice theories are inspiring other researchers that seek to understand how technological and societal lock-ins for need satisfaction come to be. An example is a recent study of needs satisfier escalation (Brand-Correa *et al* 2020). Brand- Correa, and colleagues considered orders of needs satisfiers linked to socio-technical provisioning systems (inspired by SoP) and activities (inspired by theories of social practice) in their analysis of car dependence.

Another group of studies uses life cycle approaches, primarily based on environmentally extended input-output, to estimate environmental loads from supply chains embedded in material structures of production, technology, and natural environment (e.g. (Cicas *et al* 2007, Junnila 2006, Lenzen and Dey 2002, Suh *et al* 2004, Ivanova *et al* 2015). Energy chain studies also aim to understand how economic needs are supplied by estimating 'thermodynamic work done by energy system to deliver energy services' (Brockway *et al* 2015, p 893). These studies do not, however, consider the interactions between the physical and social sides of provisioning. In those quantitative approaches, the focus remains on the material side of provisioning. The aspects of agency and institutional interrelations (present through, for example, rules, values, and norms) are not examined.

The studies outlined above show the importance of the context of provisioning systems in changing patterns of resource use, however, they do not consider provisioning in relation to examining the energy prerequisite needed for achieving the basic level of well-being.

1.2.3 Energy and well-being

I discuss the role of energy for human need satisfaction by categorizing the subject into three sections: energy poverty (section 1.2.4), minima (section 1.2.5), and maxima of energy use for well-being (section 1.2.6). Energy poverty is explored in connection with development, inequalities, and energy justice, with a focus on how we measure energy poverty. Minima and maxima parts are oriented around the question: how much energy is enough for well-being?

1.2.4 Energy poverty

The first group of studies around energy and society relates to energy poverty in connection to development, inequalities, and energy justice. I begin with introducing frameworks and studies most relevant to the development context (Global South) and end with contextualizing energy poverty studies in Global North.

The existing body of work in energy and development studies examines the consequences of lack of energy on various facets of poverty, linked to, for example, health, gender, education (e.g. (Karekezi *et al* 2012, Middlemiss 2019, Saghir 2004, Pachauri and Spreng 2011). Previously Nussbaumer proposed to capture this complexity with the Multidimensional Energy Poverty Index (MEPI) which takes inspiration from the approach of multidimensional poverty measurement presented by Alkire and colleagues (Alkire *et al* 2015). MEPI captures both the incidence and intensity of energy poverty. The key dimensions in MEPI including lighting, cooking, indoor pollution, education, access to electricity, and telecommunications help to measure the extent of deprivation. Metrics like MEPI help to capture dimensions of energy poverty but are mostly related to fuel poverty at home. Another important dimension of energy poverty is linked to transport poverty (Martiskainen *et al* 2021). A person experiencing transport poverty might not be able to afford or access transport services needed for the fulfillment of essential needs, such as education, employment, or healthcare (Martiskainen *et al* 2021, Mattioli *et al* 2017). Recently researchers highlighted the urgent need for measuring and reporting transport poverty (currently, only France measures it) as they claim that reliable and affordable transport is necessary for equitable transitions (Martiskainen *et al* 2021).

Pachauri and colleagues pointed to another important dimension of measuring energy poverty: the quality of accessed energy. They specify three features of energy access that are key to understanding the quality of the services the energy provides: reliability, accessibility, and affordability (Pachauri *et al* 2012, Pachauri and Rao 2020). What we choose as an indicator for measuring access to energy matters. For example, when only access to electricity is considered, which is the main indicator for the SDG-7 sub-target "ensure universal access to affordable, reliable and modern energy services", around 800 million lack access to electricity. But when affordability and reliability of electricity are considered, the number is three times higher – an estimated 3.5. billion lack access to electricity (Ayaburi *et al* 2020). Going beyond binary indicators provides a more nuanced analysis of drivers of energy poverty that is not only capable of providing information about the quality of energy access but is also capable of beginning to understand the purpose of energy delivery – the services it provides (Pelz *et al* 2021).

Studies of energy poverty also investigate who in the society might be the most vulnerable to experiencing it. Here, research points to the importance of gender, disability, location, and income as the main characteristics that underpin poverty status (Clancy *et al* 2007, Pachauri and Rao 2013, Bouzarovski and Simcock 2017, Middlemiss 2019, Ivanova and Middlemiss 2021, Büchs *et al* 2018).

These attributes are also emphasized in studies of energy poverty in the context of the Global North. Whilst, in the Global South access to physical infrastructure (electricity, sanitation) remains a problem, in the Global North energy poverty is characterized by a lack of affordability. Further, the reasons for lack of affordability can be due to income poverty, but also it can be linked to various forms of rent extraction, and economic conditions that deepen inequalities (e.g. living in poorly insulated housing) (Stratford 2020, Mattioli 2017, Bayliss *et al* 2020, Middlemiss and Gillard 2015). Energy poverty which is related to experiencing inadequate energy services in the home is experienced, on average, by 8% of European households and can be as high as 43% of the population in Turkey not having adequate energy services (Thomson *et al* 2017, European Commission 2022). Energy poverty also highly correlates with poor health and low subjective well-being (Thomson *et al* 2017, Ivanova and Middlemiss 2021). As a result, the lack of affordability to keep houses warm results in thousands of excess winter deaths every year (Fowler *et al* 2015, Healy 2003).

1.2.5 Minima: energy and development

A certain minimum level of energy consumption is necessary for the alleviation of poverty and the achievement of basic human needs. But how much exactly is needed to live well? This question has been central to a number of research endeavors during recent decades and answered with either a top-down or bottom-up approach.

The top-down approaches tend to analyze the relationship between environmental impacts (e.g. energy consumption, ecological- or carbon footprints) and well-being outcomes (e.g. life expectancy, HDI, life satisfaction, indicators used by SDGs) (Dietz *et al* 2012, Knight and Rosa 2011, Martínez and Ebenhack 2008, Steinberger and Roberts 2010, Lamb 2016). Results from this research show that increasing energy past moderate levels does not improve living standards (Steinberger and Roberts

2010) and that overall ecological intensity of well-being seems to decrease over time, however, it is higher for high-income countries (Dietz and Jorgenson 2014, Givens 2015).

Spreng based his estimates on climate models and concluded that the global average energy consumption of 2000 Watt/capita (63 GJ) in 2050 would be sustainable (Spreng 2005). More recently Lamb and Rao estimated that by 2050 32-53GJ/cap per year would be needed in developing countries in Africa, South Asia, and Centrally planned Asia for satisfying basic needs (related to food, shelter, basic health and hygiene, and education) and reaching 70.4 and 72.8 years for life expectancy respectively (Lamb and Rao 2015).

Others estimated current (at the time) energy needs, for example, Smil reported 50-70 GJ per capita annually in 2001 to be a global minimum requirement to meet essential physical needs and have opportunities for intellectual development (Smil 2003). This is slightly less than 74 GJ average energy consumption per person and 70 years of life expectancy in 2005 estimated by Steinberger and Roberts (Steinberger and Roberts 2010).

These estimates are mostly done at the national level, taking the total energy use and dividing it by population. How energy needed for well-being is distributed within nations is less researched. On this more granular level of analysis – household level - existing research starts with an inventory of material and service requirements to fulfill human needs for an average household, to then match it with energy needs (Goldemberg *et al* 1985, Zhu and Pan 2007). One of the first studies of this type is a bottom-up analysis on a national level of energy use per capita done by Goldemberg & colleagues. In 1985 they estimated that with shifting to high-quality energy carriers that would enable more efficient energy use, 1 KW per capita (32 GJ) would be enough to deliver energy services related to residential needs, transportation, and manufacturing necessary to satisfy basic needs worldwide (Goldemberg *et al* 1985).

Recently, Todd Moss and colleagues propose a modern energy minimum of 1,000 kWh per person (3.6 GJ) for electricity consumption related to household and non-household activities to be an absolute minimum necessary to meet basic needs (Moss *et al* 2021).

The minima of energy use for human need often mean an increase in energy consumption in the Global South, and significant reductions in energy use in the Global North. These differences are linked to multiple deprivations present in the Global South and the need for developing physical provisioning systems to provide for basic needs, for example, sanitation, education, or health. To overcome these deprivations it is estimated that more energy input will be needed. An example scenario is the Low Energy Demand (LED) scenario developed by researchers in IIASA (Grubler *et al* 2018). Grubler and colleagues recognize that the Global South will need more energy to build needed infrastructure that helps to provide for basic needs, and the Global North must reduce energy through improvements in the efficiency of building stock and transport, technologies, and broader societal and cultural transitions. This scenario is looking into the future and bids on political change that pushes for larger structural changes as the key to lowering energy demand while keeping high levels of well-being. Their estimates vary between around 30 GJ and 55 GJ per capita in Global South and North respectively. The LED scenario does not provide details about the distributional impacts of proposed changes, however, it does acknowledge the need for more detailed research that would investigate how the low energy transition would impact different segments of societies, income, and minority groups.

Another issue with estimating energy use for human need is the difficulty to compare studies as they assume different proxies for well-being and various indicators to measure prerequisites of well-being. In recent work by Rao and colleagues, a novel approach was introduced to analyze the energy requirements for well-being through estimated thresholds of 'decent living standards' (DLS) (Rao and Min 2017). In their analysis, Rao and colleagues decide the minimum material and corresponding energy requirements needed for fulfillment of well-being. They navigate with a eudaimonic conceptualization of well-being and operationalize it by proposing a list of the minimum material prerequisite needed to fulfill each specific human need. For example, based on sanitation and epidemiology studies they assessed that 10 square meters per person are sufficient to satisfy the need for living conditions. They used this conceptualization and operationalization of prerequisites for decent living and estimated energy needs per capita for South Africa, Brazil, and India to be between 12 and 20 GJ per capita in 2050 (Rao *et al* 2019). In their study, they used a bottom-up approach and employed household-level data to estimate the energy needed for a decent living. Their scenarios assumed additional energy inputs needed to build up the infrastructure necessary to improve living conditions.

In a follow-up to this analysis, Millward-Hopkins and colleagues designed a simple global model for which they used a conceptualization of DLS and estimated an average of 15.3 GJ per capita required for a decent living (Millward-Hopkins *et al* 2020). While their analysis is disaggregated by country, their unit of analysis remains at the national level.

Currently, the investigation of minima of energy use for human well-being considers in more detail inequalities in the distribution of energy for a decent living, however, this is mostly done on a high aggregation level with a top-down approach (Kikstra *et al* 2021).

Overall, given physical, social, and cultural differences in how energy is used for human needs, calculating the energy minima remains challenging. Nevertheless, these endeavors are valuable for policy insights. In addition to modeling the energy demand, there is a need for more empirical evidence that could advance the understanding of the current context of energy provision for human needs, especially on a household level.

1.2.6 Maxima: well-being and sufficiency

But the question about how much energy is needed for well-being is also a question about how much energy is enough for well-being. In the previous section, I discussed lower limits of energy use below which people do not satisfy their human needs and in this section, I consider upper limits of energy use for need satisfaction.

Previously, researchers found that proxies for measuring subjective and objective well-being, such as life expectancies or happiness, saturate at certain levels of resource use. “Limits to Growth” was one of the first works addressing issues of reconciling resource constraints with the achievement of well-being (Meadows *et al* 1972). The authors of this report conclude that limiting economic growth is necessary to avoid climate catastrophe. Similarly, Mazur and Rosa correlated several indicators of lifestyles (related to economy, health, education, culture, and life satisfaction) with total energy and electricity consumption for 55 countries (Mazur and Rosa 1974). Results showed that countries with high energy consumption, like the USA, could substantially reduce their energy use without deteriorating their health, education, or culture, however, economic indicators like the number of automobiles per person or economic growth would most likely contract (Mazur and Rosa 1974).

Another study contributing to the argument ‘less is more’ comes from Easterlin's study (Easterlin 1974, Easterlin *et al* 2010). The resulting so-called ‘Easterlin paradox’ shows that while at the low levels of income, little improvements in income correspond to high gains in happiness, this effect diminishes at a high level of income. Easterlin found that over a long period (10+years) increases in a country’s income do not correspond to increases in happiness.

Considering the link between income and energy use, a similar trend has been found when energy or carbon emissions are considered. Previous studies showed that life expectancies and energy use correlate at a low level of energy use at the national level, however, at high levels of energy use, the correlation disappears (Goldemberg *et al* 1985, Lamb and Rao 2015, Martínez and Ebenhack 2008, Pasternak 2000, Steinberger *et al* 2012, 2020). Interestingly, Rosa and Mazur found that with increases in energy consumption, suicide rates and the number of divorces increases as well (Mazur and Rosa 1974).

Overall, these studies show that to keep high levels of well-being for current and future generations we need to limit our resource use. They also prove that there are upper limits of resource use beyond which, the effect on our (and the planet’s) well-being is diminished or regressive.

The recent contributions to finding the maxima of resource use come with a sufficiency perspective. The concept of sufficiency, in Latin ‘sufficientiam’, meaning ‘enough’, invites questions related to how can we eliminate living in underconsumption as well as what consumption levels are enough not to over-consume. In contrast, questions around efficiency aim to ask how much more we can produce, earn and consume while using fewer resources. In that sense, efficiency upholds the status quo of the narrative of perpetuating growth for its own sake, whilst sufficiency begins with an examination of the social and physical status quo, by asking what we use resources for and is the way we provide well-being the most efficient?

In recent years sufficiency perspectives are becoming recognized and considered by wider audiences outside of academia including politicians and policymakers. Perhaps the most prominent examples include concepts of donut economics, sustainable consumption corridors, avoid-shift-improve, and 1.5-degree lifestyles (Creutzig *et al* 2018, 2021, Raworth 2017, Fuchs *et al* 2021, Akenji *et al* 2021). These perspectives originate in different types of studies (e.g. avoid-shit-improve in mobility studies, 1.5. degree lifestyles in consumption-based household footprinting studies), however, what connects them is recognizing the importance of power relations, political, social, and physical contexts in which societies consume resources for need satisfaction.

As already mentioned, sufficiency relates to lower limits and upper limits. While lately, several studies undertook to estimate specific quantities needed for the achievement of basic needs (Rao and Min 2017) the upper limits of energy (or resource) use are discussed less in numerical terms and more in a social-economic way by bringing on agenda issues of justice and inequalities. This approach to upper limits could be summarized by the phrase 'to each according to their need' (rather than 'equally for everyone'). Examples of the importance of this approach can be found in studies highlighting higher energy needs by those with ill-health (Ivanova and Middlemiss 2021, Büchs *et al* 2018). Excess consumption, however, comes under scrutiny, recently with more brave proposals that do not shy from naming those responsible for excess (Wiedmann *et al* 2020, Brand and Wissen 2017) and call-out which types of consumption are indeed damaging.

There are several strategies for tackling overconsumption proposed in the literature. One of them is to consider the remaining carbon budget, which imposes in a top-down matter limits to resource (or energy) use. On the individual level, the idea of budgeting often includes equally distributed quotas or blanket taxes on specifically energy-intensive types of consumption. This type of approach frequently relies on the market to 'fix' the distribution of quotas or assumes that everyone has the same needs satisfiers. Perhaps the most infamous example of the failure of this type of strategy is what happened in France with Yellow Vest Movement (Mehleb *et al* 2021). The blanket approach often misses the issues of inequality, and it is prone to regressive distribution. To avoid this type of oversight, there are calls for normative distribution of carbon budgets that prioritize equity rather than equality (Akenji *et al* 2021).

Another strategy concentrates on dismantling the context that enables overconsumption. For example, rather than focusing on overall reductions of private car transportation and recommending solutions like petrol tax, we could start by asking what needs car-transport satisfies, are there less energy-intensive alternatives, and if yes, what hinders switching to them. This leads to discussing the context of satisfying needs and the purpose of energy use. Further, by recognizing the context in which needs are satisfied we can begin to distinguish between different orders of needs satisfiers and the leverage they might have (Brand-Correa *et al* 2020, Dillman *et al* 2021, Mattioli *et al* 2020). For example, while increases in petrol tax might decreases consumption by mostly those who do not depend on the car for essential need satisfaction, it would not change the way we design our cities, decrease the political power of the automotive industry, or make urban living more affordable.

Overall, sufficiency strategies help to link insights from studies investigating minima and maxima of energy use for human need. By considering both, under and overconsumption, sufficiency strategies help to identify those most vulnerable (e.g. in energy poverty) and those in excess.

1.2.7 Input-Output perspective

Lastly, environmentally extended input-output research presents a method to reassign industrial energy use to the point of final consumption and down to the micro-level of a single household.

Traditionally analysts focused on a production side linked to energy use while analysing its links to the economy and environmental impacts (Lifset 2009). But input-output perspective also allows us to understand environmental impacts from the demand side and an example is given in Costanza and Herendeen's study where they considered a single region to analyse energy demand for the United States (Costanza and Herendeen 1984). Single region studies, however, have an issue with imports, as they assume the intensity of imports is the same as domestic production. To solve this issue, multiregional approach was needed (Peters and Hertwich 2006, Peters 2010). Resulting, Hertwich and Peters brought attention to the micro resolution of the analysis when they estimated that 72% of global GHG emissions can be associated with a household's final demand (Hertwich and Peters 2009). An array of studies followed, dedicated to understanding how much households consume and what factors contribute to differences in levels of consumption.

The existing studies mostly cover developed countries in Global North (Lenzen *et al* 2006, Weber and Matthews 2008, Büchs and Schnepf 2013, Steen-Olsen *et al* 2016, Ivanova and Wood 2020). In emerging economies and developing countries data is not as detailed. Using input-output method requires operational multiregional input-output (MRIO) databases, which tend to cover fewer countries in Global South and estimate rather than report values for them (Owen 2017, Inomata and Owen 2014, Peters *et al* 2011). This might be one of the reasons why there are still few studies corresponding to those regions, however, this trend has been slowly changing in recent years (Donato *et al* 2015, Wiedenhofer *et al* 2017, Kok *et al* 2006).

The existing input-output studies shed light on the most important drivers of energy demand on a household level. What we know for developed countries is that the indirect energy use tends to be bigger than direct (Lenzen 1998, Cohen *et al* 2005, Reinders *et al* 2003, Bin and Dowlatabadi 2005). Income and expenditure tend to be the biggest predictors of households resource use, also in the case of some developing countries (Zhang *et al* 2015, Wiedenhofer *et al* 2018, Büchs and Schnepf 2013, Wiedenhofer *et al* 2017, Lenzen *et al* 2006, Herendeen and Tanaka 1976, Weber and Matthews 2008, Zhong *et al* 2020). The urban form also acts as a strong energy use predictor due to higher direct energy use in rural households, namely the use of fuels for private transportation and heating of houses (Herendeen 1978, Lenzen 1998, Munksgaard *et al* 2008). Recent studies, however, show examples of higher energy levels for urban households, although due to consumption related to indirect energy use like leisure, e.g. air travel (Wiedenhofer *et al* 2018, Chitnis *et al* 2014, Gill and Moeller 2018). Investigated non-income factors have mixed effects on levels of energy use and include demographic factors, e.g. age, gender, population density, or education; (Lenzen *et al* 2006, Ornetzeder *et al* 2008, Räty and Carlsson-Kanyama 2010), household composition, and size (Ala-Mantila *et al* 2014, Minx *et al* 2013, Tukker *et al* 2010, Lenzen 1998, Wier *et al* 2001, Jack and Ivanova 2021), and diets (Ivanova *et al* 2015).

Household-level studies using input-output methods in Global South are less frequent. Pachauri and Spreng in their study of Indian households find that direct and indirect energy consumption is evenly divided and expenditures are the biggest contributor to increasing energy use (between 1983 and 1994) (Pachauri and Spreng 2002). In her follow-up study, Pachauri pointed out characteristics, similar to those listed above, which explain the variation in the energy demand of Indian households, including spatial differences, dwelling attributes, household head age, household size, expenditures, and income level (Pachauri 2004).

Overall, I find this research on both, developed and developing countries, highly relevant for analyzing under-studied countries presented in this thesis. Listed above physical and social characteristics of household footprints serve as a starting point for mapping and investigation of potential drivers of household energy demand. Further, household footprinting studies in Global South, however limited, provide important insights on differences in energy demand between developing and developed countries. Specifically, these studies point to examine in detail the differences in how direct and indirect energy is divided with special attention to cooking fuels.

Further, the well-established methods in input-output studies for mapping economic tables with environmental extension are useful in designing the energy model presented in this thesis.

In relation to how drivers and barriers of energy demand are analyzed, I find that household footprinting studies often limit themselves to only broad socio-economic characterizations. Therefore, I explore possible methods to conceptualize and operationalize household characteristics that could inform about socio-physical aspects of provisioning available to households on the individual and collective level.

However insightful this research is to predict the biggest drivers of high and low consumption levels, it falls short in understanding whether and to what extent consuming activities contribute to human well-being (Lamb and Steinberger 2017).

1.3 Research gap

I have so far established that energy is required for the achievement of basic well-being outcomes. Several studies have tried to establish how much energy is needed for well-being on a national level, and few tried to establish energy thresholds for meeting specific standards of living. What is **not** known is how energy use is distributed on a household level for achieving well-being; how it depends on available provisioning systems; whether there is more energy needed to achieve high levels of well-being; and what are household profiles of those who achieve well-being with low energy use. This range of exploratory questions is addressed in all three papers (chapters 2-4), with the first two articles focusing on case-study countries in Global South and the third focusing on the UK in Global North.

In addition, there are currently no studies focusing on countries in Global South that would account for final energy use on a household level and in relation to well-being outcomes. There are consequently knowledge gaps surrounding the achievement of well-being and distribution of direct and indirect energy use on a household level, understanding inequalities between households depending on types of energy available to them and their broader socio-economic characteristics. These gaps are addressed in all papers. It is also unknown how the achievement of high well-being is related to the total energy footprints on a household level in Global North countries. This question is addressed in paper three with the nationally representative total energy footprints for UK households and their well-being outcomes.

Furthermore, the lack of understanding of how components of well-being (e.g. related to mental and physical health) relate to energy demand makes it challenging to have a nuanced context of energy use for well-being. This has implications for policy that aims to change energy demand while sustaining high levels of well-being. These knowledge gaps collectively inform the research presented in this thesis.

1.4 Aim and research questions

This thesis aims to connect final energy use on a household level with well-being outcomes and analyze household characteristics in the context of provisioning systems available to those households. Drawing upon previous research, it connects disconnected concepts and methods and applies them to under-researched countries. It provides new insight into the distribution of energy use by providing analysis that goes into the core of inequalities, the purpose of energy use, and potential lock-ins in the provisioning systems that disable us from achieving high levels of well-being with low energy use. To achieve this aim, the thesis responds to the following four research questions (RQ):

- RQ1 What is the indirect and direct household energy use by different household types, in the case study countries?
- RQ2 What types and levels of household energy use are associated with the achievement of well-being?
- RQ3 What are socio-economic characteristics and availability of provisioning systems linked to households with different energy and well-being profiles?
- RQ4 What are possible lock-ins that hinder people from lowering energy demand while achieving or maintaining high levels of well-being?

By answering research questions, this thesis makes several original contributions to knowledge. First, it offers an approach for operationalizing well-being concepts, so they can be used in quantitative analysis at a household level (RQ2). Second, it analyses indirect and direct final energy use on a household level for countries never investigated before (RQ1). In doing so the thesis offers several methodological innovations linked to managing issues around lack of or missing data. Third, this thesis has used a novel methodology to characterize households profiles (RQ1, RQ2 & RQ3). Rather than solely focusing on incomes or location, the analysis builds household typologies around well-being outcomes and high and low levels of achieved well-being (RQ2). Fourth, it offers a conceptual distinction to household footprinting studies to consider provisioning systems as a separate part of the analysis, which informs about the context of energy consumption for need satisfaction (RQ3 &R Q4).

1.5 Research design

This thesis draws from the research perspectives and methods outlined above: the eudaimonic perspective on well-being, understanding of provisioning systems as culturally specific, the current advances in the MRIO method, and the research that has already been done in the area of conceptualizing minima and maxima of energy use. In particular, this thesis takes conceptual inspiration from Brand-Correa's framework for decoupling human need satisfaction from energy use (Brand-Correa and Steinberger 2017).

Below I outline in more detail the overall analytical framework (figure 1-4). Section 1.5.1 presents an operationalization of well-being used throughout the thesis, section 1.5.2 describes the operationalization of provisioning systems, section 1.5.3 introduces case-study countries and the rationale behind their selection.

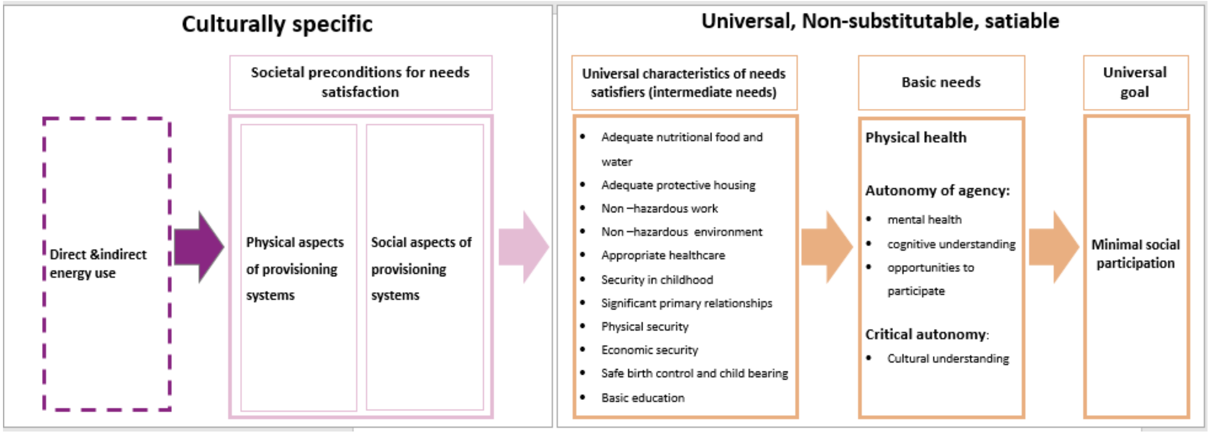

Figure 1-4 Analytical framework: situating direct & indirect energy use and provisioning systems within the theory of human need.
Note: Based on (Gough 2015) and Brand-Correa's framework (Brand-Correa and Steinberger 2017).

1.5.1 Operationalization of well-being

The operationalization of well-being used throughout this thesis is nested in the theoretical framework of human need proposed by Doyal and Gough (Doyal and Gough 1991). In their approach, they provide a clear division between basic needs, universal characteristics of those needs (intermediate needs), and diverse, culturally dependent needs satisfiers (Figure1-3). For example, a mobile phone can be seen as a vital device to fulfill the human need of significant primary relationships: however it should be seen as one of many possible satisfiers, and not as a human need in itself. Doyal & Goughs' framework helps to avoid this type of confusion and enables operationalization of well-being to be more precise. To be able to fulfill a universal goal which is minimally impaired social participation, each individual has to satisfy her basic needs. Meeting IN, in turn, is needed for those basic needs. Therefore in the analysis using indicators for IN or BN (which are the result of satisfying IN) could be enough for examining if the condition of the universal goal of well-being was met.

Data from household surveys are primarily used to create indicators for the universal characteristics of human need. The challenge was to match as closely as possible need characteristics with information in a survey that would indicate if a minimum level of a human need was achieved. Table 1-1 presents indicators used throughout the thesis. Data limitations meant that not every universal characteristic had a matching indicator from a household survey. Despite these data limitations, the indicators chosen for the study are still relevant and inform about the achievement, or not, of basic needs.

As a consequence, the chosen indicators provide information about the outcome and not necessarily about how the outcome is achieved (e.g. having adequate food vs eating specific grains or meat). Some information might be applicable for more than one human need indicator, for instance, having access to clean water needed to fulfill the adequate protective housing need is also relevant for adequate nutritional food and water.

Household questionnaires have limited information that can be used as proxies for well-being outcomes at the basic needs level. The ideal would be to have indicators for each basic need, for example, the outcome of achieving cognitive understanding could be associated with literacy, for physical health, it could be life expectancy at birth, mortality, and prevalence of disabilities[2]. This type of data, however, was not always available, so I mitigated this issue by considering indicators for IN and indirectly associating them with well-being outcomes.

Only a few IN were used to build well-being indicators for which there are two main reasons. First, if more IN indicators would be considered for the well-being indicator, I would not have a big enough sample for meaningful statistical analysis in Zambia, Vietnam, and Nepal. This shows how few households in those countries are having their basic well-being outcomes met. Second, the majority of the UK households already have achieved some of the IN like having indoor sanitation or having access to clean water, therefore, they were not included in building the well-being indicator.

The Sustainable Development Goals (SDG) include several goals which can be linked to the needs listed below (Lamb and Steinberger 2017). Here they are considered global goals, to ensure all people live in peace and prosperity (UN 2017). The noted similarities between the SDGs and human needs mean that need-based research should be relevant to international goals and policy processes.

[2] Indicators proposed by Doyal and Gough (Doyal and Gough 1991)

Table 1-1 Matched Intermediate needs and basic needs indicators with Sustainable Development Goals and presented for Zambia, Vietnam, Nepal, and the UK.

	Indicator	SDG	Data available in hh survey for:
Intermediate Needs:			
Adequate nutritional food and water	Sufficient amount of food, three or more meals per day, access to safe water, Access to appliances (cooking stove, refrigerator) Access to modern cooking fuels	2. Zero hunger	Zam, Viet, Nep Zam, Viet, Nep Zam, Viet, Nep, UK Zam, Viet, Nep, UK
Adequate protective housing	Structure that protects against weather, Access to facilities (sanitation, toilet, shower), Number of persons per room Adequate heating	6. Clean water and sanitation 7. Affordable and clean energy	Zam, Viet, Nep Zam, Viet, Nep Zam, Viet, Nep, UK UK
Non–hazardous environment	Occurrence of events like flooding, avalanches, storms etc.	16. Peace, justice and strong institutions	NA
Physical security	Air pollution, access to waste treatment, access to streets, pavements, a presence of insects and rodents, feeling safe, crime victims of family and friends.		NA
Security in childhood	Parental leave, access to a nursery, Healthcare for children: Immunization programs		UK Zam, Nep, UK Zam, Nep, UK
Significant primary relationships	Satisfaction with friends and family, parental leave	5. Gender equality	UK
Appropriate healthcare	Access to health care facilities, Spending on health care, Immunized against diseases, Self-assessment of health condition	3. Good health and well-being 5. Gender equality	Zam, Viet, Nep, UK UK Zam, Viet, Nep, UK UK
Safe birth control and childbearing	Parental leave, access to vaccinations, access to Contraception		UK NA
Economic security	Working status, type of contract, Income, Holidays, Hours per week spent on work	1. No poverty 5. Gender equality 8. Decent work and economic growth	Zam, Viet, Nep, UK Zam, Viet, Nep, UK UK UK
Non–hazardous work	Access to training and awareness related to risks at work; Availability and access to protection for work		NA Zam, UK
Basic education	Years of education, secondary school enrolment of females	4. Quality education	Zam, Viet, Nep, UK
Basic Needs:			
Physical health	Disabilities, needed hospitalization, chronic illness, Self–assessed physical health Malnutrition status	3. Good health and well-being	UK, Zam UK Zam, Nep
Autonomy	Ability to read and write, Ability to make decisions and control own life	4. Quality education 5. Gender equality	Zam, Viet, Nep, UK
Mental health	Mental ilness, Self-assessed mental health	3. Good health and well-being	UK UK
Cognitive understanding	Ability to read and write, Ability to make decisions and control own life	3. Good health and well-being 4. Quality education	Zam, Viet, Nep, UK NA

Note: In bold indicators used for building well-being indicator, SDG: Sustainable Development Goal, hh: household, Zam: Zambia, Viet: Vietnam, Nep: Nepal, NA: not applicable. SDGs matched to Intermediate needs and basic needs indicators (not exact equivalents) are based on the framework proposed by Lamb and Steinberger (Lamb and Steinberger 2017).

1.5.2 Operationalization of provisioning systems

In this thesis, provisioning systems are understood as intertwined social and physical systems within which needs are satisfied. Similarly to 'satisfiers' of human need (Figure 1-3) they are culturally and technologically specific, and provide various contexts within which production, distribution, and consumption of goods and services take place. I distinguish between physical and social aspects of provisioning systems on an individual (household) and a collective level. Individual vs collective distinction relates to interdependencies between those who consume, produce, and distribute (also highlighted in SoP). Households, as a part of socio-technical systems, are generally not able to provide for themselves independently from collective providers. They depend on collective provisioning and, in relation to what is available to them, they also decide on types of individual provisioning (e.g. depending on if there is a paved road, households might decide to use public transport or own a car). Making a clear division (when possible) between collective and individual levels of provision may enable an analysis of those types of dependencies and also power relations.

Distinguishing between physical and social provisioning is done to differentiate between 'hard' characteristics linked to technical aspects of provisioning and 'soft' associated with non-material aspects of provision.

Previous research called elements of provisioning systems as socio-economic or socio-technical characteristics (Lenzen *et al* 2006, Tukker *et al* 2010, Wier *et al* 2001, Wiedenhofer *et al* 2013, Büchs and Schnepf 2013). In those studies, collective and individual level is usually presented together without making a clear division between what is provisioned within and outside households. In this analysis, I consider them separately.

Due to data limitations, the analysis presented in Chapters 2 and 3 mostly considers the individual level of provisioning systems and the physical part of the collective provisioning systems. Table 1-2 offers examples used for the analysis and potential characteristics that could be used if appropriate data on a household level would exist.

Table 1-2 Examples of provisioning characteristics on a collective/individual level and for social and physical types.

Level	Social	Physical
Collective	Expenditures on health System of health care organization **Access to safe birth control** **Childhood care systems – parental leave** Education (spending on education per capita) Education regulations Population density Unemployment rate Gender inequality Property rights, access to public housing, slum Residency conditions	**Healthcare infrastructure** **Education infrastructure (e.g. schools)** **Transport infrastructure** **Electrification** **Sanitation infrastructure**
Individual (Household)	**Income** **Expenditures** Political orientation **Expenditure on health** **Household demographics** **Employment status** **Expenditures on education**	**Household appliances** **Access to facilities** **Dwelling type** Learning materials **Rural-urban differences** **Sanitation**

Note: In bold characteristics available in data in case-study countries (Nepal, Vietnam, Zambia, or the UK)

1.5.3 Introducing case studies

The selection of case-study countries anlaysed in this thesis was not random. The selection process was started by investigating previous studies that link well-being outcomes (e.g. life expectancy, income per capita) with resource use and carbon emissions (Pasternak 2000, Mazur and Rosa 1974, Steinberger and Roberts 2010, Lamb *et al* 2014). As a result, a group of countries within the 'Goldemberg's Corner' was chosen (Lamb *et al* 2014). Those countries have less than 1 ton of carbon emissions per capita and more than 70 years of life expectancy, e.g. Vietnam, Costa Rica, Sri Lanka, and Egypt. According to Lamb's typology (Lamb *et al* 2014), the 'Goldemberg's Corner' includes three groups of countries: transitioning producers (majority communist states), moderate GDP with low export (e.g. Sri Lanka, Colombia, Costa Rica), and moderate GDP with high export (e.g. Vietnam, Thailand, Panama). In addition, we took into consideration countries in 'the high plateau' (Pasternak 2000), with high consumption levels and high HDI (e.g. UK, Germany, Canada), and countries least developed, with very low consumption (e.g. Zambia). Consequently, a group of approximately 30 countries was selected.

Those countries were compared based on: socio-economic characteristics (type of economic system, gross national income, education, gender inequality index, religion), political system, resource-use (fuel exporter/importer), and availability of macro and microdata (consumer expenditure surveys, Input-Output data).

Depending on income level and socio-economic group within countries, different factors tend to be crucial in relation to resource use and well-being. Therefore, it was important in the first place to differentiate between low and high-income countries. Furthermore, it was important to incorporate a gender perspective into the case-study country selection, as especially in developing countries women are often primarily responsible for provisioning and using energy (Skutsch and Wamukonya 2001). Energy use for both transportation and electricity is tightly linked to progress in human well-being (Rao and Pachauri 2017). Therefore, the characterization of countries linked to those provisioning systems was important when deciding on case-studies.

The final criteria for case-studies selection were the availability of partnerships and scientific networks in a given country. The work presented in this thesis is part of the Leverhulme funded 'Living Well within Limits' (LiLi) project, which besides the quantitative part (which this Ph.D. is part of), it has a qualitative component that involved community workshops conducted in case-study countries. The project aimed to have similar or the same case studies within the quantitative and qualitative parts of the project. Therefore, it was important to have availability to contact local non-government organizations or have a contact person who could help establish a local network in each case-study country.

It is important to note that the case-study countries selection was **not** an in-depth study of the socio-political characteristics of those countries. The categories described above were used as a compass that could point towards interesting case-studies with respect to the scope of the LiLi project. The focus was kept on provisioning systems characteristics, as well as factors that might enable or hinder sustainable change within existing systems of provision. The aim was to choose countries as diverse as possible in their pathways of delivering energy for human need satisfaction.

As a result, four case study countries were selected: three in the Global South (Vietnam, Nepal, and Zambia) and one in the Global North (UK). Vietnam represents one of the 'Goldemberg's corner' countries and was especially interesting because of its socialist, single-party political system and motorcycle-dominated road transportation. Nepal represents many low-income countries with a high reliance on biofuels, where women are mainly responsible for fuel collection and cooking. Zambia, the only African case-study country, was selected due to good contacts with local non-governmental organizations and because of its interesting history of electrification. The Zambian electricity system served also as a system of provision case-study done as a part of the LiLi project ((Bayliss and Pollen 2021). Finally, the UK was selected to represent the Global North countries. It represents the 'high plateau' country, with high HDI and consumption levels.

	Nepal	Vietnam	Zambia	UK
Pop. (M)	31	95	16	66
pers / km	204	283	23	271
Income group	Lower Middle Income	Lower Middle Income	Lower Middle Income	High Income
Unemployment (%)	3.2	3.4	15	4.3
Trade	importer	exporter	importer	importer
Gender Inequality index	0.49	0.33	0.5	0.13
vhcl/1,000 inhab.	N/A	23	23	575
Change in motorisation rate	N/A	15	-7	18
Net tax on gasoline	50%	25%	50%	125%
Road density (km / km²)	13.5	48.33	N/A	172.27
Urbanisation	19%	34%	41%	83%
Urban areas (pers / km²)	14300	6060	5967	3817
Access to electricity	85%	99%	28%	100%
Watt / cap	15	149	80	547
Electricity ownership	generation half public half private, distribution public	dominated by state-owned Vietnam Electricity	state-dominated	private, large companies

Figure 1-5 Selected case-study countries' characteristics (in 2017)
Note: Change in motorization rate between 2015 and 2005; motorization rate for 2015.

1.6 Data and methods

The analysis presented in the next three chapters is based on a multiregional input-output methodology. In the following subsections, I explain the main steps necessary for the calculation of household energy footprints. This includes:

- Accessing data (household expenditure, energy data, input-output data)
- Preparing data (mapping sectors between household, energy, and input-output data)
- Calculating household final energy demand

While for Nepal, Vietnam, and Zambia the final energy model is the same (Figure 1-6), for the UK I needed to conduct additional steps related to statistically matching two household surveys before I could estimate the final energy use for households (Figure 1-7). I briefly describe this process below, with more detail provided in the corresponding chapters.

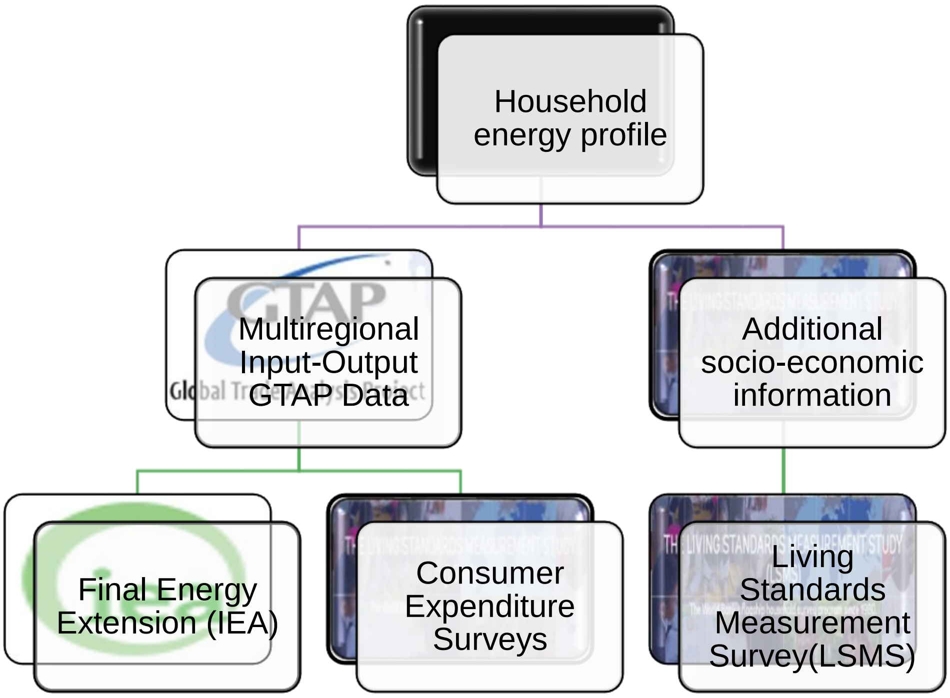

Figure 1-6 Use of data for energy model designed for Nepal, Vietnam, and Zambia.

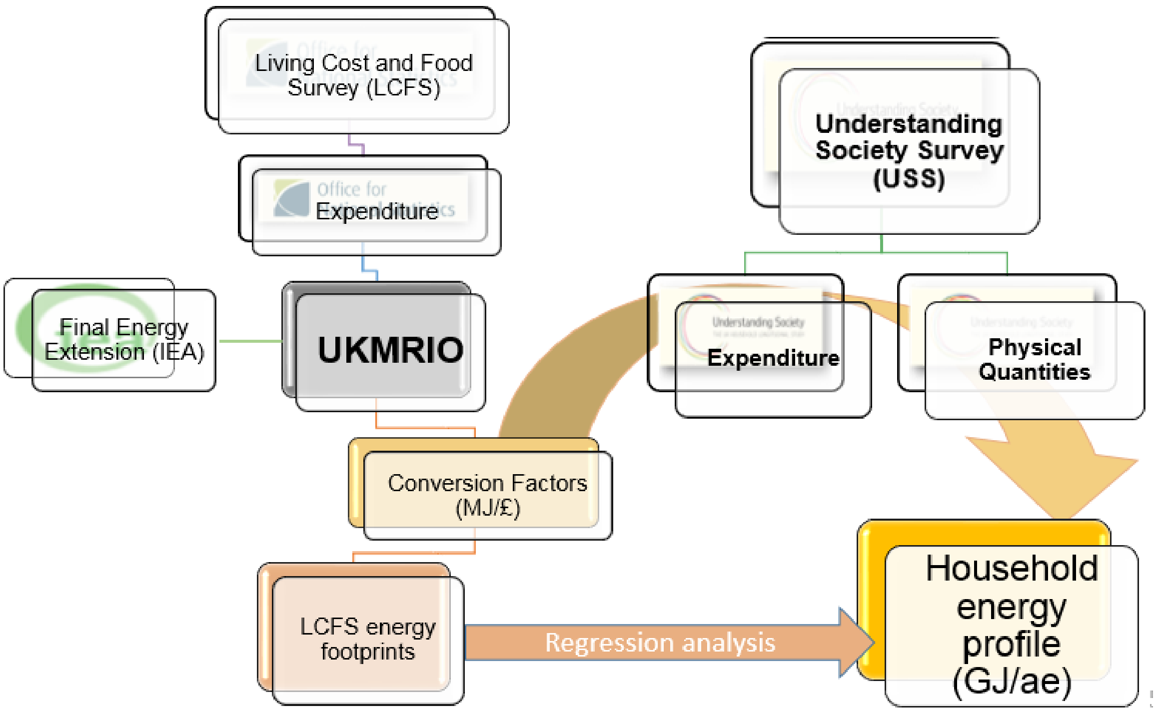

Figure 1-7 Data and methods used for estimating household energy footprints for the UK.
Note: MJ: mega joules; GJ: gigajoules, ae: adult equivalent.

1.6.1 Data

For all analysis presented in this thesis, I needed to access data related to households, energy use, and input-output tables.

<u>Household-level data</u>

Households' expenditure data – collected from nationally representative household surveys, constitute essential data required for this analysis. Each of the datasets contains information for over 10,000 individual households and linked to: expenditure, health, family, housing conditions, location, access to facilities, ownership of appliances, education level, and income.

The data for Vietnam, Nepal, and Zambia was retrieved from their national statistical offices. The household surveys used for the analysis are part of the World Bank program monitoring living conditions in many of the Global South countries.

For the UK, I used two household surveys: Living Costs and Food Survey (LCFS) and Understanding Society Survey (USS). LCFS was used at the initial stages of estimating households' footprints, while USS served as the main study on the basis of which I analyzed household characteristics and well-being outcomes.

<u>MRIO data</u>

Currently, there are five main data sources used for MRIO systems: The World Input-Output Database (WIOD), EXIOBASE3.8, Eora, OECD, and the Global Trade Analysis Data Base (GTAP) (Stadler *et al* 2018, Owen *et al* 2017, Wiedmann *et al* 2011, Timmer *et al* 2015, Lenzen *et al* 2013, OECD 2021, Peters *et al* 2011, GTAP 2011). Both Eora and GTAP have available data specifically for smaller economies that are not included in other databases, e.g. Zambia, Nepal, and Vietnam. This is specifically needed as my focus is on countries usually covered within the so-called Rest of the World group in other MRIO databases. For my analysis, it is useful to have as much sectoral resolution as possible, which makes the mapping of external data, like Consumer Expenditure Surveys (CES), to MRIO databases easier. GTAP, in particular, has a high level of detail in the agricultural sectors (20 categories), which enables easier mapping of food products from categories used in household surveys to the MRIO database. Using GTAP instead of Eora for my study is dictated by the availability of Input-Output data for Zambia and Nepal with a higher sectoral resolution than in Eora (36 and 57 respectively in GTAP, versus 26 for both countries in Eora).

To maintain consistency across the countries in the Global South in my study, I decided to use only one database. The shortcoming of this decision is missing an opportunity to use each of the MRIO databases for their strengths, like more up-to-date data or a higher sectoral resolution for some of the case-study countries. Unlike other MRIO databases, GTAP is not designed for MRIO. Additional steps have to be performed, including the reallocation of international transport, before it can be used as an MRIO system (Peters *et al* 2011).

For the UK case study, I use the UK Multiregional input-output database (UKMRIO) (Owen *et al* 2017, Barrett *et al* 2013, DEFRA 2021). The database is constructed using data from the Office for National Statistics for the UK.

Final Energy data

For energy extension used in the energy model, I retrieved data from International Energy Agency (IEA). I use final energy consumption categorized into 23 sectors with terajoules as the unit of analysis. This data is also used for the UK's foreign sectors. For domestic energy consumption in the UK, I use the National Statistic on Energy consumption data (DEFRA 2021), as it provides more detail on the residential home heating and power along with residential private transport (Owen and Barrett 2020).

1.6.2 Multiregional Input-output

Estimates of household energy footprints in all three papers presented in this thesis are based on an input-output methodology developed by Wassily Leontief (Leontief 1936, 1953). By using systems of national accounts, it allows tracking economic activities from a place where the final demand of a product originated to a place where the industrial output of production occurred (Suh 2009, Miller and Blair 2009). This method was further developed and a new multiregional model, linking single region IO tables with trade information, allowed to track economic flows between more than two regions (Suh 2009). Using multiregional input-output (MRIO) tables together with environmentally-extended IO techniques enabled the analyst to understand where on regional or international level emissions occur, 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 a direct energy use (private transportation, fuel used for heating houses) lead to the development of household carbon (or energy) footprints (Wiedmann and Minx 2008).

Figure 1-8 presents an MRIO framework that is used to quantify the energy used by households in four case-study countries. Here, the entire global economy is treated as a single system where each of the Single Region Input-Output Tables (SIOT) is placed on a diagonal of the big matrix. On the off-diagonal are situated sectoral demands from non-domestic regions (imports) for the production of domestic products (Owen 2017). On the right-hand side are placed sales to each country's final demand. Total output is obtained by summing across rows of the matrix and those sales. In figure 1-8, a column representing sales of country A is expanded to show a disaggregation of households' final demand. Possible methods for how to scale individual households to total final demand include using weights (Weber and Matthews 2008, Pachauri 2004). In the presented MRIO framework, the energy extension is an additional row that needs to be constructed with additional data and mapped to the existing MRIO database.

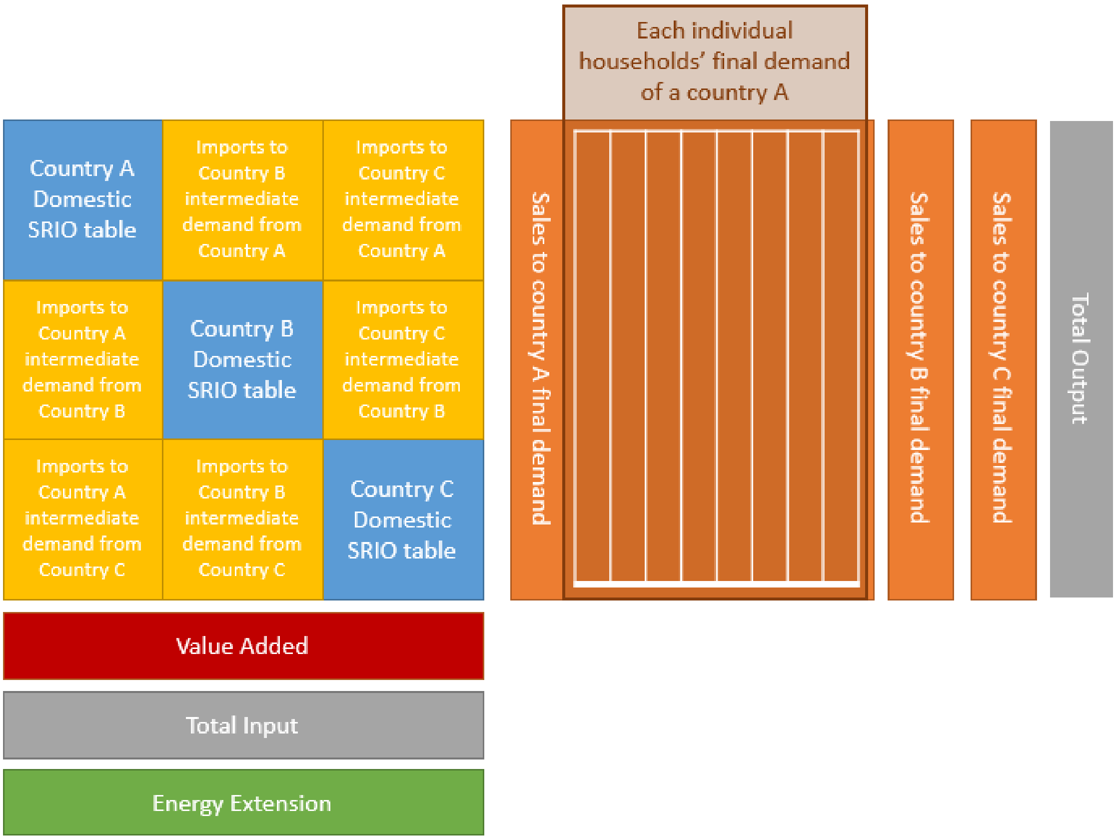

Figure 1-8: MRIO framework
Note: based on (Owen 2017).

1.6.3 Final energy for the energy extension

In the Global Energy Assessment report, final energy is defined as: "the energy transported and distributed to the point of retail for delivery to final users (firms, individuals, or institutions). Examples include gasoline at the service station, electricity at the socket, or fuelwood in the barn" (GEA 2012, p 103). Except for EXIOBASEv3.8, none of the databases have energy extension expressed as final energy. Since GTAP is used for this analysis, a new energy extension needed to be built. Data used for this task came from the IEA energy balance which is divided into three categories: 1) total primary energy supply; 2) statistical differences, transformation losses, energy industry own use; 3) and total final consumption. The latter one consists of energy used by industry (e.g. electricity, heat, coal), which is assigned to end-use sectors (e.g. transport, industry, other) (IEA 2010). The total primary energy supply can be calculated by adding categories 2 and 3. Both GTAP and end-use sectors in IEA employ similar categorization to present their data. The IEA uses International Standard Industrial Classification (ISIC rev. 3) to categorize industry activities and assign them to IEA final consumption sectors. Similarly, sectors in GTAP can be mapped to ISIC rev. 3 and Central Product Classification (CPC ver. 1.0). Using those international categorization standards, converting from IEA categories to GTAP was possible.

1.6.4 Household expenditure

Household expenditures were used for estimating each household's final energy demand, however, this required alleging household expenditure categories with GTAP's sectors. Mapping households' expenditure data to GTAP was done by using The Classification Of Individual Consumption by Purpose (COICOP) categorization. It is a reference classification published by the United Nations Statistics Division that categorizes consumption expenditure into 12 divisions corresponding to households' consumption and two other divisions: non-profit institutions serving households and individual consumption expenditure of the general government. The structure of COICOP has three levels: two-digit divisions (14 main categories), three-digit groups, and four-digit classes. Depending on the structure of household expenditure data, I used the highest four-digit resolution, or the second-highest – three-digit.

Mapping 116 COICOP categories to 57 GTAP sectors required several steps. Part of the GTAPs' sectors (1-26) corresponds to CPC categorization and the second part (14-56) to ISIC Rev. 3. Similarly, COICOP and ISIC Rev.3. can be mapped to CPC1.0. As a result, I mapped all three levels of COICOP categories to GTAP.

1.6.5 Statistical Analysis

In order to explore the associations between household socio-economic characteristics and well-being, I used statistical methods including regressions and factor analysis, and I calculated Gini coefficients. In particular, logistic regression is used in all empirical chapters. The rationale for using logistic and not, for example, linear regression is that logistic regression allows analysis in which the dependent variable is binary. The way I conceptualize and operationalize the achievement of well-being outcomes requires all considered well-being outcomes and not a part or a degree of them. Therefore, logistic regression with the binary dependent variable (e.g. having or not having basic well-being outcomes) is used. The explanatory variables were initially chosen based on the literature outlined above related to well-being, energy poverty, and input-output studies. In chapter 3, for better readability of results, I decided to reduce the number of independent (explanatory) variables by employing factor analysis. By considering correlated variables factor analysis helps to create a smaller number of new variables – factors.

In all empirical chapters, I report the results of logistic regressions in odds ratios, as I believe they are simpler to understand than coefficients. Throughout this thesis, every table presenting odds ratios also includes a key to how to read the results. In chapter 2 I expand the logistic regression to include average marginal effects (AME), which allows examining the probability that the situation described by the dependent variable (i.e. well-being) will occur while holding other independent variables at their observed values.

Chapters 2 and 3 include inequality analysis by calculating Gini coefficients and presenting graphically inequalities in form of Lorenz curves. The Gini coefficient employs frequency distribution (e.g. energy or income) in the whole population and measures the inequality of this distribution (Steinberger *et al* 2010).

1.7 Organization of thesis

This thesis is organized as follows. The first chapter is this introduction, where empirical context, literature review, research gap, questions, and design are provided, as well as an outline of data and methods used in the empirical parts of the thesis. Chapters 2 to 4 correspond to two published peer-reviewed journal papers and one submitted for a peer-review. Chapter 2 focuses on the Zambian case study country and introduces a method of linking household energy footprint with well-being outcomes. Chapter 3 builds on those methods and presents the energy requirements and links to basic well-being outcomes in Zambia, Vietnam, and Nepal. Chapter 4 changes focus from the Global South to the Global North and presents an analysis of household energy footprints in the UK and links them with the achievement of high and low well-being. Finally, Chapters 5 and 6 present discussion and conclusions.

1.8 Publications and the alternative format

This thesis includes published or submitted journal articles, conforming to the Alternative Format Thesis. These papers are incorporated as individual chapters (Chapters 2, 3, and 4). The rationale for the alternative format is the self-contained analysis applied in each empirical chapter, with results that contribute to the novel research area highly relevant for policies related to the reduction of energy demand. At the time of submission, two papers included in this work have been published in peer-reviewed journals (Energy Research & Social Science and Environmental Research Letters), totaling 18 citations (Scopus) in the literature, while the third article was submitted for a review to the Ecological Economics Journal.

Three journal papers were written as part of the thesis, and are presented in sequence as the following joint-authored publications:

Chapter	Journal paper
Chapter 2: Final energy footprints in Zambia: Investigating links between household consumption, collective provision, and well-being	Final energy footprints in Zambia: Investigating links between household consumption, collective provision, and well-being; Marta Baltruszewicz, Julia K. Steinberger, Anne Owen, Lina I. Brand-Correa, Jouni Paavola (2021). Energy Research & Social Science, vol. 73, 101960 Available at DOI: https://doi.org/10.1016/j.erss.2021.101960
Chapter 3: Household final energy footprints in Nepal, Vietnam and Zambia: composition, inequality and links to well-being	Household final energy footprints in Nepal, Vietnam and Zambia: composition, inequality and links to well-being ; Marta Baltruszewicz, Julia K. Steinberger, Diana Ivanova, Lina I. Brand-Correa, Jouni Paavola, Anne Owen (2021).; Environ. Res. Lett. 16 025011; Available at DOI: https://doi.org/10.1088/1748-9326/ABD588
Chapter 4: High energy use for fun and for necessity: what stops the UK from achieving well-being at low energy	High energy use for fun and for necessity: what stops the UK from achieving wellbeing at low energy use. Submitted to Ecological Economics Journal

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Chapter 2
Final energy footprints in Zambia: Investigating links between household consumption, collective provision, and well-being

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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 need satisfaction as it is crucial for addressing decarbonisation and human development agendas.

2.1 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 (Lenzen 1998, Cohen *et al* 2005, Reinders *et al* 2003, Bin and Dowlatabadi 2005). These studies also suggest that income and expenditure are the best predictors of household resource use in the Global North (Zhang *et al* 2015, Wiedenhofer *et al* 2018, Büchs and Schnepf 2013, Wiedenhofer *et al* 2017, Hubacek *et al* 2017b, Lenzen *et al* 2006, Herendeen and Tanaka 1976, Weber and Matthews 2008a). 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 (Herendeen 1978, Lenzen 1998, Munksgaard *et al* 2008). 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 (Lenzen *et al* 2006, Ornetzeder *et al* 2008, Räty and Carlsson-Kanyama 2010, Ala-Mantila *et al* 2014, Lenzen 1998, Minx *et al* 2013, Tukker *et al* 2010, Wier *et al* 2001, Ivanova *et al* 2015).

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 (Pachauri and Spreng 2002, Pachauri 2004, Rao *et al* 2014, 2019), and none in extractive and low-income African countries. In the most extensive research to date, Pachauri (Pachauri 2007) 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 (Pachauri 2007). Her findings resonate with those of others that have linked access to electricity to improved health and education (Riva *et al* 2018, Nussbaumer *et al* 2012, Kaygusuz 2011, Karekezi *et al* 2012).

Researching energy use in developing regions is increasingly important, particularly at the household level (Pachauri 2007). 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 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 (Boos and Holm-Müller 2016). 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.

2.2 Methods and data

Household energy footprints are best measured through consumption-based accounting using multiregional 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 (Wiedmann and Minx 2008), 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 (Miller and Blair 2009, Suh 2009, Lenzen *et al* 2004, Turner *et al* 2007, Peters and Hertwich 2009)). We refer the reader to this literature, and focus here upon the data we used and specificities of our MRIO model.

2.2.1 Data

For this analysis, we chose an MRIO database constructed from the Global Trade Analysis Project (GTAP) version 9 (see (Peters *et al* 2011) 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 (Inomata and Owen 2014). 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 (Steen-Olsen *et al* 2016). 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 (Horridge 2013).

For the energy-use extension (see (Owen *et al* 2017, Wieland *et al* 2020) 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) (IEA 2010). 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 (Kalt *et al* 2019), 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 (Owen *et al* 2017).

Household expenditure data – collected by the 2015 Living Conditions Monitoring Survey (LCMS) is used for household final demand in the MRIO model (Central Statistical Office (Zambia) and World Bank 2015). 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.

2.2.2 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 (Peters *et al* 2011). 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 A-1 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. (Oswald *et al* 2020), 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. Although GTAP uses two different international product categorizations (International Standard Industrial Classification, and Central Product Classification), they both map onto COICOP (United Nations Statistic Division 2019).

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 (Peters *et al* 2011). 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 (Steen-Olsen *et al* 2016), which does not influence the overall results.

We matched GTAP's final demand and Zambian household expenditures using the RAS balancing method (Miller and Blair 2009), 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 (IEA 2016). 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 (Figure A-1 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 (Mulombwa 1998). 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 (Mulombwa 1998). 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 (Ivanova *et al* 2015).

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 (Pachauri 2004, Weber and Matthews 2008b), 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 (Steinberger *et al* 2010).

2.2.3 Basic well-being outcomes

We used the theory of human need (THN) proposed by Doyal and Gough (Doyal and Gough 1991) as a basis for quantitatively examining basic well-being outcomes. The THN provides a "eudaimonic" (as opposed to "hedonic") understanding of wellbeing (Brand-Correa and Steinberger 2016). In THN well-being is defined as a universal goal of 'participation in some form of life without serious arbitrary limitation' (Gough 2015, p 1197) which is valid regardless of place, culture or time.

The framework distinguishes between three aspects of well-being:

a. basic needs: physical health[3], 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 need, 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[4]:

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.

[3] 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.
[4] Lack of information in the LCMS made it impossible to assign an indicator to all types of needs.

2.2.4 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 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 2-1). 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 (Scott Long and Freese 2014). 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.

Table 2-1 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) (Zambia Central Statistical Office and Central Statistical Office 2016).
Safe water	d	HHs with access to safe water within one km from home. 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.
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 5km	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 5km	d	Access to a secondary school within 5 km from home.
Health facility w/n 5km	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 <5yr.)	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.

2.3 Results

2.3.1 Household expenditure and final energy footprints

Zambia's per capita total final energy demand is similar to many of its neighbours (IEA 2019). 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 Figure 2-1). 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 (Figure 2-1).

Energy intensities and energy efficiency are important factor in explaining the proportional differences between expenditure and energy footprints observed in Figure 2-1. We find high energy intensities for cooking fuels of firewood and charcoal (Table 2-2). 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 less than 1 MJ of electricity but four times more using a charcoal fed mbaula[5] cooking stove, or six times more when cooking on open fire (Ravindranath and Ramakrishna 1997, Kaoma *et al* 1994).

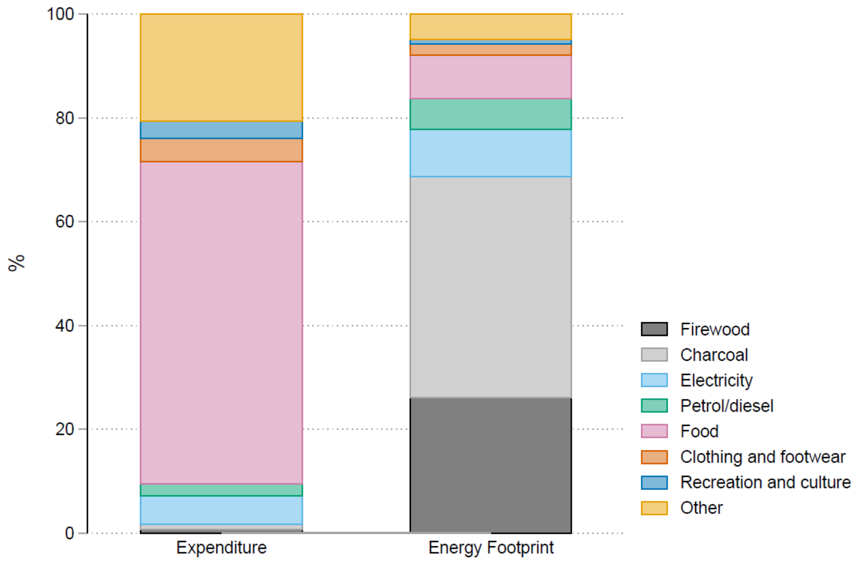

Figure 2-1 Yearly expenditures and energy footprints per capita (% of final energy consumption).

[5] 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 (Chileshe 2001)

Table 2-2 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

2.3.2 Inequalities

To better understand the differences between households' energy footprints, we calculate Gini coefficients - a common measure of inequality (Table 2-3). 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.

Table 2-3 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.

Transport EF is highly unequal, with a Gini coefficient of 0.89 (Table 2-3). Because of limited road network and poor road conditions (9.1km of roads per $100km^2$ and 9% of roads being paved (The World Bank 2017, AfDB/OECD 2006)), 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 ten times more likely to own a car (Table 2-4).

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).

Table 2-4 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).

2.3.3 Location and income differences

As expected, households in higher-income equivalised deciles[6] 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 (Figure 2-2). 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 (Figure 2-2). Moreover, only the households in highest income deciles use more substantial amounts of petrol, and its consumption by other income groups is negligible.

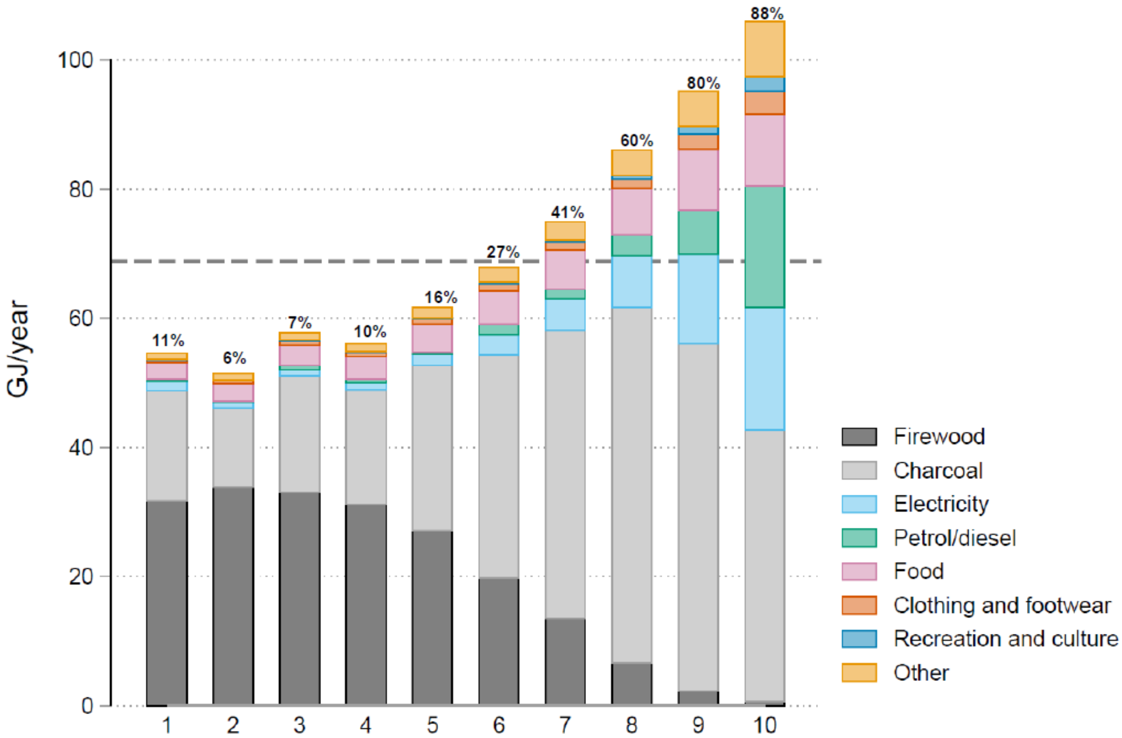

Figure 2-2 Households' final energy footprints by income deciles, GJ/ household per year.
Note: Percentage above each bar indicate a share of households connected to electricity. The dashed line indicates a national average. Values calculated using the 2015 household survey data and demographic weights.

When considering differences in household EF profiles based on location (Figure 2-3), we split the equivalised income deciles presented in Figure 2-2 between rural and urban areas. This leaves an

[6] 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.

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.

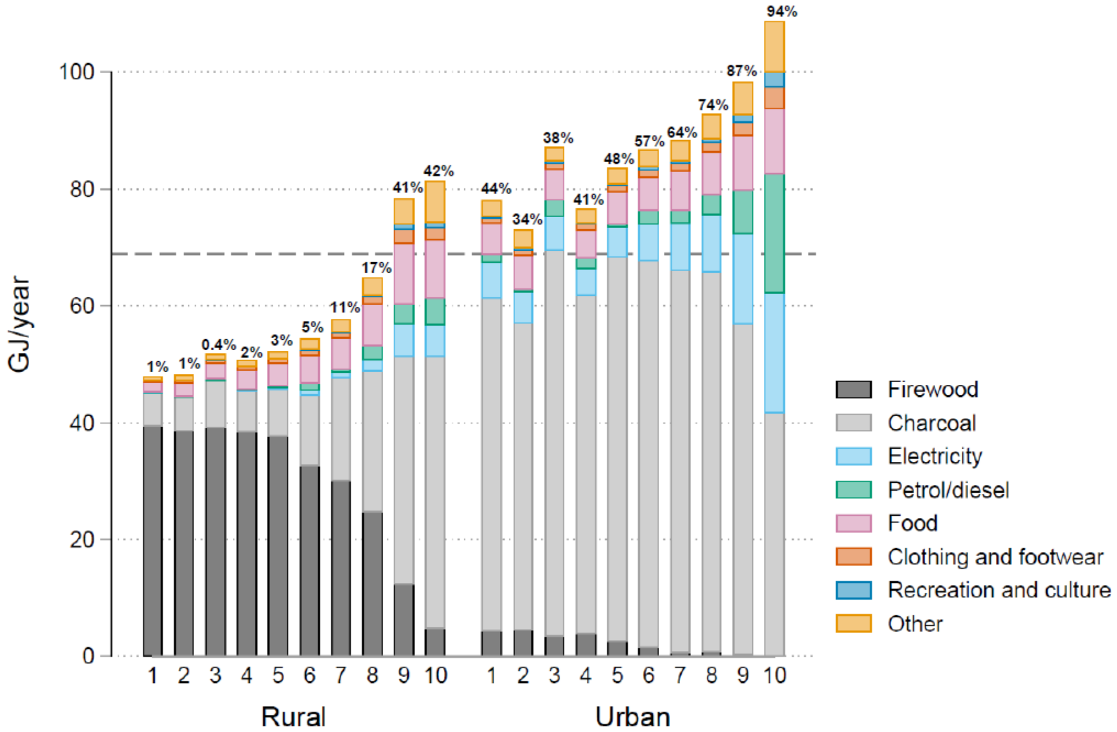

Figure 2-3: Households final energy footprint across rural/urban areas by income deciles, GJ/household per year.
Note: Percentage above each bar indicate a share of households connected to electricity. The dashed line indicates the national average. Each decile corresponds to the same level of income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

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 (Figure 2-2). Urban households use two and half times more indirect energy than their rural counterparts (Table 2-4), 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 2-4). 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 2-4). 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.

2.3.4 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 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 2-5). 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 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 2-5).

Table 2-5 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)												
No. of 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 ($/eq)	1557	904	718	477	717	448	537	259	395	228	312	294
Income ($/hh)	4424	2643	2063	1399	2000	1361	1564	743	998	655	941	848
Exp. Dir./ 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
Exp. Indir./ 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.	7.6
EF-indirect	3.8	2.3	1.6	1.4	1.9	1.0	1.4	0.8	1.1	0.7	0.	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	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.	0.0
Bicycle	27.2	25.9	37.8	50.2	45.7	53.0	46.6	44.4	43.4	40.1	4	36.9
Car	17.2	4.8	2.0	0.5	2.9	2.5	0.5	0.1	0.5	0.0	0.	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
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	5	40.7
Health facility	79.5	75.3	74.9	62.1	62.4	51.8	64.2	63.4	50.1	43.5	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	5	37.0
Secondary	53.5	38.7	45.2	26.0	26.7	17.3	35.8	24.5	18.5	10.7	2	16.1

Note: Based on the Zambian LCMS 2015 household survey and IEA energy data for 2011 values calculated using demographic weights). $ - US dollar, eq – equivalent capita, hh – household, exp- expenditure, indir-indirect, dir-direct, No.-number

Urban HENW households use a third more energy than their rural counter partners (Figure 2-4). 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 2-2). 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 2-5).

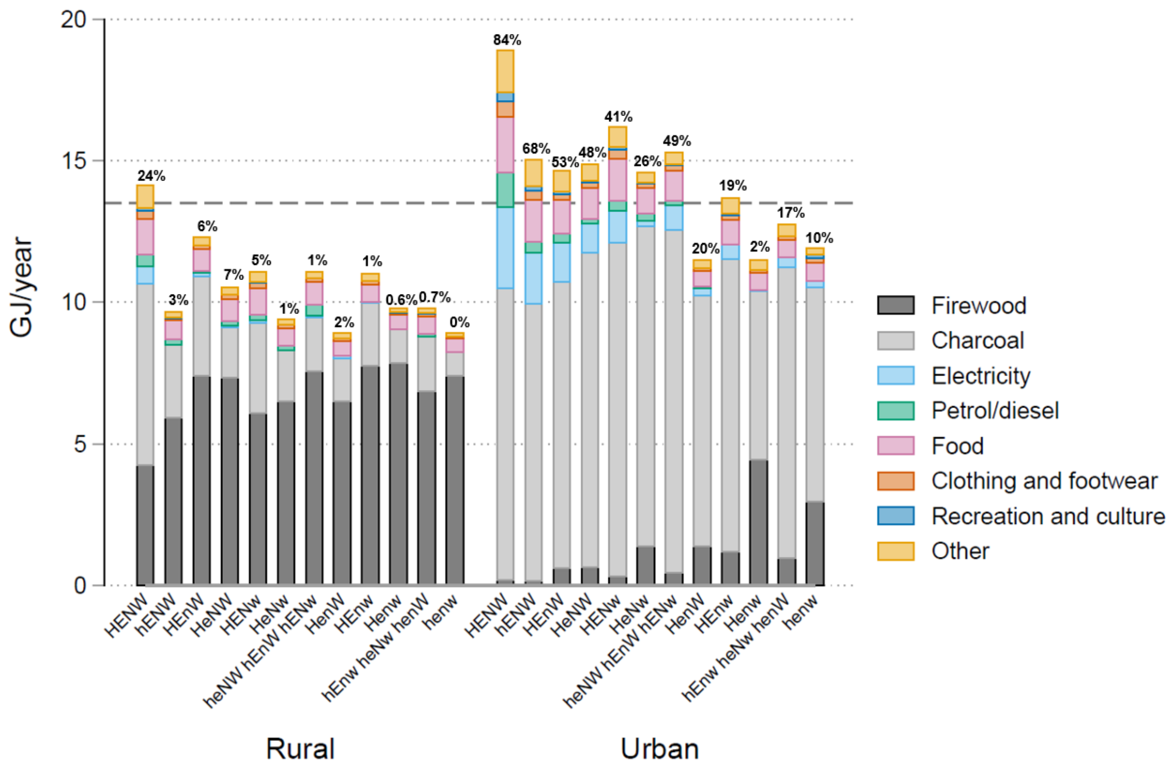

Figure 2-4 Per capita final energy footprint across sub-sample of households with children under the age of five.
Note: Values above each bar indicate the share of households having access to electricity. The dashed line indicates the national average per capita. Values calculated using the 2015 household survey data and demographic weights.

2.3.5 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 A-4, A-5). Table 2-6 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 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 more than 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 2-4). 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 A-4). 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 (Zambia Central Statistical Office and Central Statistical Office 2016, Masiye *et al* 2010).

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.

Table 2-6 Average marginal effects (change).

	All outcomes	Healthy child	Basic education	Safe water	Adequate food
N	*4264*	*4264*	*4264*	*4264*	*4264*
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 5km	0.04*		0.06**	0.04*	
Food market w/n 5km	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 <5yr.)					
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. Bolded AME values on the level of 10 percentage points. The AME for the remaining pairs of provinces and the other independent variables used in the analysis are in Supplementary materials Table A-6. Here we present 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 26-50% 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.

2.4 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. (Irfany and Klasen 2016, Wiedenhofer *et al* 2017, Seriño and Klasen 2015)). 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) (Kaygusuz 2012). Our study is also a rare example among household footprinting 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 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 (Chileshe 2001, Saket 2000). 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 (The World Bank 2017). 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. (Ivanova *et al* 2015, Bin and Dowlatabadi 2005, Reinders *et al* 2003)), 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 (Gwilliam 2003, Nugroho *et al* 2018), 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 (Rao and Min 2017, Ouedraogo 2013, Kaygusuz 2011). 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 (Hubacek *et al* 2017a, Millward-Hopkins *et al* 2020). 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.

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Chapter 3
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 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 multiregional input-output (MRIO) with energy extensions based on International Energy Agency (IEA) 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 wellbeing 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 centres, 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 wellbeing 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).

3.1 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 multi-dimensionality 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, Eisenmenger *et al* 2020, Mainali *et al* 2018, Moyer and Bohl 2019). 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 (Pachauri and Spreng 2011, Nussbaumer *et al* 2012, Kaygusuz 2012, Pachauri, S.van Ruijven *et al* 2013, Roy 2012, Kaygusuz 2011). 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 (Prasad 2011, Oparaocha and Dutta 2011, Karekezi *et al* 2012, Rao and Pachauri 2017, Crentsil *et al* 2019, Rahut *et al* 2014). 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, Rao and Pachauri 2017, Sovacool 2012). Furthermore, there is a strong association between burning inefficient traditonal fuels and respiratory infections, which disproportionally affect women and children (Smith *et al* 2004, Mannucci and Franchini 2017, Smith *et al* 2014, 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 wellbeing. 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 (Cohen *et al* 2005, Reinders *et al* 2003, Bin and Dowlatabadi 2005, Büchs and Schnepf 2013, Lenzen *et al* 2004). 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 (Büchs and Schnepf 2013, Lenzen *et al* 2006, Herendeen and Tanaka 1976, Weber and Matthews 2008, Herendeen 1978, Räty and Carlsson-Kanyama 2010, 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 *et al* 2019a, Rao and Pachauri 2017). 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)).

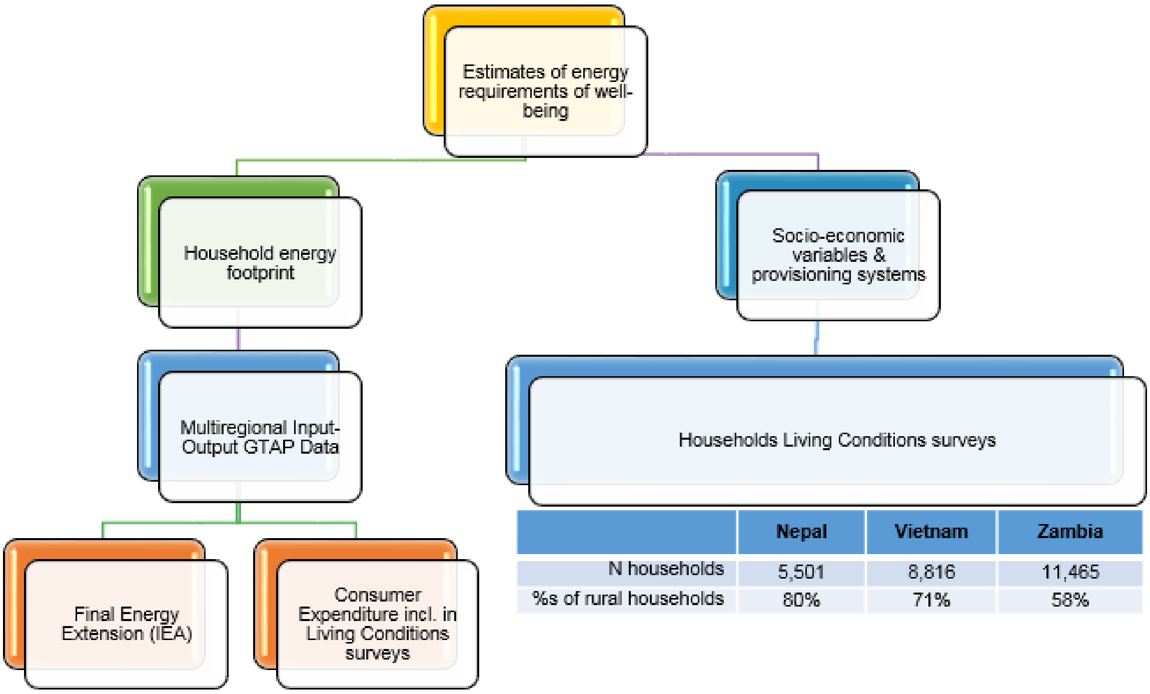
We examine the composition and inequalities related to household energy footprints and associations between energy use and well-being. We explore "basic well-being" defined as the achievement of access to clean water and food, , education, and access to alternative modern fuels. We use the terms "improved 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 Sustainable Development Goals 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.

3.2 Data and methods

3.2.1 Energy model

We calculate household energy footprints using a method described in detail in our previous study by Baltruszewicz and colleagues focusing on the case of Zambia (Baltruszewicz *et al* 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 multiregional input-output (MRIO) tables with a final energy extension using International Energy Agency (IEA) data (Figure 3-1). 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 3-1). 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 (National Planning Commission Secretariat 2011, General Statistics Office 2010).



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

Figure 3-1: Framework for estimating household energy footprints and energy requirements of well-being outcomes.
Note: 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

3.2.2 Energy footprint dictionary

We focus on final energy consumption, as opposed to primary energy or greenhouse gas emissions (GHG), because of its significance to well-being in developing countries (Fuso Nerini *et al* 2018, Kaygusuz 2012) and because we conceptualize energy use as a key for need satisfaction (Brand-Correa and Steinberger 2017, Day *et al* 2016, Rao and Baer 2012). We distinguish between direct and indirect energy use (Figure 3-2). 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 (Bates *et al* n.d.). 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 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 (Grieshop *et al* 2011).

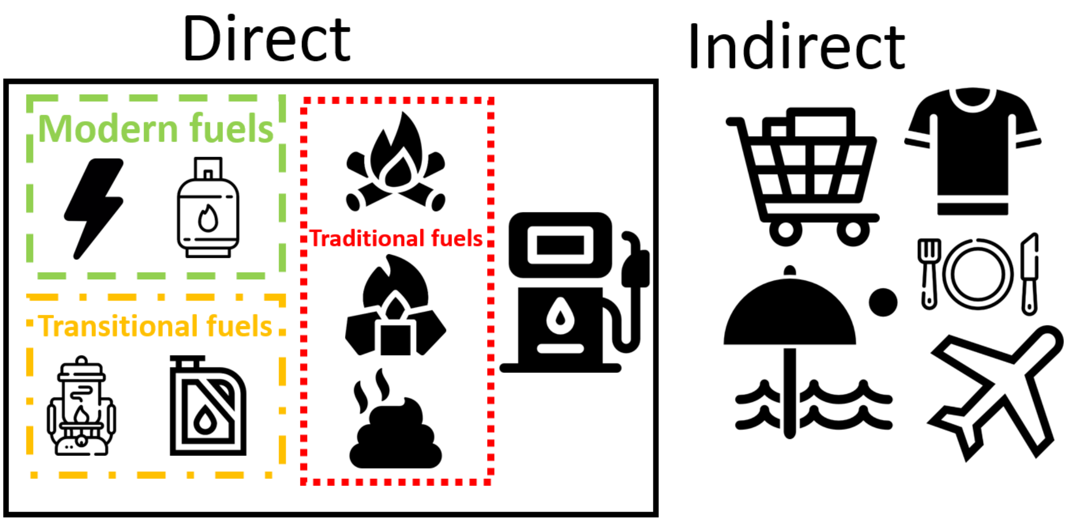


Figure 3-2 Energy footprint dictionary: direct, indirect, modern, transitional, and traditional fuels categorization
Note: Icons made by Freepik from www.flaticon.com.

3.2.3 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 need (THN) like in our previous study (supplementary materials) 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: 1) access to modern cooking fuels; 2) access to clean water close to home; 3) basic or higher education, and; 4) nutrition. Definitions of these variables, corresponding questions and linked SDG goals are indicated in Table 3-1.

Table 3-1 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 3-1). 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*) 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. Zambia: adequate food if a household has three or more meals per day	Nepal: *Concerning your family's food consumption over the past month, which of the following is true?* 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*: How many meals excluding snacks do you normally have in a day?*

These wellbeing 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 (Carlson *et al* 2015, Adhikari and Sawangdee 2011, Hobcraft 1993).

3.2.4 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 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).

3.2.5 Statistical analysis

We report direct and indirect energy footprints in GJ per capita per year. 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 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.

3.2.6 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 3-2). 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.

3.2.7 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.

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.

3.3 Results

3.3.1 Total energy footprints

Energy footprints in Nepal, Vietnam, and Zambia are less than half of the global average in per capita terms (Figure 3-3, (International Energy Agency 2011). The composition of footprints indicates 'housing' and 'transport' are major users of energy in all three countries (Figure 3-3). 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 percent of 'housing' energy footprint. But about 20 percent 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 EF.

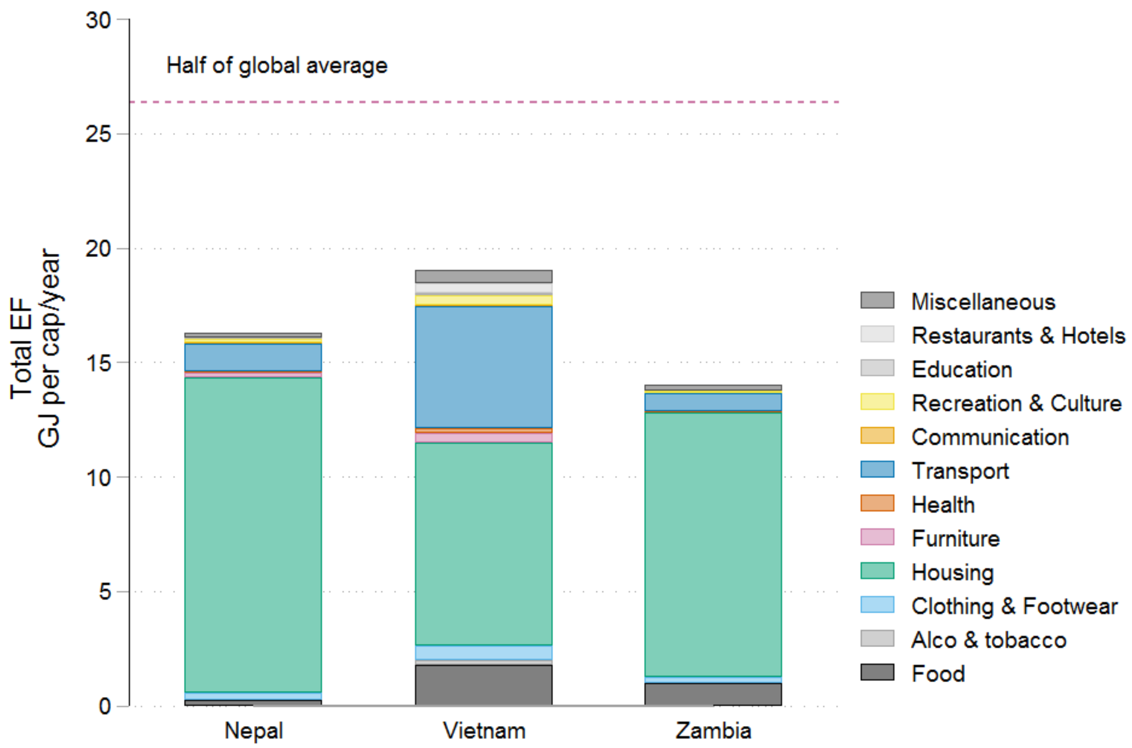


Figure 3-3 Total Energy Footprints in Nepal, Vietnam, and Zambia by consumption categories
Note: GJ per capita per year

3.3.2 Energy footprints by income deciles

When comparing household energy use by income deciles (Figure 3-4a), Vietnam and Nepal have comparable consumption for the lower half of the population, between 14 and 17 GJ per capita, while in Zambia, the EF of the first five decile is closer to 10 GJ per capita, 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.

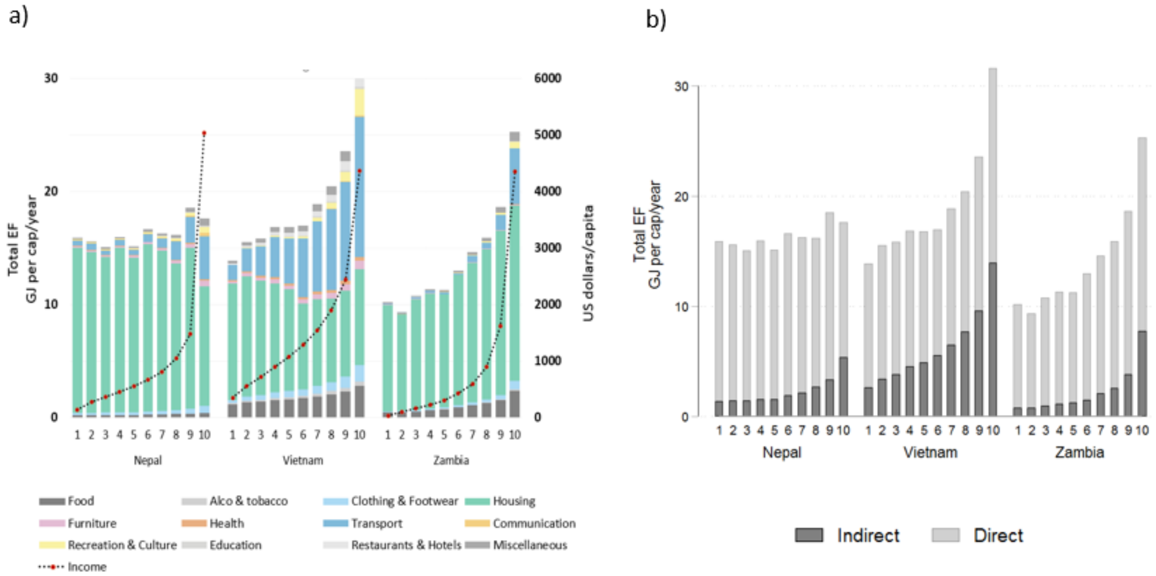


Figure 3-4 Household energy footprints by income deciles for Nepal, Vietnam, and Zambia for a) twelve consumption groups.
Note: The y-axis represents average income per capita using the equivalised OECD scale. b) total direct and indirect energy use.

3.3.3 Indirect energy footprints

Indirect energy footprints (dark gray bars in Figure 3-4b) of the poorest half of the Vietnamese population increase by a mean 0.6 GJ/cap whereas in Nepal and Zambia the rise is more modest of 0.05 GJ/cap and 0.1 GJ/cap, 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 3-4b).

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.

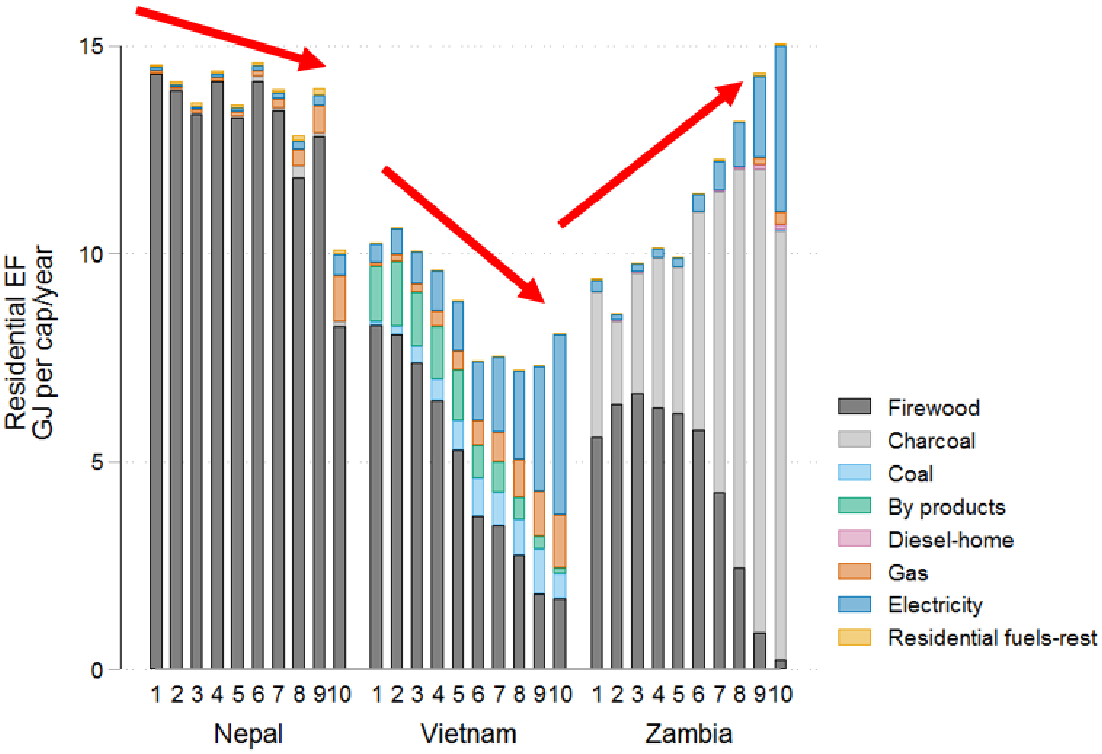


Figure 3-5 Per capita energy footprints by income deciles categorized by residential fuels in Nepal, Vietnam and Zambia

3.3.4 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 3-5). In Vietnam, there is a rapid transition to modern fuel use in higher income deciles (Figure 3-5). In Nepal, residential fuel use decreases by almost one-third in higher income deciles due to increased LPG usage (Figure 3-5). 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 3-5). Both energy sources are inefficient and cause indoor air pollution, but only charcoal is consumed by higher income households. The income level of about 1’000$ per capita is associated with only about 10% 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 decile’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 behaviour. 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.

3.3.5 Inequalities

Modern energy use is highly unequal in all countries (Figure 3-6). 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.

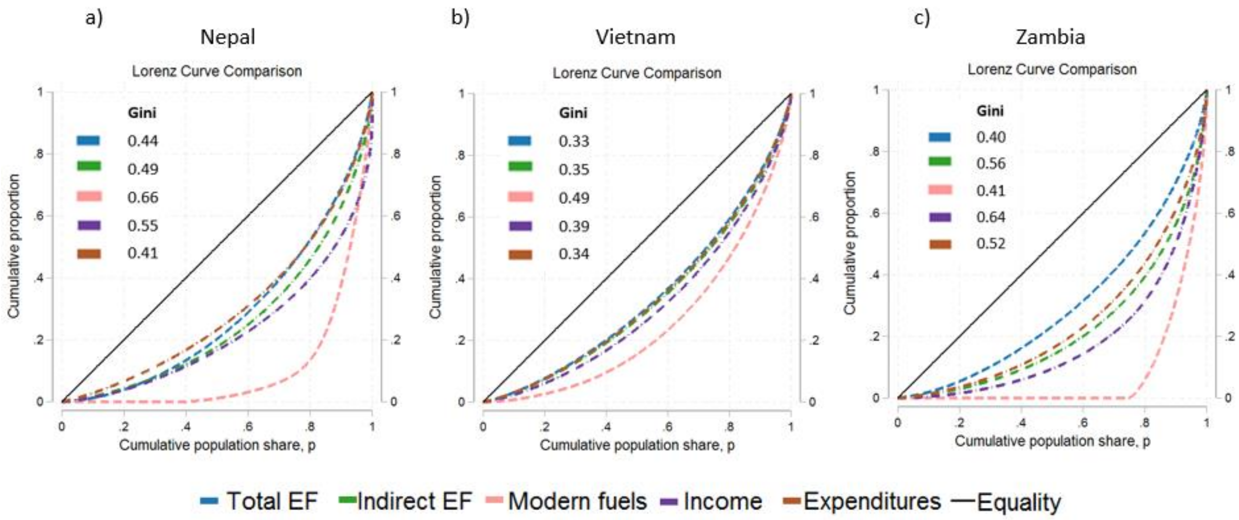


Figure 3-6 Lorenz curves and Gini-coefficients for energy footprints, income and expenditures in a) Nepal, b) Vietnam, c) Zambia.

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.

3.3.6 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 and Millward-Hopkins (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 wellbeing outcomes of interest to us and how many achieve additional characteristics for DSL (Table 3-2). 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 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 9 and 19 GJ per capita. This is 60-80% lower than the global per capita average EF in 2011 (52 GJ) (Figure 3-7).

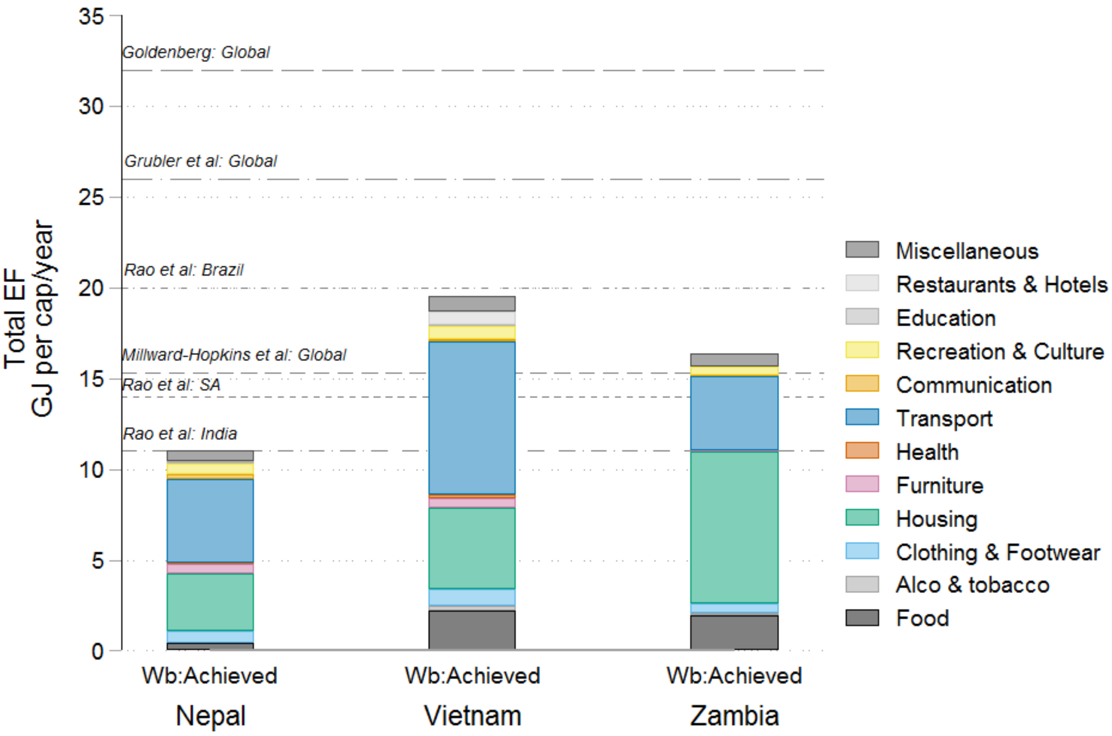


Figure 3-7 Comparison of total energy footprints for households that achieve well-being outcomes in Nepal, Vietnam, and Zambia
Note: Well-being outcomes include sufficient food, secondary education, safe water and more than 50% of modern fuel; dashed lines correspond to reported estimates for decent living at a regional (Rao et al 2019a) and global level (Grubler et al 2018, Millward-Hopkins et al 2020, Goldemberg et al 1985). Based on Millward-Hopkins et al. 2020

Table 3-2 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	11465	917	10548
(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 (≥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&2)	**1%**	**29%**	**N.A.**	**18%**	**58%**	**N.A.**	**2%**	**38%**	**N.A.**
N hhs with DSL and well-being outcomes (1&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 5km [CP]	97%	100%	97%	91%	96%	89%	63%	92%	62%
*Access to publ. transp. w/n 5km [CP]	76%	100%	75%	89%	95%	87%	57%	77%	56%
*Access to healthcare centre [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)	15 (16)	3 (2)	16 (16)	9 (10)	5 (3)	11 (12)	13 (12)	8 (11)	13 (12)
*Total EF (GJ/cap)	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 all well-being outcomes listed in the first four rows; Not achvd – corresponds to households without those well-being outcomes; pop. - population; N – households number; HH - households; Min floor space corresponds to having a minimum of 10 square meters 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 square meters 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 B-8), P - variable used to construct the protection factor, CP variable used to construct the collective provisioning factor (see Table B-7 in the Suppl. Mat.); Standard deviations in parenthesis

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[7]. These studies (see fig. 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 3-8a). Housing EF *decreases* for households that attain the four basic wellbeing outcomes in the three countries, while transport EF and categories linked to indirect energy *increased* in all countries.

3.3.7 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 3-8a). 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 3-8b). 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 3-8b). These results strongly suggest that basic well-being outcomes can be achieved with lower than average energy use per household in developing countries.

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

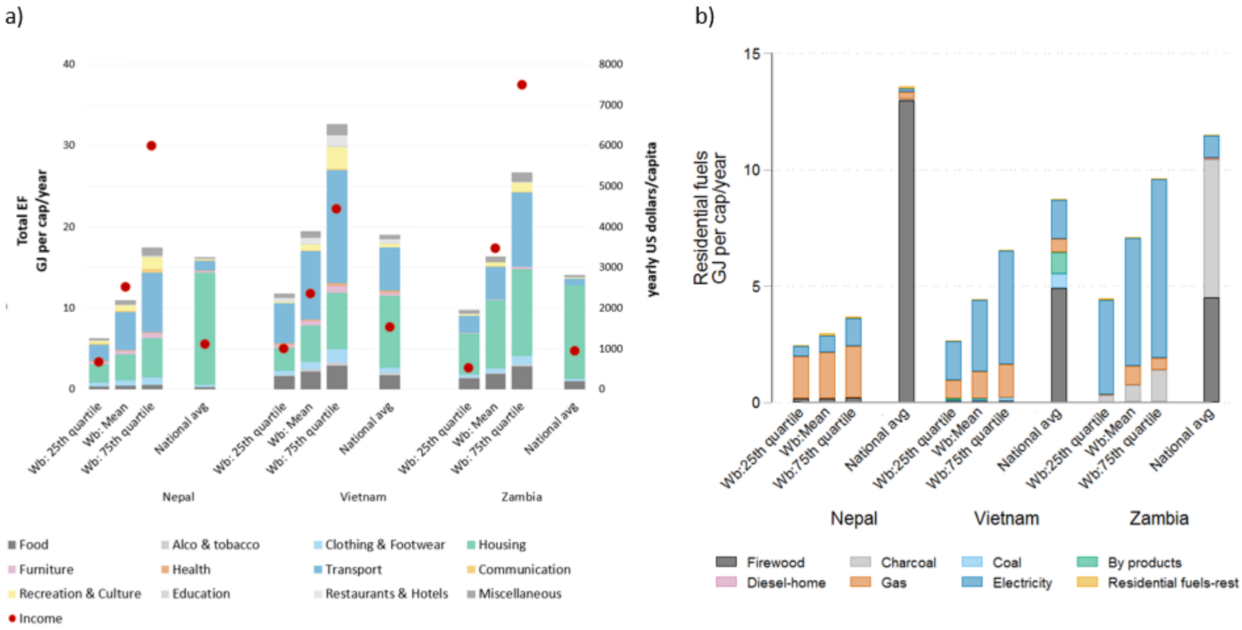


Figure 3-8 Households with basic well-being outcomes and split by income quartiles and national average for a) Total EF b) Residential fuels EF.
Note: Well-being outcomes: sufficient food, safe water, basic education, and >50% modern fuels

3.3.8 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 3-3). As noted in the method section, 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 outcomes. How the energy is delivered is more important than the amount of energy used. Access to collective provisioning 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.

Table 3-3 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)	0.947***	(-5.31)	0.960***	(-6.07)		
Total EF (GJ/cap)	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 5km			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		11465	
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 B-8). The dependent variable is coded 1 if all three binary variables equal to 1. Resulting factor analysis (see Table B-7), 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 canter, 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.

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 1) households having modern fuels; 2) households with protection; and 3) households with collective provisioning systems[8] (Figure 3-9).

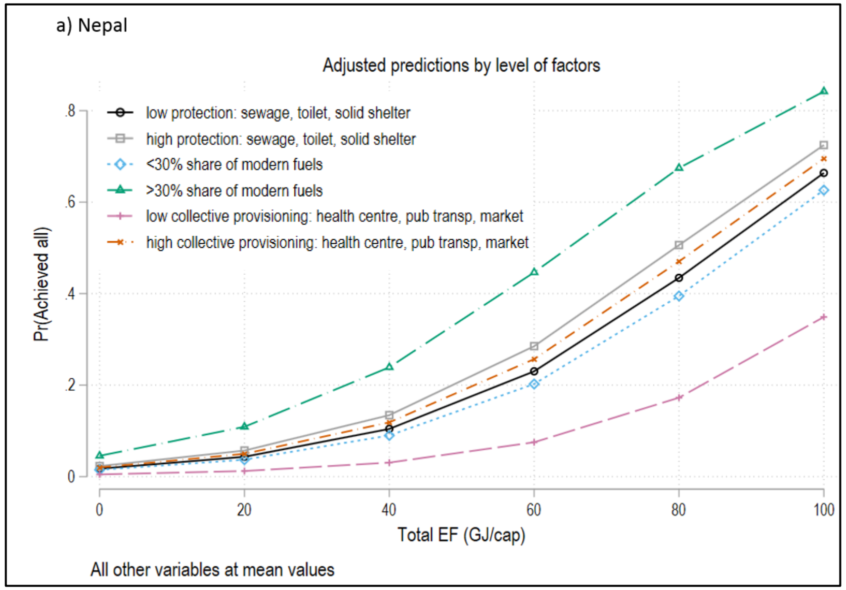
At the national average level of 15 GJ, we observe significant differences in adjusted probabilities of achieving basic well-being outcomes between investigated countries (Figure 3-9). In Nepal a high share of modern fuels increases the probability of achieving well-being outcomes by 10%. In Zambia the probability is twice as high, 20% at the level of 15GJ. Zambian households with high levels of protection and collective provisioning are also more likely, compared to Nepal, to achieve well-being outcomes (13% and 9% respectively at the level of 15GJ). In Vietnam, the general starting point of households is much better than in the other two countries. Households at the level of 15GJ, which is

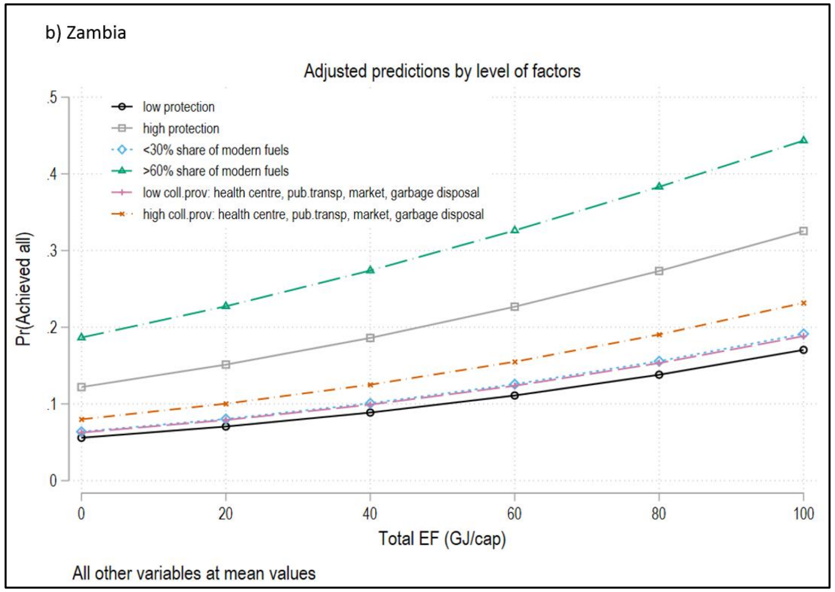
[8] To the contrary of what might be assumed, these factors and the variables included in them are not directly linked to well-being outcomes. For example, having indoor flush toilet does not automatically mean that the household has access to safe water, nor having solid shelter and minimum floor area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

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 3-9) 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 wellbeing outcomes are the ways in which energy is provided and the energy services that households are able to obtain from





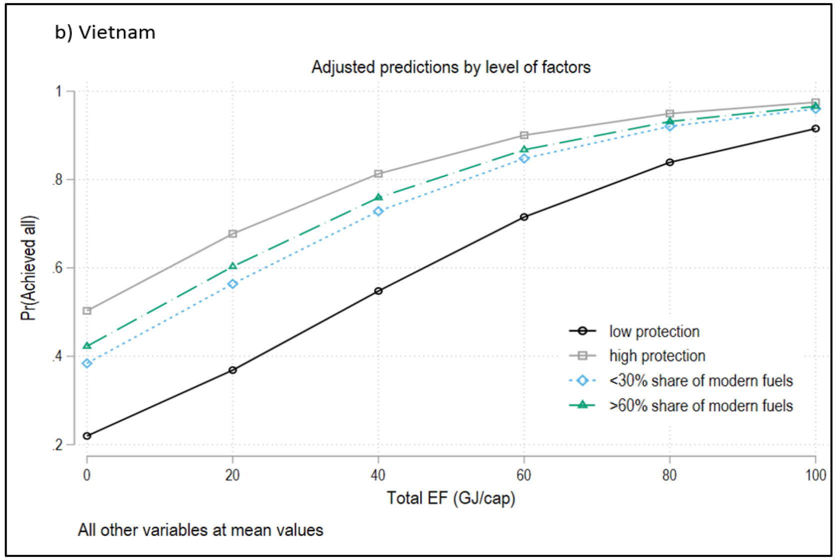


Figure 3-9 Adjusted predictions for the likelihood of achieved well-being by levels of factors and energy use.
Note: Low corresponds to factor level below or equal to 0.6. High corresponds to factor level higher than 0.6. x-axis presents the total energy footprint per capita in a given country. Probabilities are denoted on the y-axis with zero minimum and one corresponding to the maximum probability (multiply by 100 to interpret in %s).

3.4 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 (Smith *et al* 2013, Mannucci and Franchini 2017, Lelieveld *et al* 2015, Pachauri *et al* 2004, Kaygusuz 2011, Rao and Pachauri 2017, Sovacool and Drupady 2012), 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, Kumar 2018, Oparaocha and Dutta 2011, Ryan 2014).

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 3-2). Rao et al estimate similar levels – between 9 and 19 GJ per capita 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[9] (Grubler *et al* 2018)**.** Whereas in the Global North we need to challenge the consumption-oriented lifestyles and bring sufficiency on the 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

[9] Grubler et al estimated energy requirements in Global South needed to meet the 1.5 degree 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.

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 3-10), 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.

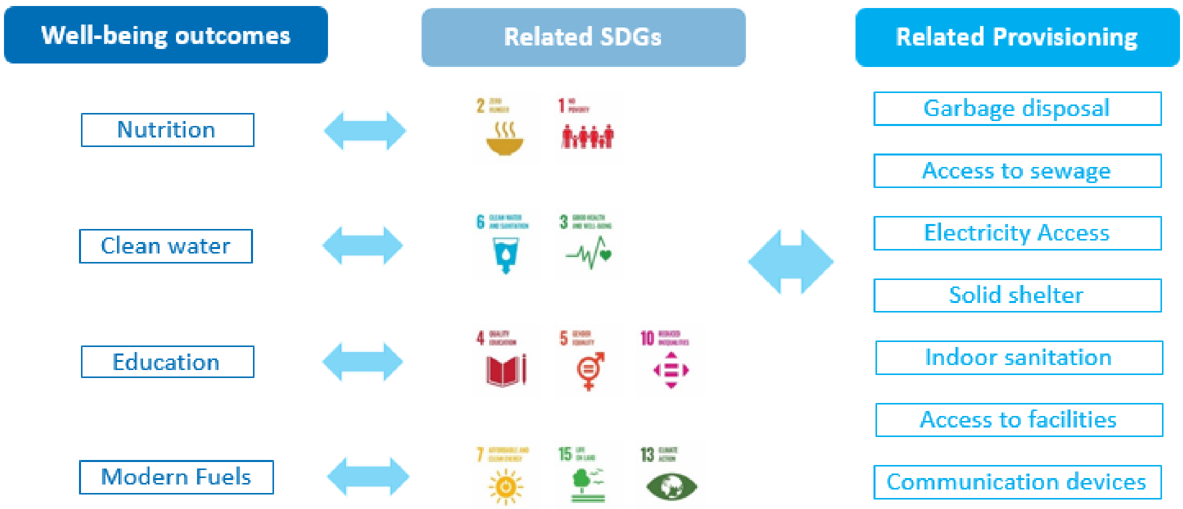


Figure 3-10 Translating provisioning variables and well-being outcomes to SDGs goals and possible synergies.

Acknowledgments

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Chapter 4
High energy use for fun and for necessity: what stops the UK from achieving well-being at low energy

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Lina I Brand-Correa and Anne Owen

Abstract

How energy facilitates human need satisfaction, for whom, and with what wellbeing outcomes is under-researched. We address this gap by investigating the relationship between household energy footprint and well-being in the UK. Our results show car and air transportation contributed the most to the total energy footprint of the rich and high-energy users. We observe high inequalities in energy distribution and emphasize the role of the top energy users with high well-being in driving excess energy use. A more detailed analysis reveals that individuals with protected characteristics are especially vulnerable to energy poverty and their contribution to overall energy demand is negligible.

Focusing on well-being steers the attention towards questions of sufficiency, overconsumption as well as the context within which we satisfy needs. In terms of lock-ins - tackling issues of energy poverty and inequalities are important for further lowering energy demand and need to be addressed in relation to climate justice.

4.1 Introduction

Current energy consumption is too high to maintain global warming within 1.5 degrees without reliance on massive negative emissions (IEA 2021). Lowering energy demand in the Global North requires changes in how we satisfy our needs and addressing overconsumption (Creutzig *et al* 2021). These changes would enable decent living for all through a more equal distribution of energy resources (Grubler *et al* 2018, Millward-Hopkins *et al* 2020, Millward-Hopkins and Oswald 2021, Rao and Baer 2012, Kikstra *et al* 2021). How we get there depends on our understanding of how energy demand is distributed now and what purposes it serves. We know that energy use and carbon emissions associated with it are highly unequally distributed, with the top 10% of income earners (mostly in the Global North) responsible for 49% of all carbon dioxide emissions (Oxfam 2015, UNEP-CCC 2021, Bruckner *et al* 2022). These findings have highlighted excess energy use by a minority (Wiedmann *et al* 2020) and raised concerns about energy and carbon justice (Jenkins *et al* 2016, Shue

1993, Gore 2020). The findings also raise questions about how much energy (and carbon) we need to satisfy our needs and achieve well-being (Walker *et al* 2016, Gough 2017, Darby and Fawcett 2018, Brand-Correa and Steinberger 2017). These issues call for recognizing the needs of vulnerable groups in energy transition scenarios (Galvin and Sunikka-Blank 2018, Büchs *et al* 2018, Ivanova and Middlemiss 2021a), acknowledging high energy intensity lifestyles stemming from status-seeking, and the need for comparisons to expose inequalities (Wiedmann *et al* 2020, Cheung and Lucas 2015, Luttmer 2005). We seek to contribute to these debates by profiling UK households' final energy use and linking it to need satisfaction. We investigate in detail the distribution, levels, and types of energy use, and identify the most important characteristics of households with low and high well-being.

Research on environmental efficiency of well-being has mostly focused on a country level and considered life expectancy, education, and income (Dietz *et al* 2009, Knight and Rosa 2011, Lamb *et al* 2014, Dietz *et al* 2012, Steinberger and Roberts 2010, Steinberger *et al* 2012, Jorgenson *et al* 2017); yet, distributional analyses are largely missing. In household-level analyses, the most common measures of well-being have included life satisfaction (Buhl *et al* 2017, Andersson *et al* 2014, Verhofstadt *et al* 2016, Lenzen and Cummins 2013) and happiness (Apergis 2018). Some studies have adopted a broader view on well-being that encompasses mental and physical health (Ambrey *et al* 2017), social capital, relative wealth (Claborn and Brooks 2019), and aspects of multidimensional poverty (Okushima 2021, Baltruszewicz *et al* 2021b, 2021a). Yet most of these studies draw from limited data to operationalize well-being. We address the data limitations using innovative research methods linking two UK-based household surveys.

Our analysis and results contribute to better understanding of energy use for need satisfaction in four main ways. First, we present a method for linking the UK living costs and food survey (LCFS) of the Office of National Statistics (ONS) and the Understanding Society Survey (USS) of the Institute for Social and Economic Research at the University of Essex, using data from the years 2018/2019. Second, we map the levels, types, and distribution of household energy footprints by income and energy deciles. Third, we link household EF with a well-being index score and analyze the relationships between the components of the index score and energy use. Fourth, we analyze the socio-economic characteristics of clusters of households defined by their levels of well-being and energy use. Furthermore, we discuss lock-ins that prevent people from lowering energy demand while maintaining high levels of well-being. Finally, we suggest policy priorities that have the potential to reduce energy demand while at the same time improving well-being.

4.2 Materials and Methods

4.2.1 Calculation of UK household energy footprint using LCFS

The Household energy footprints (HEF) presented in this paper are based on the USS data. However, this survey does not contain detailed household expenditures, which are usually necessary for calculating household footprints. Below we explain how we mitigated this challenge. First, we present a method for calculating household energy footprint using the multiregional input-output method and LCFS data. Resulting we obtain multipliers (in MJ/£) that are then applied to calculate the HEF for UK households. Both the multipliers and HEF calculated using LCFS data are then used to estimate the HEF for USS households.

Calculation of household energy footprints requires several steps. First, we need to calculate consumption-based energy use due to household demand in the UK (step 1). For this task, we use the UK Multiregional input-output database (UKMRIO) (Owen *et al* 2017, Barrett *et al* 2013, DEFRA 2021) and a dataset of industrial energy use. The UKMRIO is a database that is constructed using UK Supply and Use Tables data produced by the Office for National Statistics for the UK and trade data from EXIOBASE. The data on energy use by industry comes from two sources. For the foreign sectors in the UKMRIO database, we use final energy consumption (in terajoules) by sector and country from the International Energy Agency (IEA). For domestic energy consumption, we use the National Statistic on Energy Consumption (DEFRA 2021)which provides more detail on residential heating and power and residential private transport (Owen and Barrett, 2020). To be able to use UKMRIO and IEA data together we need to align the IEA energy use extension vector with foreign sectors in the UKRMIO database.

The calculation of consumption-based household energy footprints requires linking the energy use for the production of goods and services with the households consuming these products. The method for doing this is based on the Leontief equation, which expresses the inter-industry requirements of each sector to deliver a unit of output of final demand (Miller and Blair 2009). The Leontief input-output model is based on reported economic data and is augmented with environmental and energy extensions to help understand the environmental impacts of production and consumption of goods and services. The results of the calculation using the Leontief method is a column vector of final energy consumed by all UK households, disaggregated to products categorized by the European Standard Classification of Individual Consumption by Purpose (COICOP). We are able to report HEF by COICOP category because the UK Supply and Use Tables disaggregate household final demand by these categories. This simplifies the next step, which is disaggregating total energy footprints by household types. This is done by first calculating multipliers (step 2). We obtain them by dividing the product footprints (obtained in step 1) by the total annual spend on products by UK households. The latter information is acquired from microdataset Living Cost and Food Survey (LCFS) (ONS 2018). LCFS is an annual household expenditure survey of around six thousand households, who are asked to keep a spending diary for two weeks. The survey provides annual weights (used to reduce the effect of non-response bias and produce population totals and means), which when multiplied by household expenditure sum to the total spending of all UK households. Having multipliers allows us to move to the next step of calculation: disaggregating household final demand in the UKMRIO model using weighted LCFS household expenditure shares (step 3). The resulting UK household energy footprints (HEF) show the total energy use needed to meet the final demand of all goods and services that households consume. This includes energy directly used by the households (e.g. fuels used to heat and power the home and private transportation fuels) and indirect energy embodied in the supply chain of goods such as food or clothing. This means that the UK HEF includes energy from both domestic and foreign production.

4.2.2 Statistical Matching

The LCFS data includes socio-economic household characteristics and the Understanding Society Survey (USS) includes household well-being outcomes we need for our analysis. The USS started in 1991 as a nationally representative longitudinal survey covering e.g. education, social life, well-being, health, income, and family. While providing expenditure on groceries, restaurants, and residential fuels, the USS lacks detailed information on the rest of the household expenditure. We bridge this gap by statistically matching the USS with the LCFS. We use the USS wave 10 for the years 2018-2020. The challenge of combining the two surveys is that they were conducted on different samples of the UK population, and thus cannot be merged with a household identifier. Our solution is to extract patterns from both surveys by using common variables. The USS and LCFS surveys were conducted in the same year (2019) and statistical analysis of distributions of socio-economic characteristics such as income, age groups, household types, and location indicate comparable distributions (see Supplementary Materials). These characteristics have been previously proven as the main drivers of levels and patterns of household energy use (Büchs and Schnepf 2013, Weber and Matthews 2008, Wiedenhofer *et al* 2013, Donato *et al* 2015). This allows the use of statistical tools such as multiple regression and descriptive statistics to estimate HEF for USS households. For several HEF categories, for which we did not have USS expenditure, we estimate values using multiple regression. Examples include footprint for rail, bus, and other public transport, communication, recreation, and education (Table 4-1). When possible we used additional information to restrict estimation to only those who report activity associated with a given HEF category. For example, respondents in the USS reported what type of public transport they used and how often. Similarly, we have information on who is enrolled for education.

We use multipliers calculated from the UKMRIO model and LCFS data for estimating the consumption reported by USS households. For example, for house fuels, USS households reported their yearly expenditure. We could multiply the expenditure with multipliers expressed in MJ/£ to obtain the total MJ used by a household in 2019. In the case of electricity and gas consumption depending on the type of payment (e.g. smart meter or direct debit) and location, we adjusted the household expenditure using known regional price differences in 2019. A total of 14% of USS households did not report expenditure on electricity or electricity and gas combined. We assumed that these households are connected to electricity without reporting spending. Since the majority of households report spending on electricity and gas in one bill, we imputed spending on electricity using this form of payment. For this calculation, we used an iterative form of stochastic imputation, and only data from the USS survey (see Supplementary Materials).

For the direct energy use linked to private transportation, we calculated energy use from reported mileage and type of car (engine size) driven by the USS households and multiplied it with multipliers from HEF in LCFS. We have information about the number of purchased vehicles and their condition (new/used) and used it to calculate in the LCFS survey the average energy footprint per purchased vehicle and applied it to USS households. For leased cars, we used the average energy footprint per owned vehicle. For air transport, we used the average footprint per flight reported by LCFS households and applied it to the number of flights taken by the USS households. In both surveys, we could differentiate between the footprints for domestic and international flights.

For certain consumption categories, we were challenged by the lack of information or a weak regression model. Here we assigned an average footprint based on the LCFS households categorized by income deciles to the USS households. For example, within each income decile the USS households are assigned the same energy footprint for clothing and shoes. Although this limits nuanced comparison between specific footprinting categories, those estimates are useful for the calculation of the total energy footprints.

4.2.3 USS energy footprints – comparison with LCFS and limitations

The LCFS and USS surveys differ in their representativeness. The LCFS scales up to the UK population (27 million households) and the USS survey represents population patterns. Thus the HEF for the LCFS sums up to the final household demand in 2019, whereas the USS HEF sums up to around half of it. When comparing energy footprints of LCFS and USS samples, we find similar energy use distributions by income deciles, as well as when regional and household type groups are compared (Supplementary Materials).

When comparing the contributions of each footprinting category to the total, the biggest differences lie in international air transport (+17% for USS) and oil, gas, and electricity (-11% for USS) (Table 4-1). These discrepancies originate in differences in reported usage by households in the LCFS and the USS. In the USS, more households reported flying internationally than in the LCFS. Differences in the footprints might also be due to the method of calculation: for private transport, we based energy footprints on self-reported mileage (see the previous section), while for public transportation we used available information about the frequency of travel when restricting the number of households for which estimation of energy use was done using the regression model. We employed regression analysis to estimate energy footprint for education. Although the adjusted R^2 was moderately strong (0.39), only 260 households reported spending on education in the LCFS survey. This is due to the free education system in the UK and the low percentage of households sending their children to private schools. Hence, we expect estimated values using regression models for USS to be somewhat inflated.

We highlight that 74% of the USS footprints are **not** estimated based on regression models, but rather, calculated based on reported spending or quantity used. Of the remainder, 16% is based on using average HEF of the pertinent income decile and the remaining 10% are estimated based on using regression models.

4.2.4 Reporting total energy footprints per adult equivalent

We calculated the HEF as GJ/household, and to calculate individual footprints we divide household footprints with household sizes using the Organisation for Economic Co-operation and Development (OECD) equivalence scale. The energy footprint (EF) per adult equivalent (ae) distributes HEF among adults and children assuming children contribute less to the footprint. We use detailed USS information to examine EF related to air transport as reported by individuals in the survey instead of having total air travel footprint divided by adult equivalent.

4.2.5 Well-being

We characterize well-being with well-being outcome measures related to mental and physical health, financial situation, material deprivation, fuel poverty, and loneliness (Table 4-2). The approach is informed by a eudaimonic understanding of well-being based on the Theory of Human Need (Doyal and Gough 1991). Doyal and Gough (1991) explain that the achievement of basic human needs requires mental and physical health that allows us to participate in society and to have the autonomy to do so. These basic needs do not change with time, place, or culture. How we satisfy our basic needs is dependent on social (e.g. law, culture) and physical (e.g. infrastructure, sanitation) provisioning systems and individual choice. We use these variables to generate a well-being score (WBS). Each component of WBS is scored on a scale of 0 to 10 and the whole index has a minimum score of zero and a maximum of 70. We define an individual with a high level of well-being as one that achieves at least the average well-being score. We restricted the high well-being (HWB) outcomes to include only those who are above the poverty line and reported being able to heat the house during winter. Individuals with low well-being (LWB) have below average well-being scores.

The limitations of our analysis include missing responses to questions included in the WBS. The WBS is available for 90% of the weighted sample, leaving 10% of individuals without a score. However, we find that for the majority of socio-economic characteristics the sample is representative (see Supplementary Materials).

Table 4-1 Final energy use per category and its share in total energy use. Based on footprints calculated using USS or LCFS data.

	Category	LCFS (GJ)	(%)	USS (GJ)	(%)	Method for USS	USS-LCFS	Comment
Food and non-alcoholic beverages:	Food and alcohol	274,426	4.7%	178,967	4.8%	Multiplier	0.1%	Missing exp. in USS imputed
Clothing and footwear:	Clothing	43,041	0.7%	24,524	0.7%	Avg by income decile	-0.1%	
	Shoes	20,175	0.3%	11,497	0.3%	Avg by income decile	0.0%	
Housing, water, electricity, gas and other fuels:	Housing, water	220,632	3.7%	100,518	2.7%	Estimated (R2=0.36)	-1.1%	Pred. based on regression using LCFS footprints as a base
	Coal and coke & wood and peat	134,343	2.3%	65,333	1.7%	Multiplier	-0.5%	
	Oil, gas, electricity	1,628,962	27.6%	611,766	16.2%	Multiplier	-11.4%	Missing exp. in USS imputed
Furniture:	Furniture	217,294	3.7%	123,814	3.3%	Avg by income decile	-0.4%	
Health:	Health	84,872	1.4%	48,348	1.3%	Avg by income decile	-0.2%	
Transport:	Purchase of vehicles	59,130	1.0%	29,612	0.8%	Multiplier	-0.2%	Avg GJ per vehicle purchased
	Vehicles: leasing, other	275,960	4.7%	132,959	3.5%	Multiplier	-1.1%	Avg GJ / No. of vehicles in the household
	Fuel	970,425	16.5%	605,006	16.1%	Multiplier	-0.4%	Includes difference in car fuel and engine
	Other transport	121,847	2.1%	69,439	1.8%	Avg by income decile	-0.2%	
	Public transport rail/tube	18,121	0.3%	21,221	0.6%	Estimated (R2=0.62)	0.3%	Estimated only for users of transport
	Public transport: bus	41,349	0.7%	94,349	2.5%	Estimated (R2=0.28)	1.8%	Estimated only for users of transport
	Public transport other	281,974	4.8%	160,704	4.3%	Avg by income decile	-0.5%	Avg. only for users of transport
	Transport air domestic	44,095	0.7%	80,765	2.1%	Multiplier	1.4%	Avg GJ / flight
	Transport air international	643,665	10.9%	1,045,183	27.8%	Multiplier	16.8%	Avg GJ / flight
Communication:	Communication	32,774	0.6%	14,611	0.4%	Avg by income decile	-0.2%	
Recreation:	Recreation, package holidays	285,782	4.8%	119,744	3.2%	Estimated (R2=0.28)	-1.7%	
Education:	Education	32,532	0.6%	11,767	0.3%	Estimated (R2=0.39)	-0.2%	Only for those reporting being in education
Restaurants and hotels:	Restaurants and hotels	214,237	3.6%	72,836	1.9%	Multiplier	-1.7%	Missing exp. in USS imputed
Miscellaneous:	Miscellaneous	251,222	4.3%	143,156	3.8%	Avg by income decile	-0.5%	
	Total	**5,896,860**	**100%**	**3,766,121**	**100%**			

Note: Match between USS and LCFS is highlighted as follows: green – multiplier method and low difference, yellow – multiplier method and high difference, blue other method and low difference

Table 4-2 Variables chosen for the construction of well-being score.

Variable	Well-being outcome	Type	Definition
Mental Health Index (MHI)	Mental health	c	On a Likert scale: 0 "All of the time" 1 "Most of the time" 2 "Some of the time" 3 "A little of the time" 4 "None of the time". During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)? 1) Mental health meant accomplished less;2) Mental health meant worked less carefully; 3)Felt calm and peaceful; 4)Had a lot of energy; 5) Felt downhearted and depressed
Physical Health Index (PHI)	Physical health/ Autonomy	c	On a Likert scale: 0 "All of the time" 1 "Most of the time" 2 "Some of the time" 3 "A little of the time" 4 "None of the time". During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health? 1) Physical health limits the amount of work; 2) Physical health limits the kind of work; 3) health limits moderate activities 4) pain interfered with work 5) health limits several flights of stairs
Loneliness index (LI)	Mental Health/ Participation	c	On a Likert scale: 0 "Often" 1 " Some of the time " 2 "Hardly ever or never " How often feels: 1) lack of companionship; 2) left out; 3) isolated from others 4) lonely
Subjective well-being Index (SBW)	Mental Health/ Participation/ Autonomy	c	On a Likert scale: 0 "not at all ", 1 "no more than usual " 2 " rather more than usual " 3 "much more than usual" Have you recently … 1) been able to concentrate on whatever you're doing? 2) lost much sleep over worry? 3) felt that you were playing a useful part in things? 4) felt capable of making decisions about things? 5) felt constantly under strain?6) felt you couldn't overcome your difficulties? 7) been able to enjoy your normal day-to-day activities? 8) been able to face up to problems? 9) been feeling unhappy or depressed? 10) been thinking of yourself as a worthless person? 11) been feeling reasonably happy, all things considered?
Subjective financial situation (SFS)	Economic security	c	How well would you say you yourself are managing financially these days? Would you say you are: 0 "Finding it very difficult" 1 " Finding it quite difficult " 2 "Just about getting by " 3 "Doing alright" 4"Living comfortably"
Energy poverty	Protective housing/ adequate heating	d	In winter, are you able to keep this accommodation warm enough?
Above the poverty line	Autonomy/ Economic security	d	Based on Index from the Social Metrics Commission

Note: 'd' corresponds to dichotomous, and 'c' to categorical variable type.

4.3 Results

4.3.1 Energy footprints – levels and composition

We first compare the levels and compositions of energy footprints (EF) by income and EF deciles. All footprints are presented in GJ per adult equivalent (ae) per annum. There is a nine-fold difference in energy use between the lowest and top EF decile (panel b in Figure 4-1). This increase from 47 GJ/ ae to over 405 GJ/ae mostly arises from higher energy use for car and air transportation, which makes up the majority of the total EF (between 70 GJ/ae and 275 GJ/ae) for the top four energy deciles (6-10). International air- EF increases rapidly from 19 -23 GJ/ae for the bottom 40% of income earners to 92 GJ/ae for the top 10% of income earners (panel '*a*' in Figure 4-1). The tenth income decile has higher private transport (car and air) EF than the total EF of 60% of the population. If the top decile just stopped flights, their total EF would be reduced by over one-third – around 103 GJ/ae – the level of the total energy use of the bottom 20% of the income earners (sic).

Whereas private transport is responsible for most of the total EF of the top 50% earners and energy users, housing EF contributes the most to the EF of the bottom 50% of energy users (panel 'b' Figure 4-1). When considering differences between EF by income and energy (Figure 4-1), we observe similar energy compositions in each decile with the exception of international flights EF. Income and EF are highly correlated (Table 4-3), a common result in footprinting studies (Ivanova *et al* 2017, Oswald *et al* 2020, Wiedenhofer *et al* 2013). Much larger ranges in energy deciles rather than income deciles call to analyze the reasons behind the large spread in energy use. Therefore, in the following sections, we mainly use energy deciles.

Inequalities in energy use are further pinpointed when considering the distribution of energy use (Figure 4-2). The bottom 10% of energy users contribute only 2% to the total energy use, almost 18 times less than the top 10%. The bottom half of energy users are responsible for just one-fifth of total energy use. This is less than the share of the top 10% of energy users, which is over one-third of total energy use (figure 4-2). But are those high-energy users living better than low energy users and why do they require so much energy? In the next sections, we address these questions.

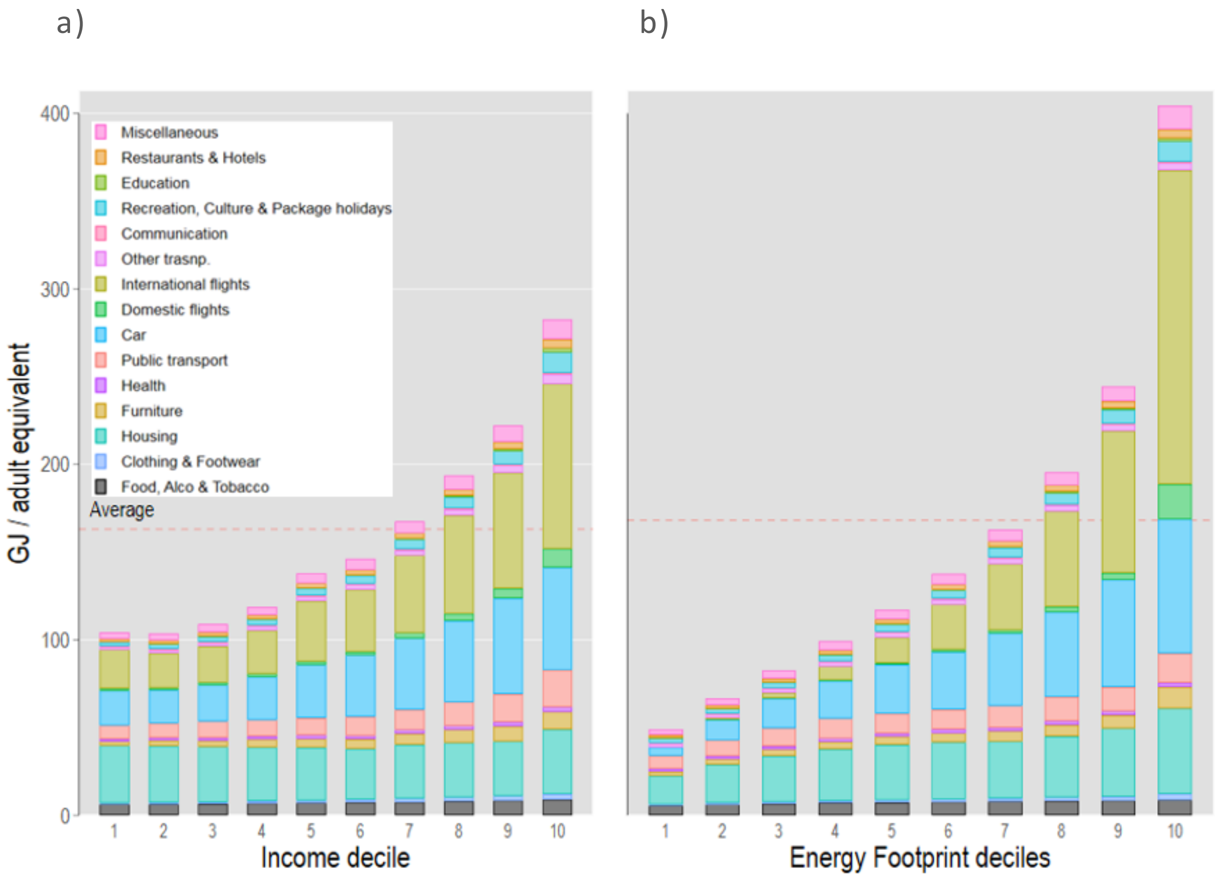


Figure 4-1 Energy footprints – levels and composition by income deciles (panel a) and by Energy footprints deciles (panel b).

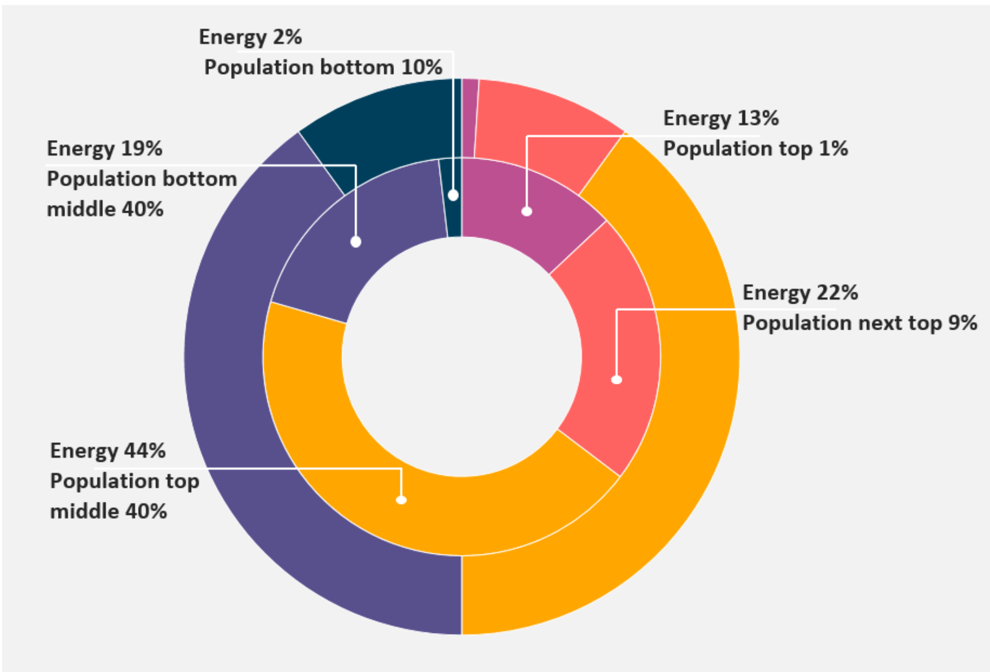


Figure 4-2 Distribution of Energy footprint in population (%). The shares of population calculated on the energy footprint basis.

Table 4-3 Correlation: Energy footprint vs income, energy footprint vs well-being; well-being vs income.

Pairwise correlations

Variables	Income (£/ae)	EF (GJ/ae)	WBS	Car-transp. EF (GJ/ae)	Air-transp. EF (GJ/ae)	Housing EF (GJ/ae)
Income (£/ae)	1.000					
EF (GJ/ae)	0.43***	1.000				
WBS	0.27***	0.27***	1.000			
Car-transp. EF (GJ/ae)	0.25*	0.52*	0.22*	1.000		
Air-transp. EF (GJ/ae)	0.32*	0.87*	0.22*	0.22*	1.000	
Housing EF (GJ/ae)	0.06*	0.27*	0.02*	0.06*	0.02*	1.000

**** p<0.01, ** p<0.05, * p<0.1*

Note: Input values are log-transformed. Gross household income divided by adult equivalent, Total energy footprint (EF) in GJ per adult equivalent, well-being score (WBS) with a score of min 0 and max 70 points.

4.3.2 Footprints vs well-being score

We now examine energy footprints in relation to well-being. We begin with an analysis using a well-being score (WBS) (section 4.2) and end with an analysis of the main characteristics that increase the odds of having high or low well-being (sections 4.3 and 4.4).

The WBS vs EF statistics (Figure 4-3) shows a saturation trend often found in international comparisons (Steinberger and Roberts 2010, Martínez and Ebenhack 2008); increments in energy at low EF levels are associated with large well-being increases but with diminishing or no returns at higher levels of EF.

There is a monotonically increasing relationship between WBS and energy footprint (Figure 4-3). The large range of WBS indicates that each EF decile includes households with various WBS scores. It is possible to have a high WBS with as little as 50 GJ/ae or with ten times as much, with 400 GJ/ae (Figure 4-1). It is thus difficult to establish an energy threshold for high WBS. Other factors, like socioeconomic characteristics and provisioning systems, are important for understanding the role of energy in the attainment of well-being. This relationship is further confirmed when taking into account the weak correlation between WBS and EF (Table 4- 3).

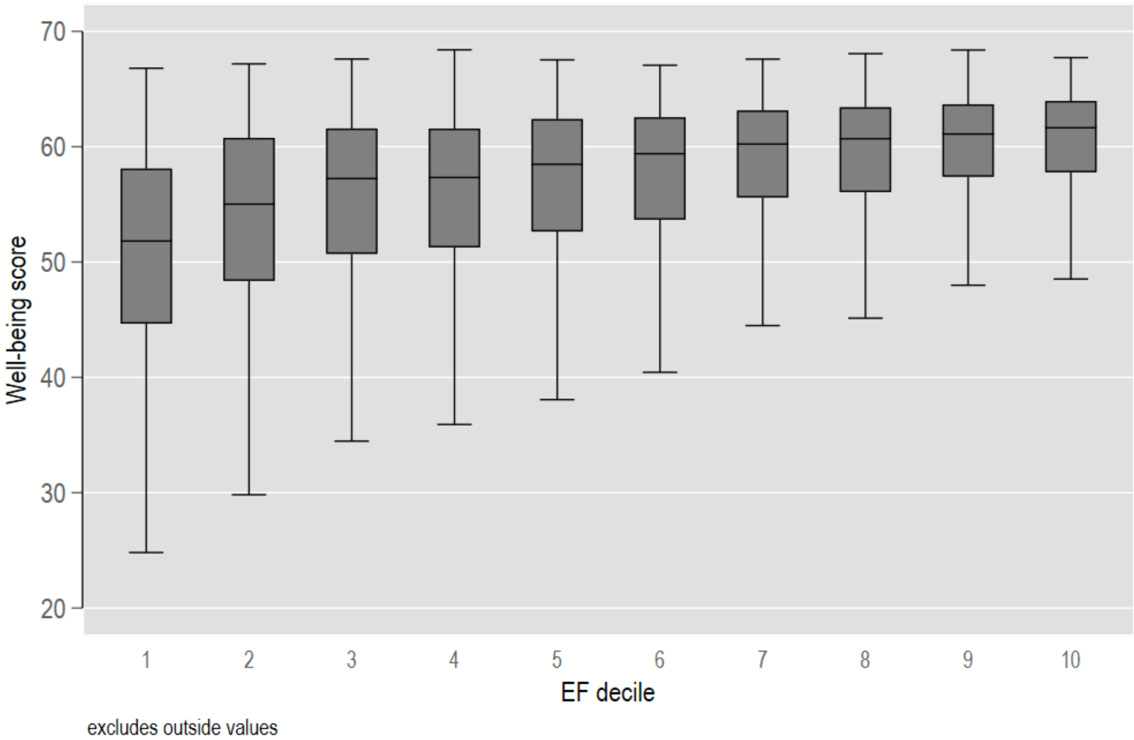


Figure 4-3 Box plot for well-being score by energy footprint decile.
Note: The top of the box is 75th percentile, the middle line corresponds to the median, the bottom line of the box is the 25th percentile. The top and bottom of whiskers correspond to upper and lower adjacent values (the most extreme values within the 1.5 interquartile range of the nearer quartile).

Next, we analyzed the relationship between components of WBS (see Table 4-2) and EF (Table 4-4) to understand how WBS is linked to energy demand for specific services, and where decoupling of well-being from energy might be possible.

The role of regression analysis presented in Table 4-4 is to show associations, not causality. In what follows we analyze the relationships between well-being components and energy footprints, and the direction and significance of those associations. The aim is to test hypotheses about the effects of the variables of interest and not to predict any specific outcome. The magnitude of the coefficient and the large goodness-of-fit parameter R^2, therefore, are not crucial to the analysis. Small R^2 are counterbalanced by large sample sizes, which are important for hypothesis testing.

The subjective financial situation, physical health, and being above the poverty line are linked to income and material services and thus to increased energy use (table 4-4). Non-material needs are linked to mental health and subjective well-being and their improvement does not increase energy demand (Rao and Wilson 2021, Stillman *et al* 2012). EF of car-transport is an important needs satisfier, as its relationship with each WB component is positive, significant, and inelastic, with an exception of subjective well-being, for which the relationship is negative (table 4-4). This might be related to previous research showing that living in areas with high car ownership decreases subjective well-being

(Lenzen and Cummins 2013). Better physical health and having adequate heating are associated with lower Housing EF, which indicates that high heating requirements might be a sign of the poor quality of dwelling and higher energy needs due to sickness or disability (Büchs *et al* 2018, Ivanova and Middlemiss 2021a). It might also imply the unaffordability of switching to more clean and efficient fuels (from inefficient biomass) or investing in thermal insulation, which often is out of reach for poor households.

Air-transport EF increases with better physical health and financial situation. This is not surprising, as income and air transport- EF are correlated (Table 4-3) and long-distance traveling might require good physical health (Ivanova and Middlemiss 2021b). WBS and air-transport EF are, however, weakly correlated (Table 4-3). There is no association between air transport and improved mental health, loneliness, or subjective well-being – reasons for traveling are more likely related to lifestyle, and flying having become a default way to reach holiday destinations. Recently, Cohen and colleagues confirmed this result, with their research spotlighting increasing feelings of guilt and denial of air transport's climate impacts, which lead to a cognitive dissonance of habit and conscience (Cohen *et al* 2011, Gössling *et al* 2020a).

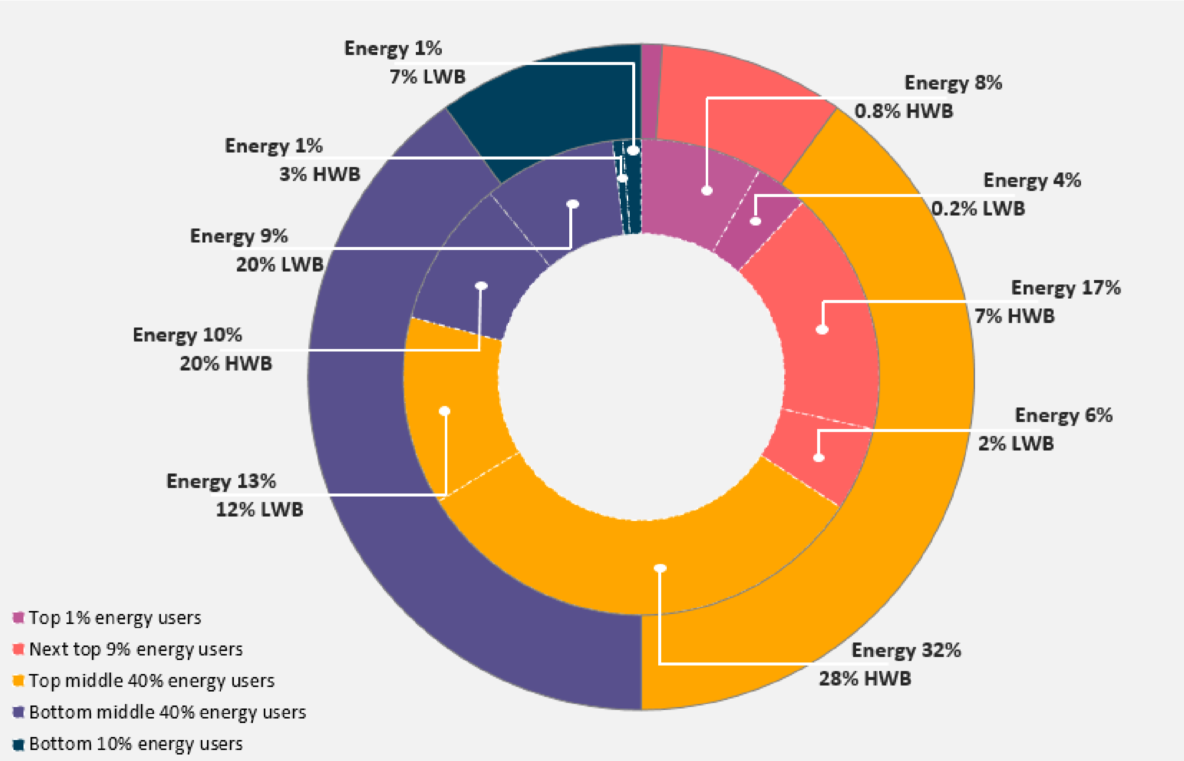
Table 4-4 OLS regression results of the natural logarithm of energy footprints in GJ per adult equivalent by Total EF (1), type of transport: Car transportation EF (2), air transportation EF (3), and Housing EF (4).

	(1) Total EF (log)	|t|	(2) Car transp. EF (log)	|t|	(3) Air-transp. EF (log)	|t|	(4) Housing EF (log)	|t|
MHI (log)	-0.04	(-1.21)	0.12^{*}	(2.26)	-0.10	(-1.61)	0.09^{**}	(2.59)
PHI (log)	0.39^{***}	(29.33)	0.45^{***}	(17.46)	0.12^{***}	(3.73)	-0.20^{***}	(-13.16)
Subj. WB (log)	-0.08^{***}	(-6.00)	-0.13^{***}	(-5.07)	0.04	(1.24)	0.07^{***}	(4.29)
Lon. Ind (log)	0.12^{***}	(7.38)	0.09^{**}	(3.15)	0.05	(1.62)	0.07^{***}	(4.05)
Subj. fin.sit (log)	0.29^{***}	(21.95)	0.20^{***}	(8.04)	0.52^{***}	(18.83)	0.08^{***}	(5.42)
Has Adeq. heat.	0.11^{***}	(6.27)	0.15^{***}	(4.18)	0.12^{**}	(2.74)	-0.12^{***}	(-5.74)
Above Pov.	0.34^{***}	(34.49)	0.47^{***}	(25.33)	0.34^{***}	(16.25)	0.08^{***}	(6.89)
constant	3.07^{***}	(54.60)	1.25^{***}	(11.65)	2.44^{***}	(20.03)	3.08^{***}	(47.56)
N	24417		21651		14571		24407	
R^2	0.15		0.06		0.06		0.01	

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$
Note: Results are weighted. Footprints with zero home energy and transport energy were excluded. We interpret the coefficients (βi) as elasticities of energy demand in relation to their well-being component score. For example, a 1% increase in the PHI results in a 0.39% increase in Total EF. If βi =1, the relationship is proportional, if βi <1, the relationship is inelastic, and if βi >1, the relationship is elastic. If -βi indicates inverse of the independent variable.

4.3.3 Energy footprint vs high and low well-being index

We compare the level and composition of EFs for those with low and high well-being using a binary variable. High well-being (HWB) here is defined as having at least an average WBS, as well as being above the poverty line and having adequate heating. Low well-being (LWB) means having a WBS below the average. Individuals with HWB constitute 59% of the sample and are responsible for two-thirds of total energy demand (Figure 4-4). Energy use within the HWB group is highly unequally distributed, as few (7.8%) are responsible for a disproportionate amount of energy demand (25%), and half of those with HWB (51%) use less than their share (43%) (Figure 4-4). Among those with LWB, a few high-energy users (2.2%) are responsible for one-tenth of the total energy (Figure 4-4). The rest with LWB (39% of the sample) contribute less than one-quarter (23%) of the total energy demand. Those with larger EF have a higher chance for well-being: among the top 10% of energy users, almost three-quarters have high well-being (72%), whereas, among the lowest 10% of energy users, fewer than one-third have high well-being 29% (Table 4-5).



Note: Outer ring corresponds to the energy group: top 1%, next top 9% top middle 40%, bottom middle 40% and bottom 10%. Inner ring corresponds to energy distribution by well-being group. HWB – high well-being; LWB – Low well-being.

Figure 4-4 Distribution of energy footprints in GJ per adult equivalent by high and low well-being groups.

Next, we delve into levels and types of energy use by energy groups and well-being status. There is little change between the energy use of high WB and low WB energy users for all energy use levels (Figure 4-5). It is not obvious what makes a difference between having or not having high levels of well-being. The reasons come to light when examining the contribution of each energy category to overall EF (Figure 4-6). In LWB groups, housing and public transport EF make a larger proportion of the total EF. For those with HWB, private transport in the form of car and air - EF is responsible for a high proportion of their total EF (between 18 and 73%). The majority with HWB and low EF reported having holidays and savings, which indicates that they are not deprived of leisure but obtain it at lower energy intensity than those with HWB and high total EF (Table 4-5).

A small share (3%) of the sample achieved high WB at a very low EF of 50 GJ/ae (Figures 4-4 and 4-5), but at the same time, top 10% with HWB used more than ten times that amount of energy (~400-800 GJ/ae). However, the majority of those with HWB use a little more than the national average amount of energy (180 GJ/ae vs 163 GJ/ae). A full quarter of the sample with HWB uses less than half the average EF, between 50 and 100 GJ/ae, however, it is still more than what is modeled in scenarios such as Low Energy Demand or Decent Standards of Living (Millward-Hopkins *et al* 2020, Rao *et al* 2014, Kikstra *et al* 2021) (around 55 GJ for Global North).

Overall, excess energy use is implicated in a small minority with HWB. Therefore, it is possible to reconcile maintenance of high WB and energy demand reduction

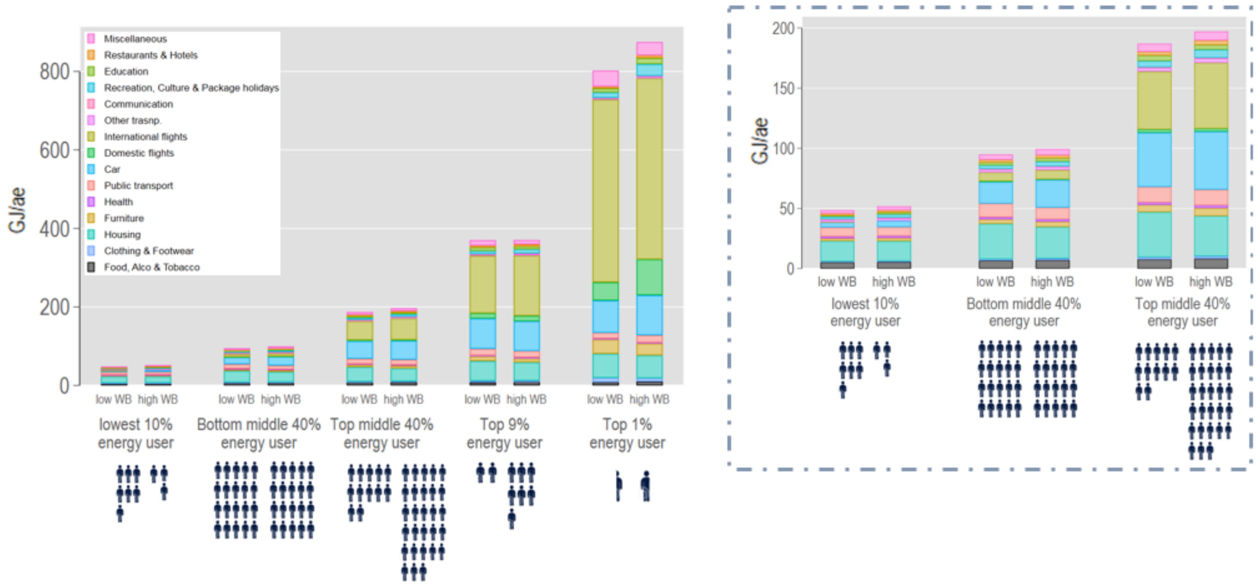


Figure 4-5 Energy footprints – levels and composition by high and low well-being and energy group.
Note: The right side of the figure shows the magnification of the left side figure for the lowest 10%, bottom middle 40%, and top middle 40% of energy users.

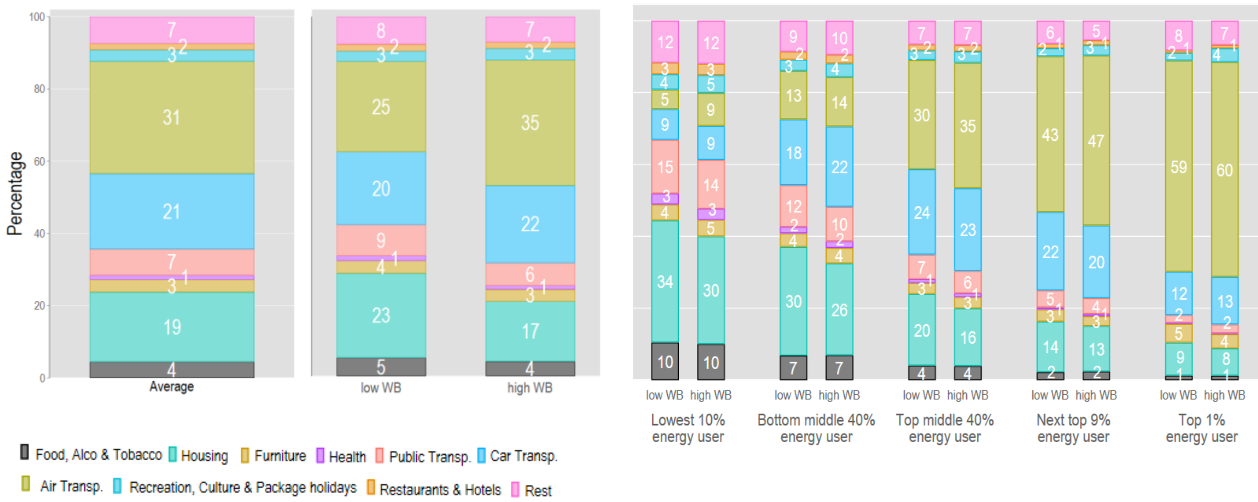


Figure 4-6 Contribution to overall energy footprint by energy footprint categories

4.3.4 Characteristics of those with high and low well-being

Out of the maximum of 70 points, those with high well-being (HWB) score on average 13 points higher than those with low well-being (LWB) (62 points vs 49 points respectively) (Table 4-5). When investigating differences between energy groups, clusters with LWB on average score lower for all WB components with the highest disparities for loneliness and subjective financial situation (average two points difference for the maximum score of 10 points per component). The difference in WBS between the lowest 10% energy users with HWB and the highest 1% with HWB is only 1 point (Table 4-5), but the difference in their energy use is over 800 GJ/ae, a seventeen fold increase (Figure 4-5). As already noted, energy footprints weakly correlate with WBS and give an incomplete picture of the differences between those with high and low well-being. For that reason, we use additional information detailed in microdata on various socio-economic characteristics to obtain a more nuanced account (Table 4-5). We describe them below.

Protected Characteristics

Protected characteristics such as gender, ethnicity, or age impact negatively the probability of having HWB. The bottom 50% of energy users with LWB are disproportionally female, single, without work, and dedicating two hours more than the high energy users on un-paid housework. In contrast, the top energy user (9% and 1%) with HWB is on average middle-aged, white, male, working long hours, having two cars but no children. This cluster contains the highest 25% of income earners in the UK with an average gross monthly income of £4100-6400 per person (Table 4-5) (ONS 2022b).

Being non-white also decreases the odds of having HWB (Table 4-5). Overall, 14% of respondents belong to a non-white group, but twice as many of them have LWB rather than HWB (5% and 9%

respectively). The direction of the age effect is a positive effect – the older the person is, the higher the odds of having HWB. This might be due to material components of well-being and on average higher odds of having accumulated wealth or receiving regular pensions (ONS 2022a).

High share of housing energy

Among the bottom 50% of energy users and especially among those with LWB, housing EF contributes the most (28-34%) to the total EF (figure 4-6). A higher share of house fuels does not mean higher absolute EF as the lowest 10% of energy users consume a mere 17GJ/ae of housing fuels while already the bottom middle 40% consumes almost twice as much (30 GJ/ae). A higher share of house fuels does not translate to warmer houses as a lack of adequate heating among LWB groups is the average rate (Table 4-5). One explanation can be poorly insulated, energy inefficient dwellings. Groups with LWB often lack decision power to renovate their homes, as they are disproportionally rentees (48% compared with 17% for those with HWB).

Over a third of households in the lowest 10% with LWB have a pre-payment meter, which is an expensive payment method. With a small income of 1100£ per person and the majority living below the poverty line (62%), these households have to choose between energy services to fulfil their needs, i.e. they might be choosing between eating, warming up their houses or buying petrol for their car (Table 4-5) (Mattioli *et al* 2018). These characteristics make those with EF and LWB vulnerable to energy poverty and to lack of ability to decide about their living conditions.

Among high energy users with HWB, the average housing EF is well above the mean (47 – 58 GJ /ae compared with the mean of 32 GJ/ae). Here, location matters: rural living allows more space, more than three bedrooms, which for the top 1% with HWB results in nearly two times higher house fuel use than the sample average (Table 4-5). While the top 10% use about a quarter more electricity and gas compared to the top middle 40%, they also use three to six times more wood and coal because fireplaces and wood burners are more common in rural settings. Within this group of high earners and energy users is a small group that struggles (2% of the weighted sample population). The top 9% of energy users with LWB includes a higher number of single households (45%) and non-white individuals (11%). Poor mental and physical health, higher levels of loneliness, and financial problems contribute to their low well-being score. One-fourth is below the poverty line and those not having adequate heating are twice as common as the sample average.

Private vs public transport – needs satisfier escalation vs need satisfaction

While private transport dominates the HWB group, dependence on public transport is important for those with LWB. Car transport EF increases almost twenty-fold from the lowest 10% to the top 1% of energy users with HWB (Table 4-5). This might in part be explained by suburban or rural living and the fact that affluent households travel longer distances by car regardless of public transport availability. In contrast, low energy users with HWB mostly live in urban areas (70%) which explains their low car ownership of 0.6 cars per person. We cannot examine the quality of public transport accessible to the rural and suburban dwellers in our sample. However, the literature highlights affordability, reliability, and flexibility inadequacies of rural public transport which can lock individuals and households into car-dependent lifestyles (Mattioli 2017, Mattioli *et al* 2020, Local Government Association 2022, Urban Transport Group 2019, Department for Transport 2021a). Whereas those inadequacies could partly explain increases in private transportation, it does not justify all of the use. In the UK, the common purposes of car trips include commuting, escorting children, shopping, and carrying heavy goods, which are related to satisfying needs of education, sustenance, or economic security (Mattioli *et al* 2016, Department for Transport 2021b). But the cluster with the highest car transport EF, the top 10% of energy users with HWB, is middle-aged, male, and without children.

The concepts of needs escalation, negative satisfiers, and car dependency can help the excess use of private transport. Needs escalation occurs when a specific product or technology "escalates in terms of overall use, and thus, in its environmental impact" (Brand-Correa *et al* 2020). Environmental impact is often linked with negative needs satisfiers, which car use is via its contribution to air pollution, upkeep costs (by possibly leading to a situation of choosing between eating or driving – see (Mattioli 2017)), and sedentary lifestyles (Brand-Correa *et al* 2020). The escalation of car use is possible due to drivers such as induced demand, relocation to car-dependent areas, and prioritizing investment in infrastructure for private transport, all of which are some of the political-economic factors behind car dependence (Mattioli *et al* 2020). Our results indicate that a car is important for satisfying needs, but that the context within which this dependency occurs is created. This leads to the situation where those with the lowest energy use and LWB might be in need of more energy-related to car use and those with HWB and high energy use, utilize private transport for all possible activities, even though more energy-efficient alternatives exist and it negatively impacts their health and air quality.

Table 4-5 Socio-economic characteristics of individuals grouped by energy users group and well-being status.

		Avg.	HWB	L WB	|t|	OR	L 10% HWB	L 10% LWB	BM 40% HWB	BM 40% LWB	TM 40% HWB	TM 40% LWB	T 9% HWB	T 9% LWB	T 1% HWB	T 1% LWB
Location	Number of obs.	28,614	16,863	11,751			673	1,647	5,248	5,235	8,081	3,751	2,296	852	565	266
	Share of population	100%	59%	41%			3%	7%	20%	20%	28%	12%	7%	2%	0.8%	0.2%
	Urban	58%	**52%**	**67%**	***	▼	**70%**	**81%**	**59%**	**70%**	**47%**	**57%**	**43%**	**51%**	49%	57%
	Suburban	24%	**30%**	**16%**	***	▲	**16%**	**8%**	**26%**	**14%**	**33%**	**23%**	32%	28%	28%	21%
	Rural	18%	**18%**	**16%**	***	▲	14%	11%	15%	16%	19%	20%	25%	21%	23%	22%
Dwelling	Number of bedrooms	3.0	**3.2**	**2.8**	***	▲	2.4	2.5	**2.9**	**2.7**	**3.3**	**3.1**	**3.5**	**3.4**	3.6	3.6
	Renting	30%	**17%**	**48%**	***	▼	**45%**	**76%**	**24%**	**52%**	**11%**	**30%**	**9%**	**26%**	10%	15%
HH size	Number of kids	0.5	**0.4**	**0.6**	***	▼	**0.3**	**0.9**	0.5	0.6	0.4	0.5	0.3	0.4	0.4	0.5
	Share of single hh	41%	**33%**	**52%**	***	▼	**55%**	**61%**	**37%**	**54%**	**29%**	**45%**	**26%**	**45%**	**21%**	**49%**
	Household size	2.8	**2.7**	**2.9**	***	▼	**2.3**	**3.1**	2.7	2.8	**2.7**	**2.9**	**2.6**	**2.9**	2.7	2.6
Ind. char	Age	50	**52**	**47**	***	▲	**62**	**47**	**54**	**48**	**50**	**45**	**50**	**43**	**49**	**44**
	Male	47%	**51%**	**42%**	***	▲	45%	43%	**51%**	**41%**	**51%**	**43%**	**52%**	**41%**	**64%**	**46%**
	Non-white	6%	**5%**	**9%**	***	▼	6%	8%	**5%**	**9%**	**4%**	**9%**	**5%**	**11%**	8%	14%
Education	16 > yrs edu	40%	**45%**	**32%**	***	▲	16%	16%	**34%**	**28%**	**52%**	**42%**	62%	56%	69%	55%
	12 to 15 yrs edu	21%	**21%**	**22%**	*	▼	18%	20%	21%	21%	**21%**	**25%**	**19%**	**25%**	14%	23%
	<= 11 yrs edu	39%	**34%**	**46%**	***	▼	67%	63%	**45%**	**51%**	**27%**	**33%**	19%	19%	17%	22%
Work	Not working	43%	**39%**	**49%**	***	▼	71%	70%	**46%**	**52%**	34%	35%	29%	29%	16%	21%
	Working h/w	37.2	**38.1**	**35.7**	***	▲	34.7	31.0	**35.8**	**34.0**	38.6	38.1	40.7	38.9	44.9	43.1
	Housework h/w	9.4	**9.0**	**10.0**	***	▼	**9.7**	**10.0**	**9.6**	**10.4**	8.7	9.6	8.2	8.7	7.3	7.9
Travel	No. of cars	1.5	**1.7**	**1.3**	***	▲	0.6	0.6	**1.3**	**1.1**	**1.8**	**1.6**	2.0	1.7	1.7	1.5
	No. of dom. flights	0.2	0.2	0.1		NA	0.0	0.0	0.0	0.0	**0.1**	**0.1**	0.8	0.7	5.1	2.5
	No. of EU flights	0.8	**1.1**	**0.5**	***	▲	0.0	0.0	0.1	0.1	1.1	1.0	3.0	2.8	**8.3**	**9.5**
	Number. of int. flights	0.3	0.4	0.2		NA	0.0	0.0	0.1	0.1	0.4	0.3	**1.2**	**1.2**	4.4	3.3

	Table 4-5 continues …	Avg.	HWB	L WB	|t|	OR	L 10% HWB	L 10% LWB	BM 40% HWB	BM 40% LWB	TM 40% HWB	TM 40% LWB	T 9% HWB	T 9% LWB	T 1% HWB	T 1% LWB
	Cannot afford holidays	23%	**10%**	**38%**	***	▼	**30%**	**56%**	**17%**	**46%**	**7%**	**21%**	**4%**	**16%**	1%	4%
Income & poverty	Gross mthly inc. (£ ae)	2,300	**2,700**	**1,800**	***	▲	**1,300**	**1,100**	**1,900**	**1,600**	**3,000**	**2,300**	**4,100**	**3,100**	**6,400**	**3,600**
	Below poverty line	18%	0%	43%	**NA**	NA	0%	62%	0%	45%	0%	33%	0%	25%	0%	34%
Income & poverty	No adqt heating	5%	0%	11%	NA	NA	0%	16%	0%	12%	0%	8%	0%	12%	0%	2%
	Pre-payment meter	14%	**7%**	**24%**	***	▼	**12%**	**34%**	**11%**	**27%**	**4%**	**15%**	3%	10%	**0%**	**5%**
Well-being	Avg. well-being score	57	62	49	**NA**	NA	61	46	62	49	**62**	**51**	62	52	62	54
	Mental Health index	7.1	**7.4**	**6.8**	***	▲	**7.4**	**6.7**	**7.4**	**6.8**	**7.4**	**6.8**	**7.4**	**6.8**	**7.3**	**6.9**
	Physical Health index	8.4	**9.1**	**7.4**	***	▲	**8.3**	**7.0**	**9.0**	**7.3**	**9.2**	**7.8**	**9.2**	**8.1**	**9.4**	**8.2**
	Loneliness index	8.4	**9.2**	**7.3**	***	▲	**9.2**	**7.3**	**9.2**	**7.3**	**9.2**	**7.2**	**9.2**	**7.3**	**9.1**	**7.7**
	Subjective well-being	6.9	**7.5**	**6.0**	***	▲	**7.6**	**6.0**	**7.6**	**6.1**	**7.5**	**6.0**	**7.5**	**5.9**	**7.4**	**6.0**
	Subjective financial sit.	7.9	**8.7**	**6.8**	***	▲	**8.4**	**6.4**	**8.4**	**6.7**	**8.7**	**7.1**	**9.0**	**7.2**	**9.2**	**6.4**
Energy footprint (GJ/ae)	Total EF	160	**183**	**128**	***	▲	**50**	**47**	**97**	**92**	**194**	**183**	364	362	863	792
	Housing EF	32	**32**	**31**	***	▲	17	17	**26**	**30**	**34**	**38**	47	50	58	63
	El,, oil, and gas EF	25	**25**	**25**	**	▲	13	14	**22**	**25**	**26**	**29**	**33**	**33**	31	35
	Biomass fuels EF	2.8	**3.0**	**2.4**	**	▼	0.0	0.0	**0.6**	**0.7**	**3.1**	**4.5**	9.1	12.7	19.3	21.6
	Car EF	35	**41**	**27**	***	▲	**5**	**4**	**23**	**18**	**48**	**45**	76	78	**102**	**82**
	Air –travel EF	53	**67**	**33**	***	▲	5	3	14	13	**73**	**58**	176	155	459	401

Note: HWB – high well-being; LWB – Low well-being, BM – bottom middle, TM – Top middle; T – Top. Blank space in |t| and OR indicates no significant relationship, NA means not applicable for the variable, and stars relate t: t statistics expressed at significance levels * p < 0.05, ** p < 0.01, *** p < 0.001. The significance levels are for the odds ratios of the probability that the individual will have HWB to the probability that the individual will have LWB given the increase / the achievement of the independent variable. Each of the independent variables is considered in turn. Red and green triangles correspond to odds ratio: one indicates no effect, positive effects are greater than one (green) and negative effects are between zero and one (red triangle). For example, the odds ratio of having HWB depending on living in an urban area are less than 1 (red triangle), meaning living in urban area decreases odds of having HWB. Data based on USS, wave 10.

4.4 Discussion

This research addresses a gap in footprinting studies by going beyond drivers and barriers of household footprints to focus on the social outcomes of energy use, in terms of need satisfaction and well-being. We contribute to current footprinting studies by presenting the first analysis of the direct and indirect energy demand for the UK using final energy use and linking it to well-being outcomes. Our results highlight issues of energy poverty as well as excess energy use. As a result, this analysis goes to the core of energy justice: some households use so little energy that they cannot achieve high well-being, while others use over ten times more.

We found that high well-being is possible already at 50-100GJ/ae, which is below the national average energy footprint (EF), and achieved by 3%-23% of the population. This is an encouraging result as it shows that living well within limits is already possible in existing physical and social contexts. However, half of the households (25%) with low EF (<100 GJ/ae) have low well-being and are vulnerable to energy poverty. Earlier studies have found that fuel poverty often leads to a "heat or eat" dilemma experienced by low-income families, older people, and the disabled (Ivanova and Middlemiss 2021a, Walker and Day 2012, Frank *et al* 2006). Buchs highlights that those who are "sick and stuck at home" require *more* housing energy to stay warm (Büchs *et al* 2018). Our results resonate with this: households with low well-being and poor physical health have higher EF related to electricity, oil, and gas than those with high well-being. Currently, energy poverty is framed in terms of resource scarcity or efficiency and not in terms of inequality, income poverty, and austerity (Middlemiss 2019). Not recognizing that households' poverty is multidimensional may lead to a lack of comprehensive response, or missing those who need the help the most (Gillard *et al* 2017, Rosenow *et al* 2013, Sovacool 2015, Middlemiss and Gillard 2015). A comprehensive governmental response is needed. An example is current government incentives for retrofitting. However, the uptake is slow. The strong push for change often comes outside the government, from protest groups such as Insulate Britain, which fight for retrofit programs that help reduce energy demand and improve lives of the most vulnerable and often invisible groups.

Another issue of energy poverty relates to transport poverty. We found that among those with high well-being private transportation EF is systematically higher. Mattioli and colleagues (Mattioli *et al* 2018) have demonstrated how access to affordable car transportation matters for the achievement of well-being within existing provisioning systems because of the absence of alternative means of transportation to get to work or access essential services and social activities. Lower-income households on low energy budgets spend a larger share of their expenditure on car fuel and they often need to reduce other energy expenditures to afford a car (Mattioli *et al* 2018, Mattioli 2017, Martiskainen *et al* 2021). These lower-income households are often pushed to car ownership because alternatives do not exist, especially in a rural setting (Mattioli 2017). High-income and high-energy users also heavily rely on private transportation but in addition to need satisfaction, their car use also sustains a high energy-intensive lifestyle. Using a car to walk a dog, gardening and pet care, and disposal of waste are examples of the escalation of need (and want) satisfiers (Brand-Correa *et al* 2020, Mattioli *et al* 2016). The reliance on cars for needs and wants satisfaction is created and maintained by the political economy of car dependence. The difficulty to escape the dependency stems from land-use patterns designed to serve a car-oriented lifestyle, undermining public transport and the creation of car culture by the automobile industry (Mattioli *et al* 2020, Brand-Correa *et al* 2020). In a situation when private transport constitutes the majority of the footprint of high and wealthy energy users, the introduction of stringer taxation on high emitters and limiting access to damaging to environment and humans products (e.g. SUV) are necessary (Boyle, David *et al* 2021).

Some of our most striking findings are related to flying. For the top 10% of energy users, flying contributes over half of their total EF, and their air - EF is many times larger than the average total EF. Flying is increasingly considered an excess contributing to the climate crisis (Gössling *et al* 2020b). Public policies in the UK and internationally have omitted to tackle emissions from aviation. With new subsidies on domestic flights, the UK government is promoting energy-intense lifestyles of income elites. Excess energy use to fly could be addressed by frequent flyer levies which could also distribute flying more equally across the income spectrum. The purpose of flying should be considered though when designing interventions as there is a difference between weekend shopping trips to Paris and trips to reconnect and care for family abroad.

Our detailed analysis of energy distribution among UK households in relation to well-being is an important missing element in existing energy demand scenarios for the UK (Barrett *et al* 2021). With the need to understand distributional impacts from the energy reduction scenarios, our study highlights characteristics of those most vulnerable in society and those living in unabated excess energy. Our results emphasize the need for more energy demand research through a gender and racial lens. We observed the importance of disaggregating data by ethnicity, as we find that those most vulnerable to energy poverty are often non-white and female, whereas those who most often overshoot energy use are white men. Taking into consideration the historical context of colonialism in the UK the issue of energy demand is also a justice issue. New ideas of how to tackle energy demand reduction include personal carbon or/and energy allowances. Equal distribution of allowances can risk not meeting people's needs and could have regressive distributional effects. Equity principles such as sufficiency, understood as to everybody according to their needs (but not wants), might help bring about more equal outcomes for all.

Realizing the 1.5-degree scenario pathway entails significant changes to the way in which we travel, work and live. It also requires reducing social inequalities. Growing income and pursuit of rural living have locked many into energy-intensive lifestyles. Those living in urban areas have lower EF but are not immune to energy-intense lifestyles, as flying to distant destinations has become an expected and affordable way of holidaying (Wiedenhofer *et al* 2018). Without policies aiming for sufficiency, we will not be able to mitigate the effects of our lifestyles. Living a sufficient lifestyle does not doom us to 'go back to caves' (Millward-Hopkins *et al* 2020). Our analysis suggests that more efficient energy services e.g. the provision of alternative modes of public transport and improvements in the housing sector could substantially lower energy demand without adversely affecting well-being outcomes. However, this will not be enough without targeting high energy users who drive the country's energy demand beyond limits. Failing to recognize the inherent inequalities and responsibilities of those few for driving energy excess can wreck the energy reduction efforts (Wiedmann *et al* 2020). Sufficiency can mean flourishing for all but sustaining the status quo of unchecked energy-intensive lifestyles of a few rich can be also disastrous for all.

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Chapter 5
Discussion

5.1 Introduction

I begin this chapter with a summary of findings from the previous three chapters. I summarize the results by addressing the four research questions presented in section 5.2. Then, in sections 5.3 to 5.7, I discuss how research done in this thesis contributes to academic knowledge on the subject. Sections 5.3 and 5.4 focus on methodological contributions. I discuss case-study selection, novel use of final energy, statistical matching, and the importance of accounting for both direct and indirect energy use. In section 5.5, I discuss the methodological contribution of conceptualizing and operationalizing well-being for the analysis on a household level. Section 5.6 presents insights from analyzing energy demand in light of provisioning systems. The chapter concludes with section 5.7, which focuses on discussing contributions to inequalities studies.

5.2 Summary of findings

Prior to discussing the importance of the findings, I summarize the results of my research and highlight important points that are further discussed in sections 5.3 to 5.7. Here, the following subsections refer to research questions, also presented at the beginning of this thesis in chapter 1. I take each of the research questions in turn and provide evidence presented in the thesis to show how each has been answered.

5.2.1 RQ1: What is the indirect and direct household energy use by different household types, in the case study countries?

In Chapter 1, Figures 1-6 and 1-7 show the energy model framework applied in chapters 2, 3, and 4 to calculate household indirect and direct energy use in Nepal, Vietnam, Zambia, and the UK. For each of the case-study countries, I obtained nationally representative household-level surveys. This data together with final energy use data from the International Energy Agency and GTAP multiregional input-output database served as inputs for developed energy models. The estimation of household energy footprints included uses of input-output analysis, regression analysis, additional statistical data for quantifying direct energy use, and methods for distributing final household demand among household types. The result of calculations is household final energy use divided by consumption categories.

In Chapter 2, I explored the differences in levels and types of energy use and concluded that energy use in Zambia is highly unequally distributed in income terms, spatially, and with regard to modern fuel use (Figure 2-3). Direct energy use including traditional fuels constitutes the majority of energy footprints of rural households. Whilst there is a positive association between income and indirect energy footprints, it is negligible for the poorest half of the population. Furthermore, the footprint for car transport is highly unequally distributed as only the richest own vehicle.

In Chapter 3, I compared household energy footprints between Nepal, Vietnam, and Zambia. I analyzed energy use by income deciles as well as by types and levels of consumption. I found, similarly to chapter 2, that direct energy use dominates overall footprints and higher levels of indirect energy use are associated with higher incomes (Figure 3-4). Interestingly, I found decreases in the direct energy use with growing income in Nepal and Vietnam (Figure 3-5). This is a consequence of the increased use of modern fuels in the form of gas and electricity. I also noted the occurrence of energy stacking in all three case-study countries, which is connected with issues around accessibility, reliability, and affordability of modern fuels. Inequalities are the highest for modern fuels, even when compared with income or the total energy footprints distributions (Figure 3-6). This indicates that inequalities are linked to types of energy use rather than amounts of energy used.

In Chapter 4, which presents the UK case study, I focused on levels and types of household energy footprints and inequalities surrounding the distribution of those footprints. Here, I found higher inequalities in energy distribution by energy footprint deciles than income deciles (Figure 4-1). Moreover, private transportation in form of car and air transport contributed the most (60%) to the total energy footprint for the richest income decile. The inequalities in levels of energy use were further confirmed in Figure 4-2, which shows that while the bottom 10% of energy users contribute only 2% to energy demand, the top 10% of energy users require 35% of the total energy use.

5.2.2 RQ2: What types and levels of household energy use are associated with the achievement of well-being?

This research question is covered firstly by the conceptualization and operationalization of well-being, and secondly by linking well-being outcomes with estimated household energy footprints. In chapter 1 (section 1.4.1) I showed how I constructed binary variables related to having or not having access to specific human needs satisfiers, and in relation to specific well-being outcomes. Here, I built on the Theory of Human Need (Doyal and Gough 1991), which is derived from the eudaimonic school of thought.

In chapter 2 I showed that urban households with basic well-being outcomes use a third more energy than their rural counter partners (Figure 2-4). The difference stems from high indirect energy footprints. Households with well-being outcomes use more than the national average energy demand. Whilst in rural areas differences between households with and without well-being outcomes result from higher usage of charcoal, in urban areas electricity use plays a significant role.

In chapter 3 I showed that it is possible to achieve basic well-being outcomes and use less energy than the national average. The composition of the footprints, however, differs from the observed national averages (Figure 3-8). This is especially true for the case of housing energy footprints, which are lower for households with well-being outcomes in the three countries. In contrast, transport energy footprint and indirect energy use increase for households with well-being. The overall energy footprints of the households who achieve basic well-being outcomes in Nepal, Vietnam, and Zambia are between 60% and 80% lower than the global per capita average energy footprint in 2011.

In chapter 4 I found that households with high well-being in the UK contribute two-thirds of total energy demand and the energy within this group is highly unequally distributed (Figure 4-4). Only 7.8% of top energy users with high well-being are responsible for a disproportionate amount of energy demand (25%). Households with high well-being are characterized by the use of private transport (air and car transport). High well-being with low levels of energy use is, however, possible. A small share (3%) of investigated households achieve high well-being at 50 GJ per adult equivalent per year, which is very low in relation to other UK households, but around three times higher when compared with results for Nepal, Vietnam, and Zambia in chapter 3. Relatively low energy footprints of those UK households are possible due to almost nonexistent air-transport energy footprints and very low footprints for car transport.

5.2.3 RQ3: What are socio-economic characteristics and availability of provision systems linked to households with different energy and well-being profiles?

Chapter 2 used logistic regression to analyze which socio-economic characteristics and provisioning systems are important for well-being attainment (Table 2-6). It is found that location and access to provisioning including access to schools, electricity, and indoor sanitation are the two most important characteristics accounting for differences in energy use between Zambian households. Moreover, they are more important for household need satisfaction than individual of durables, or even income.

Table 3-2 in chapter 3 presents the percentage of the population in Nepal, Vietnam, and Zambia achieving basic well-being outcomes, Decent Standards of Living (DSLs) (Rao and Min 2017), and selected socio-economic characteristics – all informing about well-being outcomes but also characterizing dimensions of poverty. Results showed that households with well-being outcomes (having access to modern fuels, having basic education, sufficient food, and access to clean and safe water), on average also have other decent living standards (Rao and Min 2017). With use of statistical methods such as logistic regression and factor analysis, I found that households with basic well-being outcomes also have higher odds of having solid shelter, toilet, and sewage. Margin plots depicted in Figure 3-9 show it is collective provisioning in the form of access to a health center, public transport, markets within 5 km from home, and garbage disposal in Nepal and Zambia that have an effect on higher odds of having well-being.

Overall, chapters 2 and 3 lead 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.

Chapter 4 used descriptive statistics and regression analysis to determine what are the characteristics of households with high and low well-being. Figure 4-6 showed those with low well-being on average use a higher share of their total energy footprint on house fuels. Those households on average are also more likely to be in energy poverty (not having adequate heating) and be below the poverty line. Further, the analysis presented in Table 4-5 revealed that protective characteristics like gender, ethnicity, or age impact negatively the odds of having high well-being. Similar to the results presented in chapters 2 and 3, chapter 4 revealed the importance of location, and thus access to certain provisioning systems. Households with high well-being on average live in urban areas where public transport might be more accessible and reliable. Public transport, however, dominates in the group with low well-being, and the high well-being group on average uses private transport, regardless of the public transport availability.

5.2.4 RQ4: What are possible lock-ins that hinder people from lowering energy demand while achieving or maintaining high levels of well-being?

Lock-ins in the case study countries situated in the Global South primarily relate to not being able to achieve basic well-being outcomes. I found that on average households which achieve basic well-being outcomes have already low energy requirements. With the use of logistic regression, chapter 2 revealed that lock-ins to achieve basic well-being outcomes are linked to location, access to electricity, and indoor sanitation. When investigating specific well-being outcomes, I found that increased probability of having basic education is linked to electrification, the probability of having safe water increases for urban households, and higher probabilities of having adequate food are associated with location and indirect energy footprints.

In chapter 3, by using logistic regression and with presented adjusted probabilities lines in Figure 3-9 I demonstrated how without access to protection (i.e. solid shelter, sewage, and safe toilet), collective provisioning and modern fuels, households have almost no real chance of achieving basic well-being outcomes. Chapter 3 concludes that resolving issues of a lack of well-being relates to multiple dimensions of poverty, socio-cultural processes and inequalities including gender issues.

Throughout chapters 2 and 3 I contradicted the narrative that achieving well-being outcomes requires increased income or individual (rather than collective) consumption of energy. I found that focusing on how energy is provided and for what outcomes on well-being is more relevant than how much energy is used. Moreover, I highlighted that achieving well-being outcomes can be linked with lower energy footprints. Overall, chapters 2 and 3 highlight access to provisioning systems as one of the main lock-ins hindering the achievement of basic well-being outcomes.

In terms of lock-in of high energy users, chapter 4 highlights the dependence on private transportation in hindering individuals from lowering their energy demand. I linked issues related to private transportation (including car and air transport) to the political economy of car dependence, lack of stringer taxation of high emitters (e.g. frequent fliers levy) and no limitation in access to damaging to the environment and humans products (e.g. SUV). In section 5.7 I provided further discussion and related lock-ins also to inequality issues. Chapter 4 concludes that more efficient energy services e.g. the provision of alternative modes of public transport and improvements in the housing sector could substantially lower energy demand without adversely affecting well-being outcomes.

5.3 Methodological contributions: choice of case studies

I designed my research to include case-study countries from both the Global North and South. I navigated my choice by developing a set of indicators related to demography, transportation and automotive industry, physical and social infrastructure (e.g. roads, electrification, urbanization, unemployment, trade characteristics), and political systems. Besides set indicators, the limiting factor was the availability of data and the need to align the case-study countries with the qualitative part of the LiLi project which involved workshops with local communities. I concluded selection with a choice of very diverse countries spanning three continents, namely Nepal, Vietnam, Zambia for Global South countries, and the UK for Global North.

As a result, the research presented in chapters 2 and 3 are the first studies in Nepal, Vietnam, and Zambia on a household level for total energy footprints. As discussed in chapter 1, previous studies employing IO has mostly focused on carbon footprints - as opposed to energy - when investigating households in the Global South (Büchs and Schnepf 2013, Ivanova and Wood 2020, Weber and

Matthews 2008) and the majority of them use the national level and extrapolate results using a representative country as a blueprint for the whole region (or continent) (Kaygusuz 2012). Empirically, this thesis contributes to input-output studies by presenting household-level analysis using secondary data for countries never investigated before. By investigating under-researched countries we inform about patterns of energy demand for well-being, which extends studies with a focus on the multidimensionality of poverty or energy access (Alkire and Santos 2014, Rao and Pachauri 2017). Therefore, this thesis provides an important contribution that links characteristics of multifacet poverty, energy consumption with well-being outcomes at the level of analysis rarely conducted in Global South countries.

In chapter 4 I presented a first study in the UK that introduces total energy footprints, as opposed to only direct energy consumption (Chatterton *et al* 2016), and I linked those footprints with well-being characteristics by utilizing a novel methodological approach. I applied existing statistical tools to estimate energy footprints for households interviewed for the Understanding Society Survey (USS). This methodological application allowed me to unlock a myriad of possibilities for investigating various socio-economic characteristics of households and individuals in relation to their total footprint. Previous studies used limited information related to energy use available in the USS (Büchs *et al* 2018) and this study adds to them by firstly estimating total energy footprints (indirect plus direct) and linking it with high and low levels of well-being.

5.4 Methodological contributions: indirect and direct final energy use

Available studies in household-level footprinting in the Global South, mainly consider carbon footprints, instead of energy, and rarely account for both direct and indirect footprints. However, in order to better understand patterns of energy use, inequalities in energy distribution, and access to energy services, both direct and indirect energy use need to be considered.

Through introducing several methodological innovations I was able to quantify direct and indirect energy footprints in chosen case-study countries. One of the main obstacles to quantifying direct energy footprints, mainly associated with the use of residential fuel use is the fact that sustenance farming is the most common economic activity in many countries across the Global South. This thesis contributes to solving this type of issues by showing a method for estimating energy footprints for products outside of the monetary market like firewood used for cooking. This enabled the analysis to complete the direct part of the energy footprints.

The results from a first application to Zambia for the year 2011 (chapter 2), show that the products outside of the monetary market, in form of collecting firewood and self-produced charcoal, contribute the most to the total energy footprints and constitute the major share of direct energy footprints.

Including both direct and indirect footprints has two important implications. First, by including the total energy footprints rather than focusing on only direct EF we were able to discuss potential rebound effects. For example, in chapter 3 we show that although urban households with access to private mobility and higher incomes have higher footprints related to transportation, and indirect footprints, for many of those households their total footprints were still lower than for their rural counter partners with very low indirect footprints but very high direct footprints related to use of inefficient traditional fuels. In other words, by including indirect and direct footprints we were able to show that the benefits of switching from traditional to modern fuels for cooking can outweigh the rebound effect of higher indirect footprints and increased mobility. The second important implication of using total energy footprints is that it provides input for potential modeling of energy distribution for energy transition scenarios. By mapping the total energy footprints on a micro-level of a household and splitting it into specific categories, we were able to portray levels and types of energy use depending on location, income, household size, and other important socio-economic characteristics. This gives input for understanding how energy demand is distributed and what, in the social and physical context available to households, enables or disables them to lower or increase their energy use.

In addition to including in our analysis direct and indirect energy use, we chose 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.

Overall, by using final and complete (indirect and direct) energy footprints, the analysis presented in this thesis has implications for both further research and policies. It contributes to the research by providing novel methods for analyzing direct and indirect footprints, which can be an important input for modeling efforts of energy transition scenarios for the Global South. These scenarios further feed into possible policy designs.

5.5 Energy demand and well-being – framing research

Methodologically, this thesis makes a contribution through analysis that links final energy demand with well-being on a household level. This contribution extends our knowledge of energy demand by moving beyond existing studies, which tend to frame their research questions around types and levels of energy use (Reinders *et al* 2003, Spreng 2005, Lenzen *et al* 2006, Wiedenhofer *et al* 2013, Cohen *et al* 2005, Lenzen *et al* 2004, Druckman and Jackson 2008, Weiss de Abreu *et al* 2021, Rahmani *et al* 2020, Chen *et al* 2019). While previous analysis on a household level allows us to consider distribution and inequalities in energy consumption, linking it with well-being adds to the "why" and "how" of energy use analysis. This approach opens up new areas of research and provides alternative ways of understanding the energy demand and possible energy transitions.

With the aim of making these connections between energy demand and well-being, the traditional way of analyzing household footprints does not suffice. In particular, navigating analysis with income or levels of expenditure does not inform about people's health or ability to have autonomy and participate in society, but it rather informs about the health of the economy (Roser 2021). In other words, when well-being is diagnosed with economic growth, the remedy is to grow consumption and increase incomes (Hickel and Kallis 2019, Hickel 2016). But when a holistic approach is considered (Brand-Correa and Steinberger 2017) the pathways for decoupling human well-being from increases in economic growth and intertwined energy consumption can be investigated.

In order to explore possibilities for decoupling, I framed my research following the theoretical framework developed by Brand-Correa and Steinberger for analyzing the relationship between energy services and human needs (Brand-Correa and Steinberger 2017). This thesis contributes methodologically by conceptualizing and operationalizing this framework and applying it to a household-level analysis. I navigated with the theory of human need, which helped me conceptualize well-being in light of human needs outcomes (Doyal and Gough 1991). In my analysis, I operationalize well-being by choosing variables that inform about achieving basic human needs (e.g. health) through intermediate needs satisfiers (education, access to clean water and modern fuels, etc). The result was the creation of well-being indicators that inform about the achievement of basic well-being in chapters 2 and 3 or high and low levels of well-being in chapter 4.

This conceptual contribution extends our understanding of the energy distribution for well-being at the household level. The thesis shows that reducing poverty and achieving high levels of well-being can be done with low levels of energy demand, which is in line with what's been found by studies at the national level (Millward-Hopkins *et al* 2020, Rao and Min 2017). I showed that changes in total energy consumption and incomes are less important for the achievement of well-being than access to modern fuels and collective services (chapters 2 and 3). Moreover, I found that in all case-study countries high energy use does not guarantee high well-being. In chapter 2 I highlight that high energy users are not immune from having malnourished children. Moreover, the high residential fuel use also can imply inefficient traditional fuel use (Chapters 2 and 3). In this context, lower energy use on residential fuel can be indicative of better health, and access to modern and more efficient energy sources. In the Global North, specifically for residential fuels, I found a similar relation (chapter 4). A relatively large share of total footprints used on residential energy could be an indication of having poorly insulated dwellings and being in economic and energy poverty, as residential energy needs leave with little resources for fulfilling other basic needs.

These results remind us that by focusing solely on the amount of total energy use, we are missing a vital piece of information - does this energy deliver desirable well-being outcomes? By considering energy demand split into meaningful categories and matching them with human need satisfaction, this thesis unravels a more detailed picture that generates insights into understanding the relationship between final energy use and multiple deprivations at the household level (Alkire and Santos 2014, Rao and Pachauri 2017). This type of analysis makes it easier to question consumption in a meaningful way. Focusing on well-being steers the attention towards questions of sufficiency, overconsumption as well as the context within which we satisfy needs. Efficiency can be discussed not only in the way of gains in energy reduction but in the light of gains for well-being (is this way of delivering energy and energy services the most efficient for the achievement of well-being?). For sufficiency, it opens up a possibility to question the design of provisioning systems to deliver well-being.

5.6 Provisioning systems – context of energy use

The context in which energy is used is crucial for just energy transitions. Without understanding the physical and social landscape within which individuals consume energy for need satisfaction, there is a risk of regressive energy policies (Owen and Barrett 2020, Mehleb *et al* 2021). As established in section 1.2.2, the provisioning systems provide a context for the delivery of human need satisfaction. Studies proposing theoretical frameworks such as practice theory and systems of provision dissect and help to understand the often invisible landscape within which the energy is used (Shove and Walker 2014, Fine *et al* 2018), but they lack a quantitative approach that could allow empirically study those intertwined connections between well-being, provisioning systems, and energy. To understand these dependencies an interdisciplinary approach is needed (Brand-Correa and Steinberger 2017).

Therefore, in this thesis, I considered the broader context of household's energy demand. I proposed a lens of provisioning systems, which relate to physical (e.g. electricity access, sanitation, public transport) and social (e.g. laws, culture) characteristics. This approach to analysis provides a better understanding of possible lock-ins to the reduction of energy consumption for need satisfaction.

For the Global South case-study countries, the results showed that households with access to collective provisioning in form of health centers, public transport, markets, and garbage disposal have a higher probability of satisfying basic needs. They also, on average, had lower energy footprints of residential fuel use than the national average or their counter partners without basic well-being outcomes. I found these results confirmed at the global level, with Vogel and colleagues' study showing that, whereas countries with a high level of equitable collective provisioning have positive socio-ecological performance, countries that bet on an economy driven by extractivism and economic growth have detrimental socio-ecological performance, and on average need much more energy to satisfy the needs of their citizens (Vogel *et al* 2021). Overall, the most important insight here is that rather than increasing overall energy use, improvements in collective provisioning systems are more important for achieving basic well-being outcomes.

These empirical contributions highlight the importance of provisioning systems in the delivery of human well-being and extend research focusing on the political context of provisioning systems (Bayliss and Pollen 2021, Bayliss *et al* 2020). Specifically, this thesis provides further evidence for the fact that those who use the least energy suffer the most in their ability to access energy services for the delivery of well-being. In chapter 2, I showed that the differences between urban and rural households can be narrowed down to a difference in electricity access. When being connected to such essential provisioning is linked to gaining education, earning potential, and health, and when only a few are privileged in that connection, access to provisioning systems becomes a social justice issue.

Perhaps the most important finding here is that collective provisioning systems can deliver a reduction in energy footprints. In the Global South, delivery of collective services can help in achieving development goals and at the same time contribute to lowering footprints. Therefore, collective services should be highlighted in policy processes as one of the most important development strategies for poverty reduction and climate change mitigation, as there is no conflict between those efforts (IPCC 2022).

Relating these results to mechanisms of poverty in the post-colonial world, the provisioning systems perspective helps to strengthen the observation that poverty does not just happen, but it is created (Hickel 2018). One of the many economic tools actively stopping countries from investing in their physical and social infrastructure is a neo-colonial structural adjustment (Hickel 2016). The same organizations, which loudly push for growth as a solution to extreme poverty, quietly impose market deregulation and high-interest debt in return for continued membership in the international economic club (Fenton *et al* 2014). The growth promises failed to be delivered, but debt needed to be paid. Thus servicing debts is continually prioritized over investments in collective physical and social infrastructure (Abosede Durokifa and Chikata Ijeoma 2018). Structural adjustment has been ongoing in Zambia and Nepal since the 80s in the past century, while these reforms were strongly opposed in Asia, including Vietnam. Today, structural adjustment is replaced with a Poverty Reduction and Growth Facility (PRGF), with similar effects on exacerbating poverty.

What do we measure if we want to understand poverty and achievement of well-being? The choice of the lens through which we choose to see improvements in the human condition is often a political choice with real consequences for people. Therefore, rather than navigating with economic activities, I explored possibilities for the achievement of human well-being through the lens of provisioning systems, which enables direct informing about poverty and the human condition.

5.7 Inequalities in energy access

As established in the introduction (section 1.3), the impacts of energy distribution in relation to well-being achievement on a household level are under-researched. What we know relates mainly to the global and national level of analysis with research highlighting the deep divide in energy access between the Global South and North (Grubler *et al* 2018, Millward-Hopkins *et al* 2020, Oswald *et al* 2021, Keyßer and Lenzen 2021, Kikstra *et al* 2021, Steckel *et al* 2013). But the aggregated data at the national level, however important for a general overview, tends to hide inequalities within national averages, at the household level. Moreover, we still do not have many household-level studies linking inequalities with total energy footprints in the Global South and even less with well-being.

Therefore, this thesis makes an empirical contribution by analyzing at the household level disparities in energy distribution and relating them to inequalities in achieving well-being I demonstrated that disaggregating energy by types and relating it with different components of well-being outcomes gives new insights into understanding who is vulnerable to energy poverty, high energy lock-ins, or energy overconsumption, as well as where, and how. Four insights emerge from the research.

The first insight relates to inequalities in access to modern fuels. Specifically, the analysis presented in chapters 2 and 3 enabled me to investigate who is affected the most by lack of access to modern energy, and how. Results of the analysis showed large spatial divides between rural and urban households, which is confirmed by existing research showing that rural households are usually the ones to lack access to electrification and modern cooking fuels as well as being in poverty (Pachauri *et al* 2013, 2012, Riva *et al* 2018). Moreover, the access to modern energy resources is more unequal than inequalities linked to income or indirect energy use. Lack of accessibility and affordability of modern fuels, makes it a social justice issue (Kumar 2018, Tarekegne 2020, Sovacool *et al* 2016), as there are known ill-health effects from indoor pollution on human health – especially for women and children (Balmes 2019, Lelieveld *et al* 2015, Mannucci and Franchini 2017). Overall, inequalities in energy access relate to the types of energy used, rather than to the total amounts of energy consumed.

The second insight relates to the importance of protected characteristics when analyzing energy demand. This was especially important in chapter 4 when investigating characteristics related to gender, race, and age. We showed that those with a low energy footprint and low well-being on average tend to include female pensioners and non-white individuals. By making a link between protected characteristics, energy demand, and well-being status, this research connects previous findings within energy poverty and energy; and gender studies (Büchs *et al* 2018, Clancy *et al* 2007, Ivanova and Middlemiss 2021, Middlemiss and Gillard 2015, Pachauri and Rao 2013, Petrova and Simcock 2019, Simcock *et al* 2021). Further, finding that it is statistically significant to disaggregate data by protective characteristics highlights the importance of considering those vulnerable and often underrepresented groups when designing scenarios for energy transitions or energy redistribution policies.

The third insight relates to inequalities in air transport. Empirically, this thesis contributes with a powerful analysis of mobility (in chapter 4), as it showed in rare detail transportation disaggregated to the car, air, and public transport at the household level (while still including the rest of the indirect and direct footprints). Relating results to the urgent need to mitigate climate change, I found that connecting well-being and footprints related to mobility provides the basis for discussing overconsumption issues and helps bring sufficiency conversations (Fuchs *et al* 2021a, 2021b, Jaccard *et al* 2021). For air-transport, relating energy demand with components of well-being clearly showed how little effect on the achievement of well-being has increased in flying. With recent studies addressing issues of excessive lifestyles and warning about affluence linked with increased footprints (Wiedmann *et al* 2020), this thesis adds to this research by further presenting empirical evidence of highly unequally distributed air-travel footprints. In other words, by providing evidence of who, where, and how exceeds sufficient limits of energy use and with what effects on their well-being, this thesis contributes to stimulating the energy sufficiency agenda.

The fourth insight also relates to inequality in access to mobility, specifically to private vehicle transportation. The analysis presented in this thesis shows that with increases in income the energy demand for private mobility services grows. Emerging work on mobility for human need highlights two contrasting forms of use. (Mattioli *et al* 2017, 2020). First, it highlights the importance of private mobility as a lock-in mechanism for need satisfaction, in which individuals do not have a choice but to own a car. The contrasting second form of use is when individuals chose car over available to them alternatives like walking, cycling or public transport. Empirically, this thesis contributes to those studies by analyzing mobility through the lens of need satisfaction and providing insights into understanding the overconsumption but also underconsumption of energy. Specifically, by analyzing low energy demand households, I provided an insight into the role of private transportation in human need satisfaction connected to satisfying economic security, leisure, or participation in society. At low levels of energy use, car transport acts as an enabler for achieving well-being. This insight should not necessarily be read as an argument for increases in car transportation, but rather as pointing to the physical lock-ins within provisioning systems that disable alternatives. In the absence of affordable collective transportation and not being able to afford housing in areas that have more to offer in terms of collective services (Bouzarovski and Simcock 2017, Lowans *et al* 2021), households are pushed to rely on private transportation (Mattioli *et al* 2016, Mattioli 2017).

Overall, as insights presented here can be also observed at more aggregated levels of a national and international analysis, this thesis contributes to this research with micro-level analysis that brings an important insight from a household-level perspective. By providing a nuanced picture of who, where, and how uses energy for human need satisfaction, this thesis informs policy efforts within energy re-distribution and we add important detail to the research areas studying distributional impacts of energy transitions scenarios (Poblete-Cazenave *et al* 2021).

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Chapter 6
Conclusion

6.1 Introduction

In conclusion, I demonstrate how the research presented fulfills the overarching aim (section 6.2). Section 6.3 highlights the main contributions and section 6.4 most important limitations of the work and links them with recommendations for future work in section 6.5. I end with final conclusions and remarks.

6.2 Over-arching aim

The central question posed at the outset of this thesis asked: how much energy is needed to live well and achieve well-being? We know that energy is necessary for satisfying human needs and energy production of energy directly contributes to greenhouse gas emissions and climate change (IPCC 2013, IEA 2021). In order to be able to live well within environmental limits, we need to understand how to reduce energy demand while achieving or preserving high levels of well-being, or in the case of the majority of the world's population: how much energy is needed to achieve human well-being (Steinberger and Roberts 2010, Ayres and Warr 2009, Lamb and Steinberger 2017, Keyßer and Lenzen 2021, Brand-Correa and Steinberger 2017). The main motivation for this Ph.D was to gain more insight into the under-researched demand side of energy use and well-being. The research set out with an overarching aim to connect final energy use on a household level with well-being outcomes and analyze household characteristics in the context of provisioning systems available to those households.

This thesis fulfilled this aim by exploring energy consumption on a household level and linking it to well-being outcomes in three countries in Global South: Vietnam, Nepal, and Zambia, and one case-study country in the Global North: the United Kingdom. This thesis brings together concepts and frameworks nested in ecological economics, industrial ecology, well-being, and poverty studies, in order to explore links between energy demand and well-being on a household level.

The thesis begins in chapter 1 by reviewing previous literature which informed developing analytical framework (see section 1.2). In chapter 2, an energy model and conceptualization of well-being using Theory of Human Need are used to describe links between the achievement of basic well-being outcomes and direct and indirect energy use in Zambia. Chapter 3 then uses the same energy model to analyze household energy profiles and their link to well-being in Zambia, Vietnam, and Nepal. Factor analysis and logistic regression were then used to analyze associations between available provisioning systems, well-being outcomes, and energy profiles. Chapter 4 delves into the Global North perspective and analyzes energy footprints for UK households and links them with the achievement of high or low levels of well-being. Chapter 5 summarized the findings to identify the most important results and their usefulness for current research and policy.

6.3 Contributions to the knowledge base

The following methodological and empirical contributions have been made in this research:

- This thesis has demonstrated a method for conceptualizing and operationalizing for quantitative analysis well-being concepts nested in the eudaimonic understanding. In doing so, it has been able to build on the framework for decoupling human need satisfaction from energy use (Brand-Correa and Steinberger 2017) to analyze a set of well-being and provisioning systems indicators and their relation to energy demand. This is in contrast to existing literature linking well-being and resource use, which has tended to focus on an aggregated national level, emissions rather than energy use, and hedonic well-being.
- This study has highlighted the possibility of achieving well-being with low energy demand. In an application of the energy model with the human need approach, it calculated energy consumption to achieve basic well-being outcomes on a household level in four case-study countries – finding that access to collective provisioning systems acts as an enabler of achieving well-being.
- This study has highlighted the challenge of achieving basic human needs in a context where access to affordable, reliable, and accessible provisioning systems is constrained. By choosing to navigate with provisioning systems characteristics rather than traditional economic features, it is shown that rather than income and overall energy consumption, the access to collective provisioning in form of electricity, markets, health care, and public transport are vital and key to being able to achieve well-being than solely focusing on growing incomes and increasing consumption.
- This study has argued that the energy demand for well-being and impacts of energy distribution is more nuanced than what is observed with the analysis on the national level. The relationships like energy-income, or energy - well-being outcomes –are not simply linear but with more detailed analysis, these relationships reveal a more nuanced picture where other socio-economic characteristics play a significant role in understanding energy use for well-being.

- This study has argued that with access to modern energy sources, the total energy demand for satisfying well-being can be reduced.
- This study calculated that based on the UK – a Global North case-study country, very low energy demand for high levels of well-being are possible but achieved by a minority, while a top 10% of energy users use disproportional amounts of energy to achieve the same level of well-being.
- This study has used consumption-based multiregional input-output method to calculate direct and indirect household energy footprints using final energy use. These calculations are done for countries never investigated with these methods before, as often difficulty of data accessibility and lack of specific expenditure proves to be problematic. This analysis shows specific solutions that can be implemented to address data issues. Rather than omitting products outside of the monetary market, the analysis uses additional household characteristics to estimate energy footprints related to house fuels.
- This study has used a novel methodology to overcome challenges in calculating household total energy footprints with missing expenditures that are the basis for footprinting calculations. By utilizing statistical matching between two household surveys, this study estimates household footprints for the UK case study using statistical tools such as regression analysis, and descriptive statistics, as well as additional socio-economic information to identify groups with specific consumption profiles.

6.4 Limitations of the study

This section describes specific limitations of the research conducted in this Ph.D. This thesis relied on multiple secondary data sources, methods, and assumptions that are not immune to some limitations. Chapters 2, 3, and 4 acknowledge limitations relevant to each section, but here I summarize them.

One of the main limitations is embedded in translating the theory of human need into indicators and proxies on a household level. Operationalizing well-being is subject to data limitation, as each country investigated in this thesis had a different set of variables available for creating well-being indicators or to inform about well-being outcomes. It was not possible to find a match for each basic need or intermediate need (as conceptualized in the THN) as in the secondary data, one is limited to what households are asked in the surveys. Another difficulty was in chapter 3 where I introduced analysis for three countries. Even though for Zambia and Nepal I had more information linked to children's health, I could not use it as the Vietnam survey did not contain that information. Finding a common denominator for well-being indicators for all three countries reduced the possibility of more robust data analysis, as opposed to if each country would be analyzed on its own. The example is presented in chapter 2 where I took Zambia as a stand-alone case study. Here I used additional information related to children's health and we presented a more nuanced analysis concerning well-being outcomes than in chapter 3. Nevertheless, chapter 3 did a prompt reflection on the issue of achieving basic well-being outcomes and addressing multidimensional poverty.

A second methodological challenge with designing well-being indicators is related to sample size which contains households with well-being. In chapter 3 I found that if building the well-being variable would include components of DSL, the sample would be too small to be able to run any meaningful statistical analysis. For example, including DSL characteristics (e.g. solid shelter, clean cooking device, safe toilet) resulted in 1.4% of Nepalese sample and 2.1% of Zambian sample. This severely limited the possibility of running meaningful quantitative statistical tests.

A third methodological challenge with operationalizing well-being has been the issue of comparison with other studies using a eudaimonic understanding of well-being (Millward-Hopkins *et al* 2020, Rao and Min 2017, Claborn and Brooks 2019). These studies also depend on available data to build their well-being indicators, which results in different components of well-being included in each study. What is included in the proxies of well-being at a micro level, in the end, depends on research questions and if primary or secondary data is used.

Following the data imperfections, another limitation relates to statistical matching done in chapter 4. It is always preferable to use the original household expenditure for whom footprints are calculated. The decision to use two independent household surveys and estimate household footprints for the households in the USS survey using trends and distributions of energy footprints in the LCFS survey is not ideal and subject to uncertainties of under-or over- estimation. However, I found that categories contributing the most to the overall energy footprints could be calculated using original information from the USS. The regression models used to estimate public transport, housing water, recreation, and education constitute a little share (10%) of the overall footprint for USS households.

The final methodological limitation linked to household survey datasets relates to self-reported data, specifically expenditure, that might have been over-or under-estimated. Despite these limitations, the results add to our understanding of the size and distribution of energy footprints in investigated countries and their relationships with basic well-being outcomes.

The next methodological limitation ascribes to the difficulty to estimate energy footprints for products outside of the monetary markets. The calculation of household energy footprints relies on self-reported household expenditures, and in Global South countries spending on house fuels is often outside of this reporting as households often use collected firewood. I proposed a methodological innovation that uses other available characteristics linked to how fuels are used to estimate the expenditure or energy used. I recognize, however, that this type of accounting is subject to underestimation or overestimation.

As to the design of energy models introduced in this thesis, the limitation is typical for any type of input-output modeling and is largely connected with data misalignment. Input-Output (IO) tables are not designed for matching with household expenditure categorization. The sectors in the IO are highly aggregated when compared with detail available in household expenditure. So matching between IO and household sectors and product categories is not easy, nor perfect. Specifically, it is difficult to tell what ratio of inputs from IO sectors constitutes the production of a specific product for the household demand. Therefore energy footprints presented here should be taken as estimates and not as exact energy consumed even though they are comparable with other analyses (Rao *et al* 2019a, Millward-Hopkins *et al* 2020).

Similar misalignment issues arise when using the final energy from the International Energy Agency (IEA). The final energy used in each country is categorized into 23 industries that are using it. This is a high level of aggregation which makes it difficult to bridge with IO tables. Moreover, IEA does not cover all sectors in developing countries (as specified in chapter 3). Specifically, this limits the estimates done on certain products such as food. Indeed results for energy footprints for food are somewhat lower than what is reported in other countries in Global South with similar socio-economic characteristics (Rao *et al* 2019b).

Finally, despite the limitations and uncertainties described above, the research presented in this thesis provides important considerations for energy demand and well-being analysis. With the use of the concepts and methods presented in this thesis and being transparent about the limitations and uncertainties that come with the data, there is still the potential for valuable research on a household level in countries of Global North and South.

6.5 Suggestions for further research

There are many areas of future research that could follow from the limitations and research presented in this thesis. In the first place expanding this research to other case-study countries with the use of presented here energy model is the most obvious. There is a need for more studies on energy demand and well-being on a household level in the, but not limited to, Global South countries. In this thesis, I presented some examples from Africa and Asia but a similar analysis could also be present in other regions with different socio-economic and cultural characteristics. One example could be countries of the former Soviet Union. There is emerging research pointing to some of those countries as potentially interesting for further investigation, as their continuous reductions in energy intensities are in contrast to other countries within and outside the region (Lamb *et al* 2022).

In order to uncover lock-ins and enablers of switching from high to low energy demand, research should provide evidence using longitudinal studies. The need for further investigating impacts of modeling energy distributions for energy transition scenarios would benefit from employing panel household data for at least two reasons. First, some panel surveys have a number of households present in each iteration of data collection. This gives a possibility to track changes in household energy demand over time. Our life trajectory usually includes major lifestyles changes including moving away from the family house, starting a family or retiring. With each of those life stages, the potential energy demand and well-being outcomes change. Being able to analyze those life trajectories in relation to well-being and energy demand would be invaluable to better inform energy transition scenarios and potential distribution impacts inherent in those scenarios. Second, analyzing provisioning systems in the context of changing lifestyles of households would enable for investigating in more detail the enablers and lock-ins of achieving high well-being with low energy demand. In addition, considering social aspects of provisioning systems, such as political systems, laws, and regulations, investigating changes in energy demand and linked well-being could strengthen research areas of degrowth, and climate policies as well as contribute to the research of the effectiveness of welfare systems for climate mitigation.

This potential research avenue (pursued in this thesis through quantitative analysis) could be strengthened by a qualitative analysis. This thesis is a part of a larger project that benefitted from qualitative research, utilizing Max Neef's human need matrix, done during a field trip in Zambia and the UK. The results gave a deeper understanding of the context within which energy is consumed at a household level and helped to direct the statistical analysis. Future research could build upon methods proposed in this thesis that draw from various research areas, including ecological economics and sociology, and also expand the quantitative analysis with qualitative methods. Specifically, more insight is needed into motivations and choices within mobility services. This thesis shows how significantly mobility contributes to overall household energy footprints and it showed that mobility is an important category for households with higher incomes and high levels of well-being. With the aim of decoupling personal travel from need satisfaction (or in terms of air-transport - decoupling wants from energy-intensive activities) focusing on mobility services in relation to energy demand and well-being is vital for energy transition scenarios. What role private transportation plays at different life stages (Mattioli *et al* 2022, Mattioli 2020), and how does it link to increases or decreases in energy demand and overall well-being? These are important questions that are relevant for policy and transition studies.

Finally, through this study, it became evident that there are important angles of analyzing energy demand and well-being that were not explored in-depth in this thesis. For example, disaggregating the data by race emerged as a quite important characteristic to consider in an analysis. Future studies could solely focus on this dimension while analyzing household footprints, specifically in the context where race is an important layer for discussing just climate mitigation scenarios. Other important dimensions to build the analysis around are spatial differences, age, household size, disability, or gender.

6.6 Concluding remarks

At the time of writing these final remarks, the IPCC is in process of releasing its sixth Assessment Report from Working Group 3 (IPCC 2022). One of the headline statements of the report highlights the potential of demand-side mitigations options for reducing global GHG emissions. The reduction potential can be unlocked by changing end-use service provision while improving basic well-being for all. These insights resonate with the analysis presented in this thesis. Perhaps the most important result of my work is the analysis of provisioning systems in relation to energy use and well-being, which shows that access to collective services can result in lower energy demand. This insight stands in opposition to both the "doom and gloom" and "techno-optimist" narratives that currently dominate political messaging (Lamb *et al* 2020). The solutions to living well within limits are known and, as I indicate in this thesis, could lead to a more equal society. This thesis adds to demand-side studies that show that a sustainable world can be achieved. With all the evidence and accumulated knowledge of how to achieve living well within limits, what better source of the common purpose do researchers have than to switch the narrative to one of hope.

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Appendix A
Supporting information to Chapter 2: Final energy footprints in Zambia: Investigating links between household consumption, collective provision, and well-being

A.1 Working with data from the International Energy Agency (IEA)

A.1.1 Marine and aviation bunkers

The final energy extension is build based on IEA data from year 2011. The data needed to be adjusted with values for marine and aviation bunkers. First the total world values for international marine and aviation bunkers are taken out from IEA energy data for 2011. Next, the total output from GTAP was used to calculate proportion for each country for sector 49 (shipping) and 50 (aviation).

$$X_{j,i} = \frac{S_{j,i}}{S_j}$$

$X_{j,i}$ is a proportion share of sector ***j*** in country ***i,*** calculated by dividing spends on sector ***j*** in country ***i*** with total spends on sector ***j*** in all countries.

These proportions obtained from spends on shipping and aviation sectors in GTAP were used to calculated total energy use (TJ) corresponding to marine and aviation bunkers in each country.

A.1.2 IEA – residential sector

The residential sector, being the direct household energy use sector, was taken out from the mapping IEA to GTAP and it is added separately by the end of the energy calculation for each country.

A.1.3 IEA – road sector

The values for energy use in road sector do not distinguish between how much of the energy was used by household in form of private transportation and how much energy was used due to, for example, road freight. Therefore, road has to be split up into 3 components:

1) Direct energy/fuel use of households
2) Indirect energy/fuel use of households (i.e. embodied in trade for households etc.)
3) Commercial energy/fuel use

Based on Oswald calculations (Oswald *et al* 2020), we computed the ratios for private and commercial transport based on spending shares on sectors 47 and 48: Transport n.e.c and Trade in GTAP. In the GTAP classification Transport n.e.c includes commercial vehicle use and other transportation services like parcels deliveries. Trade sector, on the other hand, includes private fuel purchases.

The estimations were calculated as follows:

$$K_i = \frac{N_i}{N_i + M_i} * F_i$$

$$P_i = F_i - K_i$$

$$P_{di} = \frac{M_i}{M_i + N_i} * P_i$$

Where ***N*** corresponds to spends (in $) on Transport n.e.c in country ***i, M*** corresponds to spends in Trade sector in country ***i***, ***F*** is total road energy use (TJ) for country ***i***, ***K*** is commercial road energy use (TJ) in country ***i***, ***P*** is the private road energy (TJ) in country ***i***, and finally P^d corresponds to private direct road energy use (TJ). As a result, Oswald estimated that commercial road energy use constitutes between 20% and 50% of the total road energy for 70% of the countries represented in the IEA. Further, he estimated that the private road energy share and private direct energy share are both between 50% and 80% for 70% of the countries.

A.1.4 IEA to GTAP mapping

Approximately a half of GTAP sectors (sectors from 1 to 13 and from 19 to 26) correspond to International Standard Industrial Classification of All Economic Activities (ISIC) **rev 3** classification and the other half corresponds to Central Product Classification, version 1.0 (CPC 1.0) with GTAP sectors 14 to 18 and from 27 to 56. Sector 57th titled dwelling does not have any correspondence.

This split requires mapping to IEA to be done in two separated steps:

1. The first half of GTAP sectors is mapped to CPC whereas IEA sectors are mapped to ISIC rev 4. This requires firstly making a correspondence between CPC and ISIC rev 3 to then map sectors to ISIC rev 4 in which IEA sectors are presented.

2. The sectors for the IEA final energy have their concordance mapped to ISIC **rev 4**. Since the second half of GTAP sectors is mapped to ISIC rev 3, bridging between versions must be firstly made. ISIC

categorization is presented on three levels: division (e.g.2), group (e.g.20) and class (e.g. 201). After this matching GTAP with IEA sectors is quite straightforward. This mapping can include more than one IEA sector being mapped to GTAP sector.

The road sector is still mapped to GTAP, however only partial values of the total road energy is taken in the calculation. During quantification of energy footprints, values for direct household energy use for road and residence is added separately in the end of calculations in form of two values spread across household spending categories connected to road (fuel, diesel, petrol) and residential use (coal, electricity, kerosene etc) according to household's spending shares on these energy items.

As a result, the concordance matrix is a one to many (IEA to GTAP) mapping. This means that any given IEA sector can correspond to more than one GTAP sectors.

Table A-1 Correspondence table: IEA to GTAP

IEA id	IEA Sectors name	GTAP sectors name	GTAP id
1	Iron and Steel	Ferrous metals	35,
2	Chemical and petrochemical	Petroleum, coal products Chemical, rubber, plastic products Ferrous metals	32, 33, 35
3	Non-ferrous metals	Petroleum, coal products Metals nec	32, 36,
4	Non-metallic minerals	Mineral products nec	34,
5	Transport equipment	Motor vehicles and parts Transport equipment nec Machinery and equipment nec Manufactures nec	38, 39, 41, 42
6	Machinery	Chemical, rubber, plastic products Metal products Motor vehicles and parts Transport equipment nec Electronic equipment Machinery and equipment nec Manufactures nec	33, 37, 38, 39, 40, 41, 42
7	Mining and quarrying	Coal Oil Gas Minerals nec Construction	15, 16, 17, 18, 46
8	Food and tobacco	Paddy rice Vegetables, fruit, nuts Crops nec Animal products nec Wool, silk-warm cocoons Bovine meat products Meat products nec	1, 4, 8, 10, 12, 19, 20, 21,

		Vegetables, oils and fats Dairy products Processed rice Sugar Food products nec Beverages and tobacco products Chemical rubber, plastic products	22, 23, 24, 25, 26, 33
9	Paper, pulp and printing	Textiles, Paper products, publishing Metal products Manufactures nec	27, 31, 37, 42,
10	Wood and wood products	Wood products Leather products Manufactures nec	29, 30, 42
11	Construction	Construction	46
12	Textile and leather	Textiles Wearing apparel Leather products Mineral products nec Motor vehicles and parts Manufactures nec	27, 28, 29, 34, 38, 42
13	Non-specified (industry)	Textiles Wearing Apparel Leather products Wood products Paper products, publishing Chemical, rubber, plastic products Mineral products nec Metal products Transport equipment nec Machinery and equipment Manufacturer nec	27, 28, 29, 30, 31, 33, 34, 37, 39, 41, 42
14	Domestic aviation	Air transport	50
15	Road	Transport nec	48
16	Rail	Transport nec	48
17	Pipeline transport	Transport nec Electricity Gas distribution	48, 43, 44
18	Domestic navigation	Water transport	49,
19	Non-specified (transport)	Transport nec Recreational and other services	48, 55,
20	Residential	Taken out from mapping and added seperatly (direct household energy use)	
21	Commercial and public services	Fishing, Minerals nec, Textiles,	14, 18, 27,

		Wood products, Paper products, publishing Petroleum, coal products, Chemical, rubber, plastic products, Mineral products nec Metal products Motor vehicle and parts Transport equipment nec, Electronic equipment, Machinery and equipment Manufactures nec Water, Construction, Trade Transport nec Communication Financial services nec Insurance Business services nec Recreational and other services Public admin, defence, education, health	30, 31, 32, 33, 34, 37, 38, 39, 40, 41, 42, 45, 46, 47, 48, 51, 52, 53, 54, 55, 56
22	Agriculture/forestry	Paddy rice, Wheat, Cereal grains nec Vegetables, fruit, nuts Oil seeds, Sugar, cane, sugar beet, Plant-based fibres, Crops nec Bovine, cattle, sheep and goats, horses, Animal products nec Raw milk, Wool, silk-worm cocoons, Forestry	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
23	Fishing	Fishing	14
24	Non-specified (other)	Public Admini, Defense, Education, Health Dwellings	56, 57

A.2 COICOP to GTAP correspondence

The third, direct, mapping to GTAP sectors is done with the original Zambian expenditure categorization. This concordance matrix has 233 rows by 57 columns. The mapping uses the standard COICOP to GTAP concordance as an intermediate (65 COICOP cat by 57 GTAP sectors). This bridging is not straight forward nor there exists an official document that would present concordance between COICOP and GTAP. Concordance between CPC and COICOP, however, exists. The following steps need to be then done for mapping:

CPC to COICOP → CPC to ISIC rev 3 → ISIC rev 3 to GTAP

The steps needed to build Zambian COICOP to GTAP mask include following:

1. Building mask between standard COICOP categorization and GTAP (65 by 57) which uses CPC and ISIC rev 3 to bridge between different categorizations.

2. Building a mask between Zambian categorization and standard COICOP categorization (233 by 65).

3. Using the mask build in step 2 as an intermediate, make a Zambian COICOP to GTAP mask (233 by 57).

Mapping between Zambian COICOP categories and standard COICOP (step 2) is done without any official guidelines. Most of the categories are straight forward to link, as they are similar or named in the exact same way.

Please refer to excel file: supplementary materials to see COICOP-GTAP correspondence matrix (**Table S2**) and Zambian COICOP – GTAP correspondence (**Table S3**)

A.3 Expenditure equivalents – direct energy

Zambian households do not only rely on the monetary market for obtaining house fuels - one-third of surveyed households reported using collected wood or self-produced charcoal for their cooking fuels. This imposed a challenge for calculating a household's energy footprint, which relies on expenditures as a main input for the household final demand.

To be able to account for the direct energy use of households that do not purchase their fuels, an expenditure equivalents were calculated. This was calculated for four out of nine fuel products reported to be used by households:

- Charcoal – 33.6 % of all households reported using charcoal
- Firewood – 44% of all households reported using firewood
- Electricity – 20% of all households reported using electricity for cooking and 35% for lighting
- Petrol – 7% of all households reported to use petrol.

For the remaining five products: paraffin, kerosene, diesel for home use, gas, and coal only 3% of households reported any spends on these products, hence they were not used in the calculation.

In Zambia the price of firewood or charcoal depends on the geographical location and accessibility to the forest (Mulombwa 1998). Amount of wood purchased by a household varies depending on income and the number of meals per day consumed. This information along with the type of cooking device and purpose of electricity use was available in the LCMS so households which reported expenditures on cooking fuels could be used to match households with similar characteristics but no spends. For the allocation of the direct energy expenditure, district level (74 district) proved to be the most robust with on average 265 households per district. Calculation of average spends was done per capita. For the equivalents related to spends on transport (petrol used) household location, income level and reported spends on petrol were used.

Variables chosen for the analysis and their characteristics are as follows:

- I used the original household expenditures: reported in a monthly expense on a given product.

- Expenditures are used in their original currency Kwacha

- The original dataset includes households that have spends on the direct energy and 3932 households that do not have any spends on the direct energy

Figure A-1 Variables included in the calculation of average spends on direct energy products.

Taking conditions illustrated above (Fig. S1), not every district had an example of a household that would meet all the above conditions. Within households that do not have spends on firewood there is a large group of households, which meet one of the conditions in each group listed above (e.g. are from district 5, use brazier, are from small scale stratum and have two meals per day), but do not have their match within households that have spending on firewood. If that is a case, the match will be done excluding variable corresponding to number of meals or snacks per day. The hierarchy of exclusion is illustrated in the Table A-2, which is an example for the firewood case

All calculations are made based on per capita values. Total in tables below presents number of households that meet certain conditions. For each direct energy product, I assumed different conditions that need to be met for a household to be assigned an average. For example, there were 3227 households, which reported no spends on direct energy, but indicated using collected or purchased firewood for cooking. To assign an average of spending that they could have had, I used households that reported spends on the direct energy. Then, depending on the availability of data I matched average spending to households that are coming from the same district, stratum, use the same cooking device and have the same number of meals.

Conditions for selecting household for assigning firewood:

- Households that do not have spends on the direct energy

- Households that collect or purchase firewood for cooking.

Table A-2 Collected and purchased firewood case: steps for assigning average spends to households that have no spends on direct energy

Number of matched observations when selecting	**2539**	+ extra **267**	+ extra **169**	+ extra **30**	+ extra **162**	+ extra **34**	+ extra **10**	+ extra **8**	+ extra **8**	Total: 3227
district	x	x	x	x	province	province	province	province	region	
stratum	x	x	x	x	x	x	x	x	x	
Cooking dev	x	x			x	x			x	
meals	x		x		x		x		x	

Results of calculating equivalised expenditure on the distribution of the total energy footprints, direct-EF and total expenditures and direct-expenditures are presented in figures A-2, A-5 below. Figures to the left correspond to distributions before calculating equivalised expenditure and figures to the right are after equivalised expenditures were added to the dataset for the analysis.

a) BEFORE

b) AFTER

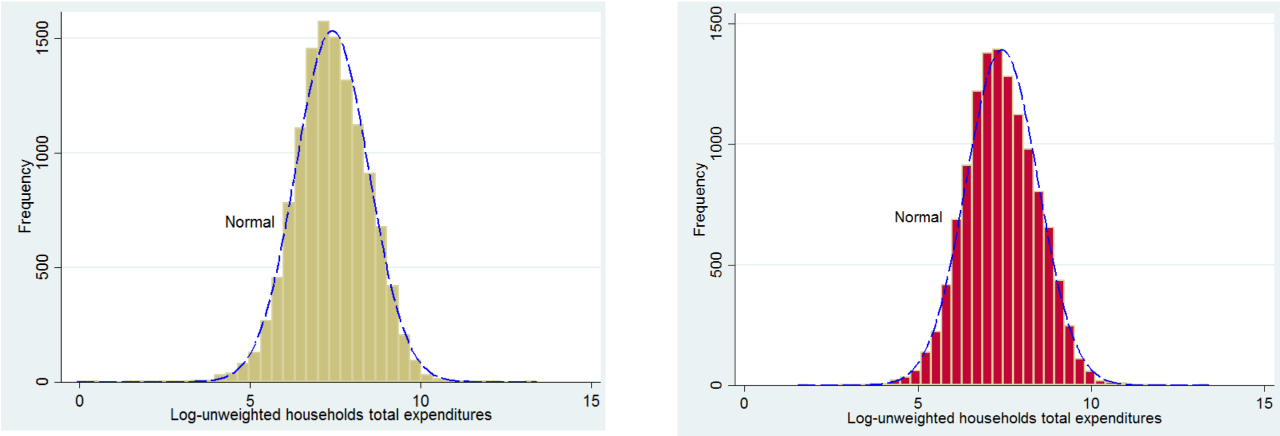

Figure A-2 Total household expenditures. Unweighted, log-transformed expenditures before applying equivalised expenditures a), and after b).

a) BEFORE

b) AFTER

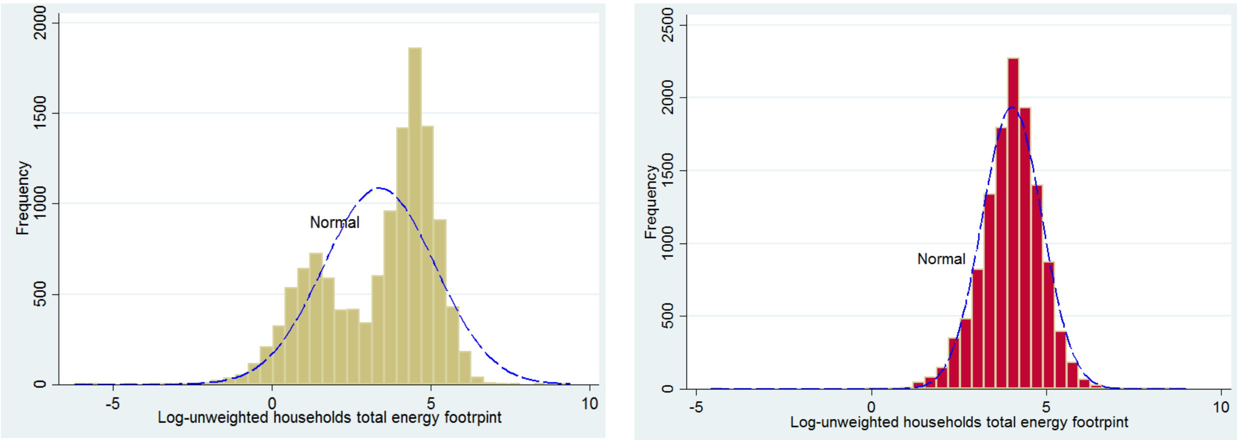

Figure A-3 Total household energy footprint. Unweighted, log-transformed energy footprints calculated before use of equivalised expenditures a), and after b).

a) BEFORE

b) AFTER

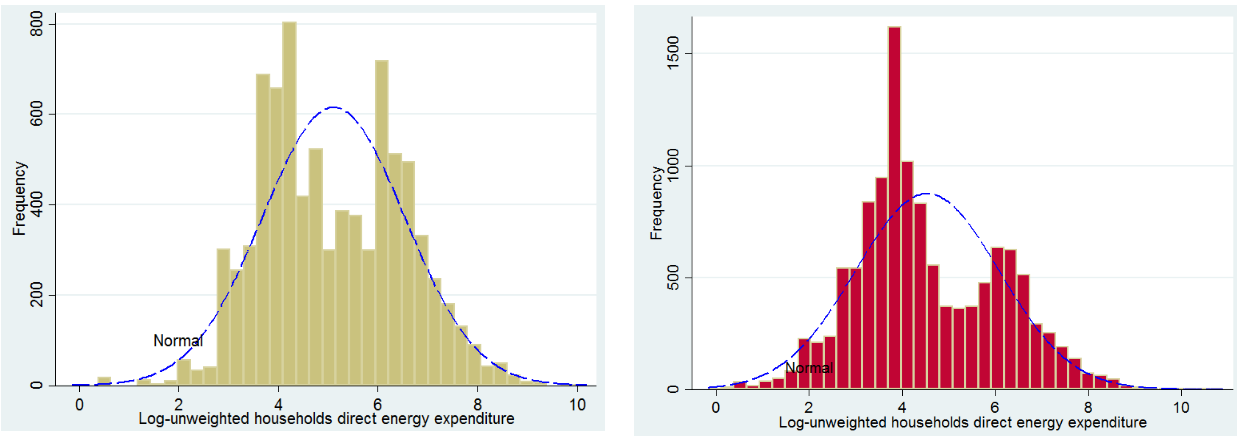

Figure A-4 Direct household expenditures. Unweighted, log-transformed expenditures linked to the direct-energy use, before applying equivalised expenditures a), and after b).

a) BEFORE b) AFTER

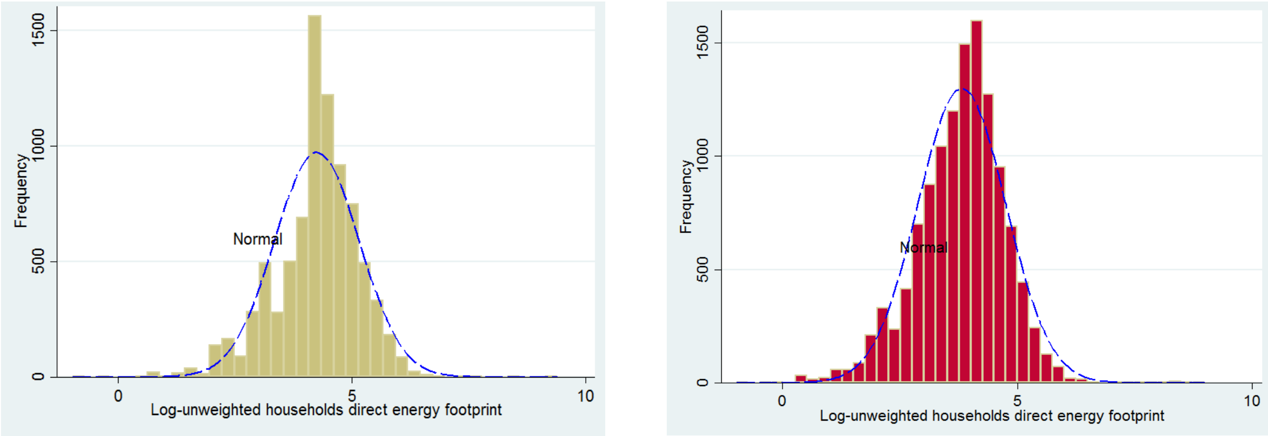

Figure A-5 Direct household energy footprint. Unweighted, log-transformed direct-energy footprints calculated before use of equivalised expenditures a), and after b).

A.4 Selection of variables for the analysis

The selection of variables relevant to the analysis is based on three factors:

1) Literature and knowledge about the country's context. Socio-economic characteristics linked to household size, location, and income are chosen based on previous research, which shows the importance of these variables for household footprints, e.g. (Oswald *et al* 2020, Wiedenhofer *et al* 2013, Donato *et al* 2015, Büchs and Schnepf 2013). In addition, studies investigating countries in Global South point to the importance of, for example, electricity and sanitation access for outcomes related to education or health (Pachauri and Daniel 2004, Oparaocha and Dutta 2011, Kumar 2018)

2) Provisioning systems are an important part of our analysis, therefor variables linked to physical and social provisioning are considered. This includes, for example, access to markets, public transport, schools, sewage systems, and electricity.

3) We base our understanding of well-being on the theory of human need proposed by Gough and Doyal (Doyal and Gough 1991). Based on their proposal of possible variables that might inform about needs achievement, and based on available data in Zambian LCMS, we proposed, where possible, variables corresponding to intermediate and basic needs (Table A-3).

These variables served as a primary input for selecting logistic regression models.

Table A-3 Variables considered for the analysis. Selection based on the conceptualization of Theory of Human Need (Doyal and Gough 1991).

INTERMEDIATE NEEDS	Selected variables (LCMS survey)
Adequate nutritional food and water	
adequate food	HHs with three or more meals per day.
access to safe drinking water	HHs with access to safe water within one km from home.
treating drinking water	
access to water	
Adequate protective housing	
durable materials used for walls, roof, floor	Type of materials used to build walls, roof and floor. Non-durable materials include grass/straw/thatch, mud brick, hardboard, plastic, pole, iron sheets. In the analysis variables corresponding to having palm roof and the traditional hut were primarily used as proxies of having solid shelter.
adequate space per person	Square meters per person (calculated using only living areas in the dwelling, without kitchen and bathroom and considering the number of persons living in the household)
toilet	HH has an indoor or outdoor flush toilet.
sanitary system connection	Dwelling connected to the sewage system
Non-hazardous work environment	No data available
Non-hazardous physical environment	No data available
Appropriate healthcare	
access to healthcare facilities	Access to a health facility within 5 km from home.
children under age of 5 vaccination	Children with a full course of vaccine (incl. BCG, DPT, Polio, and measles vaccines)
access to maternal healthcare	No data available
Security in childhood	No data available
Significant primary relationships	No data available
Physical security	No data available
access to clean cooking fuels	Type of main cooking fuel used by household (charcoal, wood, electricity, gas)
Economic security	
self-assessed poverty	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?'
access to paid work	Income
Safe birth control and childbearing	
access and knowledge about preconception	No data available

Table A-3 **continues…**	
Basic education	
Attended school	Education level including mother's education (households with children under the age of five); household's head and household's spouse education
highest grade	
BASIC NEEDS	
Physical Health	
disability and not able to participate in normal activities	Presence of disability and type of disability (data not used in the analysis due to the limited number of observations)
children under age of 5 malnutrition status	Available: stunting, underweight, and weighting. Malnutrition based on Z-scores calculated based on World Health Organization guidelines.
chronic illness	No data available
Autonomy	
disability and not able to participate in normal activities	No data available
Mental Health	
disability and not able to participate in normal activities	No data available
Cognitive Understanding	
literacy	No data available
Opportunities to Participate	
time - use (household work)	No data available

A.5 Logistic regression

Table A-4 Odds ratio for all outcomes, healthy child, basic education, safe water, and sufficient food

	(1) All outcomes		**(2) Healthy child**		**(3) Basic edu**		**(4) Safe water**		**(5) Suff. food**	
Province:										
Copperbelt vs Central	**0.41****	(-3.16)	**0.49***	(-2.14)	0.93	(-0.30)	0.84	(-0.73)	**0.36*****	(-4.27)
Eastern vs Central	**0.37*****	(-3.53)	0.89	(-0.37)	**0.25*****	(-6.14)	**2.05*****	(3.42)	0.97	(-0.17)
Luapula vs Central	**0.34*****	(-3.44)	**0.49***	(-2.25)	**0.55***	(-2.56)	1.18	(0.73)	**0.29*****	(-5.49)
Lusaka vs Central	0.83	(-0.61)	0.68	(-0.88)	**0.41****	(-2.96)	**1.82***	(2.13)	1.84	(1.89)
Muchinga vs Central	**0.33*****	(-3.84)	1.03	(0.08)	**0.56****	(-2.66)	**0.54****	(-2.72)	**0.56****	(-2.62)
Northern vs Central	**0.19*****	(-5.66)	0.81	(-0.65)	**0.58***	(-2.43)	**0.33*****	(-5.10)	**0.28*****	(-5.61)
North Western vs Central	**0.44****	(-2.79)	**0.37****	(-2.70)	0.65	(-1.64)	0.77	(-1.07)	**0.54***	(-2.45)
Southern vs Central	1.11	(0.42)	0.92	(-0.27)	0.71	(-1.62)	1.44	(1.73)	**3.86*****	(6.00)
Western vs Central	0.58	(-1.60)	0.68	(-1.17)	1.02	(0.07)	**0.53****	(-2.85)	**0.63***	(-2.08)
Household size	1.07	(1.20)	1.05	(0.68)	**1.13****	(2.89)	**1.15****	(3.02)	0.99	(-0.32)
Number of children age>5	1.20	(1.43)	**1.99*****	(6.00)	1.07	(0.68)	0.91	(-0.99)	1.19	(1.84)
Number of children	**0.75***	(-2.11)	**0.50*****	(-5.39)	**0.78***	(-2.24)	0.90	(-1.03)	0.97	(-0.26)
Female headed household	0.80	(-1.02)	1.24	(1.07)	**1.64****	(3.03)	0.97	(-0.16)	1.02	(0.13)
Household head's age	0.99	(-1.08)	1.00	(0.24)	**0.96*****	(-6.50)	1.00	(0.55)	1.00	(-0.44)
Not poor	**2.56*****	(5.41)	**1.46***	(2.43)	**1.60*****	(4.01)	1.08	(0.70)	**1.93*****	(5.89)
Income ($/OECD cap)	**1.00***	(2.38)	1.00	(0.19)	**1.00*****	(4.12)	1.00	(0.26)	1.00	(0.93)
EF Miscellaneous goods and services (GJ/cap)	1.14	(0.31)	**3.44***	(2.39)	1.05	(0.10)	1.61	(0.96)	0.79	(-0.43)
Indirect EF (GJ/cap)	**1.33****	(2.89)	0.94	(-0.49)	**1.35****	(3.04)	1.05	(0.55)	**1.91*****	(4.76)
Bicycle	0.77	(-1.60)	0.99	(-0.04)	1.05	(0.45)	1.09	(0.80)	**1.33***	(2.47)
Car	**2.75*****	(3.33)	**2.36***	(1.96)	2.21	(1.52)	1.64	(1.37)	**3.04***	(2.00)
Mobile phone	**1.92*****	(3.52)	1.07	(0.41)	**1.61*****	(4.03)	1.06	(0.54)	**1.28***	(2.25)
Secondary school w/n 5km	**1.51***	(2.16)	0.86	(-0.98)	**1.42****	(2.80)	**1.28***	(2.05)	0.97	(-0.26)
Food market w/n 5km	**1.53***	(2.38)	**0.68****	(-2.68)	1.00	(-0.03)	**1.36****	(2.65)	1.02	(0.12)
Health facility w/n 5km	1.36	(1.70)	1.20	(1.15)	1.17	(1.28)	**1.33***	(2.43)	1.22	(1.65)
Public transport w/n 5 km	1.08	(0.52)	0.97	(-0.22)	1.17	(1.39)	**1.25***	(2.03)	0.92	(-0.74)
Detached house	**1.64****	(3.06)	0.85	(-0.88)	1.35	(1.92)	**1.64*****	(3.38)	**1.58****	(3.02)
Flush toilet	**3.07*****	(4.99)	1.08	(0.25)	**3.81*****	(3.91)	**4.56*****	(3.88)	1.76	(1.76)
% rural households w/n district	1	(.)								
26-50 vs 0-25	0.99	(-0.02)	1.59	(1.09)	1.32	(0.99)	**0.43*****	(-3.58)	0.72	(-1.30)
51-75 vs 0-25	**2.45***	(2.41)	2.11	(1.47)	**2.13***	(2.38)	1.10	(0.34)	1.29	(0.79)
76-100 vs 0-25	2.07	(1.88)	2.26	(1.61)	1.79	(1.73)	0.77	(-0.88)	1.08	(0.23)
% electrified households w/n district	1	(.)								
21-40 vs 0-20	**1.63***	(2.42)	1.39	(1.55)	**1.64*****	(3.41)	**1.59****	(3.12)	1.19	(1.18)
41-70 vs 0-20	**2.75****	(3.25)	1.83	(1.76)	**2.01****	(2.93)	**1.80***	(2.37)	1.38	(1.25)
71+ vs 0-20	**4.21****	(3.02)	2.14	(1.13)	**5.54*****	(3.77)	1.25	(0.57)	1.68	(1.18)
Mother's edu (children <5yr.)										
Junior sec. (8-9 yr.) vs no edu			**1.58***	(2.32)						
Senior sec. (10-12 yr.) vs no edu			**1.82***	(2.11)						
Tertiary (12+yr.) vs no education			3.25	(1.93)						
_cons	0.014***	(-7.53)	**6.30****	(2.75)	0.38*	(-2.19)	0.33**	(-2.66)	0.22***	(-3.34)
N	4264		4264		4264		4264		4264	
McFadden pseudo R^2	0.40		0.086		0.29		0.19		0.28	
McKelvey & Zavoina pseudo R^2	0.58		0.20		0.56		0.37		0.53	
AIC	4284411		4408128		6565848		7057630		6547653	
BIC	4284627		4408363		6566064		7057847		6547869	
chi2	576.6		143.1		426.6		433.2		491.4	

Exponentiated coefficients; z statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A-5 Odds ratio for healthy child by provinces.

	Central		Copperbelt		Eastern		Luapula		Lusaka		Munchinga		Northern		North Western		Southern		Western	
Household size																				
Number of children age>5	1.28	(1.18)	0.94	(-0.33)	0.95	(-0.46)	1.06	(0.30)	**2.24***	(2.48)	**0.53****	(-2.84)	0.95	(-0.27)	0.83	(-0.87)	1.35	(1.53)	1.15	(0.61)
Number of children	2.11	(1.88)	**2.58****	(2.58)	1.76	(1.76)	**2.40*****	(3.55)	**3.60***	(2.06)	**4.39***	(2.28)	2.34	(1.82)	**2.29****	**(2.77)**	1.06	(0.20)	**3.99*****	(4.20)
Female headed household	0.52	(-1.79)	0.38*	(-2.40)	0.72	(-1.06)	**0.45***	(-2.49)	**0.086****	(-2.90)	0.35	(-1.54)	**0.39***	(-2.25)	0.50	(-1.55)	0.62	(-1.20)	0.22**	(-3.04)
Household head's age	1.40	(0.42)	1.05	(0.08)	0.89	(-0.21)	1.39	(0.62)	**87.7****	(2.86)	1.15	(0.15)	0.55	(-0.97)	1.55	(0.69)	0.91	(-0.15)	0.87	(-0.25)
Not poor	1.00	(-0.13)	1.03	(1.03)	1.01	(0.45)	1.00	(0.22)	0.95	(-1.01)	**1.09****	(2.66)	1.02	(0.83)	1.00	(-0.11)	1.00	(-0.21)	1.01	(0.73)
Income ($/OECD cap)	0.69	(-0.68)	**2.98***	(2.42)	1.74	(1.47)	1.77	(1.59)	1.47	(0.50)	0.71	(-0.61)	1.31	(0.47)	0.66	(-0.70)	0.97	(-0.07)	1.32	(0.45)
EF Misc. (GJ/cap)	1.00	(-0.12)	1.00	(0.37)	1.00	(1.12)	1.00	(0.15)	**1.00***	(-2.38)	1.00	(-1.29)	1.00	(0.31)	1.00*	(2.21)	1.00	(-1.60)	1.00	(1.36)
Indirect EF (GJ/cap)	1.15	(0.10)	2.97	(1.42)	275.4	(1.65)	5.22	(0.39)	**376.6*****	(3.57)	119.2	(1.35)	0.94	(-0.03)	11.3	(0.76)	0.099	(-1.91)	**24656.6***	(2.04)
Bicycle	0.47	(-1.02)	2.52	(1.28)	0.12	(-1.16)	42.9	(1.71)	0.12*	(-2.05)	**0.029****	(-2.86)	3.71	(0.85)	0.11	(-1.33)	**12.2*****	(3.47)	1.72	(0.27)
Car	1.24	(0.38)	1.45	(0.71)	0.52	(-1.72)	0.93	(-0.19)	**10.1***	(1.97)	**7.25****	(2.89)	0.89	(-0.25)	**0.23****	(-2.94)	0.77	(-0.62)	3.59	(1.60)
Mobile phone	**0.071****	(-2.82)	**14.4***	(2.46)	0.29	(-0.81)	0.79	(-0.16)	1	(.)	**0.033***	(-1.96)	1	(.)	6.40	(0.94)	12.0	(1.77)	1	(.)
Secondary school w/n 5km	0.73	(-0.59)	**0.28***	(-2.09)	0.99	(-0.03)	1.74	(1.14)	1.10	(0.16)	**4.36***	(2.11)	2.23	(1.77)	2.17	(1.52)	1.07	(0.17)	1.03	(0.05)
Food market w/n 5km	0.57	(-1.12)	1.20	(0.29)	0.84	(-0.47)	0.40	(-1.79)	**0.14***	(-2.22)	0.55	(-0.87)	1.33	(0.66)	**3.36***	(2.09)	0.90	(-0.21)	0.99	(-0.01)
Health facility w/n 5km	0.53	(-1.00)	0.40	(-1.24)	**0.32****	(-2.87)	0.79	(-0.59)	0.19	(-1.62)	1.51	(0.53)	0.47	(-1.80)	0.36	(-1.83)	1.63	(1.14)	0.56	(-0.91)
Public transport w/n 5 km	0.88	(-0.31)	1.14	(0.19)	1.38	(0.79)	1.44	(1.00)	1.06	(0.08)	2.76	(1.36)	1.32	(0.62)	**3.62***	(2.20)	1.12	(0.24)	0.72	(-0.60)
Detached house	0.74	(-0.47)	0.66	(-0.76)	0.67	(-1.06)	1.31	(0.60)	**21.1****	(2.82)	**0.089****	(-2.99)	1.67	(1.03)	0.50	(-1.35)	1.13	(0.28)	1.74	(1.09)
Flush toilet	0.86	(-0.30)	0.52	(-1.25)	0.81	(-0.50)	1.46	(0.71)	1.75	(0.71)	2.25	(0.89)	**0.23***	(-2.28)	0.85	(-0.24)	1.57	(0.83)	0.16	(-1.66)
% rural hh w/n district	4.70	(1.92)	0.66	(-0.61)	1	(.)	146.3	(1.36)	0.91	(-0.07)	1	(.)	2.58	(0.73)	2.48	(0.55)	1.26	(0.23)	3.89	(0.55)
26-50 vs 0-25																				
51-75 vs 0-25			1.00	(-0.00)	1	(.)	1	(.)			1	(.)			1	(.)	1.64	(0.39)		
76-100 vs 0-25	1.23	(0.34)			0.65	(-0.81)	0.70	(-0.53)	1.52	(0.26)	6.30	(1.25)	1.17	(0.29)	0.44	(-1.61)	3.19	(1.12)	0.81	(-0.32)
% electrified hh w/n district	1.41	(0.58)	0.31	(-1.57)	0.74	(-0.67)	1.33	(0.31)	2.22	(0.72)	3.31	(0.75)	2.30	(1.03)	**0.13***	(-2.47)	0.87	(-0.17)	0.16	(-1.64)
21-40 vs 0-20																				
41-70 vs 0-20	**4.15***	(2.52)	1.24	(0.29)			0.88	(-0.19)	1	(.)	**47.2****	(2.70)	2.21	(0.92)	3.12	(1.61)	0.26	(-1.64)	**0.22***	(-2.07)
Mother's education (children <5yr.)	1	(.)	0.58	(-0.83)	1	(.)	0.79	(-0.28)	1	(.)	27.2	(1.83)	1	(.)	1	(.)	1.28	(0.21)		
Junior sec .vs no education																				
Senior sec vs no education	**3.96***	(2.06)	**8.87****	(3.13)	1.02	(0.04)	0.76	(-0.51)	3.16	(1.55)	1.89	(0.76)	0.77	(-0.49)	**4.32***	(2.10)	1.30	(0.53)	**0.31***	(-2.06)
Tertiary vs no education	3.18	(1.71)	**5.61***	(2.54)	0.20	(-1.75)	2.31	(0.87)	3.84	(1.31)	**146.1***	(2.36)	0.88	(-0.16)	1.17	(0.25)	**7.58***	(2.41)	0.38	(-1.45)
Household size	4.05	(1.20)	**13.3***	(2.57)	1	(.)	1	(.)	1	(.)	1	(.)	5.26	(0.89)	0.11	(-1.21)	10.7	(1.04)	1	(.)
Total expenditure per capita	1.00	(1.21)	**1.00***	(-2.03)	1.01	(1.24)	0.99	(-1.77)	**1.01***	(2.26)	**1.01****	(2.67)	1.00	(-0.80)	1.01	(0.91)	**0.99*****	(-3.50)	1.00	(-0.54)
_cons	5.34	(1.05)	53.5**	(2.76)	17.2**	(2.80)	8.45	(1.95)	9.18	(0.89)	3.98	(0.65)	15.7*	(2.13)	41.6**	(3.28)	4.95	(1.35)	93.4**	(2.92)
N	408		434		507		401		235		291		410		350		500		362	
p-value	0.004		0.000		0.072		0.023		0.002		0.001		0.013		0.016		0.001		0.008	
McFadden pseudo R^2	0.16		0.26		0.12		0.16		0.39		0.37		0.12		0.30		0.13		0.20	
McKelvey & Zavoina	0.35		0.47		0.33		0.33		0.78		0.68		0.25		0.56		0.38		0.47	
AIC	315661		517737		641811		438990		305758		111065		400492		238550		467904		267870	
BIC	315765		517847		641909		439094		305838		111157		400592		238651		468022		267963	
chi2	47.9		64.7		32.3		41.0		46.6		50.6		42.1		42.6		57.7		42.3	

Exponentiated coefficients; *t* statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

A.6 Average Marginal Changes

Table A-6 AME for all outcomes, healthy child, basic education, safe water and sufficient food.

	All outcomes		Healthy child		Basic edu		Safe water		Sufficient food	
	Change	**p-value**	**Change**	**p-value**	**Change**	**p-value**	**Change**	**p-value**	**Change**	**p-value**
Province:										
Copperbelt vs Central	-0.10	0.00	-0.07	0.04	-0.01	0.76	-0.03	0.46	-0.19	0.00
Eastern vs Central	-0.10	0.00	-0.01	0.71	-0.23	0.00	0.13	0.00	-0.01	0.87
Luapula vs Central	-0.11	0.00	-0.07	0.02	-0.10	0.01	0.03	0.46	-0.23	0.00
Lusaka vs Central	-0.02	0.54	-0.03	0.40	-0.15	0.00	0.11	0.03	0.11	0.05
Muchinga vs Central	-0.11	0.00	0.00	0.93	-0.10	0.01	-0.12	0.01	-0.11	0.01
Northern vs Central	-0.16	0.00	-0.02	0.51	-0.09	0.02	-0.22	0.00	-0.24	0.00
North Western vs Central	-0.09	0.00	-0.11	0.01	-0.07	0.10	-0.05	0.28	-0.12	0.01
Southern vs Central	0.01	0.67	-0.01	0.78	-0.06	0.11	0.07	0.08	0.22	0.00
Western vs Central	-0.06	0.10	-0.03	0.25	0.00	0.95	-0.13	0.00	-0.09	0.04
Eastern vs Copperbelt	-0.01	0.77	0.06	0.08	-0.21	0.00	0.16	0.00	0.18	0.00
Luapula vs Copperbelt	-0.02	0.58	0.00	0.98	-0.09	0.04	0.07	0.15	-0.04	0.36
Lusaka vs Copperbelt	0.07	0.03	0.04	0.42	-0.14	0.01	0.14	0.01	0.30	0.00
Muchinga vs Copperbelt	-0.02	0.52	0.07	0.04	-0.09	0.05	-0.09	0.07	0.08	0.07
Northern vs Copperbelt	-0.06	0.02	0.05	0.11	-0.08	0.08	-0.19	0.00	-0.05	0.29
North Western vs Copperbelt	0.01	0.81	-0.04	0.43	-0.06	0.22	-0.02	0.72	0.07	0.13
Southern vs Copperbelt	0.11	0.00	0.06	0.06	-0.05	0.29	0.10	0.02	0.41	0.00
Western vs Copperbelt	0.03	0.34	0.04	0.33	0.02	0.73	-0.09	0.06	0.10	0.03
Luapula vs Eastern	-0.01	0.77	-0.06	0.02	0.13	0.00	-0.10	0.00	-0.22	0.00
Lusaka vs Eastern	0.08	0.03	-0.02	0.55	0.08	0.12	-0.02	0.67	0.11	0.05
Muchinga vs Eastern	-0.01	0.70	0.01	0.64	0.13	0.00	-0.25	0.00	-0.10	0.01
Northern vs Eastern	-0.05	0.03	-0.01	0.76	0.14	0.00	-0.35	0.00	-0.23	0.00
North Western vs Eastern	0.01	0.56	-0.10	0.01	0.15	0.00	-0.18	0.00	-0.11	0.01
Southern vs Eastern	0.12	0.00	0.00	0.90	0.17	0.00	-0.06	0.08	0.22	0.00
Western vs Eastern	0.04	0.25	-0.02	0.39	0.23	0.00	-0.26	0.00	-0.08	0.05
Lusaka vs Luapula	0.09	0.02	0.04	0.42	-0.05	0.37	0.08	0.14	0.34	0.00
Muchinga vs Luapula	-0.00	0.94	0.07	0.01	0.00	0.92	-0.16	0.00	0.12	0.00
Northern vs Luapula	-0.04	0.09	0.05	0.08	0.01	0.78	-0.26	0.00	-0.01	0.87
North Western vs Luapula	0.02	0.42	-0.04	0.34	0.03	0.51	-0.08	0.06	0.11	0.01
Southern vs Luapula	0.12	0.00	0.06	0.02	0.04	0.22	0.04	0.33	0.44	0.00
Western vs Luapula	0.05	0.15	0.04	0.25	0.11	0.01	-0.16	0.00	0.14	0.00
Muchinga vs Lusaka	-0.09	0.01	0.04	0.40	0.05	0.31	-0.23	0.00	-0.22	0.00
Northern vs Lusaka	-0.13	0.00	0.02	0.72	0.06	0.27	-0.33	0.00	-0.34	0.00
North Western vs Lusaka	-0.07	0.08	-0.08	0.17	0.08	0.18	-0.16	0.01	-0.22	0.00
Southern vs Lusaka	0.03	0.30	0.03	0.49	0.09	0.05	-0.04	0.39	0.11	0.04
Western vs Lusaka	-0.04	0.34	-0.00	0.99	0.15	0.00	-0.24	0.00	-0.20	0.00
Northern vs Muchinga	-0.04	0.09	-0.02	0.46	0.01	0.85	-0.10	0.02	-0.13	0.00
North Western vs Muchinga	0.02	0.37	-0.11	0.01	0.02	0.56	0.07	0.13	-0.00	0.91
Southern vs Muchinga	0.13	0.00	-0.01	0.73	0.04	0.23	0.19	0.00	0.33	0.00

Table A-6 continues…	All outcomes		Healthy child		Basic ed		Safe water		Sufficient food	
	Change	p-value	Change	p-value	Change	p-value	Change	p-value	Change	p-value
Western vs Muchinga	0.05	0.13	-0.04	0.23	0.10	0.01	-0.00	0.93	0.02	0.60
North Western vs Northern	0.07	0.01	-0.09	0.03	0.02	0.68	0.17	0.00	0.12	0.01
Southern vs Northern	0.17	0.00	0.01	0.68	0.03	0.33	0.29	0.00	0.45	0.00
Western vs Northern	0.09	0.00	-0.02	0.59	0.10	0.01	0.10	0.04	0.15	0.00
Southern vs North Western	0.10	0.00	0.10	0.01	0.02	0.70	0.12	0.01	0.33	0.00
Western vs North Western	0.03	0.45	0.08	0.09	0.08	0.09	-0.08	0.12	0.03	0.57
Western vs Southern	-0.07	0.03	-0.03	0.35	0.06	0.09	-0.20	0.00	-0.30	0.00
Household size										
+1	0.01	0.24	0.00	0.49	0.02	0.00	0.03	0.00	-0.00	0.75
+SD	0.02	0.24	0.01	0.48	0.05	0.00	0.06	0.00	-0.01	0.75
Marginal	0.01	0.23	0.00	0.49	0.02	0.00	0.03	0.00	-0.00	0.75
Number of children age>5										
+1	0.02	0.16	0.05	0.00	0.01	0.50	-0.02	0.32	0.03	0.06
+SD	0.03	0.17	0.07	0.00	0.02	0.50	-0.03	0.33	0.04	0.06
Marginal	0.02	0.15	0.07	0.00	0.01	0.50	-0.02	0.32	0.03	0.07
Number of children										
+1	-0.03	0.03	-0.08	0.00	-0.04	0.02	-0.02	0.31	-0.00	0.80
+SD	-0.04	0.02	-0.16	0.00	-0.07	0.02	-0.03	0.31	-0.01	0.80
Marginal	-0.03	0.04	-0.07	0.00	-0.04	0.02	-0.02	0.30	-0.00	0.80
Female headed household	-0.02	0.29	0.02	0.26	0.08	0.00	-0.00	0.88	0.00	0.90
Household head's age										
+1	-0.00	0.28	0.00	0.81	-0.01	0.00	0.00	0.59	-0.00	0.66
+SD	-0.01	0.27	0.00	0.81	-0.07	0.00	0.01	0.58	-0.00	0.66
Marginal	-0.00	0.28	0.00	0.81	-0.01	0.00	0.00	0.59	-0.00	0.66
Not poor	0.09	0.00	0.04	0.02	0.08	0.00	0.01	0.49	0.11	0.00
Income ($/OECD cap)										
+1	0.00	0.02	0.00	0.85	0.00	0.00	0.00	0.79	0.00	0.35
+SD	0.03	0.02	0.00	0.85	0.12	0.00	0.01	0.79	0.02	0.35
Marginal	0.00	0.02	0.00	0.85	0.00	0.00	0.00	0.79	0.00	0.35
EF Misc. goods & services (GJ/cap)										
+1	0.01	0.76	0.08	0.00	0.01	0.92	0.08	0.31	-0.04	0.66
+SD	0.01	0.76	0.04	0.00	0.00	0.92	0.04	0.33	-0.02	0.66
Marginal	0.01	0.75	0.12	0.02	0.01	0.92	0.09	0.34	-0.04	0.66
Indirect EF (GJ/cap)										
+1	0.03	0.00	-0.01	0.63	0.05	0.00	0.01	0.58	0.10	0.00
+SD	0.07	0.01	-0.01	0.64	0.11	0.00	0.02	0.58	0.21	0.00
Marginal	0.03	0.00	-0.01	0.63	0.05	0.00	0.01	0.58	0.11	0.00
Bicycle	-0.03	0.11	-0.00	0.97	0.01	0.65	0.02	0.42	0.05	0.01
Car	0.12	0.00	0.06	0.01	0.13	0.12	0.09	0.15	0.18	0.03
Mobile phone	0.06	0.00	0.01	0.69	0.08	0.00	0.01	0.59	0.04	0.03
Secondary school w/n 5km	0.04	0.03	-0.01	0.32	0.06	0.01	0.04	0.04	-0.01	0.79
Food market w/n 5km	0.04	0.02	-0.04	0.01	-0.00	0.98	0.06	0.01	0.00	0.90
Health facility w/n 5km	0.03	0.09	0.02	0.26	0.03	0.20	0.05	0.02	0.03	0.10

Table A-6 continues…	All outcomes		Healthy child		Basic edu		Safe water		Sufficient food	
	Change	**p-value**	**Change**	**p-value**	**Change**	**p-value**	**Change**	**p-value**	**Change**	**p-value**
Public transport w/n 5 km	0.01	0.61	-0.00	0.83	0.03	0.17	0.04	0.05	-0.01	0.46
Detached house	0.05	0.00	-0.02	0.39	0.05	0.06	0.09	0.00	0.08	0.00
Flush toilet	0.14	0.00	0.01	0.80	0.23	0.00	0.23	0.00	0.09	0.07
% rural households w/n district										
26-50 vs 0-25	-0.00	0.98	0.06	0.32	0.04	0.31	-0.16	0.00	-0.05	0.20
51-75 vs 0-25	0.08	0.01	0.08	0.19	0.12	0.01	0.02	0.74	0.04	0.42
76-100 vs 0-25	0.07	0.05	0.09	0.15	0.09	0.06	-0.05	0.38	0.01	0.81
51-75 vs 26-50	0.09	0.00	0.03	0.33	0.08	0.02	0.17	0.00	0.10	0.01
76-100 vs 26-50	0.07	0.02	0.03	0.25	0.05	0.19	0.11	0.01	0.07	0.09
76-100 vs 51-75	-0.02	0.38	0.01	0.69	-0.03	0.21	-0.06	0.00	-0.03	0.19
% electrified households w/n district										
21-40 vs 0-20	0.05	0.02	0.03	0.13	0.09	0.00	0.08	0.00	0.03	0.24
41-70 vs 0-20	0.10	0.00	0.06	0.08	0.12	0.00	0.11	0.02	0.05	0.22
71+ vs 0-20	0.16	0.01	0.07	0.20	0.30	0.00	0.04	0.57	0.09	0.24
41-70 vs 21-40	0.06	0.07	0.02	0.35	0.04	0.34	0.02	0.57	0.02	0.53
71+ vs 21-40	0.11	0.05	0.04	0.45	0.22	0.00	-0.04	0.51	0.06	0.40
71+ vs 41-70	0.06	0.22	0.01	0.73	0.18	0.00	-0.06	0.22	0.03	0.55
Mother's education (children <5yr.)										
junior sec. 8-9 vs primary			0.04	0.01						
senior sec. 10-12 vs primary			0.05	0.02						
tertiary vs primary 1-7			0.09	0.00						
senior sec. 10-12 vs junior sec.			0.01	0.63						
tertiary vs junior sec. 8-9			0.04	0.14						
tertiary vs senior sec. 10-12			0.03	0.27						
Average Predictions Pr(y|base)	0	1	0	1	0	1	0	1	0	1
	0.77	0.23	0.12	0.88	0.50	0.50	0.37	0.63	0.43	0.57

A.7 Selected socio-economic characteristics of households with children under the age of 5.

Table A-7 Household characteristics across households categorised by achieved or not well-being outcomes. Based on the Zambian LCMS 2015 household survey and IEA energy data for 2011 (data representative for the whole population - values calculated using demographic weights).

	All	Three outcomes met				Two outcomes met			One outcome met			None
	HENW	hENW	HEnW	HeNW	HENw	HeNw	heNW hEnW hENw	HenW	HEnw	Henw	hEnw heNw henW	henw
Sample size												
Total	125	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												
Number of	11.6	10.1	9.4	5.6	9.5	5.8	7.8	4.5	8.9	5.0	6.2	4.3
Income & Expenditure per cap												
Average	7	6	5	5	5	4	5	3	4	3	4	3
Income	155	904	718	477	717	448	537	259	395	228	312	294
Standard	160	1080	839	443	947	537	769	240	465	217	282	576
Expenditure	72.8	41.3	29.5	19.3	18.5	10.2	19.8	9.5	11.2	6.6	10.1	8.1
Standard	95.1	63.8	47.7	40.4	36.2	28.3	33.5	15.2	21.4	11.6	20.4	14.2
Expenditure	669	438	356	324	364	254	299	173	223	156	191	162
Standard	577	389	715	267	321	255	222	202	174	131	134	182
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
Standard	9.5	6.5	8.1	9.1	6.6	6.2	7.2	6.4	7.1	6.0	7.1	5.6
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
Standard	3.2	2.1	1.8	1.1	2.1	0.8	1.6	0.6	0.9	0.6	0.7	0.7
Appliances and durables (%)												
Mobile	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	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	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	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	53.5	38.7	45.2	26.0	26.7	17.3	35.8	24.5	18.5	10.7	25.5	16.1

Table A-8 Household characteristics across rural and urban regions in Zambia. Based on the Zambian LCMS 2015 household survey (data representative for the whole population - values calculated using demographic weights).

		Rural			Urban		
	Zambia	Total	Not electrified	Electrified	Total	Not electrified	Electrified
Share of population living in		58.20%	55.70%	2.50%	41.80%	13.70%	28.10%
Income							
Income (US $ / hh)	2424	1103	959	4268	4174	1729	5362
Standard deviation	6212	2179	1533	6847	5403	2225	6055
Energy Footprint							
Direct EF (GJ per hh)	72.2	57.4	56.9	68.4	82.3	63.9	91.3
Standard deviation	186.6	202.2	205.9	88.5	69.6	44.3	77.5
Indirect EF (GJ per hh)	9.9	5.5	5.1	15.5	15.8	7.3	19.9
Standard deviation	12.4	5.6	4.7	11.8	16.0	5.6	17.7
Accessibility							
Electricity access	31.4%	4.4%			67.3%		
Access to clean water at home	58.1%	42.3%	40.3%	85.5%	79.0%	63.3%	86.7%
Accessibility (within 5 km)							
Food market	64.1%	41.3%	40.3%	64.0%	94.2%	93.0%	94.8%
Health facility	63.2%	48.4%	47.6%	66.0%	82.8%	80.9%	83.7%
Public transport	57.6%	42.2%	41.1%	67.0%	77.9%	73.8%	79.9%
Secondary school	32.6%	13.1%	12.1%	35.8%	58.3%	54.5%	60.1%
Mobility							
Car ownership	6.7%	1.4%	0.8%	13.3%	13.7%	0.9%	20.0%
Bicycle	34.8%	46.0%	46.0%	46.2%	20.1%	26.6%	16.9%
Motorbike	1.1%	1.4%	1.3%	4.7%	0.7%	0.4%	0.8%
Appliances							
Mobile phone	61.3%	46.1%	44.2%	86.9%	81.4%	67.6%	88.2%
Refrigerator	12.0%	1.4%	0.2%	26.5%	26.0%	1.9%	37.7%
Indoor toilet	15.6%	1.5%	0.1%	30.7%	34.2%	3.4%	49.2%
Education							
Number of finished grades (hh head)	8.0	6.3	6.1	11.0	10.2	7.9	11.3
Health							
Chronically malnourished children (stunted)	49.0%	50.3%	50.4%	46.8%	46.5%	49.8%	44.5%
Diet							
3+ meals (incl. snacks) per day	55.1%	42.7%	40.9%	81.6%	71.4%	48.1%	82.8%

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Appendix B
Supporting information to Chapter 3: Household final energy footprints in Nepal, Vietnam and Zambia: composition, inequality and links to well-being

B.1 Income deciles

In this section, we present a method for calculating weighting income deciles per capita and household. We use the following abbreviations for calculations:

inc – Income per household in the survey. It is the unweighted income per household as it was reported by households taking part in the survey. In all of the surveys, information about income was collected via several questions. The income then was calculated using guidelines from the statistic report available for each country.

wt_hh – Household weights provided for each household in the survey. For example, the Nepalese survey consists of 5504 households and each has its individual household weight. When summing weights, $\sum_{hh=1}^{5504} wt\_hh_{hh}$ it is equal to 5,361 340- the number of households in Nepal

wt_ind – Individual weights. They are provided by each survey and are equal to household weight multiplied by household size. In case of Nepal summed individual weights $\sum_{hh=1}^{5504} wt\_ind_{hh}$ are equal to 26, 600 394 – number of people in Nepal

S – Household size

EF – weighted energy footprint. Following the Nepalese example, each value in the 5504x1 vector corresponds to a total energy footprint for a group of households. The sum of EF for all 5504 groups of households corresponds to the EF for the household final demand in GTAP. So the $\sum_{hh=1}^{5504} EF_{hh}$ is total energy use by the Nepalese population.

B.1.1 Income deciles income per household based on the whole population (using weights)

Below we describe calculation steps required to arrive at weighted household income deciles on the example of Nepal.

1. Sorting income per household (inc) from smallest to largest.

2. $P_h = \frac{wt\_hh_{\ h}}{\sum_{h=1}^{5504} wt\_hh_{\ h}}$

Where P_h is a share that each household (row) represents.

we divide the **household weights** of each group of households (row) by the total number of households in the population.

3. $C_h = \sum_{h=1}^{5504} P_h + P_h - 1$

Where C_h is a Cumulative percent of step 3. In each row, we add value from the previous to obtain the cumulative percent.

4. For $d = [1,10]$
$D_d = C_h \leq d * 10$

Calculating deciles: for decile 1: for C (0,10]

6. $E\_hh_c = \frac{EF_{c_i}}{wt\_hh_i}$

Where E_hh is the energy footprint per household. Please note, that it is the same as an unweighted energy footprint per household.

Since EF is the weighted energy footprint (for all households in Nepal), we need to use non-weighted energy footprint to calculate EF per household. We take the energy footprint of each household for a given category (e.g. electricity, wood, biogas, etc.) and divide it by household weights (number of households in the Nepalese population that this energy footprint corresponds to).

5. for $d = [1,10]$

$$E\_av_{c_d} = \frac{\sum_{d=1}^{10} \sum_{c=1}^{8} E\_hh}{\sum_{d=1}^{10} h}$$

Calculating average energy footprint per household for each category in each decile.

$E\_av_{c_d}$ - is an average energy footprint for category c in decile d

For example, for the biogas category, I select all observations within the average energy footprint for biogas. Next, I sum all of the average footprints per household in decile one and divide by a number of summed observations.

The number of observations in each decile differs (see Table B-1). Each observation in the income decile vector (1x5504) corresponds to a different number of households in the Nepalese population. For example, within decile one we have 515 observations. That means that these 515 observations refer to 535, 843.6 households in the whole of Nepal (see Table B-2), which is 10% of all Nepalese households.

Table B-1 Number of observations (rows) corresponding to each income decile.

decile_inc_ hh_wght	Freq.	Percent	Cum.
1	515	9.36	9.36
2	495	8.99	18.35
3	509	9.25	27.60
4	511	9.28	36.88
5	516	9.38	46.26
6	530	9.63	55.89
7	561	10.19	66.08
8	566	10.28	76.36
9	615	11.17	87.54
10	686	12.46	100.00
Total	5,504	100.00	

Table B-2 Number of households that each weighted income decile corresponds to.

Decile	Sum of Household weights
1	535, 843.6
2	536, 275.5
3	536, 240.1
4	535, 178.3
5	537, 080.1
6	535, 038.9
7	537, 229.7
8	536, 073.4
9	536, 096.2
10	536, 284.3
TOTAL	**5,361,340.1 households**

B.1.2 Income deciles based on per OECD capita income (using weights)

Based on the Nepalese example

1. Sorting inc_p_oecd from smallest to largest - 5504 rows sorted
2. $P_h = \frac{wt\_ind_{\ h}}{\sum_{h=1}^{5504} wt\_ind_{\ h}}$

Where P_h is a percent of the whole Nepalese population that the given observation (row) corresponds to.

For each row that corresponds to a group of households, we calculate what percent of the whole Nepalese population corresponds. We divide the **individual weights** of each household group (row) by the total number of people in the population (26, 600, 394 persons).

3. $C_h = \sum_{h=1}^{5504} P_h + P_h - 1$

Where C_h is a Cumulative percent of step 3. In each row, we add value from the previous to obtain the cumulative percent.

4. For $d = [1,10]$

$D_d = C_i \leq d * 10$

Calculating deciles: for decile 1: for C (0,10]

5. $E\_cap_c = \frac{EF_{c_h}}{wt\_ind_h}$

Where E_cap is average energy footprint representing a group of households (row).

We take the energy footprint of each group of households for a given category and divide it by individual weights (number of people in the population that this energy use corresponds to). This way we obtain energy footprint per person.

6. for $d = [1,10]$

$$Ecap\_av_{c_d} = \frac{\sum_{d=1}^{10} \sum_{c=1}^{8} E\_cap}{\sum_{d=1}^{10} h}$$

Calculating the average energy footprint for each category in each decile.

E_{c_d} - is an average energy footprint for category c in decile d

For example, for kerosene, we select the average energy footprint per capita for all observations that belong to the decile one and we sum it. Next, we divide the summed average energy footprints by a number of observations in the survey sample that this decile corresponds to (508 observations for decile one in Table B-3). The number of observations (rows) in each decile will be different because each row (out of 5504) corresponds to a different number of persons in the whole population (Table B-4).

Table B-3 Number of observations in each decile.

inc_wght_decile	Freq.	Percent	Cum.
1	508	9.23	9.23
2	493	8.96	18.19
3	461	8.38	26.56
4	474	8.61	35.17
5	476	8.65	43.82
6	495	8.99	52.82
7	534	9.70	62.52
8	603	10.96	73.47
9	675	12.26	85.74
10	785	14.26	100.00
Total	5,504	100.00	

Note: inc_wght_decile corresponds to income decile number.

Table B-4 Number of persons per decile

Decile	Sum of individual weights
1	2654163
2	2665628
3	2657914
4	2661532
5	2660114
6	2659149
7	2658630
8	2662645
9	2660578
10	2660042
TOTAL	**26,600,394**

B.2 COICOP to GTAP correspondance

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 B-3). Although GTAP uses two different international product categorizations (International Standard Industrial Classification, and Central Product Classification), they both map onto COICOP (United Nations Statistic Division 2019).

Mapping to GTAP sectors is done with the original household expenditure categorization in each country. This concordance matrix has 233 rows by 57 columns in Zambia; 135 by 57 in Vietnam and 140 by 57 in Nepal. The mapping uses the standard COICOP to GTAP concordance as an intermediate (65 COICOP cat by 57 GTAP sectors). This bridging is not straight forward nor there exists an official document that would present concordance between COICOP and GTAP. Concordance between CPC and COICOP, however, exists. The following steps need to be then done for mapping:

CPC to COICOP → CPC to ISIC rev 3 → ISIC rev 3 to GTAP

The steps needed to build the county's COICOP to GTAP mask include the following:

1. Building a mask between standard COICOP categorization and GTAP (65 by 57) which uses CPC and ISIC rev 3 to bridge between different categorizations.

2. Building a mask between the country's categorization and standard COICOP categorization.

3. Using the mask build in step 2 as an intermediate, make a country's COICOP to GTAP mask.

The mapping between the country's COICOP categories and standard COICOP (step 2) is done without any official guidelines. Most of the categories are straight forward to link, as they are similar or named in the same way.

Expenditures in the household surveys 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 (Glen P. Peters, Andrew, and Lennox 2011). Because GTAP's household final demand was assumed to be the "true" vector, Zambian [Vientamease and Nepalease] household expenditures, after converting from the local currency to US dollars and adjusting for inflation, were matched to GTAP's. The difference between GTAP's final demand and household spends reported in surveys was around 18%, 17%, and 33% for Zambia, Nepal, and Vietnam respectively. This is a common observation (Steen-Olsen, Wood, and Hertwich 2016), which does not influence the overall results.

B.3 Expenditure equivalents – direct energy

Following section is a part of a publication and supplementary materials: *Energy footprints and well-being in Zambia: a household-level investigation* (Baltruszewicz et al. ,2020 under review with Energy research and Social Science Journal)

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 [for example], one-third of surveyed households reported using collected wood or self-produced charcoal for cooking. This creates a challenge for calculating the 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. The following sub-sections explain the process done for Nepal and Zambia. In Vietnam, there was no need for expenditure equivalents as all products were purchased on the monetary markets.

B.3.1 Nepal

In Nepalese household survey respondents were asked either about the quantity of collected firewood or, if they purchased their firewood, how much they spend on it. Households could report quantities in bhari, cart or kilogram. Bhari is a measure of weight used predominantly in North India and Nepal and it is a part of the measuring system predating the metric system introduced after British colonization. If households decided to provide quantities used in bhari or cart, the role of the interviewer was to provide equivalent in kilograms. Since rarely bhari corresponds to the same amount of kilograms – the reported quantities varied substantially. These differences also mean that the price per kg of firewood largely differed across the country. To standardize the price we used an average price per kg of collected wood and recalculated expenditures per household based on reported physical quantities. Resulting expenditures could be used to calculate energy footprints based on actual material use rather than varying prices.

However, we found that 849 Nepalese households (15%) that reported purchasing their wood without corresponding physical quantities (in the survey category "purchased wood" in section 6a of the household survey) and these expenditures were the only available measure corresponding to their firewood usage. To be able to use both categories (purchased wood and collected firewood) uniformly, the physical quantity of "purchased wood" needed to be estimated. We observed that households that purchased their wood have four times higher average expenditure on wood than households that were asked to estimate their collected firewood spends (four times higher expenditure than spends per kg using the average, constant price). Since bhari unit is the most commonly used we assumed that these households purchased their bundle wood in bhari.

We checked two possibilities for calculating the average price per bhari. First, we calculated the average price per bhari in each district. This calculation was based on households that reported their collected firewood usage (in bhari) and estimated price per bhari. The result yields large differences (Figure B-1), so instead of using different prices in each district, we used the national mean price spend per bhari (41 rupees). This price was used to estimate how many bhari each household purchased (expenditure on purchased wood/41 rupees).

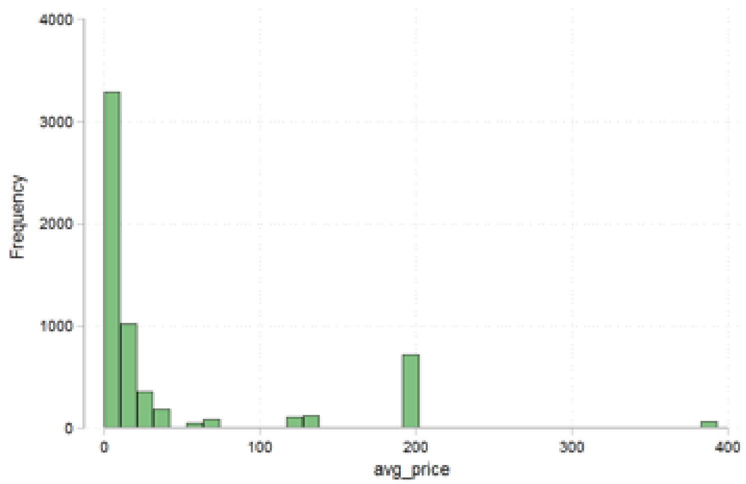

Figure B-1 Average price (rupees) per bhari of firewood in Nepalese districts

The result was multiplied with the average number of kilograms in one bhari (Figure B-2), which is 32.78 kg (calculated based on reported kg of firewood). Finally, we could use the estimated weight of used fuel to calculate household expenditure on purchased wood using the constant average used to calculate “collected firewood” spends. As a result, all use of firewood is based on the same average price.

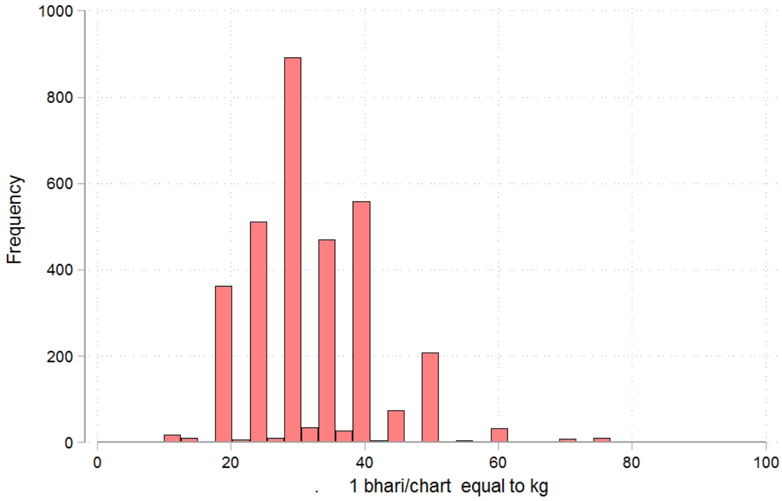

Figure B-2 Household distribution of number of kilograms corresponding to weight unit bhari. X-axis – kilograms; Y –axis – frequency – number of households.

B.3.2 Zambia

Following section is a part of a publication and supplementary materials: *Energy footprints and well-being in Zambia: a household-level investigation* (Baltruszewicz et al. ,2020 under review with Energy research and Social Science Journal)

Zambian households do not only rely on the monetary market for obtaining house fuels - one-third of surveyed households reported using collected wood or self-produced charcoal for their cooking fuels. This imposed a challenge for calculating a household's energy footprint, which relies on expenditures as a main input for the household final demand.

To be able to account for the direct energy use of households that do not purchase their fuels, an expenditure equivalents were calculated.

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. 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 (Mulombwa 1998). 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 (Mulombwa 1998). 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.

B.4 Direct vs indirect EF

We distinguish between direct and indirect energy use as well as between traditional, transitional and modern fuels (Figure B-10). 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 mining of coal to produce electricity. However, some fuels do not have supply chains and are accounted for only as direct energy. Collected firewood is an example of residential fuel, which does not have any embedded supply chain.

Table B-5 Residential and road fuel categorization.

Fuel category	Direct/ Indirect (supply chain)	Fuel type
Firewood (collected)	Direct	Traditional
Firewood (purchased)	Direct + Indirect	Traditional
Charcoal (self-produced)	Direct	Traditional
Charcoal (purchased)	Direct + Indirect	Traditional
Coal/ coal briquette	Direct + Indirect	Traditional
Farm by products	Direct	Traditional
Kerosene oil	Direct + Indirect	Transitional
Cylinder gas (LPG)/ natural gas	Direct + Indirect	Modern
Electricity	Direct + Indirect	Modern
Biogas	Direct	Modern
Paraffin	Direct + Indirect	Transitional
Diesel residential use	Direct + Indirect	Transitional
Petrol, diesel for vehicles	Direct + Indirect	NA

Note: Direct energy considers no supply chain, whereas direct+indirect refers to a fuel that has an upstream embodied energy in form of supply chain including all stages of production (e.g. mining, refining, transformation, transport) and usage directly by a household.

B.5 Estimation of residential fuel use

The International Energy Agency (IEA) reports residential energy use split into several energy product categories (see Figure B-11). Further, IEA provides a more detailed description of these product categories. For example, within oil products, we have kerosene, fuel oil, and LPG (see Table B-6). We use this categorization together with household expenditures on residential fuels to calculate estimates of shares of fuel used in each country. For example, for Nepal IEA reported 6.2 PJ energy used in 2011 which was split within kerosene, fuel oil, and LPG. What share of the total 6.2 PJ corresponds to each type of fuel we calculated based on household expenditures.

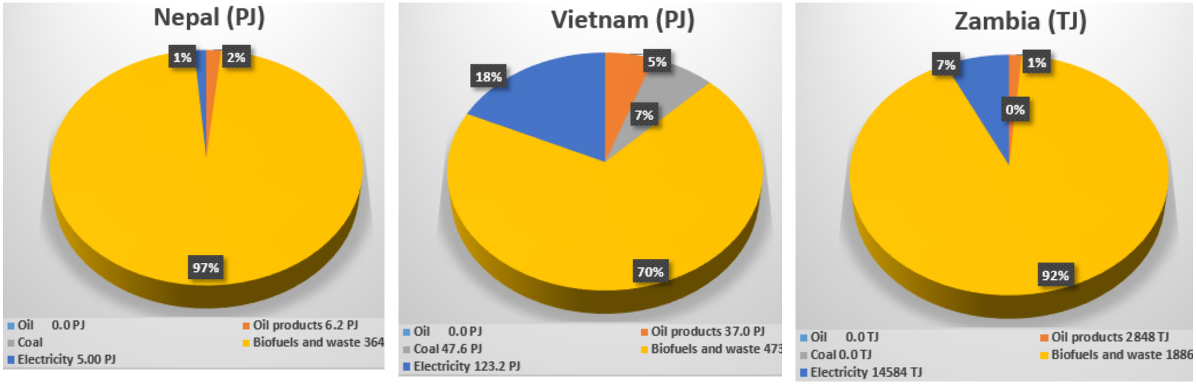

Figure B-3 Residential final energy use in 2011split by energy products in Nepal, Vietnam and Zambia (Source: IEA (2011) Sankey Diagram).

B.5.1 Nepal

Using solely expenditures for calculating shares for each energy product (e.g. gas, kerosene) yielded skewed results for some energy products. For example, in the household survey, only 4% of the population reported using biogas, compared with 65% for firewood and 16% of the population for bundle wood and 1% for charcoal. When using expenditures to estimate share for biogas, we obtained 25% of the total direct residential energy use being assigned to biogas. Therefore, we recalculated shares using household expenditure and additional information about physical quantities of energy products used by households, to estimate how the total energy values from IEA (e.g. oil products, biofuels, and waste) should be split between different energy sources (e.g. kerosene, LPG, firewood, charcoal)

Below we present a used method for estimating energy products shares:

1. Using historic price statistics or based on own calculations, we estimated price per unit of used fuel. See table B-6 for used sources for calculations
2. Based on energy conversion tables we calculated corresponding energy (MJ) per unit of used fuel.
3. We estimated energy use per household for each fuel type.
4. Next, we summed these energy estimates and calculated with what share each fuel corresponds to their parent category. For example, considering the parent category ‘oil product’ - 15% corresponds to kerosene and 85% to LPG use
5. These shares could be then applied in the energy model to calculate household energy footprints corresponding to direct residential fuels.

Following we used household expenditure on each energy product to calculate shares with which each household contributes to overall energy use within a given energy product. For example, 15% of oil products corresponding to kerosene is equal to 0.093 PJ. This number then needs to be disaggregated among all households using kerosene in Nepal. To be able to know what share of 0.093PJ assigns to each household we calculated shares based on expenditures on kerosene.

Note on biogas consumption:

For biogas, our aim was to as realistically as possible distribute the energy use among households based on IEA total final energy use which provides shares of energy use corresponding to biomass, electricity and petroleum based energy sources.

In the Nepalese household survey respondents were asked to estimate expenditures corresponding to their home produce. In section 6.11 they were asked: "Were any of the following items produced and consumed by your household over the past 12 months?" and following in section 6.12: "What is the monetary value in the local market of the items produced and consumed yourself during the past 12 months?" Households were asked about the production of various foods, furniture, tailoring, shoemaking, water fetching, and biogas. Since the only information we have available is the estimate of the price that would be paid on the local market, and considering that biogas is mainly self-produced, we assumed that the equivalent product bought on a local market would be LPG.

Considering that biogas is used to replace mainly LPG and kerosene we assumed that households when asked to give monetary value in the local market of the items produced by them, provided the equivalent of what they would have to pay for LPG if they would not use biogas. Hence, the assumptions are based not on the technology or method used to produce energy sources but on the price equivalence.

Table B-6 IEA energy product categorization and corresponding price and share for Nepal energy products

Products included in the IEA	Corresponding cat. in Nepal household survey	Unit	Corresponding price	Source	Corresponding energy (MJ)	share
Oil products						
Kerosene	Kerosene	Litre	68.5 NPR	(Nepal Economic Forum 2011)	34.48	15%
LPG	gas	cylinder	1325 NPR	(Nepal Economic Forum 2011)	654.62	85%
Biofuel &waste						
Primary solid biofuels and charcoal	Firewood	Kg	0.36 NPR	Own estimates based on information available in the survey	18	73.6%
	Wood	Kg	0.36 NPR		18	24.3%
	Coal, charcoal	kg	0.72 NPR		30	1.8%
Biogas	Biogas	cylinder	1325 NPR	Assumed the same as LPG	654.62	0.3%
Electricity						
Electricity	Electricity					100%

B.6 Well-being outcomes

Following section is a part of a publication and supplementary materials: *Energy footprints and well-being in Zambia: a household-level investigation* (Baltruszewicz et al. ,2020 under review with Energy research and Social Science Journal)

We used the theory of human need (THN) proposed by Doyal and Gough (Doyal and Gough 1991) as a basis for quantitatively examining well-being outcomes. The THN provides a “eudaimonic” (as opposed to “hedonic”) understanding of wellbeing (Brand-Correa and Steinberger 2016). In THN well-being is defined as a universal goal of ’participation in some form of life without serious arbitrary limitation’ (Gough 2015, 1197) which is valid regardless of place, culture or time.

The framework distinguishes between three aspects of well-being:

a. basic needs: physical health[10], 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[11]:

- 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 well-being outcomes.

[10] 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.
[11] Lack of information in the LCMS made it impossible to assign an indicator to all types of needs.

B.7 Factor analysis

To reduce the number of the socio-economic household variables used for the logistic regression analysis, we employed factor analysis to arrive at new uncorrelated factor variables. In the factor analysis number of correlated variables are used to create a smaller number of new variables – factors. Each of the factors is composed of variables with high loadings (≥0.3). We then named factors based on these variables. Table B-7 consists of the results of the factor analysis done for Nepal, Vietnam, and Zambia. E corresponds to eigenvalues, L stands for loading, and V is for total variance explained by the variable. Resulting three factors are linked to protection, and collective provisioning systems.

Table B-7 Factor analysis results: eigenvalues, loadings, and variation explained

Variable	Nepal	Vietnam	Zambia
Factor: protection	E: 2.02	E: 2.54	E: 2.7
Sewage	L:0.92	L: 0.95	L: 0.98
	V: 0.41	V: 0	V: 0
Toilet	L: 0.86	L: 0.98	L: 0.97
	V0.69	V: 0.21	V: 0.32
Solid shelter	L:0.66	L: 0.82	L: 0.89
	V: 0.88	V: 0.74	V: 0.62
Factor: collective provisioning Nepal	E: 1.96		
Access to public transport w/n 5 km	L: 0.80		
	V: 0.66		
Access to health-centre w/n 5 km	L: 0.78		
	V: 0.70		
Access to market w/n 5 km	L: 0.84		
	V: 0.59		
Factor: collective provisioning Zambia			E: 2.05
Access to public transport w/n 5 km			L: 0.64
			V: 0.84
Access to health centre w/n 5 km			L: 0.79
			V: 0.69
Access to market w/n 5 km			L: 0.83
			V: 0.46
Garbage disposal			L: 0.49
			V: 0.90

Note: E: eigenvalue, L: loading, V: variation explained

B.8 Logistic regression

The functional form of the logistic regression model and the conversion to odds ratio using exponential function are given in equations 1 and 2. Zi refers to log-odds, α is constant, γ, δ, and θ are vectors of coefficients and εi is an error term. The sign of coefficient and odds ratio relates to direction change.

$$Z_i = \ln\left[\frac{P_i}{1-P_i}\right] = \alpha + \gamma H_i + \delta Q_i + \theta Y_i + \varepsilon_i \quad (1)$$

$$Odds\ ratio = \left[\frac{P_i}{1-P_i}\right] = e^{\alpha + \gamma H_i + \delta Q_i + \theta Y_i + \varepsilon_i} \quad (2)$$

Table B-8 presents variables chosen for the logistic regression done using each of the well-being outcomes in turn (results presented in Table B-12).

Table B-8 Variables chosen for logistic regression analysis.

Variable	Type	Definition
Safe water	d	Households with access to safe water (coded 1)
Has > 50% of modern fuels	d	Households with 50% or more of modern fuels (coded 1)
Adequate food	d	Households with adequate food (coded 1)
Basic education	d	Households with basic education, hh head and spouse (coded 1)
Not poor	d	Households self-assessing their poverty status, poor are coded 0 and not poor 1
Household size	c	Number of people living in the household
Minimum floor area	d	Households with a minimum of 10 square meters per person are coded 1 and households with less floor area per person are coded 0
Electricity access	d	Households with electricity access are coded 1 and without access 0
Residential Fuels	c	Yearly per capita energy footprint of residential fuels.
Total EF	c	Yearly total energy footprint per capita.
Share of modern fuels	c	Share of modern fuels in total residential fuel use.
Access to market w/n 5km	d	Households with access to market within 5 km from home are coded 1, households without access or further than 5km are coded 0
Public transp. w/n 5 km	d	Households with access to public transport within 5 km from home are coded 1, households without access or further than 5km are coded 0
Factor: protection	c	Factor consisting of variables corresponding to access to a safe toilet (shielded from external environment and with safe waste storage and/or treatment), solid shelter, which includes durable walls and floor and living with a minimum of 10 square meters of floor area per person, access to sewage
Factor: collective provisioning Nepal	c	Factor consisting of variables corresponding to having access to health canter, public transport and market within 5 km from home
Factor: collective provisioning Zambia	c	Factor consisting of variables corresponding to having garbage disposal and access to health canter, public transport and market within 5 km from home
Garbage disposal	d	Households with access to garbage disposal (coded 1)
Refrigerator	d	Ownership of refrigerator (coded 1)
Washing machine	d	Ownership of washing machine (coded 1)
Clean cooking device	d	Ownership of clean cooking device (coded 1)
Phone	d	Ownership of at least one mobile or landline phone (coded 1)
Television	d	Ownership of Television (coded 1)
Computer	d	Ownership of computer (coded 1)
Satellite	d	Ownership of satellite (coded 1)
Car	d	Ownership of car (coded 1)
Motor cycle	d	Ownership of motorcycle (coded 1)

Note: ‘d’ corresponds to dichotomous, and ‘c’ to continuous variable type.

B.8.1 Tetrachoric correlations

Tables 9-11 present tetrachoric correlations for binary variables used in logistic regressions. Whereas it could be assumed that variables “safe water”, “having sewage” or “ having toilet” would be highly correlated, this is not the case for all case-study countries. We observe no correlations for several variables, for which one could assume a connection. For example, in Nepal, there is no correlation between having sewage and safe water access (adjusted correlation coefficient equal to 0.11). In Vietnam, having secondary education does not correlate with having access to the secondary school within 5 km from home (coefficient equal to 0.19). In Zambia, having a sufficient amount of food is weakly correlated with having access to a market (coefficient equal to 0.34) and not correlated with having access to a health centre (0.21).

Table B-9 Nepal: Tetrachoric Correlations.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1. Achvd all	1.00	-0.47	0.34	0.12	0.48	0.54	0.15	0.42	0.46	0.40	0.50	0.45	0.49	0.43	0.37	0.46	0.41	0.31	0.31	0.47	0.58	0.38	0.72	0.70	0.75	0.55
2.rural	-0.47	1.00	-0.29	0.09	-0.61	-0.67	-0.13	-0.74	-0.63	-0.54	-0.57	-0.65	-0.65	-0.54	-0.48	-0.53	-0.65	-0.43	-0.48	-0.69	-0.76	-0.56	-0.29	-0.20	-0.54	-0.77
3.Not poor	0.34	-0.29	1.00	0.15	0.30	0.27	0.12	0.27	0.39	0.28	0.32	0.34	0.36	0.31	0.24	0.36	0.26	0.16	0.15	0.32	0.36	0.17	0.63	0.11	0.31	0.37
4.Min floor	0.12	0.09	0.15	1.00	0.02	0.19	0.14	-0.12	0.28	0.27	0.14	0.10	0.22	0.15	0.12	0.17	0.02	-0.04	0.00	0.08	0.08	-0.02	0.22	0.03	0.11	-0.01
5.Solid shelter	0.48	-0.61	0.30	0.02	1.00	0.55	0.03	0.54	0.60	0.44	0.54	0.64	0.59	0.52	0.40	0.56	0.53	0.36	0.37	0.65	0.69	0.51	0.33	0.30	0.51	0.70
6.Toliet	0.54	-0.67	0.27	0.19	0.55	1.00	0.11	0.68	0.63	0.48	0.63	0.63	0.68	0.57	0.43	0.59	0.38	0.23	0.33	0.60	0.83	0.34	0.35	0.21	0.62	0.69
7.Garb disp	0.15	-0.13	0.12	0.14	0.03	0.11	1.00	0.34	0.10	0.15	0.13	0.04	0.26	0.26	0.20	0.16	-0.02	-0.11	-0.01	0.01	0.21	-0.09	0.19	-0.07	0.19	0.24
8.Sewage	0.42	-0.74	0.27	-0.12	0.54	0.68	0.34	1.00	0.58	0.48	0.52	0.59	0.57	0.62	0.46	0.46	0.58	0.48	0.62	0.65	0.76	0.53	0.27	0.11	0.50	0.81
9.Fridge	0.46	-0.63	0.39	0.28	0.60	0.63	0.10	0.58	1.00	0.71	0.65	0.77	0.68	0.67	0.68	0.69	0.57	0.42	0.73	0.73	0.72	0.59	0.41	0.23	0.50	0.71
10.Wash. Mach.	0.40	-0.54	0.28	0.27	0.44	0.48	0.15	0.48	0.71	1.00	0.48	0.52	0.55	0.61	0.60	0.58	0.78	0.26	0.68	0.45	0.59	0.28	0.33	0.13	0.50	0.61
11.Phone	0.50	-0.57	0.32	0.14	0.54	0.63	0.13	0.52	0.65	0.48	1.00	0.73	0.85	0.56	0.81	0.69	0.48	0.31	0.41	0.65	0.68	0.38	0.41	0.26	0.54	0.64
12.TV	0.45	-0.65	0.34	0.10	0.64	0.63	0.04	0.59	0.77	0.52	0.73	1.00	0.65	0.48	0.59	0.73	0.62	0.47	0.51	0.84	0.69	0.58	0.40	0.31	0.45	0.68
13.PC	0.49	-0.65	0.36	0.22	0.59	0.68	0.26	0.57	0.68	0.55	0.85	0.65	1.00	0.76	0.57	0.68	0.58	0.36	0.39	0.70	0.74	0.51	0.43	0.15	0.57	0.70
14.Sattelite	0.43	-0.54	0.31	0.15	0.52	0.57	0.26	0.62	0.67	0.61	0.56	0.48	0.76	1.00	0.56	0.60	0.47	0.42	0.70	0.51	0.61	0.43	0.35	0.13	0.49	0.63
15.Car	0.37	-0.48	0.24	0.12	0.40	0.43	0.20	0.46	0.68	0.60	0.81	0.59	0.57	0.56	1.00	0.57	0.39	0.25	0.68	0.38	0.50	0.24	0.32	0.18	0.43	0.51
16.Motorcycle	0.46	-0.53	0.36	0.17	0.56	0.59	0.16	0.46	0.69	0.58	0.69	0.73	0.68	0.60	0.57	1.00	0.47	0.34	0.42	0.66	0.65	0.43	0.48	0.17	0.51	0.63
17.Pub. Transp.	0.41	-0.65	0.26	0.02	0.53	0.38	-0.02	0.58	0.57	0.78	0.48	0.62	0.58	0.47	0.39	0.47	1.00	0.58	0.59	0.63	0.60	0.59	0.26	0.31	0.39	0.65
18.Health center	0.31	-0.43	0.16	-0.04	0.36	0.23	-0.11	0.48	0.42	0.26	0.31	0.47	0.36	0.42	0.25	0.34	0.58	1.00	0.54	0.50	0.41	0.78	0.16	0.20	0.30	0.50
19.Market	0.31	-0.48	0.15	0.00	0.37	0.33	-0.01	0.62	0.73	0.68	0.41	0.51	0.39	0.70	0.68	0.42	0.59	0.54	1.00	0.47	0.43	0.49	0.18	0.21	0.30	0.52
20.El access	0.47	-0.69	0.32	0.08	0.65	0.60	0.01	0.65	0.73	0.45	0.65	0.84	0.70	0.51	0.38	0.66	0.63	0.50	0.47	1.00	0.67	0.58	0.37	0.34	0.44	0.80
21.Cook dev.	0.58	-0.76	0.36	0.08	0.69	0.83	0.21	0.76	0.72	0.59	0.68	0.69	0.74	0.61	0.50	0.65	0.60	0.41	0.43	0.67	1.00	0.56	0.39	0.20	0.66	0.89
22.Sec. school	0.38	-0.56	0.17	-0.02	0.51	0.34	-0.09	0.53	0.59	0.28	0.38	0.58	0.51	0.43	0.24	0.43	0.59	0.78	0.49	0.58	0.56	1.00	0.17	0.19	0.44	0.55
23.Suff. Food	0.72	-0.29	0.63	0.22	0.33	0.35	0.19	0.27	0.41	0.33	0.41	0.40	0.43	0.35	0.32	0.48	0.26	0.16	0.18	0.37	0.39	0.17	1.00	0.30	0.45	0.37
24.Safe Water	0.70	-0.20	0.11	0.03	0.30	0.21	-0.07	0.11	0.23	0.13	0.26	0.31	0.15	0.13	0.18	0.17	0.31	0.20	0.21	0.34	0.20	0.19	0.30	1.00	0.22	0.20
25. Basic Edu	0.75	-0.54	0.31	0.11	0.51	0.62	0.19	0.50	0.50	0.50	0.54	0.45	0.57	0.49	0.43	0.51	0.39	0.30	0.30	0.44	0.66	0.44	0.45	0.22	1.00	0.65
26.Modern fuels	0.55	-0.77	0.37	-0.01	0.70	0.69	0.24	0.81	0.71	0.61	0.64	0.68	0.70	0.63	0.51	0.63	0.65	0.50	0.52	0.80	0.89	0.55	0.37	0.20	0.65	1.00

Note: Binary variable Achvd all refers to households (coded 1) with sufficient food, safe water and basic education.

Table B-50 Vietnam: Tetrachoric Correlations.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1.achvd	1.00	-0.35	0.45	0.22	0.43	0.56	0.45	0.44	0.47	0.50	0.43	0.36	0.48	0.22	0.38	0.34	0.17	0.40	0.40	0.44	0.51	0.24	0.69	0.59	0.81	0.40
2.rural	-0.35	1.00	-0.30	-0.08	-0.36	-0.58	-0.68	-0.62	-0.54	-0.66	-0.27	-0.25	-0.55	-0.12	-0.29	-0.22	-0.19	-0.44	-0.39	-0.45	-0.41	-0.68	-0.28	-0.21	-0.35	-0.60
3.Not poor	0.45	-0.30	1.00	0.37	0.41	0.46	0.33	0.47	0.58	0.64	0.56	0.47	0.53	0.36	0.72	0.51	0.31	0.23	0.38	0.50	0.53	0.34	0.71	0.35	0.38	0.43
4.Min floor	0.22	-0.08	0.37	1.00	0.21	0.28	0.12	0.22	0.32	0.25	0.23	0.24	0.24	0.14	0.22	0.10	0.14	0.15	0.26	0.24	0.29	0.10	0.30	0.14	0.21	0.15
5.Solid shelter	0.43	-0.36	0.41	0.21	1.00	0.68	0.45	0.60	0.51	0.53	0.40	0.41	0.47	0.24	0.23	0.37	0.24	0.36	0.36	0.38	0.55	0.21	0.30	0.31	0.39	0.41
6.Toliet	0.56	-0.58	0.46	0.28	0.68	1.00	0.61	0.96	0.63	0.72	0.46	0.43	0.59	0.23	0.40	0.35	0.32	0.54	0.53	0.58	0.65	0.32	0.39	0.40	0.53	0.58
7.Garb disp	0.45	-0.68	0.33	0.12	0.45	0.61	1.00	0.62	0.49	0.61	0.33	0.27	0.51	0.13	0.28	0.16	0.32	0.50	0.46	0.43	0.48	0.33	0.34	0.29	0.39	0.53
8.Sewage	0.44	-0.62	0.47	0.22	0.60	0.96	0.62	1.00	0.65	0.72	0.44	0.37	0.61	0.23	0.39	0.38	0.30	0.55	0.42	0.48	0.60	0.30	0.37	0.32	0.40	0.64
9.Fridge	0.47	-0.54	0.58	0.32	0.51	0.63	0.49	0.65	1.00	0.84	0.60	0.57	0.69	0.41	0.47	0.56	0.21	0.57	0.37	0.58	0.66	0.22	0.47	0.26	0.45	0.62
10.Wash. Mach.	0.50	-0.66	0.64	0.25	0.53	0.72	0.61	0.72	0.84	1.00	0.55	0.43	0.74	0.30	0.51	0.53	0.19	0.59	0.32	0.51	0.60	0.29	0.46	0.33	0.48	0.68
11.Phone	0.43	-0.27	0.56	0.23	0.40	0.46	0.33	0.44	0.60	0.55	1.00	0.56	0.57	0.47	0.35	0.61	0.29	0.22	0.35	0.47	0.62	0.27	0.46	0.34	0.44	0.41
12.TV	0.36	-0.25	0.47	0.24	0.41	0.43	0.27	0.37	0.57	0.43	0.56	1.00	0.34	0.77	0.31	0.50	0.27	0.26	0.43	0.64	0.63	0.26	0.40	0.22	0.36	0.37
13.PC	0.48	-0.55	0.53	0.24	0.47	0.59	0.51	0.61	0.69	0.74	0.57	0.34	1.00	0.26	0.42	0.56	0.14	0.57	0.32	0.44	0.53	0.23	0.39	0.23	0.50	0.56
14.Sattelite	0.22	-0.12	0.36	0.14	0.24	0.23	0.13	0.23	0.41	0.30	0.47	0.77	0.26	1.00	0.20	0.41	0.15	0.18	0.21	0.43	0.41	0.10	0.27	0.14	0.20	0.22
15.Car	0.38	-0.29	0.72	0.22	0.23	0.40	0.28	0.39	0.47	0.51	0.35	0.31	0.42	0.20	1.00	0.34	-0.02	0.47	0.14	0.64	0.30	0.06	0.69	0.13	0.28	0.42
16.Motorcycle	0.34	-0.22	0.51	0.10	0.37	0.35	0.16	0.38	0.56	0.53	0.61	0.50	0.56	0.41	0.34	1.00	0.08	0.27	0.11	0.24	0.40	0.08	0.37	0.20	0.35	0.35
17.Pub. Transp.	0.17	-0.19	0.31	0.14	0.24	0.32	0.32	0.30	0.21	0.19	0.29	0.27	0.14	0.15	-0.02	0.08	1.00	-0.36	0.64	0.45	0.43	0.60	0.30	0.41	0.13	0.22
18.Health center	0.40	-0.44	0.23	0.15	0.36	0.54	0.50	0.55	0.57	0.59	0.22	0.26	0.57	0.18	0.47	0.27	-0.36	1.00	0.13	0.31	0.31	-0.27	0.24	-0.25	0.52	0.54
19.Market	0.40	-0.39	0.38	0.26	0.36	0.53	0.46	0.42	0.37	0.32	0.35	0.43	0.32	0.21	0.14	0.11	0.64	0.13	1.00	0.57	0.55	0.52	0.40	0.26	0.38	0.35
20.El access	0.44	-0.45	0.50	0.24	0.38	0.58	0.43	0.48	0.58	0.51	0.47	0.64	0.44	0.43	0.64	0.24	0.45	0.31	0.57	1.00	0.68	0.42	0.48	0.35	0.45	0.52
21.Cook dev.	0.51	-0.41	0.53	0.29	0.55	0.65	0.48	0.60	0.66	0.60	0.62	0.63	0.53	0.41	0.30	0.40	0.43	0.31	0.55	0.68	1.00	0.40	0.46	0.40	0.47	0.62
22.Sec. school	0.24	-0.68	0.34	0.10	0.21	0.32	0.33	0.30	0.22	0.29	0.27	0.26	0.23	0.10	0.06	0.08	0.60	-0.27	0.52	0.42	0.40	1.00	0.28	0.45	0.19	0.21
23.Suff. Food	0.69	-0.28	0.71	0.30	0.30	0.39	0.34	0.37	0.47	0.46	0.46	0.40	0.39	0.27	0.69	0.37	0.30	0.24	0.40	0.48	0.46	0.28	1.00	0.35	0.38	0.39
24.Safe Water	0.59	-0.21	0.35	0.14	0.31	0.40	0.29	0.32	0.26	0.33	0.34	0.22	0.23	0.14	0.13	0.20	0.41	-0.25	0.26	0.35	0.40	0.45	0.35	1.00	0.24	0.26
25. Basic Edu	0.81	-0.35	0.38	0.21	0.39	0.53	0.39	0.40	0.45	0.48	0.44	0.36	0.50	0.20	0.28	0.35	0.13	0.52	0.38	0.45	0.47	0.19	0.38	0.24	1.00	0.34
26.Modern fuels	0.40	-0.60	0.43	0.15	0.41	0.58	0.53	0.64	0.62	0.68	0.41	0.37	0.56	0.22	0.42	0.35	0.22	0.54	0.35	0.52	0.62	0.21	0.39	0.26	0.34	1.00

Note: Binary variable Achvd all refers to households (coded 1) with sufficient food, safe water and basic education.

Table B-11 Zambia: Tetrachoric Correlations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1.achvd	1.00	-0.66	0.61	0.40	0.66	0.69	0.47	0.76	0.74	0.42	0.56	0.70	0.69	0.76	0.69	0.16	0.32	0.36	0.51	0.76	0.76	0.33	0.82	0.80	0.83	0.64
2.rural	-0.66	1.00	-0.50	-0.36	-0.75	-0.73	-0.69	-0.81	-0.74	-0.48	-0.58	-0.74	-0.63	-0.75	-0.60	-0.01	-0.48	-0.58	-0.84	-0.85	-0.75	-0.48	-0.48	-0.53	-0.71	-0.64
3.Not poor	0.61	-0.50	1.00	0.31	0.53	0.56	0.44	0.65	0.67	0.49	0.52	0.65	0.66	0.69	0.68	0.28	0.20	0.23	0.37	0.65	0.64	0.23	0.59	0.36	0.61	0.58
4.Min floor	0.40	-0.36	0.31	1.00	0.32	0.42	0.31	0.49	0.47	0.38	0.24	0.39	0.50	0.47	0.44	0.08	0.15	0.18	0.27	0.43	0.49	0.17	0.20	0.22	0.46	0.45
5.Solid shelter	0.66	-0.75	0.53	0.32	1.00	0.74	0.70	0.80	0.71	0.47	0.57	0.77	0.58	0.75	0.61	0.02	0.38	0.39	0.56	0.84	0.78	0.31	0.53	0.61	0.66	0.65
6.Toliet	0.69	-0.73	0.56	0.42	0.74	1.00	0.63	0.96	0.80	0.60	0.57	0.79	0.75	0.83	0.76	0.10	0.37	0.38	0.55	0.85	0.82	0.36	0.57	0.58	0.71	0.69
7.Garb disp	0.47	-0.69	0.44	0.31	0.70	0.63	1.00	0.68	0.63	0.51	0.35	0.59	0.47	0.59	0.57	-0.06	0.30	0.28	0.46	0.70	0.70	0.14	0.37	0.40	0.53	0.56
8.Sewage	0.76	-0.81	0.65	0.49	0.80	0.96	0.68	1.00	0.85	0.67	0.59	0.83	0.76	0.86	0.78	0.03	0.39	0.43	0.62	0.91	0.88	0.36	0.57	0.65	0.77	0.75
9.Fridge	0.74	-0.74	0.67	0.47	0.71	0.80	0.63	0.85	1.00	0.66	0.56	0.84	0.74	0.84	0.77	0.10	0.35	0.36	0.57	0.88	0.83	0.31	0.62	0.58	0.75	0.69
10.Wash. Mach.	0.42	-0.48	0.49	0.38	0.47	0.60	0.51	0.67	0.66	1.00	0.37	0.54	0.62	0.60	0.67	-0.01	0.19	0.19	0.30	0.62	0.67	0.11	0.37	0.18	0.58	0.42
11.Phone	0.56	-0.58	0.52	0.24	0.57	0.57	0.35	0.59	0.56	0.37	1.00	0.71	0.55	0.66	0.55	0.34	0.39	0.33	0.46	0.64	0.58	0.36	0.51	0.41	0.60	0.48
12.TV	0.70	-0.74	0.65	0.39	0.77	0.79	0.59	0.83	0.84	0.54	0.71	1.00	0.77	0.92	0.76	0.28	0.38	0.40	0.56	0.91	0.83	0.38	0.63	0.56	0.73	0.71
13.PC	0.69	-0.63	0.66	0.50	0.58	0.75	0.47	0.76	0.74	0.62	0.55	0.77	1.00	0.82	0.75	0.16	0.38	0.35	0.49	0.76	0.74	0.35	0.58	0.47	0.76	0.53
14.Sattelite	0.76	-0.75	0.69	0.47	0.75	0.83	0.59	0.86	0.84	0.60	0.66	0.92	0.82	1.00	0.79	0.26	0.40	0.41	0.56	0.89	0.83	0.42	0.64	0.60	0.78	0.67
15.Car	0.69	-0.60	0.68	0.44	0.61	0.76	0.57	0.78	0.77	0.67	0.55	0.76	0.75	0.79	1.00	0.22	0.28	0.29	0.41	0.76	0.76	0.25	0.61	0.51	0.71	0.57
16.Motorcycle	0.16	-0.01	0.28	0.08	0.02	0.10	-0.06	0.03	0.10	-0.01	0.34	0.28	0.16	0.26	0.22	1.00	0.00	0.02	-0.02	0.10	-0.01	0.00	0.20	0.09	0.18	-0.09
17.Pub. Transp.	0.32	-0.48	0.20	0.15	0.38	0.37	0.30	0.39	0.35	0.19	0.39	0.38	0.38	0.40	0.28	0.00	1.00	0.52	0.53	0.43	0.38	0.52	0.24	0.35	0.34	0.24
18.Health center	0.36	-0.58	0.23	0.18	0.39	0.38	0.28	0.43	0.36	0.19	0.33	0.40	0.35	0.41	0.29	0.02	0.52	1.00	0.67	0.46	0.38	0.63	0.21	0.37	0.37	0.25
19.Market	0.51	-0.84	0.37	0.27	0.56	0.55	0.46	0.62	0.57	0.30	0.46	0.56	0.49	0.56	0.41	-0.02	0.53	0.67	1.00	0.68	0.60	0.60	0.34	0.47	0.53	0.48
20.El access	0.76	-0.85	0.65	0.43	0.84	0.85	0.70	0.91	0.88	0.62	0.64	0.91	0.76	0.89	0.76	0.10	0.43	0.46	0.68	1.00	0.94	0.41	0.61	0.65	0.78	0.85
21.Cook dev.	0.76	-0.75	0.64	0.49	0.78	0.82	0.70	0.88	0.83	0.67	0.58	0.83	0.74	0.83	0.76	-0.01	0.38	0.38	0.60	0.94	1.00	0.32	0.62	0.62	0.77	0.88
22.Sec. school	0.33	-0.48	0.23	0.17	0.31	0.36	0.14	0.36	0.31	0.11	0.36	0.38	0.35	0.42	0.25	0.00	0.52	0.63	0.60	0.41	0.32	1.00	0.21	0.35	0.34	0.21
23.Suff. Food	0.82	-0.48	0.59	0.20	0.53	0.57	0.37	0.57	0.62	0.37	0.51	0.63	0.58	0.64	0.61	0.20	0.24	0.21	0.34	0.61	0.62	0.21	1.00	0.45	0.58	0.50
24.Safe Water	0.80	-0.53	0.36	0.22	0.61	0.58	0.40	0.65	0.58	0.18	0.41	0.56	0.47	0.60	0.51	0.09	0.35	0.37	0.47	0.65	0.62	0.35	0.45	1.00	0.55	0.55
25. Basic Edu	0.83	-0.71	0.61	0.46	0.66	0.71	0.53	0.77	0.75	0.58	0.60	0.73	0.76	0.78	0.71	0.18	0.34	0.37	0.53	0.78	0.77	0.34	0.58	0.55	1.00	0.66
26.Modern fuels	0.64	-0.64	0.58	0.45	0.65	0.69	0.56	0.75	0.69	0.42	0.48	0.71	0.53	0.67	0.57	-0.09	0.24	0.25	0.48	0.85	0.88	0.21	0.50	0.55	0.66	1.00

Note: Binary variable Achvd all refers to households (coded 1) with sufficient food, safe water and basic education.

B.8.2 Logistic regression results

Our main analysis considers households with all three well-being outcomes achieved. Considering all of the outcomes simultaneously was important for our analysis, as these outcomes correspond to the bare minimum standards that each household should achieve. We did not, therefore, consider using multinomial regression as the importance of our analysis was in achieving all three well-being outcomes.

Here we provide additional analysis for those who are interested in the effects of each basic well-being outcome considered in the analysis. We modelled separate logistic regression models for each of the well-being outcomes (clean water, modern fuels, education, adequate food) as a separate dependent variable (Table B-12).

Results show that households that assess themselves not to be poor have nine times higher odds in Nepal, six times higher odds in Vietnam, and two times higher odds in Nepal to have adequate food (holding all the other variables at their means) than their poor counterparts. Households with adequate food have also four times higher odds to have clean cooking device than households with insufficient amount of food.

Collective provisioning (access to markets, public transport, health centre) plays an important role in Nepal and Zambia concerning access to clean and safe water. In both countries, households with safe water have also three-time higher odds of having other collective provisioning accessible to them. Note that these provisioning do not include access to sewage, which is often assumed to be related to having access to clean and safe water.

In Nepal and Vietnam having 'protection' increases the odds of having education by three times. It is an interesting result, as it indicates that having a safe toilet, sewage, solid shelter, and minimum floor area (at least 10 square meters per person), which usually is linked to health aids, here it is also beneficial for education outcomes

In Zambia households with modern fuels have eight times higher odds of having protection. In the case of Nepal and Vietnam location is significant for fuel accessibility. Households without modern fuels have 15 times smaller odds in Nepal and five times smaller odds in Vietnam to be urban. In Zambia households with access to more than 50% of modern fuels have also three and a half higher odds of having basic education.

Table B-12 Odds ratio for achieving adequate food, basic education, clean fuels and clean water in Nepal, Vietnam and Zambia

	Adequate Food			Clean Water			Modern Fuels			Basic Education		
	Nepal	Vietnam	Zambia	Nepal	Vietnam	Zambia	Nepal	Vietnam	Zambia	Nepal	Vietnam	Zambia
Safe water	1.398^{**}		1.360^{***}						2.724^{***}		1.302^{**}	1.554^{***}
	(2.88)		(4.57)						(4.29)		(2.83)	(4.25)
Has > 50% of modern fuels											0.734^{***}	
											(-3.87)	
Adequate food				1.452^{***}		1.356^{***}		2.093^{***}		1.832^{*}		1.232^{*}
				(3.42)		(4.51)		(4.00)		(2.23)		(2.13)
Basic education					1.348^{***}	1.563^{***}		0.693^{***}	3.353^{***}			
					(3.32)	(4.25)		(-3.29)	(7.13)			
Household size		0.923^{*}				1.031^{*}	0.711^{***}	0.657^{***}	0.898^{***}	0.795^{***}	0.826^{***}	0.905^{***}
		(-2.47)				(2.22)	(-9.50)	(-7.40)	(-3.66)	(-5.99)	(-7.72)	(-4.55)
Rural		1.516^{**}	1.314^{**}		0.632^{**}		0.0670^{***}	0.215^{***}	0.544^{**}		1.304^{**}	0.545^{***}
		(2.75)	(3.23)		(-3.11)		(-19.79)	(-11.11)	(-3.27)		(3.28)	(-6.13)
Income per cap	1.001^{***}	1.001^{***}	1.000^{***}				1.000^{**}	1.001^{***}	1.000^{***}			1.000^{***}
	(4.97)	(3.92)	(4.86)				(2.91)	(5.34)	(6.22)			(6.34)
Not poor	8.898^{***}	5.976^{***}	2.373^{***}							1.354^{*}	1.640^{***}	1.955^{***}
	(15.46)	(16.17)	(12.70)							(2.38)	(4.84)	(6.67)
Garbage disposal	1.735^{***}			0.826^{*}	2.671^{***}	0.531^{*}		1.456^{***}			1.315^{***}	
	(5.65)			(-2.14)	(7.30)	(-2.15)		(3.54)			(3.92)	
Electricity access	1.336^{*}			1.580^{***}		1.459^{*}					2.118^{***}	
	(2.51)			(4.15)		(2.42)					(3.57)	
F: collective prov. Nepal				2.970^{***}								
				(6.01)								
F: collective prov. Zambia						2.758^{***}						
						(12.03)						
F: protection			1.870^{***}		3.330^{***}	2.353^{***}		1.366^{**}	7.784^{***}	3.541^{***}	2.676^{***}	1.541^{**}
			(5.12)		(10.98)	(5.80)		(2.59)	(10.09)	(6.84)	(13.16)	(3.11)
Public transp. w/n 5 km		1.336^{*}									0.822^{*}	
		(2.13)									(-2.07)	
Access to market		1.770^{***}			1.429^{***}						1.251^{*}	
		(4.27)			(3.40)						(2.03)	

Table B – 12 continues…	Adequate Food			Clean Water			Modern Fuels			Basic Education		
	Nepal	Vietnam	Zambia	Nepal	Vietnam	Zambia	Nepal	Vietnam	Zambia	Nepal	Vietnam	Zambia
Refrigerator		**1.556***						**3.712*****		**1.505****	**1.205***	
		(2.53)						(10.76)		(2.60)	(2.55)	
Washing machine					**1.933****	**0.228****		**4.874*****		**2.112***	**1.628*****	
					(2.69)	(-3.02)		(7.20)		(2.32)	(3.87)	
Clean cooking device		**1.334****	**3.744*****		**1.585*****			**2.273*****		**2.365*****	**1.335*****	**1.731*****
		(2.59)	(7.54)		(4.55)			(4.85)		(5.43)	(3.58)	(3.30)
Residential Fuels (GJ/cap)		**0.949****		**0.991*****			**0.546*****	**0.373*****			**0.983****	**0.949***
		(-2.97)		(-3.91)			(-21.75)	(-20.16)			(-2.61)	(-2.18)
Total EF (GJ/cap)		**1.055****						**1.151*****			**1.011***	**1.049***
		(3.23)						(10.06)			(2.05)	(2.13)
Share of modern fuels		**1.005***			**1.004****	**1.012*****						**1.007****
		(2.47)			(2.81)	(3.68)						(3.05)
Car			**1.945***			**1.759***						
			(2.47)			(2.13)						
Motor cycle					**0.813***		**9.198*****			**2.062*****	**1.644*****	**2.066****
					(-2.22)		(10.79)			(4.65)	(6.46)	(2.90)
Mobile phone	**1.714*****	**1.440*****	**1.565*****	**1.352****	**1.349****	**1.250****				**2.958*****	**1.714*****	**1.924*****
	(4.75)	(3.35)	(6.48)	(2.93)	(3.14)	(3.19)				(5.12)	(7.03)	(6.21)
Television	**1.423****		**1.782*****	**1.613*****								**1.258***
	(2.59)		(6.18)	(4.02)								(2.06)
Computer										**1.653****	**1.994*****	**2.666*****
										(3.10)	(5.53)	(3.37)
Satellite											**0.877***	**1.499****
											(-2.10)	(2.96)
_cons	0.541***	0.263***	0.210***	0.969	1.811**	0.392***	65.23***	12.09***	0.00865***	0.0209***	0.115***	0.0851***
	(-4.50)	(-5.13)	(-14.97)	(-0.17)	(3.25)	(-9.58)	(18.93)	(6.31)	(-15.03)	(-11.08)	(-7.98)	(-12.10)
N	5501	8816	11465	5501	8816	11465	5501	8816	11465	5501	8816	11465
pseudo R^2	0.225	0.298	0.205	0.084	0.194	0.160	0.604	0.693	0.327	0.264	0.175	0.362
chi2	424.0	922.6	929.1	320.9	852.2	736.8	735.4	724.3	657.2	725.8	1031.1	1079.0

Exponentiated coefficients; *t* statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

B.9 Household socio-economic characteristics

Table B-13 presents summary statistics for selected socio-economic characteristics of households in Nepal, Vietnam, and Zambia. We present results for an average household and households with and without well-being outcomes. In addition, we differentiate between top and bottom quartiles based on equivalised income per capita for households with well-being outcomes. The regional differences are striking. Households with well-being outcomes overwhelmingly tend to be urban in all three countries with the biggest divides in Zambia where only 8% of households with well-being outcomes are rural.

Households with well-being outcomes overwhelmingly (>81%) have access to a safe toilet and solid shelter, even when we consider households with lower incomes (25^{th} quartile). Unsurprisingly, these households also tend to have clean cooking devices, since the prerequisite for achieving all well-being outcomes is to have 50 percent or more usage of modern fuels. Considering ownership of the refrigerator and washing machine, we observe significant differences between top and bottom income quartile (households with well-being outcomes). For refrigerator, it is a two-fold difference and for the washing machine between fivefold for Nepal and Vietnam to tenfold difference for Zambia.

Interestingly, well-being outcomes can be achieved with a significantly varying income level. For the bottom income quartile, it is almost half the national average for Nepal and Zambia and one third less than the national average in Vietnam. At the same time, when we turn our attention to the top income group (25^{th} quartile) we observe between three and an eightfold increase in the income per capita from the national average. This is an important result as it shows that well-being outcomes do not necessarily depend on increased income levels and possibly higher consumption.

Table B-13 Selected socio-economic characteristics of households in Nepal, Vietnam, and Zambia.

	The whole population			HH with wellbeing outcomes			HH without wellbeing outcomes			Top 25% (hh with wellbeing)			Bottom 25% (hh with wellbeing)		
	Nep	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**
sample size	5504	8837	11558	410	2420	917	5091	6396	10548	103	526	345	99	659	166
population size	0%	0%	0%	5%	30%	6%	95%	70%	94%	0.2%	6%	0.2%	4%	94%	2%
Rural	80%	71%	58%	24%	46%	8%	83%	83%	61%	16%	26%	3%	34%	65%	14%
Wellbeing outcomes															
Achieved all outcomes	5%	30%	6%	100%	100%	100%	0%	0%	0%	100%	100%	100%	100%	100%	100%
Adequate food	84%	92%	55%	100%	100%	100%	83%	88%	52%	100%	100%	100%	100%	100%	100%
Safe water	83%	90%	64%	100%	100%	100%	82%	86%	62%	100%	100%	100%	100%	100%	100%
Education	10%	65%	29%	100%	100%	100%	5%	49%	25%	100%	100%	100%	100%	100%	100%
> 50% Modern fuels	15%	42%	8%	100%	100%	100%	0%	0%	0%	100%	100%	100%	100%	100%	100%
Dwelling characteristics															
Solid shelter	29%	87%	29%	84%	97%	86%	27%	83%	26%	86%	99%	88%	81%	95%	83%
Min floor space	48%	82%	66%	54%	86%	92%	48%	80%	65%	74%	92%	99%	43%	82%	84%
Owns dwelling	90%	97%	70%	53%	93%	32%	92%	99%	73%	68%	92%	28%	46%	97%	39%
Safe toilet	54%	69%	30%	99%	93%	89%	52%	58%	27%	100%	98%	97%	99%	85%	84%
Appliances															
Clean cooking device	23%	81%	15%	98%	97%	90%	20%	75%	10%	96%	99%	96%	96%	96%	86%
Refrigerator	8%	41%	11%	44%	72%	59%	6%	28%	9%	77%	90%	80%	28%	50%	34%
Phone	62%	79%	61%	98%	93%	91%	60%	73%	59%	100%	96%	93%	95%	86%	85%
Television	44%	89%	37%	85%	95%	94%	42%	87%	34%	97%	98%	96%	75%	94%	96%
Computer	5%	15%	5%	38%	35%	28%	4%	7%	3%	62%	62%	45%	21%	11%	14%
Washing machine	1%	17%	0.4%	6%	43%	3%	0.3%	6%	0.3%	14%	72%	7%	3%	15%	1%
Satellite or cable	2%	56%	19%	15%	65%	74%	1%	52%	16%	33%	67%	86%	4%	58%	52%
Collective provision															
Safe garbage disposal	56%	41%	6%	67%	68%	27%	56%	29%	5%	71%	85%	39%	64%	51%	10%
Connected to sewage	8%	48%	15%	46%	81%	77%	6%	34%	11%	50%	93%	93%	37%	63%	59%
Electricity access	69%	97%	30%	100%	100%	99%	68%	96%	26%	100%	100%	100%	100%	100%	99%

Table B-13 continues…

	The whole population			HH with wellbeing outcomes			HH without wellbeing outcomes			Top 25% (hh with wellbeing)			Bottom 25% (hh with wellbeing)		
	Nep	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**
Economic characteristics															
Not poor	50%	89%	59%	77%	99%	95%	49%	85%	57%	79%	100%	99%	74%	95%	91%
Total Exp. per cap (USD$)	634 (590)	1242 (890)	568 (764)	1655 (1026)	1840 (1018)	1730 (1446)	583 (509)	984 (682)	501 (643)	2326 (1193)	2783 (1212)	2609 (1820)	1126 (508)	1097 (473)	1102 (967)
Income per OECD cap (USD$)	1109 (4356)	1523 (1440)	944 (1600)	2580 (2690)	2344 (1915)	3483 (3286)	1036 (4410)	1168 (983)	797 (1297)	6137 (3539)	4441 (2833)	7521 (3296)	725 (296)	997 (260)	512 (285)
Income per household (USD$)	2895 (13739)	3469 (3355)	2376 (3949)	5808 (6817)	5187 (4393)	8087 (7300)	2750 (13979)	2725 (2438)	2043 (3374)	14242 (9619)	9902 (6347)	16473 (7532)	1515 (874)	2209 (895)	1419 (868)
Vehicles															
Bicycle	38%	57%	36%	35%	50%	14%	38%	61%	37%	41%	38%	12%	33%	60%	24%
Motorcycle	9%	76%	1%	42%	91%	0.3%	7%	69%	1%	62%	98%	0.5%	27%	83%	0.2%
Car	1%	1%	7%	5%	2%	39%	0.4%	0.2%	5%	15%	6%	60%	1%	0.1%	24%
Energy Footprints (GJ/cap)															
Indirect	3 (3)	7 (5)	3 (4)	6 (6)	10 (6)	9 (9)	2 (3)	5 (3)	2 (3)	10 (10)	16 (8)	14 (11)	4 (2)	6 (3)	5 (6)
Direct	15 (16)	13 (12)	13 (13)	5 (7)	12 (9)	10 (14)	16 (16)	14 (12)	13 (13)	8 (8)	18 (10)	15 (17)	3 (2)	7 (6)	6 (9)
Residual fuels	15 (16)	9 (10)	13 (12)	3 (2)	5 (3)	8 (11)	16 (16)	11 (12)	13 (12)	4 (2)	7 (4)	10 (12)	3 (1)	3 (2)	5 (5)
Vehicle fuel	1 (3)	5 (6)	1 (5)	3 (6)	8 (8)	5 (13)	0.4 (3)	3 (5)	0.4 (4)	5 (8)	13 (9)	9 (18)	1 (2)	5 (6)	3 (10)
Public transport	0.4 (1)	0.2 (1)	0.1 (0)	1 (1)	0.4 (1)	0.2 (0)	0.4 (1)	0.2 (0)	0.1 (0)	1 (1)	0.5 (1)	0.2 (0)	1 (1)	0 (1)	0.1 (0)
Total EF	18 (16)	20 (14)	16 (15)	12 (10)	22 (14)	19 (22)	18 (17)	19 (13)	16 (14)	19 (14)	33 (16)	29 (27)	7 (3)	12 (8)	11 (14)
Type of fuels															
Firewood	14 (16)	5 (10)	5 (8)	0.1 (1)	0.1 (0)	0.01 (0)	15 (16)	7 (11)	5 (8)	0.2 (1)	0.1 (0)	0.01 (0)	0.1 (0)	0 (0)	0 (0)
% in tot resid fuels	95%	55%	37%	4%	1%	0.1%	96%	65%	38%	5%	1%	0.1%	5%	2%	0%
Charcoal	0.1 (2)	0.0 (0)	6.9 (11)	0.01 (0)	0.0 (0)	0.7 (2)	0.1 (2)	0.0 (0)	7.3 (12)	0.0 (0)	0.0 (0)	1.2 (3)	0.0 (0)	0.0 (0)	0.3 (1)
% in tot resid fuels	1%	0%	53%	0.3%	0%	9%	1%	0%	55%	0.1%	0%	11%	0%	0%	6%
Coal	0.0 (0)	0.6 (3)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.9 (3)	0.0 (0)	0.0 (0)	0.1 (1)	0.0 (0)	0.0 (0)	0.03 (0)	0.0 (0)
% in tot resid fuels	0%	7%	0.01%	0%	2%	0%	0%	8%	0.01%	0%	2%	0%	0%	1%	0%
By products	0.0 (0)	1.1 (4)	0.0 (0)	0.0 (0)	0.03 (0)	0.0 (0)	0.0 (0)	1.5 (4)	0.0 (0)	0.0 (0)	0.00 (0)	0.0 (0)	0.0 (0)	0.05 (0)	0.0 (0)
% in tot resid fuels	0%	12%	0%	0%	1%	0%	0%	13%	0%	0%	0.1%	0%	0%	2%	0%
Diesel at home	0.0 (0)	0.0 (0)	0.04 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.1 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)	0.0 (0)
% in tot resid fuels	0%	0%	0.3%	0%	0%	0%	0%	0%	0.3%	0%	0%	0%	0%	0%	0%

Table B-13 continues…

	The whole population			HH with wellbeing outcomes			HH without wellbeing outcomes			Top 25% (hh with wellbeing)			Bottom 25% (hh with wellbeing)		
	Nep	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**	**Nep**	**Viet**	**Zam**
Gas	0.4 (1)	0.6 (1)	0.1 (2)	2.1 (1)	1.2 (1)	0.8 (9)	0.3 (1)	0.4 (1)	0.0 (1)	2.3 (1)	1.5 (1)	0.6 (10)	1.9 (1)	0.9 (1)	0.1 (2)
% in tot resid fuels	2%	7%	0.4%	69%	26%	10%	2%	3%	0.0%	60%	22%	5%	75%	31%	2%
Electricity	0.2 (0)	1.8 (2)	1.1 (3)	0.7 (1)	3.2 (3)	6.2 (5)	0.2 (0)	1.2 (1)	0.8 (2)	1.3 (1)	5.1 (4)	8.7 (5)	0.5 (0)	1.8 (1)	4.4 (3)
% in tot resid fuels	1%	19%	8%	24%	70%	81%	1%	10%	6%	33%	75%	83%	19%	63%	91%
Access to Facilities															
Secondary School	90%	97%	66%	100%	99%	77%	90%	96%	66%	100%	99%	77%	100%	98%	69%
Public Transport	76%	89%	57%	100%	95%	77%	75%	87%	56%	100%	96%	76%	100%	93%	83%
Agriculture centre	51%	99%	62%	87%	99%	30%	49%	98%	63%	85%	99%	22%	91%	99%	34%
Bank	40%	55%	22%	95%	66%	58%	37%	50%	19%	98%	74%	63%	95%	58%	51%
Post Office	80%	90%	21%	97%	95%	53%	79%	87%	19%	98%	96%	56%	97%	94%	53%
Health Centre	90%	100%	63%	99%	100%	79%	89%	100%	62%	99%	100%	78%	100%	100%	81%
Market	97%	91%	63%	100%	96%	92%	97%	89%	62%	100%	97%	91%	100%	96%	91%

Note: HH means households, top, and bottom 25% corresponds to the 25^{th} income quartile, where income is calculated based on equivalized OECD per capita income.

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Appendix C
Supporting information to Chapter 4: High energy use for fun and for necessity: what sops the UK from achieving well-being at low energy

C.1 Preparation for statistical matching

The overall goal of the statistical matching is to calculate energy footprints for Understanding Society Survey (USS) using data related to expenditures and footprints in Living Costs and Food Survey (LCFS). The USS contains information related to well-being and many variables related to socio-economic and environmental behavior. We use the LCFS dataset to estimate average footprints or use the multipliers calculated using LCFS to obtain household energy footprints for the USS.

LCFS contains 5,465 households and the USS has 19,252 households. Both surveys were conducted between the years 2018 and 2019. LCFS represents 27,419,000 households (the total number of households in the UK in 2018) and USS represents 15,682 households. The main difference is that LCFS scales up to the UK population size and the USS survey reflects proportions in the population.

C.1.1 Common variables

First, we selected variables that are common between Living Costs and Food expenditure Survey (LCFS) and Understanding Society Survey (USS). The second step was to analyse if the distribution of selected variables is similar in both datasets. Below in Table C-1, we present common variables between LCFS and USS surveys. In a column titled “notes,” we provide a number of missing values for either USS or LCFS survey. In green, we marked similar distributions between LCFS and USS.

Table C-1 Overview: common variables between USS and LCFS. In green similar distributions between both surveys, in red poorer matches between distributions.

Common variable	type	Unit	notes
Income	C	£ per year	
Total hours worked by adults	C	Hrs/week	142 missing values for USS
Total hours worked by hh head	C	Hrs/week	142 missing values for USS
Household size	C	persons	
Number of adults	C	persons	
Number of kids	C	persons	
Number of couples	C	couples	
Age (hh head)	C	number	4 missing values for USS
Number of bedrooms	C.	bedrooms	6 incl. 6 and above
Exp on el, gas, oil combined	C	£ per year	
At least one person has 16 or more years of education in the household	B	0-no; 1-yes	964 missing values for LCFS; 294 missing values for USS
At least one person has 12 to 15 years of education in the household but nobody 16 years or more	B	0-no; 1-yes	964 missing values for LCFS; 294 missing values for USS
Nobody in household has more than 11 years education	B	0-no; 1-yes	964 missing values for LCFS; 294 missing values for USS
HH type: 1 male, aged 65+, no children; 1 female, age 60+, no children 1 adult under pensionable age, no children 1 adult, 1 child 1 adult, 2 or more children Couple both under pensionable age, no children Couple 1 or more over pensionable age, no children Couple with 1 child Couple with 2 children Couple with 3 or more children 2 adults, not a couple, both under pensionable age, no children 2 adults, not a couple, one or more over pensionable age, no children 2 adults, not a couple, 1 or more children 3 or more adults, no children, incl. at least one couple 3 or more adults, 1-2 children, incl. at least one couple 3 or more adults, >2 children, incl. at least one couple 3 or more adults, no children, excl. any couples 3 or more adults, 1 or more children, excl. any couples	Cat.		In red hosehold types with a poor match between USS and LCFS
Flies domestically	B	0-no; 1-yes	142 missing values for USS
Flies internationally	B	0-no; 1-yes	142 missing values for USS

Table C–1 continuous …

Number of domestic trips	C	Number per hh	5434 missing values for USS
Number of international trips	C	Number per hh	5434 missing values for USS
House owned outright	B	0-no; 1-yes	
House owned with a mortgage	B	0-no; 1-yes	
Renting privately	B	0-no; 1-yes	
Number of cars	C	number	90 missing values for USS
Non-white	B	0-no; 1-yes	395 missing values for USS
Female-headed	B	0-no; 1-yes	1 missing value for USS
Urban/rural	B	1 – urban; 2- rural	15 missing values for USS
Region: North East; North West; Yorkshire and the Humber; East Midlands; West Midlands; East of England; London; South East; South West; Wales; Scotland; Northern Ireland	Cat		15 missing values for USS
OAC – output area classification. Three levels: 1. Supergroups; 2. Groups; 3. Subgroups	cat		17 missing values for LCFS
Frequency of using bus	cat	1 - hh never uses	142 missing values for USS
Frequency of using train/tube	cat	2 – at least 1 pers uses	142 missing values for USS
Frequency of using taxi	cat	infrequently 3 – at least 1	142 missing values for USS
Frequency of using public transport	cat	pers uses frequently	142 missing values for USS

Note: C – continuous, cat – categorical; hh- household; B - Binary

There are several variables with 142 missing values for the USS survey. These variables are built based on the answers from individuals from the file titled "Substantive data for responding adults (16+), incl. proxies" in the USS survey. These individuals did not finish (or partake) in the questionnaire module related to their household, hence we decided to omit these households in the analysis.

For 1289 households the household head was **not** interviewed for the "indresp" questionnaire ("Substantive data for responding adults (16+), incl. proxies") so that is why we have missing values for working time related to the household head

Eight households have negative values for their House fuels footprint. We dropped them from the analysis.

For analysis, I assumed zeros for missing values for domestic and international flights for USS.

C.1.2 EF categories used for matching

We aggregated 305 expenditure categories to 18 and use them for predicted energy footprints (see Table C-2). Aggregation for most of the categories follows COICOP categorization on the highest level (e.g. Clothing and footwear, Health, communication, etc.). Some of the categories like transport (COICOP 7) or house fuels (COICOP 4) we split to match exisiting data in the USS survey. For example, since in both LCFS and USS surveys we have expenditures on electricity, gas, and oil, we took those categories from "COICOP4: Housing, water, electricity, gas, and other fuels" and split it into "Housing" "House fuels,: coal, coke wood and peat", and "house fuels: oil, gas, and electricity".

Table C-2 Aggregated EF categories used for matching.

No.	Name of category	Corresponding COICOP category
1	Food and alcohol and tobacco	1 & 2
2	Clothing and footwear	3
3	Housing, water, refuse, repairs & maintenance, other	4.1, 4.2, 4.3, 4.4.1, 4.4.2, 4.4.4,
4	House fuels rest: coal and coke & wood and peat	4.5.4, 4.5.5
5	House fuels: oil gas el	4.5.1, 4.5.2, 4.5.3
6	Furnishings, household equipment, and routine household maintenance	5
7	Health	6
8	Purchase of vehicles	7.1
9	Personal travel (fuel, hire)	7.2.2.1, 7.2.2.2, 7.2.2.3, 7.3.4.5, 7.3.4.6
10	Transport rail, road and water	7.3.1, 7.3.2, 7.3.3, 7.3.4.3, 7.3.4.4,7.3.4.8,
11	Transport air	7.3.4.1, 7.3.4.2
12	Other transport products and services related to private transport (parts, maintenance, service, driving license)	7.2.1.1, 7.2.1.2, 7.2.1.3, 7.2.1.4, 7.2.3.1, 7.2.3.2, 7.2.4.1, 7.2.4.2, 7.2.4.3, 7.2.4.4, 7.2.4.5
13	Communication	8
14	Recreation and culture	9
15	Education	10
16	Restaurants and hotels	11
17	Package holidays	11.2.1, 11.2.2
18	Miscellaneous goods and services	12

C.2 Matching strategy

C.2.1 Multipliers

For some footprints, we have available expenditures in the USS. Households reported spending on:

- Electricity, electricity, and gas combined, gas, oil – I created a new variable that summed up all the spending
- expenditures in grocery shops
- expenditures on alcohol
- expenditures on snacks and meals taken outside of the home

Using these spends we multiplied them with multipliers calculated using LCFS and resulting we obtained energy footprints:

- Electricity, gas and oil = 0.04437 GJ/£
- Electricity= 0.00267 GJ/£
- Gas = 0.09914 GJ/£

- Oil = 0.0084 GJ/£
- Electricity and gas combined = 0.04678 GJ/£
- Grocery =0.00299 GJ/£
- Alcohol =0.00055 GJ/£
- Meals and snack outside home =0.00369 GJ/£

C.2.2 Regression analysis and use of predicted values

One of the methods for matching EF between LCFS and USS is to run the regression models with variables that are common in both datasets and then use the command "predict" in STATA to linearly predict EF values for missing observations in the USS survey.

Table C-3 presents adjusted R^2 for each EF category after running a step-wise regression analysis. All regression analysis is done using only LCFS data (since USS does not have any energy footprints). We run two types of analysis: one without any transformed variables and the second with log-transformed energy footprints and incomes. We started the analysis with 18 categories (). Some of the models have very weak adjusted R^2 (red font in Tale C-3). This prompted us to use average footprints per income category instead of regression analysis.

Table C-3 Adjusted R^2 for regression models for EF categories using LCFS data.

	Dependent variable:	adjusted R^2	(Log) adjusted R^2
1	Food and alcohol	0.34	0.33
2	Clothing and footwear	0.07	0.1
3	Housing, water, refuse, repairs & maintenance, other	0.35	0.26
4	House fuels rest: coal and coke & wood and peat	0.27	0.08
5	House fuels: oil gas el	0.54	0.37
6	Furnishings, household equipment, and routine household maintenance	0.05	0.12
7	Health	0.03	0.05
8	Purchase of vehicles	0.11	0.09
9	Personal travel (fuel, hire)	0.15	0.06
10	Transport rail, road and water	0.13	0.12
11	Transport air	0.11	0.15
12	Other transport products and services related to private transport (parts, maintenance, service, driving license)	0.11	0.10
13	Communication	0.11	0.22
14	Recreation and culture	0.06	0.24
15	Education	0.04	0.29
16	Restaurants and hotels	0.18	0.23
17	Package holidays	0.12	0.13
18	Miscellaneous goods and services	0.02	0.30

C.2.3 Average Energy Footprints

A number of EF categories for USS households we calculated using the average EF for a given category based on LCFS data. This required using additional information in both surveys. For example, in LCFS and USS surveys households reported the number of purchased vehicles in the past 12 months. We could use this information to calculate an average energy footprint per bought vehicle (based on LCFS) and apply that to the USS survey. Overall, this method helps to show more realistic energy consumption per household for categories where spending is not a preferable indicator for the size of energy footprint. A good example is footprints related to air transportation. A plane ticket to Poland from Leeds can cost 17£ whereas a ticket from London to Edinborough can be as much as 100£. Those prices do not reflect the amount of energy needed to make both trips, or milage. Using average EF per trip based on LCFS data (which uses as an extension vector the total energy used by households reported by the IEA agency) seems to be a more realistic option.

The other type of average used to estimate footprints is energy footprints per income decile. Since income has a similar distribution in LCFS and USS we used it to calculate the average energy footprint per income group using LCFS households and then applied this average to households in the USS in the corresponding income group.

C.3 Statistical matching – method, and analysis for selected EF category

C.3.1 Food & alcohol

In the USS survey households reported spending on three categories corresponding to food and alcohol:

1. Groceries*: "About how much has your household spent in total on food and groceries in the last four weeks from a supermarket or other food shop or market? Please do not include alcohol but do include non-food items such as paper products, home cleaning supplies and pet foods"*.
2. Alcohol: *About how much have you {if HHGRID.hhsize greater than 1} and other members of your household spent in total on alcohol in the last four weeks? Please include alcohol purchased from a supermarket or off licence and from pubs, restaurants or other venues.*
3. Meals and snacks : *And about how much have you and other members of your household spent in total on meals, snacks or non-alcoholic drinks purchased outside the home in the last four weeks? Please include items bought from takeaways, restaurants, sandwich shops, work or school canteens but do not include alcohol.*

For each of these spending categories in the USS survey, we multiply with a corresponding multiplier calculated based on LCFS data. For example, we summed spending in USS on groceries and alcohol and multiplied it with a multiplier based on COICOP 1 & 2 categories in LCFS data. For meals and snacks in USS, we used multiplier corresponding to Restaurants and hotels in LCFS (Table C-4).

Table C-4 Lookup table: LCFS categories to USS.

COICOP categories	Aggregated name	USS expenditure item
COICOP 1 Food	Food and alcohol	Groceries
COICOP 2: Alcoholic Beverages & Tobacco		Alcohol
COICOP 11: Restaurants and hotels incl.: 1.Restaurants and café meals 2. Alco beverages 3. Takeouts 5. Hot and cold food 6. COnfectionairy 7. Ice cream 8. soft Drink 9. contract catering 10. school meals 11/ Melas at work	Restaurants and hotels	Meals and snacks

The calculation multiplies unweighted yearly household expenditure from USS (the four weeks expenditure is divided by 4 and multiplied by 52) with a multiplier calculated using LCFS energy footprint and expenditures (GJ/$).

In the USS 723 households did not report any spending on groceries nor alcohol. This is not realistic so we imputed expenditure for these households using available household characteristics in USS corresponding to expenditure on electricity, gas, and oil, income, ethnicity, number of bedrooms, and household types.

C.3.2 Electricity, gas and heating oil

Since households in the USS reported their yearly spending on electricity, gas, oil, and other fuels, we split categories included in COICOP 4 to account for this information (Table C-5). For electricity, gas, oil, and other fuels we calculated multipliers based on LCFS data. For other fuels households in the USS survey were asked how much they spend on any other house fuels besides electricity, gas, and oil. We assume these spends correspond to possible fuels like coal, coke, paraffin, wood, or hot water. Hence the multiplier for those spends was calculated using COICOP 4.4.3.1 and 4.4.3.2.

Table C-5 Categorization of COICOP 4 category: Housing, water, electricity, gas, and other fuels; the corresponding question in the USS and used multipliers.

COICOP categories	Aggregated name	The corresponding question in USS survey	Multiplier (GJ/$)
COICOP 4.1: rents, central heating repairs,	**Housing, water, refuse**		
COICOP 4.2: house maintenance, paint, wallpaper, timber, equipment hire, small materials			
COICOP 4.3: other regular housing payments incl. services, refuse collection			
COICOP 4.4: Coal and Coke; paraffin, wood, peat, hot water, etc.	**Other fuels**	In the last year, how much has your household spent on other fuel, including solid fuel?	2.2527
COICOP 4.4: electricity, gas, oil for central heating	**El, gas, and oil**	In the last year, how much has your household spent on oil? In the last year, how much has your household spent on gas, including Calor Gas? In the last year, how much has your household spent on electricity? In the last year, how much has your household spent on gas and electricity combined?	**El**: 0.00267 **Gas**: 0.09914 **Oil**: 0.0084 **El&gas:** 0.04678 **El&gas&oil:** 0.04437

C.3.2.1 Electricity and gas usage based on regional price differences

Electricity and gas prices differ between regions in Great Britain (Table C-6). ONS provides data for average prices for electricity and gas by region and method of payment. Table C-6 presents an average for each region based on the years 2018 and 2019. The definition of the payment methods are as follows:

- prepayment -a ‘pay as you go’ method, users topping up an allowance and usage drawing on their balance.

- credit - households settle the bill on the electricity or gas, they used upon receipt but do not pay a recurring set payment

- direct debit - recurring set payment

The data for gas does not exist for Northern Ireland, so the overall national average is assumed. Averages for electricity and gas are calculated by summing the average for electricity and the average for gas. In the USS survey, each household has a regional identifier, which can be used to assign different prices of electricity, gas, or electricity and gas combined by region. In the survey majority of households use the combined method for paying for electricity and gas (52% in Table C-7). If households reported expenditures on electricity and gas separately then they would have zero expenditures on electricity and gas paid in one bill and vice versa, if households reported spending on electricity and gas in one bill they would have zero expenditure on electricity and gas paid separately.

Table C-6 Prices by regions and method of payment: electricity, gas and electricity and gas combined (unit: £/kwh of used energy + fixed cost per kwh)

gov office region name	El Credit	El D. debit	El pre-pay	Avg el	Gas Credit	Gas D.debit	Gas Pre-pay	Avg gas	El gas Credit	El gas D.debit	El gas Pre-pay	Avg el gas
East Midlands	0.196	0.177	0.181	0.181	0.047	0.042	0.043	0.043	0.243	0.219	0.224	0.224
Eastern	0.202	0.181	0.185	0.186	0.048	0.043	0.044	0.044	0.250	0.224	0.229	0.230
London	0.201	0.182	0.179	0.187	0.050	0.045	0.045	0.046	0.250	0.227	0.224	0.233
Wales	0.208	0.189	0.191	0.193	0.048	0.043	0.044	0.044	0.257	0.232	0.235	0.237
North East	0.199	0.180	0.184	0.184	0.047	0.042	0.043	0.043	0.246	0.221	0.227	0.227
Scotland	0.205	0.187	0.189	0.191	0.048	0.043	0.044	0.044	0.253	0.230	0.233	0.235
North West	0.199	0.180	0.183	0.184	0.048	0.043	0.044	0.044	0.247	0.223	0.227	0.228
Northern Ireland	0.171	0.161	0.169	0.166	0.048	0.043	0.044	0.044	0.219	0.204	0.213	0.210
South East	0.207	0.186	0.188	0.190	0.049	0.044	0.045	0.045	0.256	0.230	0.234	0.235
South West	0.212	0.192	0.193	0.196	0.050	0.045	0.046	0.046	0.262	0.236	0.239	0.241
West Midlands	0.201	0.181	0.185	0.185	0.048	0.043	0.044	0.044	0.250	0.223	0.229	0.229
Yorkshire	0.197	0.177	0.181	0.182	0.047	0.042	0.043	0.043	0.245	0.219	0.224	0.225

Table C-7 Mode of payment for electricity and gas, based on USS survey 2018/2019.

	Frequency	Percent	Cumulative
Inapplicable	3,581	18.6	18.6
Refusal	11	0.06	18.66
Don’t know	200	1.04	19.7
One bill	9,911	51.48	71.18
Separately	5,549	28.82	100

C.3.2.2 Differences between one bill and a separate bill for electricity and gas

When gas and electricity are reported in one bill the expenditures on average are 30% higher than when expenditures on those fuels are paid separately (Table C-8). This statistic does not include imputed values, nor regional differences. There are more spent on separate electricity and gas.

Households that choose to pay for gas and electricity in one bill reported higher spending (average 96£ per month) and those who pay separately reported spending on average 67£ per month.

Table C-8 Descriptive statistics for method of payment for electricity and gas.

	Observations	Mean (£)	Std.Dev.	Min	Max
In one bill	8,843	96.216	47.15	0	750
Separately	10,409	67.64	64.76	0	11105

Using regional average price for combined electricity and gas will not get rid of the problem of the difference between the method of reporting and expenditure differences corresponding to it. However, the difference might stem also from the preferred method of payment. The majority of households paying for elelctricty and gas in one bill choose to pay monthly by direct debit (49%), or by standing order also once per month (39%). For those who pay separately for electricity and gas, a similar share of households chose to pay by monthly direct debit (32%) or pre-paid meter (27%) for electricity, and similarly, for gas - households chose to pay by monthly direct debit (30% or pre-paid meter (30%).

C.3.2.3 Imputation for electricity and gas expenditure

Before calculating the energy use (kWh) for households using price per kWh (£/kWh) and expenditure, we needed to impute expenditures for households that did not report any spending on electricity (2,704 observations, which equals 14% of the sample). We assumed that these households are connected to electricity, but they did not report any spending. Since the majority of households report spending on electricity in one bill with gas, we imputed spending on electricity using both spends on electricity and gas. Imputations are done using "mi" command in STATA which *is essentially an iterative form of stochastic imputation. However, instead of filling in a single value, the distribution of the observed data is used to estimate multiple values that reflect the uncertainty around the true value. These values are then used in the analysis of interest, such as in a OLS model, and the results combined. Each imputed value includes a random component whose magnitude reflects the extent to which other variables in the imputation model cannot predict it's true values. Thus, building into the imputed values a level of uncertainty around the "truthfulness" of the imputed values* (UCLA 2021, White *et al* 2011, Young and Johnson 2011).

A common misconception of missing data methods is the assumption that imputed values should represent "real" values. The purpose when addressing missing data is to correctly reproduce the variance/covariance matrix we would have observed had our data not had any missing information.

MI has three basic phases:

1. Imputation or Fill-in Phase: The missing data are filled in with estimated values and a complete data set is created. This process of fill-in is repeated m times.

2. Analysis Phase: Each of the m complete data sets is then analyzed using a statistical method of interest (e.g. linear regression).

3. Pooling Phase: The parameter estimates (e.g. coefficients and standard errors) obtained from each analyzed data set are then combined for inference.

We used MVN imputation algorithm. As a result, 10 imputed datasets were created. The proportion of missing variables that were imputed are presented in Table **Error! Reference source not found.**C-9. The following variables were used in the imputation model: income, council tax band, region, number of bedrooms, the total number of working hours for adults in the household, household head age, household type, frequency of using public transportation, urban/rural, expenditure on oil fuel, expenditure on other types of house fuels (e.g. wood, coal).

The resulting imputed expenditure corresponds to 13% of the total reported expenditure.

Table C-9 Number of missing observations for USS households, that were imputed.

Variable	Number of missing observations	Share of total observations
Expenditure on electricity and gas	2,708	14%
Income	96	0.5%
Household head age	4	0.02%
Urban/rural	15	0.08%

C.3.2.4 Using regional price differences to calculate energy usage

After imputation of spending on electricity and gas combined, we could calculate energy usage (kWh) using average regional prices. The multiplication of kwh/£ spend times total expenditure is based on regional price differences. When households reported paying bills separately for as and electricity, we used corresponding prices that differ by region. For combined bills on electricity and gas and imputed expenditure, we used the average for combined electricity and gas. The resulting energy use in kWh could be then converted to GJ by dividing by 277.778.

$$\frac{kwh}{£} * £ = kwh$$

$$1\ GJ = 277.778\ kwh$$

The energy footprint for electricity, oil and gas is then a sum of spends times price per kWh for each type of energy payment: separately for electricity and gas, combined for electricity and gas, and energy use on oil using a multiplier.

$$EF_{el_{gas}} = \frac{kwh_{el}}{£_{el}} * £_{el} + \frac{kwh_{gas}}{£_{gas}} * £_{gas} + \frac{avgKwh_{elgas}}{avg£_{elgas}} * £_{elgas}$$

$$EF_{el_{gas}} = \frac{EF_{el_{gas}}}{277.778\ kwh} = GJ$$

$$EF_{el_{gas_{oil}}} = EF_{el_{gas}} + £_{oil} * \frac{GJ_{gas}}{£_{gas}} = GJ$$

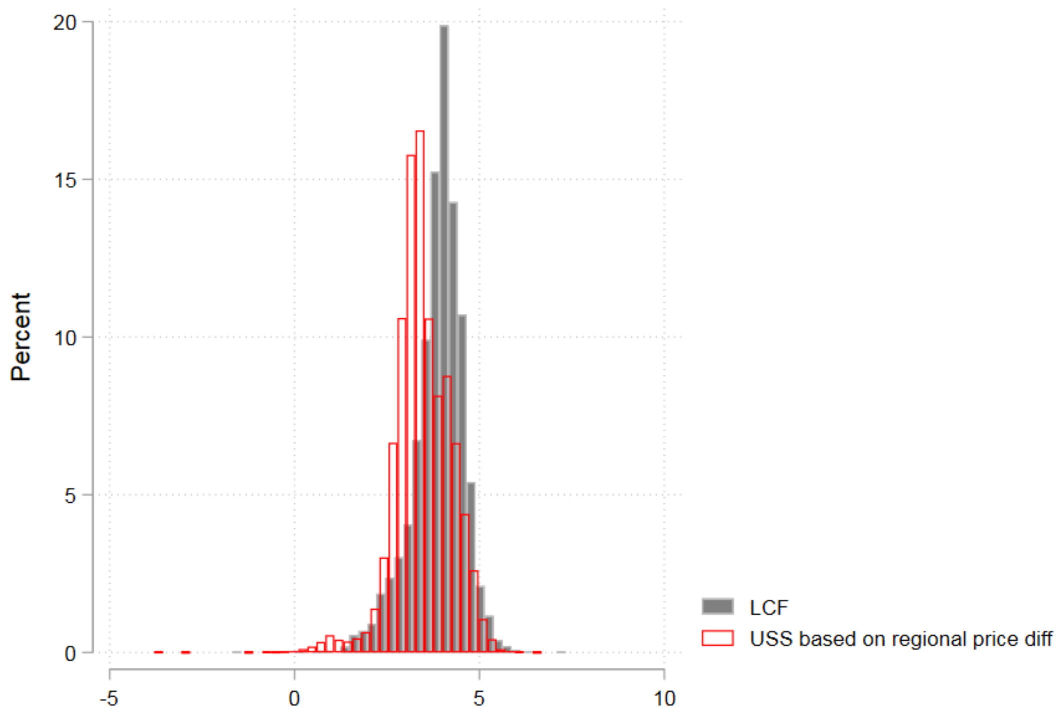

Figure C-1 Comparison between EF for electricity, oil, and gas for households in LCFS survey (gray) and for households in USS survey (red bars). The USS is based on reported expenditures on fuels including imputed expenditures for electricity and gas when data was missing. EF for USS is calculated using regional electricity and gas price differences and by applying multiplier for oil.

C.3.3 Recreation and package holidays

We combined COICOP categories 9 “recreation and Culture” with COICOP 11.2.1 “Holidays in UK” and 11.2.2 “Holidays abroad”. We used regression analysis (Table C-10) to predict energy footprints in logarithmic form for households in USS. The package holidays does not include flights, which are a separate category.

Table C-10 Regression model for predicted EF for recreation and package holidays. Based on LCFS sample (unweighted households).

	(1)	
	LCFS recreation and holidays (log)	
Yearly household income (log)	0.36^{***}	(12.29)
Non white	-0.77^{***}	(-13.58)
Electricity and gas and oil exp.	0.00^{*}	(2.23)
Region: South East	0.18^{***}	(3.54)
Region: Northern Ireland	-0.32^{**}	(-3.01)
Number bedrooms	0.22^{***}	(10.20)
Urban	-0.25^{***}	(-4.90)
Flies internationally	0.20^{***}	(3.78)
Household head age	0.01^{***}	(7.58)
No more than 11 yrs of education	-0.17^{***}	(-3.73)
Frequent user of public transport	0.23^{***}	(5.81)
Number of international fly-trips	0.03^{***}	(4.20)
Renting	-0.16^{**}	(-3.28)
Flying domestically	0.43^{**}	(3.24)
HH: 1 adult, 1 child	0.30^{**}	(2.67)
HH: 1 adult, 2 or more children	0.24^{*}	(2.01)
HH: Couple both under pension age, no kids	0.31^{***}	(5.95)
HH: Couple with one child	0.31^{***}	(4.33)
HH: Couple with two children	0.39^{***}	(5.48)
HH: Couple with 3 children or more	0.53^{***}	(5.06)
HH: 3 or more adults, no children, at least one couple	0.28^{***}	(4.44)
HH: 3 or more adults, 1-2 children, at least one couple	0.34^{***}	(3.92)
_cons	-3.57^{***}	(-11.31)
N	4453	
R^2	0.28	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The results in Table C-11 show a comparison in the distribution of energy footprints estimated using LCFS and USS.

Table C-11 Summary of original weighted household energy footprint for recreation and package holidays based on LCFS survey and based on predicted EF for the USS survey.

Survey	mean	Number of obs	Std dev	min	max
LCFS	10	5,465	29	0	1340
USS	7	15,120	18	0.72	3587

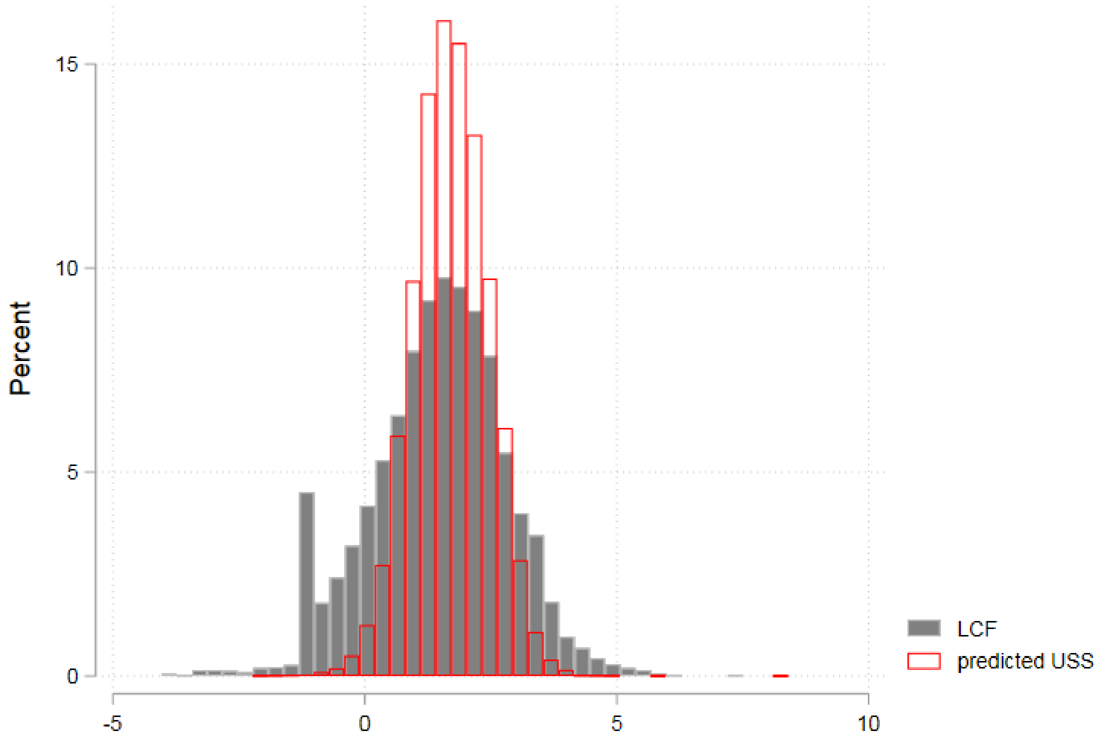

Figure C-2 Histogram for recreation and package holidays. In black values for the reported EF in LCFS. Red Bars indicate EF based on predicted EF for USS. Bins widths are the same for LCFS and USS.

C.3.4 Housing, water, refuse

Table C-12 presents the regression model used to predict values for the category “housing, water, refuse”. The adjusted R^2 is 0.36 which makes this model moderately strong. Table C-13 presents the mean comparison and Figure C-3 histogram for original LCFS footprints and predicted values for USS.

Table C-12 Regression model for predicted EF for housing, water and refuse. Based on LCFS sample (unweighted households).

	(1)	
	LCFS housing, water, refuse (log)	
City council tax: band B	0.24^{***}	(7.55)
City council tax: band C	0.29^{***}	(8.63)
City council tax: band D	0.38^{***}	(10.04)
City council tax: band E	0.40^{***}	(9.32)
City council tax: band F	0.43^{***}	(7.93)
City council tax: band G	0.51^{***}	(7.89)
City council tax: band H	0.54^{***}	(3.60)
OAC groups: Inner City Students	0.34^{**}	(2.60)
OAC groups: Aspiring and Affluent	0.38^{***}	(3.84)
OAC groups: Endeavoring Ethnic Mix	0.50^{***}	(6.00)
OAC groups: Ethnic Dynamic	0.56^{***}	(3.88)
OAC groups: Aspirational Techies	0.30^{***}	(3.96)
OAC groups: Constrained Flat Dwellers	-0.73^{***}	(-6.84)
OAC groups: White Communities	-0.36^{***}	(-5.34)
Number of couples in the HH	0.32^{***}	(12.08)
Number of bedrooms	0.14^{***}	(10.50)
HH head working (hrs/week)	0.02^{***}	(17.63)
Number of international flights	0.02^{***}	(4.20)
Region: North West	-0.11^{***}	(-3.33)
Region: Yorkshire and the Humber	-0.12^{**}	(-3.21)
Region: London	-0.19^{***}	(-4.90)
Region: South East	-0.15^{***}	(-4.68)
Region: Wales	-0.21^{***}	(-4.59)
Region: Scotland	0.15^{***}	(3.93)
HH: 1 adult, 1 child	0.35^{***}	(4.98)
HH: Couple 1 or more over pension age	0.19^{***}	(5.47)
HH: Couple with 1 child	0.10^{*}	(2.47)
HH: Couple with 2 children	0.18^{***}	(4.43)
HH: 3 or more adults, no children, excl. any couples	0.28^{***}	(3.70)
Renting	0.90^{***}	(28.96)
Owning with mortgage	-0.18^{***}	(-6.69)
HH head: female	0.06^{**}	(2.62)
_cons	0.62^{***}	(14.46)
N	5032	
R^2	0.36	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-13 Summary of original weighted household energy footprint for housing, water, and refuse and USS energy footprints based on predicted values.

Survey	mean	Number of obs	Std dev	min	max
LCFS	8.04	5,465	7.05	0	88
USS	6.44	15,540	6.44	0.91	113

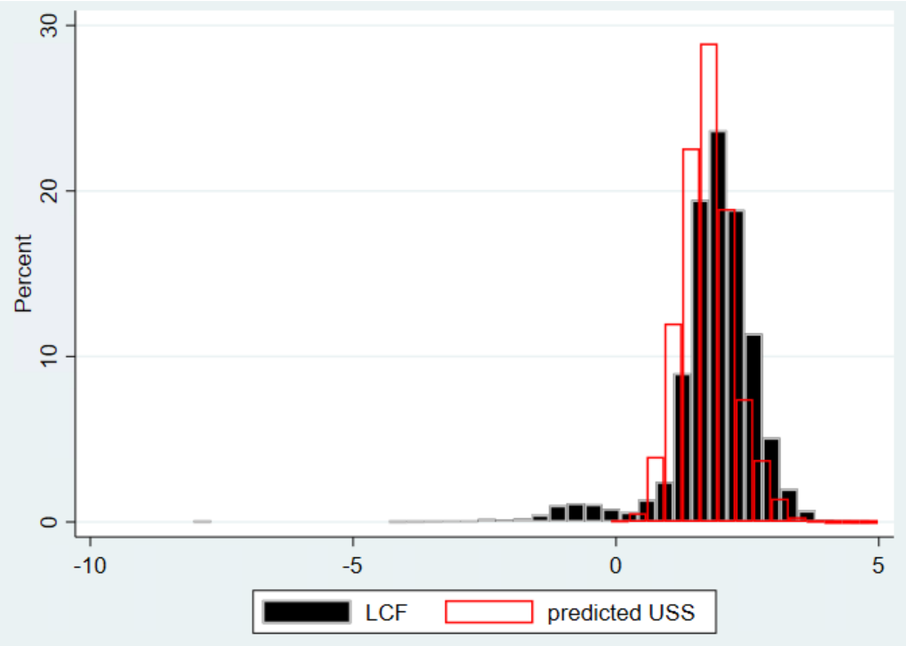

Figure C-3 Histogram for log-transformed unweighted household energy footprints for housing, water, refuse. USS values correspond to footprints calculated with predicted values. The widths of all the bins in the histogram are the same.

C.3.5 Rail, Road and water transport

To calculate the USS EF for public transport we created additional variables informing about the frequency of using transportation. In the USS survey respondents were asked what is their main mode of transport to work and how often they use different modes of transportation (at least once a day, less than once a day but at least 3 times a week, once or twice a week, less than that but more than twice a month, once or twice a month, less than that but more than twice a year, once or twice a year, less than that or never). We could infer the frequency of transport use from available variables in LCFS corresponding to seasonal and other than seasonal tickets. We assumed that if a household purchases season tickets they are frequent users of public transport. Table C-14 summarize how the variables corresponding to the frequency of traveling are built.

Table C-14 Categorization of frequency of traveling by public transport: used information from LCFS and USS for building the variable.

Variable categorization	category	LCFS	USS
0 - household does not use pub transp. 1 - household uses infrequently one or more modes of pub transport (no one in the hh uses frequently) 2 - household often uses one or more modes of pub transp. (at least one person in the hh)	Rail, tube (1 – infreq.)	- Rail and tube other than season tickets - Combined fares other than season tickets	- Train/tube main mode of transp. to work Or/and -at least once a day/at least 3times per week, once or twice a week
	Rail, tube (2 – freq)	- Rail and tube season tickets - Combined fares season tickets - School travel	- more than twice a month/more than twice a year/ once or twice a year
	Bus (1 – infreq.)	- bus and coach season ticket	- Bus main mode of transp. To work Or/and -at least once a day/at least 3times per week, once or twice a week
	Bus (2 – freq)	- Bus and coach season tickets - Combined fares season tickets - School travel	- more than twice a month/more than twice a year/ once or twice a year
	Taxi (1 – infreq.)	- reported spends on taxi	- reported use of taxi to work but not as the main mode.
	Taxi (2 – freq)		- Taxi main mode to work
	Public transport (1 – infreq.)	If indicated frequent use one of the following modes: taxi, train/tube, bus/coach	
	Public transport (2 – freq.)	Nobody in the household uses any modes frequently but one or more modes infrequently	

C.3.6 Rail/tube

The following regression model was used to estimate energy footprints for USS households that travel by rail or tube.

Table C-15 Regression model for predicted EF for train/tube. Based on LCFS sample (unweighted households).

	(1) **LCFS rail/tube (log)**	
HH: Couple both under pensionable age, no children	0.64^{*}	(2.54)
HH: Couple with 1 child	1.27^{***}	(3.73)
HH: Couple wih 3 or more children	1.09^{*}	(2.32)
HH: 2 adults, not a couple, one or more over pensionable age	-3.37^{***}	(-3.64)
HH: 2 adults, not a couple, 1 or more children	-3.98^{***}	(-4.16)
HH: 3 or more adults, 1-2 children, incl. at least one couple	0.97^{*}	(2.17)
Region: North West	1.17^{*}	(2.60)
Region: West Midlands	0.82^{*}	(2.04)
Region: East of England	2.41^{***}	(6.84)
Region: London	1.43^{***}	(4.74)
Region: South East	2.11^{***}	(6.72)
Region: Scotland	1.62^{***}	(3.94)
Number of couples	-0.72^{**}	(-2.82)
Number of bedrooms	-0.24^{*}	(-2.41)
HH adults working hours (hrs/week)	0.01^{***}	(3.98)
OAC groups: Rural Tenants	1.51^{***}	(3.74)
OAC groups Comfortable Cosmopolitans	-1.93^{***}	(-3.76)
OAC groups: Ageing city Dwellers	-2.98^{***}	(-3.81)
OAC groups Challenged Terraced Workers	-1.73^{*}	(-2.06)
No more than 11 yrs of education	-1.05^{**}	(-3.20)
Owns house outright	-1.14^{***}	(-4.35)
Rents	-0.52^{*}	(-2.25)
_cons	1.14^{*}	(2.57)
N	192	
R^2	0.62	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-16 Summary of original weighted household energy footprint for train/ tube and USS energy footprints based on predicted values.

Survey	mean	Number of obs	Std dev	min	max
LCFS	0.66	5,465	4	0	90
USS average	13	1,762	22	0.007	374

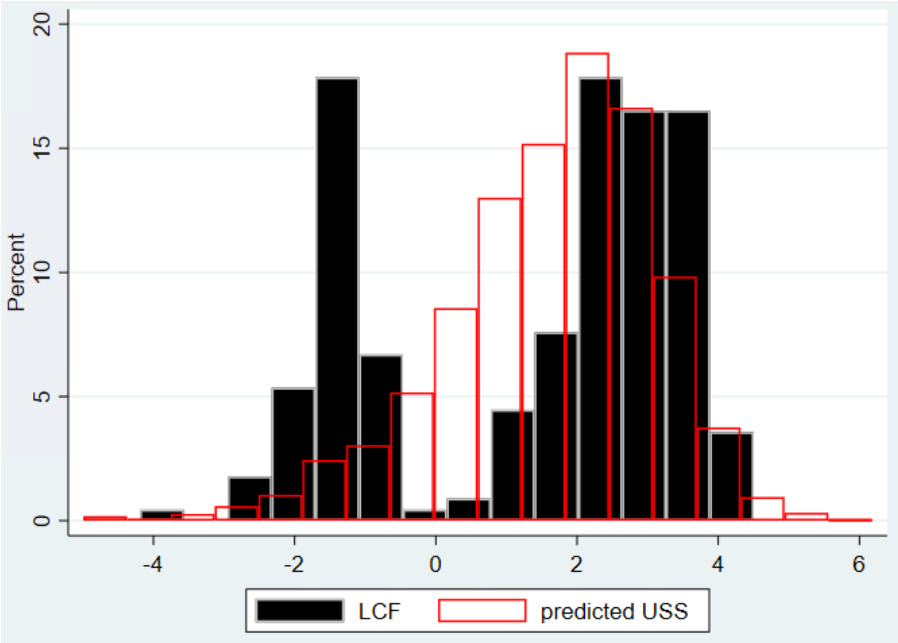

Figure C-4 Histogram for log-transformed unweighted household energy footprints for rail/tube. USS values correspond to footprints calculated with predicted values. The widths of all the bins in the histogram are the same

C.3.7 Bus/Coach

There is a significantly higher number of households that use regularly bus/coach in USS survey compared with LCFS surveys. In the USS there are over five thousand households with at least one person in the household using bus frequently. In LCFS it is only 277 (5% compared with 27% for USS). Resulting predicted EF for bus for USS households have much higher total EF (summed for the whole sample) than for LCFS households.

Table C-17 Frequency (number of respondents) of using bus/coach between LCFS and USS household.s

	LCFS	USS
Households never uses	4,550	5,698
At least one person uses infrequently	638	8,083
At least one person uses frequently	277	5,327

Table C-18 Regression model for predicted EF for bus. Based on LCFS sample (unweighted households).

	(1) LCFS Bus (log)	
HH: 1 adult under pensionable age, no children	0.64*	(2.38)
HH: 1 adult, 1 child	0.81*	(2.50)
HH Couple both under pensionable age, no children	0.78**	(3.09)
HH: Couple with 1 child	0.50*	(2.30)
HH: 2 adults, not a couple, both under pensionable age	1.01**	(2.95)
HH: 2 adults, not a couple, one or more over pensionable age	1.79**	(3.12)
HH: 2 adults, not a couple, 1 or more children	0.87**	(2.63)
HH: 3 or more adults, no children, incl at least one couple	0.77**	(2.89)
HH: 3 or more adults, no children, exclu any couples	1.21***	(4.27)
Number of children	0.50***	(4.67)
Number of bedrooms	-0.19**	(-3.16)
Work hours adults (hrs/week)	0.01***	(3.44)
Region: Wales	-1.87***	(-4.51)
_cons	2.70***	(9.95)
N	209	
R^2	0.28	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-19 Summary of original weighted household energy footprint for bus and USS energy footprints based on predicted values.

Survey	mean	Number of obs	Std dev	min	max
LCFS	1.58	5,465	8	0	185
USS average	21	4,340	17	0.7	278

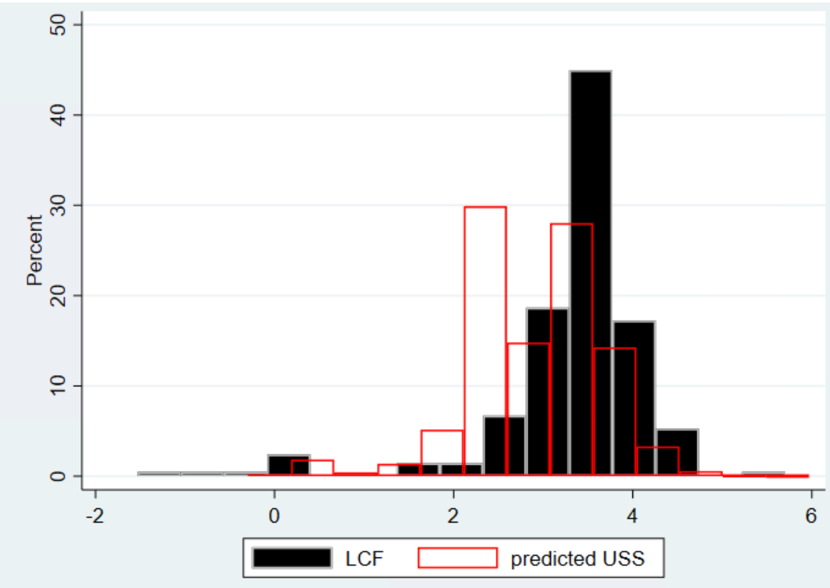

Figure C-5 Histogram for log-transformed unweighted household energy footprints for bus. USS values correspond to footprints calculated with predicted values. The widths of all the bins in the histogram are the same

C.3.8 Education

We were limited by available information about expenditure on private education. In the UK only a few households reported spending on education. The majority of students attend public, state-paid schools(Department for Education 2019). Therefore, the number of observations used for the regression model with the log-transformed dependent variable in the LCFS data is 260 households (Table **Error! Reference source not found.**C -20). The USS survey does not hold information about type of school attended (public or private). However, we know who in the housheolds attends college or higher education, which usually are behind paywall and would have associated expenditure. We compared USS and LCFS surveys for shares of households that have person(s) attending college or higher education by income decile.

Table C-20 Share of households having expenditure on education. The left side corresponds to USS survey and households with members in college or higher education (that is private in UK) and the right side corresponds to households in LCFS, which have expenditures on education (including primary and secondary education).

Decile (share within decile)	USS Not in highe education (%)	At college (%)	LCFS No expenditure (%)	Has expenditure (%)
1	93.51	6.49	98.27	1.73
2	97.2	2.8	98.55	1.45
3	95.64	4.36	97.4	2.6
4	95.78	4.22	97.12	2.88
5	94.38	5.62	96.43	3.57
6	92.57	7.43	96.42	3.58
7	92.73	7.27	94.0	6.00
8	92.42	7.58	93.15	6.85
9	89.28	10.72	91.35	8.65
10	87.63	12.37	87.69	12.31
Total	**92.8**	**7.2**	**95.21**	**4.79**

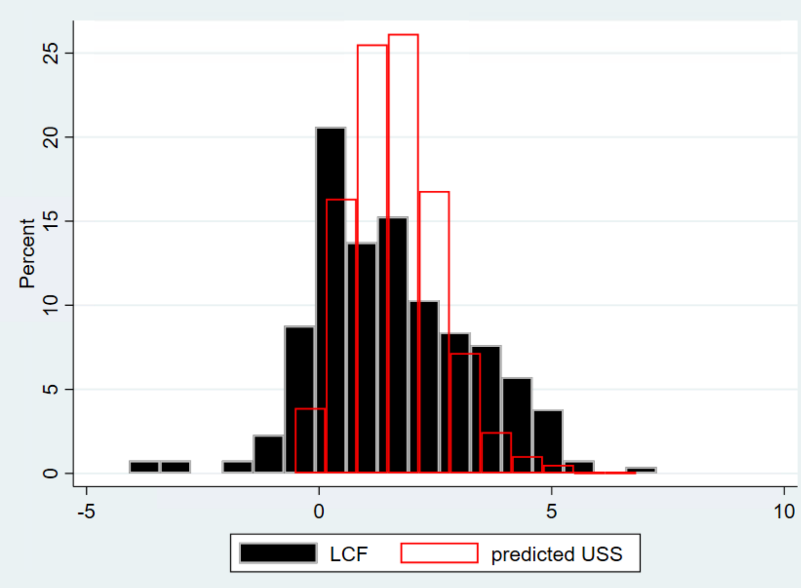

Figure C-6 Histogram for education. In black values for the reported EF in LCFS. Red Bars indicate EF based on predicted EF for USS. Bins widths are the same for LCFS and USS.

The predicted values for USS households are only for the 9th and 10th income decile and those households with children between ages of 5 and 15 and those aged 16+ still in education (including higher education). This restriction makes it possible to exclude households, which members are not in education.

Table C-21 Regression model for predicted EF for education. Based on LCFS sample (unweighted households).

	(1) LCFS education (log)	
Income (log)	0.57***	(3.84)
OAC groups: Rural Tenants	1.07**	(3.15)
OAC groups Aspirational Techies	2.58***	(4.14)
OAC groups Rented Family Living	1.05*	(2.23)
OAC groups Urban Proffesionals and Families	0.67*	(2.22)
OAC groups: Challenged Diversity	1.19*	(2.56)
Region: North West	0.76*	(2.28)
Region: London	1.15***	(4.25)
Region: South East	0.51	(1.95)
Region: South West	1.05**	(2.97)
Number of bedrooms	0.30***	(3.39)
HH head working hours (hrs/week)	0.03**	(3.16)
HH: 2 adults, not a couple, both under pensionable age, no children	1.46**	(3.05)
HH: 2 adults, not a couple, one or more over pensionable age, no children	3.50*	(2.33)
HH: 3 or more adults, no children, incl at least one couple	0.68*	(2.35)
HH uses infrequently onre or more modes of transport	-0.56*	(-2.22)
Owns house with mortgage	-0.81***	(-4.07)
_cons	-6.29***	(-4.17)
N	260	
R^2	0.39	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table C-22 Summary of original weighted household energy footprint for education, based on LCFS survey and based on predicted EF for the USS survey.

Survey	mean	Number of obs	Std dev	min	max
LCFS	1.18	5,465	13	0	726
USS	10	1,426	25	0.59	790

C.3.9 Health

The regression model used for predicted energy footprints for the Health category has a very poor explanatory power for variation in the sample. There are several reasons for this result. Availability of national health services (NHS) results in 54% of households in the LCFS reporting their spending on health. These expenditures were either on private health services or partly paid by NHS and partly private. The number in the sample would be much lower if the spending on pharmacy, glasses, and similar miscellaneous products wouldn't be included. We do not have expenditure reslated to 6.1 COICOP categories (Table C -23), however, we used information about the type of services (private/NHS) to infer household spend on health in USS. The resulting average energy footprints per income decile are only applied to households that reported paying for and attending the appointments at the GP, hospital or using medical services in the last 12 months. Services mentioned in the USS refer to: health visitor, district nurse, home-help, meals on wheels, social worker, chiropodist, alternative medical practitioner, psychotherapist, speech therapist, hospital consultant, family planning clinic, and having tests and services done: dental check-up, eyesight test, chest/other Xray, blood pressure, cholesterol test, blood test, cervical smear, breast screening, other tests.

Table C-23 Health EF: corresponding COICOP categories and related questions in USS survey.

COICOP categories	The corresponding question in USS survey
6.1.1.1 NHS prescription charges and payments 6.1.1.2 Medicines and medical goods (not NHS) 6.1.1.3 Other medical products 6.1.1.4 Non-optical appliances and equipment	
6.1.2.1 Purchse of spectacles, lenses, prescription sunglasses 6.1.2.2 Accessories/repairs to spectacles/lenses	
6.2.1.1 NHS medical, optical, dental and medical auxillary services	Which of these health check-ups and tests have you had in the last 12 months? Was it all free or did you have to pay anything for this Did you get this [service] on the NHS or was it private? How many times have you talked to, or visited a GP or family doctor about your own health?Was/were your hospital stay(s) free under the National Health Service or paid for privately?
6.2.1.2 Private medical, optical, dental and auxillary services	
6.2.2 In-patient hospital services	

C.3.10 Purchase of vehicles: cars, motorcycle, bicycle, and car leasing

We split EF purchased vehicles into two categories:

1) 8a: specific to purchased cars,
2) 8b: and into a purchased motorcycle, bicycle, and car leasing.

Table C-24 Share of COICOP categories for the total EF purchased vehicles

EF category	LCFS category (COICOP+name)	Weighted household EF	Corresponding share
8a: Purchase of vehicles: cars	7.1.1.1 New cars/vans outright purchase	19047	5%
	7.1.1.2 New cars/vans loan/HP purcase	12157	3%
	7.1.2.1 Secondhand cars/vans outright purchase	42198	12%
	7.1.2.2 Secondhand cars/vans loan/HP purcase	10717	3%
8b: Purchase of vehicle rest (leasing, motorcycle, bicycle)	**7.1.3.1 Outright purchase of new or secondhand motorcycles**	922	0.26%
	7.1.3.2 Loan/HP purchase of new or secondhand motor cycles	111	0.03%
	7.1.3.3 Purchase of bicycles and other vehicles	718	0.20%
	7.3.4.7 Car leasing	274835	76%
	Total	360704	100%

C.3.10.1 purchased cars/vans

In the USS survey households are asked several questions about their cars including the size of the engine if the car is used or new and the age of the car. We assumed that cars that are up to one year old were purchased in the past 12 months.

In the LCFS survey, we have information regarding: number of cars owned by the household, number of cars (used or new) bought in the past 12 months, and how much they paid for it.

Using EF for new/used cars purchased within the last 12 months in LCFS, we calculated the average energy footprint for:

a) Used car: on average purchase of a used car corresponds to 12.24 GJ per car
b) New car: on average purchase of a new car corresponds to 18.25 GJ per car
c) Mix: average based on ef for a used and new car, 18.31 GJ per car

The category c) is used because some households in the USS survey did not know if their car is used or new.

C.3.10.2 car leasing, motorcycle, and bicycle purchase

In the LCFS survey, 399 households reported lease cars, 21 bought motorcycles outright, 4 bought motorcycles on loan, 22 bought bicycles. Out of 399 households leasing their car, 51 would have leased one of their cars and purchased a car/van in the last year, 2 would lease a car and bought a motorcycle, and one would lease a car and bought a bicycle in the last year. 38 households would have more than one car (so they lease one car in addition to own another car(s)). Since the number of bought motorcycles and bicycles is very low and corresponds to less than 0.5% of the total footprint for purchased vehicles (Table C-24), we decided to incorporate the purchase of motorcycles and bicycle with the leasing of a car and I calculated the average EF per owned vehicle based on this aggregate. The average for category 8b is calculated by taking unweighted EF for 7.1.3.1-3 and 7.3.4.7 and dividing it by the number of cars in the household. The resulting average is 6.8 GJ per car owned per household. We used this value to multiply it by the number of cars per household in the USS survey.

Note: in the USS survey there is no information about car leasing. We assume some of the cars were not bought outright or on a loan but were used via a leasing contract. To account for this we applied the average EF corresponding to leasing, motorcycle, and bicycle purchase to each household in USS that owns a car (average EF multiplied by number of cars).

C.3.11 Private transport (car)

In the USS files, in the file with household responses, we have information available about "number of cars" along with their specifications (e.g. engine size, fuel type age, etc.). Besides technical specifications for the type of cars owned, respondents also specified who in the household is the main driver for the car. In the file with individual responses, we have information about each person's mileage. For some households, it was possible to match the main driver with her/his mileage. In other cases, if household-owned just one car, or more than one but with the same engine size and fuel type, it was possible to assign mileage to the type of car. For the rest of the households for which we could not identify the type of car used or type of fuel or both, we used averages. Table C–25 shows the type of car and corresponding engine size (in liters) and fuel intensity. This categorization served as a basis for the calculation of fuel expenditure (mileage multiplied by fuel intensity), which in turn when multiplied by the average price of fuel per liter yielded household total spending on private transportation.

Table C-25 Fuel use intensity (L/km or kWh/km) by type of car. Based on (Ivanova et al 2015).

Type of car	City car	Compact	Family car	Large car
Engine size (liters)	<=1.4	1.4 to 2.0	2.1 to 3.0	Over 3.0
Petrol (in L/km)	0.058	0.058	0.074	0.099
Diesel (in L/km)	0.048	0.048	0.058	0.082
Hybrid (petrol-electric) (in L/km)	0.029	0.029	0.041	0.058
Electricity (in kWh/km)	0.125	0.125	0.147	0.188
LPG (in L/km)	0.095	0.095	0.131	0.136

We make an assumption that on average a car could be driven for 38.8 miles per gallon (NimbleFins 2017). In 2018/2019 the prices per liter were: 1.25£ per liter for unleaded petrol and 1.31£ per liter for diesel. We calculated the average based on weekly prices (ONS 2022). For respondents whose fuel type was unknown we calculated one average price of 1.28 £ per liter. 1 gallon is equal to 4.54609 liters, so on average, we assume 8.5348 miles per liter of fuel and 6.6678 miles per one pound (£) spend. The multiplier (to be multiplied with spends) is derived from LCFS data.

C.3.12 Other transport

The other transport corresponds to around 1% of total EF in LCFS. Table C - 26 presents COICOP categories that are included in the categorization. The aggregated category corresponds to the initial categorization done at the beginning of the exploratory analysis (see)

Table C-26 COICOP categories included in the calculation of the multiplier for private transportation.

Aggregated category	COICOP category included in calculation of the multiplier	Share of the total LCFS EF	EF share (sums to 100%)
Other transport	7.2.1.1 Car/van accessories and fittings	0.004%	0.2%
	7.2.1.2 Car/van spare parts	0.04%	2%
	7.2.1.3 Motorcycle accessories and spare parts	0.001%	0.04%
	7.2.1.4 Bicycle accessories and spare parts	0.01%	0.5%
	7.2.3.1 Car of van repairs, servicing and other work	0.8%	46%
	7.2.3.2 Motor cycle repairs and servicing	0.01%	1%
	7.2.4.1 Motoing organisation subscription	0.05%	3%
	7.2.4.2 Garage rent other costs, car washing	0.1%	5%
	7.2.4.3 Parking fees, tolls and permits	0.1%	7%
	7.2.4.4 Driving lessons	0.03%	2%
	7.2.4.5 Anti-freeze, battery water, cleaning materials	0.03%	2%
Personal travel (fuel, hire)	**7.2.2.3 Other motor oils**	0.01%	0%
	7.3.4.5 Other personal travel and transport services	0.3%	18.2%
	7.3.4.6 Hire of self drive cars, vans, bicycles	0.2%	14%
SUM		**1.8%**	**100%**

C.3.13 Domestic and international air transport

When calculating an average EF per flight (domestic or international) we recognized that some of the households in the USS did report spending on air travel but did not indicate how many trips they did (252 households for domestic which is 71%, 666 households for international, which is 44%). In those instances, we assumed that they had one trip, so their EF was not divided by a number of flights (which was reported to be zero). This results in a much higher average EF per trip as if when we would not include these not reported trips (domestic changed from 5.5GJ/trip to 18.01 5GJ/trip, international from 14.915GJ/trip to 36.45GJ/trip).

In the LCFS survey, there is a limited number of households that reported the number of flights taken domestically and internationally. However, all of the households reported their expenditures on flying (up to 15 trips). In the USS we have information regarding the number of flights taken domestically, within Europe, and outside Europe. We aggregated flights taken within Europe and outside to one "international" category.

C.4 Comparison between LCFS and USS energy footprints

Table C–28 summarizes energy footprints reported in LCFS and calculated for USS households. All footprints are expressed in yearly GJ for weighted households. This means that the total EF based on LCFS corresponds to the total energy used by households in the UK in the year time (2018/2019). For USS it is all the energy used by households in the sample (the sums of weights scale up to the sample size, not population). The weights in USS, however, reflect proportions in the population . The USS total EF is half the size of the total LCFS EF. This is in line with the total number of households that are represented in USS, which is 15,682 – 57% of the number of households represented in LCFS (27,419 households). When comparing shares that each of the footprinting categories contributes to the total, we observe the biggest differences for public transport, education, and air- travel. Those discrepancies come from differences in reported usage by households. In USS more households reported using public transport than private transportation. These differences might also come from the method of calculation. We employed regression analysis to predict EF for education. Although the adjusted R2 was moderately strong (0.29), only 260 households reported spends on education in the LCFS survey. This is linked to the free education system in the UK and a relatively low percentage of households choosing to send their children to paid schools. Hence, we expect predicted values for USS to be somewhat inflated.

Note, that not all EF for USS were calculated using regression models. Out of 16 categories (Table C-28) more than half was calculated using other methods than regression analysis. Four were calculated using reported expenditures by USS households (e.g. house fuels, oil, gas, electricity). Using multiplier (GJ/£) from LCFS data, the calculation was straightforward (multiplying reported spends with multiplier). For categories “Food” and “restaurants and hotels”, we used reported by USS households expenditures and we filled in the “blanks” (some households didn’t report any spending) with imputations. The remaining five categories we calculated using average EF based on LCFS data and average EF by income decile. For purchased vehicles in both surveys, we have information about the number of purchased vehicles and their condition (new/used). We used this information to calculate in the LCFS survey the average energy footprint per purchased vehicle and applied it to USS households Similarly for leased cars, we used the average energy footprint per owned vehicle. For domestic and international air travel we calculated the average EF per trip taken.

It is worth noting that 24.6% of USS footprints are **not** predicted but calculated using reported spending. 16% is based on using average EF by income decile, 50% is based on physical quantities (number of trips, number of vehicles) and the remaining 9.3% is based on using regression models and predicted values.

Figure **Error! Reference source not found.**C - 7 presents the distribution of footprints based on LCFS data and based on calculations done for USS households.

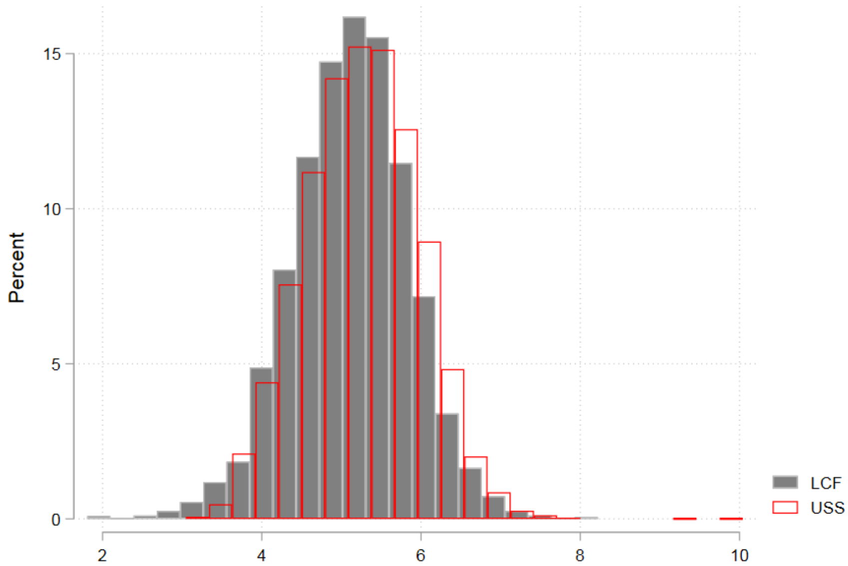

Figure C-7 Histogram for total USS and LCFS energy footprints. Values are log-transformed and non-weighted. In black values for the reported EF in LCFS. Red Bars indicate USS EF. Bins widths are the same for LCFS and USS

Table C-27 Summary of original total weighted household energy footprint based on LCFS data and for total weighted EF based on USS data.

Survey	mean	Number of obs	Std dev	min	max
LCFS	215	5,473	186	6.09	3301
USS average	233	15,552	278	23.15	22,564

Table C-28 Total weighted household energy footprint – comparison between LCFS and predicted values for USS.

	Category	LCFS (GJ)	(%)	USS (GJ)	(%)	Method for USS	USS-LCFS	Comment
Food and non-alcoholic beverages:	Food and alcohol	274,426	4.7%	178,967	4.8%	Multiplier	0.1%	Missing exp. in USS imputed
Clothing and footwear:	Clothing	43,041	0.7%	24,524	0.7%	Avg by income decile	-0.1%	
	Shoes	20,175	0.3%	11,497	0.3%	Avg by income decile	0.0%	
Housing, water, electricity, gas and other fuels:	Housing, water	220,632	3.7%	100,518	2.7%	Estimated (R2=0.36)	-1.1%	Pred. based on regression using LCFS footprints as a base
	Coal and coke & wood and peat	134,343	2.3%	65,333	1.7%	Multiplier	-0.5%	
	Oil, gas, electricity	1,628,962	27.6%	611,766	16.2%	Multiplier	-11.4%	Missing exp. in USS imputed
Furniture:	Furniture	217,294	3.7%	123,814	3.3%	Avg by income decile	-0.4%	
Health:	Health	84,872	1.4%	48,348	1.3%	Avg by income decile	-0.2%	
Transport:	Purchase of vehicles	59,130	1.0%	29,612	0.8%	Multiplier	-0.2%	Avg GJ per vehicle purchased
	Vehicles: leasing, other	275,960	4.7%	132,959	3.5%	Multiplier	-1.1%	Avg GJ / No. of vehicles in the household
	Fuel	970,425	16.5%	605,006	16.1%	Multiplier	-0.4%	Includes difference in car fuel and engine
	Other transport	121,847	2.1%	69,439	1.8%	Avg by income decile	-0.2%	
	Public transport rail/tube	18,121	0.3%	21,221	0.6%	Estimated (R2=0.62)	0.3%	Estimated only for users of transport
	Public transport: bus	41,349	0.7%	94,349	2.5%	Estimated (R2=0.28)	1.8%	Estimated only for users of transport
	Public transport other	281,974	4.8%	160,704	4.3%	Avg by income decile	-0.5%	Avg. only for users of transport
	Transport air domestic	44,095	0.7%	80,765	2.1%	Multiplier	1.4%	Avg GJ / flight
	Transport air international	643,665	10.9%	1,045,183	27.8%	Multiplier	16.8%	Avg GJ / flight
Communication:	Communication	32,774	0.6%	14,611	0.4%	Avg by income decile	-0.2%	
Recreation:	Recreation, package holidays	285,782	4.8%	119,744	3.2%	Estimated (R2=0.28)	-1.7%	
Education:	Education	32,532	0.6%	11,767	0.3%	Estimated (R2=0.39)	-0.2%	Only for those reporting being in education
Restaurants and hotels:	Restaurants and hotels	214,237	3.6%	72,836	1.9%	Multiplier	-1.7%	Missing exp. in USS imputed
Miscellaneous:	Miscellaneous	251,222	4.3%	143,156	3.8%	Avg by income decile	-0.5%	
	Total	**5,896,860**	**100%**	**3,766,121**	**100%**			

Note: Match between USS and LCFS is highlighted as follows: green – multiplier method and low difference, yellow – multiplier method and high difference, blue other method and low difference

Both surveys have missing values. This causes missing values in the final energy footprints for USS households. One way to deal with this is to assume that these households did not have spends on the following categories and assign zeros to all missing values.

Table C-29 Number of missing values for USS energy footprint categories.

Category	Number of missing values in the USS survey
House fuels	15
Clothing and footwear + Furniture + Misc	772
Housing, water, refuse, repairs & maintenance, other	16
Purchase of vehicle rest (leasing, motorcycle, bicycle)	82
Fuel	4446
Train/tube	16903
Bus/coach	13784
Communication	100
Recreation and culture + package holidays	639
Education	17364
Restaurants and hotels	110

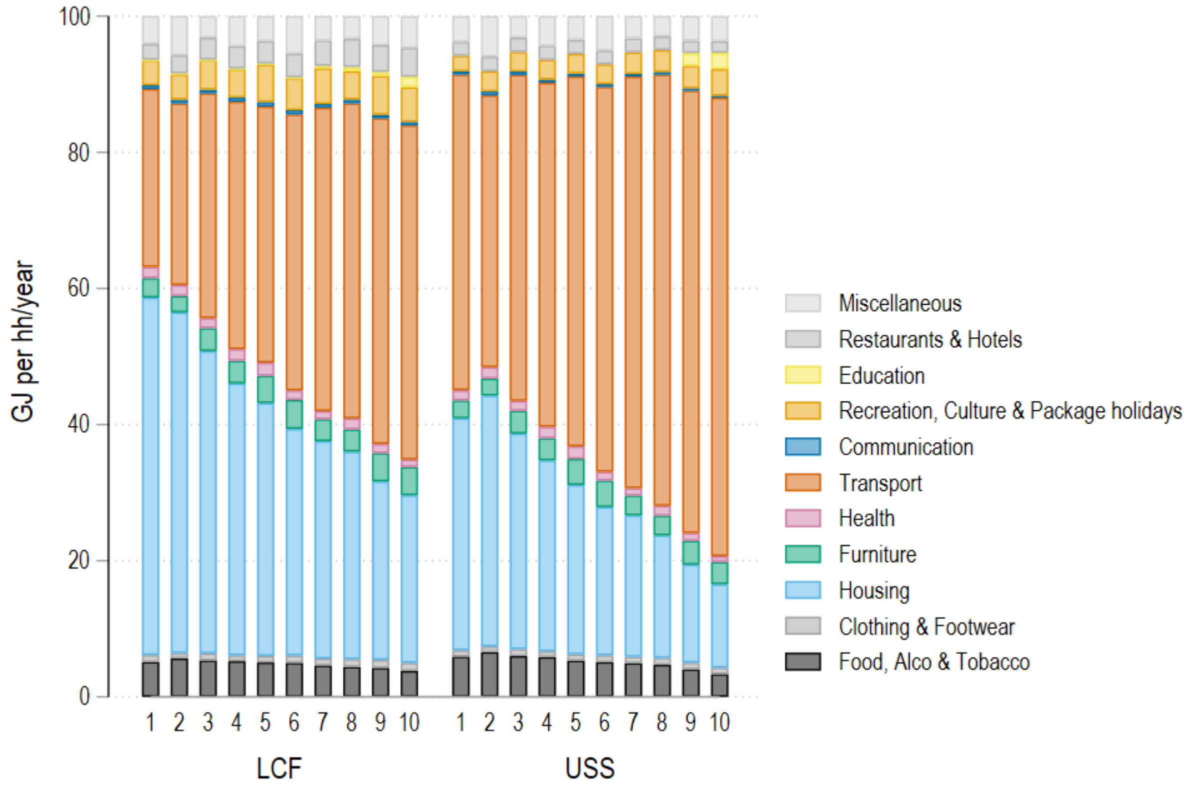

Figure C-8 Energy Footprints for LCFS and USS by income deciles

C.5 Comparison between USS samples

Figures C-9 to C-13 present a comparison between all households within USS and reduced USS sample (due to availability of data) to USS households with well-being scores. The distributions presented in the figures are by income, household size, age, rural/urban, and non-white groups. Figures present very similar distributions.

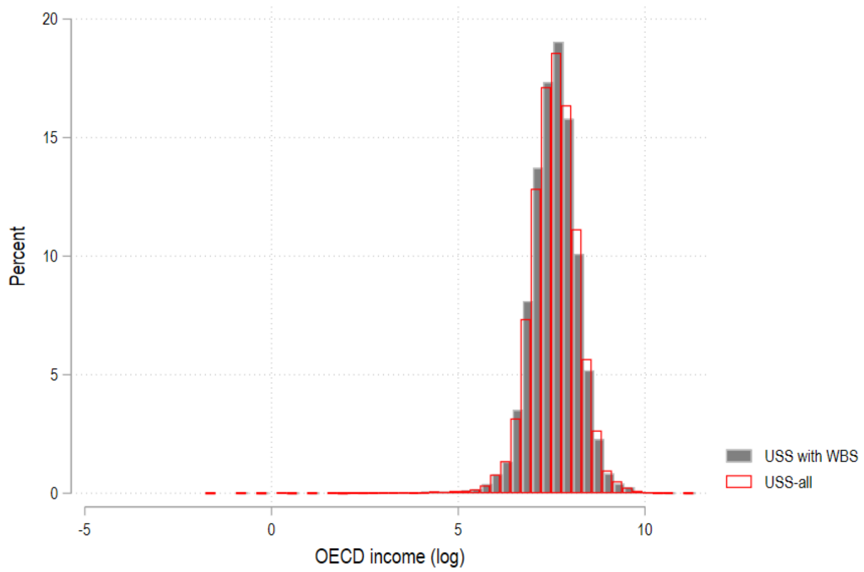

Figure C- 9 Histogram for OECD income (log). In red values for all USS, in black USS with well-being score.

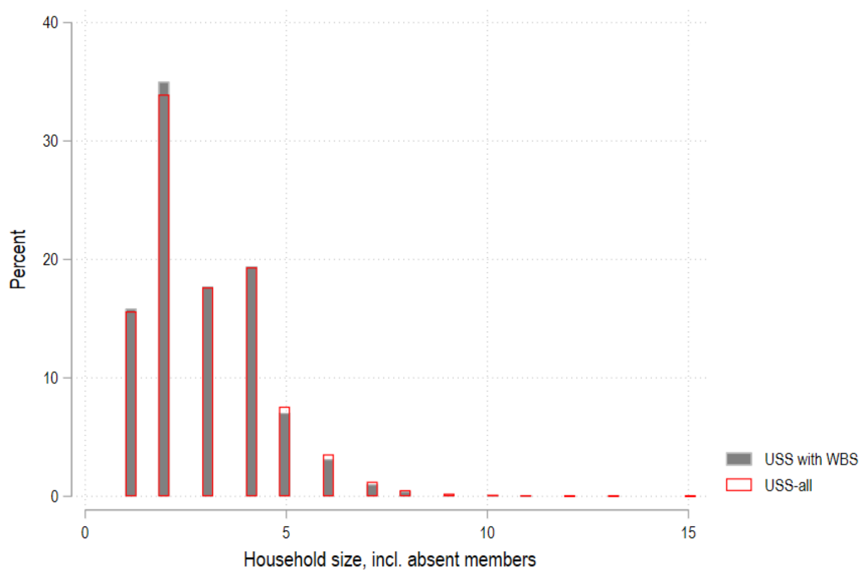

Figure C- 10 Histogram for household size. In red values for all USS, in black USS with well-being score.

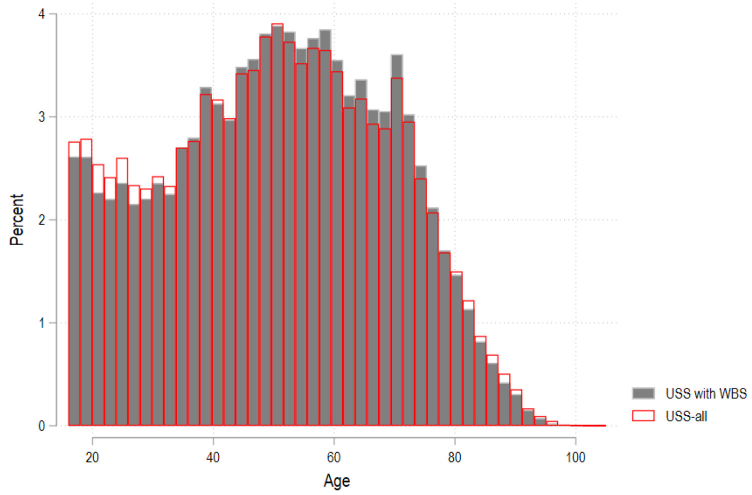

Figure C- 11 Histogram for age. In red values for all USS, in black USS with well-being score.

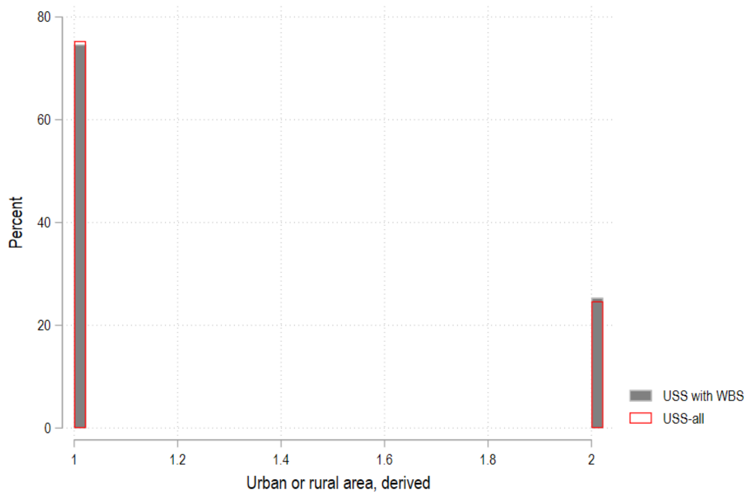

Figure C- 12 Histogram for urban (1)/ rural (2) areas. In red values for all USS, in black USS with well-being score.

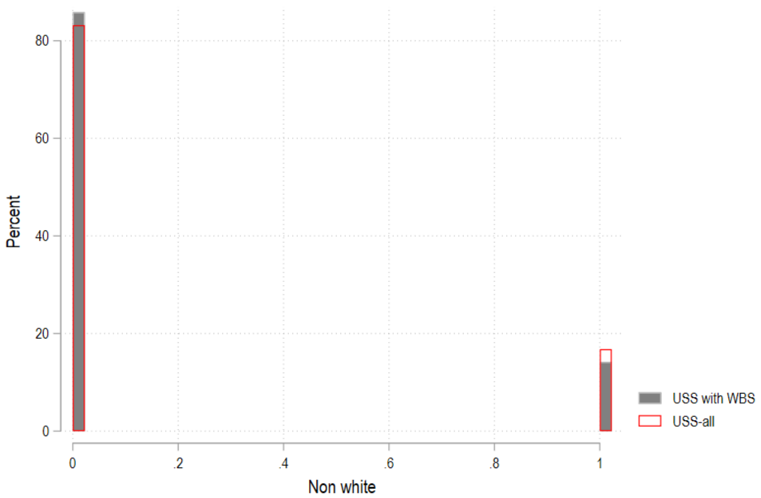

Figure C- 13 Histogram for non-white groups (1). In red values for all USS, in black USS with well-being score.

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