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ENERGY, POVERTY AND DEVELOPMENT: A PRIMER FOR THE SUSTAINABLE DEVELOPMENT GOALS

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ABSTRACT

The seventh goal of the Sustainable Development Goals (SDGs) is dedicated to ensuring access to affordable, reliable, sustainable and modern energy for all by 2030. While energy was implicit in the Millennium Development Goals (MDGs), the SDGs explicitly recognise the direct linkage between energy access and consumption and poverty and development. This evolution of the development agenda is closely related to an expanded understanding of poverty, as it moves beyond a monetary definition, to be seen as a more holistic measure of overall quality of life. Energy has thus become recognised as an important aspect of alleviating extreme poverty. However, what remains unclear is the impact that poverty reduction will have on worldwide energy consumption. There is a significant amount of literature concerning the connection between energy consumption—in particular electricity—and development, ranging from engineering modelling to development policy. Nevertheless, there is a lack of attention given to the direct causal relationship between poverty reduction and energy consumption. This paper reviews a variety of the current literature concerning energy and electricity consumption and poverty and development, to show that there is a need to directly address how poverty levels will shape future energy consumption. This relationship will have an impact on a number of issues critical to the achievement of the SDGs ranging from health to gender and the environment.

1 INTRODUCTION

In the last two decades, the international development agenda has increasingly recognised the importance of energy consumption in the fight against poverty and inequality. Energy was included in the MDGs as an indicator for environmental sustainability under MDG7. However, as studies increasingly noted, energy has greater implications beyond the environment (Rehfuess et al. 2006; Birol 2007; Sachs 2012; Sovacool 2012). Thus, the seventh goal of the 2015 SDGs committed to ensuring access to affordable, reliable, sustainable and modern energy to all by 2030. In particular, the goal specified the need to focus on supplying modern and sustainable energy services for all in developing countries (United Nations 2015). The SDGs directly address the centrality of energy to economic and social well-being, as well as to issues such as health and climate change, reflecting United Nations Secretary-General Ban Ki-moon's statement at the Rio+20 conference that "energy is the golden thread that connects economic growth, social equity and sustainable development" (United Nations 2012).

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The relationship between energy consumption and poverty has been addressed in a variety of literature, from development studies to economics. However, far from demonstrating a simple relationship, the energy–development nexus is multifaceted and highly contested. This review focuses particularly on household energy consumption to assess the main trends in the current literature concerning the connection between the consumption of energy—particularly electricity—and poverty and inequality. The residential sector accounts for between 16 and 50 per cent of total energy consumed, and averages 31 per cent worldwide (Swan and Ugursal 2009). One study found that in India, including the direct and indirect energy, household consumption accounts for 75 per cent of all energy consumed (Pachauri and Spreng 2002). The Secretary-General's Advisory Group on Energy and Climate Change (AGECC 2010) identified access to modern fuels for cooking, lighting and heating as a basic human need; however, more than 1 billion people around the world still do not have access to electricity. The residential sector is thus central to energy usage, and to development practices. Given the significance of household consumption, an integrated approach needs to be taken to analyse its direct relationship with poverty, and how this relationship affects the SDGs.

To explore the current approaches to the energy–poverty nexus, this working paper is structured in the following way. The subsequent section will analyse the literature concerning energy consumption and Gross Domestic Product (GDP). There is a widely recognised correlation between energy consumption and GDP; however, it is clear from the variety of conclusions drawn that there is little consensus on the direction of the causal relationship. The variation in results suggests that the link between the two is highly context-specific. Given the connections between energy and development, this paper will then examine the literature concerning energy poverty. Energy poverty, having increased in visibility following the MDGs and the SDGs, is to be recognised as an important dimension of poverty, welfare and well-being. The literature demonstrates the key interaction of energy with experiences of poverty; however, it also reveals the challenges associated with the concept. In particular, the energy poverty literature highlights the wide impacts of energy use on other development criteria.

The SDGs emphasise the need for households to transition to clean and modern energy fuels. Thus, this article will move on to discuss studies which utilise the 'energy ladder' hypothesis to explain the fuel substitutions of households. The energy which people have access to in their homes is central to energy poverty; however, household energy access and consumption cannot be accurately portrayed in macro studies, due to the impact of cultural preference, tradition and other context-specific factors. There is a need to grasp how the current literature approaches the measurement of household consumption, but with micro analyses to include the varying socio-economic factors which affect energy patterns. The final section of this paper will address this issue, assessing the relevant approaches taken to household consumption at the micro level. Throughout, this review demonstrates that there are numerous challenges which closely relate to the energy–poverty nexus, including environmental, gender and health.

The SDGs recognise that energy and its usage have important implications for a wide variety of factors important to sustainable development. Indeed, in 2004 the International Energy Agency (IEA) and the Organisation for Economic Co-operation and Development (OECD) stated that poverty reduction goals could only be met if "governments act decisively to accelerate the transition to modern fuels and to break the vicious cycle of energy poverty and human underdevelopment". In the future, the developing world will become the chief contributor to energy consumption (Wolfram et al. 2012). There is a need to understand and predict how poverty will shape this dynamic.

2 ENERGY CONSUMPTION AND GROSS DOMESTIC PRODUCT (GDP)

The correlation between energy consumption and the level of economic development and growth is widely recognised. As Barnes and Floor (1996) note, an increase in income is "unequivocally" related to increasing use of modern fuels. This assumption resonates in international development policy, and can be recognised in both the MDGs and SDGs. In an article assessing the MDGs, Rehfuess et al. (2006) acknowledge the significance of the "strong link between income and access to energy services". In this way, the SDGs interpret universal energy as essential to increasing incomes. However, as scholarship has shown, correlation between consumption and economic growth does not equal causation (Payne 2010a). The wide range of literature addressing this relationship has produced a variety of results, which have been broadly classified into four hypotheses (see Payne 2010a; 2010b; Kahsai et al. 2012): conservation, feedback, growth and neutrality. These four hypotheses demonstrate the complexity of the connection between energy consumption and economic growth. Furthermore, recent studies extending the connection towards issues of development are crucial in showing that the relationship is highly dependent on context.

A strong literature has emerged on the causality between energy consumption and income dating back to the seminal work by Kraft and Kraft (1978). In their article, they used data on gross energy inputs and Gross National Product (GNP) to inform a Granger causality test, and found that in the USA there is unidirectional causality running from GNP to energy consumption. Their results suggested that an increase or decrease in GNP had a causal impact on energy consumption. Kraft and Kraft's work became the benchmark for the first hypothesis, the conservation hypothesis, which stipulates a unidirectional relationship from economic growth to energy consumption (Kahsai et al. 2012). The conservation hypothesis has been supported by a number of studies, including Cheng and Lai (1997), Al-Iriani (2006) and several others (Soytas and Sari 2003; Akinlo 2008). Similar to Kraft and Kraft, these studies largely utilise Sims or Granger causality tests. The causal relationship espoused by the four hypotheses is important because, as Kraft and Kraft demonstrated, it has a significant impact on policy. Kraft and Kraft, and other studies advocating the conservation hypothesis, infer that energy conservation strategies will have little impact on economic growth (Asafu-Adjaye 2000). In the delicate development balance the SDGs seek to achieve, this is extremely important. However, a variety of studies published after Kraft and Kraft (1978) yielded mixed and often contradictory results.

Whereas Cheng and Lai (1997) found unidirectional causality between GDP and energy in Taiwan, Yang (2000) found that there existed bidirectional causality between the two variables. It is important to note that the two articles use different variables to quantify GDP: Cheng and Lai use GDP based on Consumer Price Index (CPI), whereas Yang transforms the nominal GDP series into real GDP using GDP deflators. Nevertheless, Yang's assessment provides strong evidence for the second hypothesis: the feedback hypothesis, which emphasises a relationship between energy consumption and economic growth in which causality runs in both directions (Kahsai et al. 2012). Empirical support for the feedback hypothesis has been identified in a variety of countries. Using Engle-Granger methodology, Asafu-Adjaye (2000) found that the feedback hypothesis was present in the Philippines and Thailand. Using Granger causality, Soytas and Sari (2003) found evidence for the feedback hypothesis in Argentina, while Akinlo (2008) demonstrated its role in Gambia, Ghana and Senegal. The feedback hypothesis asserts that electricity consumption and economic growth are complementary, meaning that an increase in energy consumption will lead to economic growth, and vice versa (Kahsai et al. 2012).

TABLE 1
A comparison of the causality results from a selection of studies

Author	Year	Energy consumption variable	Income variable	Case study country	Method	Causality conclusion
Kraft, J., and A. Kraft	1978	Gross Energy Consumption (GEC)	Gross National Product (GNP)	USA	Sims and Granger causality tests	Conservation hypothesis
Akarca, A.T., and T.V. Long	1980	GEC	GNP	USA	Sims causality test	Neutrality hypothesis
Yu, E.S.H., and B.K. Hwang	1984	GEC in British thermal unit (Btu)	GNP	USA	Sims causality test	Neutrality hypothesis
Cheng, B.S., and T.W. Lai	1997		Gross Domestic Product (GDP) based on Consumer Price Index (CPI)	Taiwan	Granger causality, as developed by Hsiao (1981)	Conservation hypothesis
Yang, H-Y.	2000	Kilolitres of oil equivalent	GDP, through GDP deflators	Taiwan	Granger causality	Feedback hypothesis
Yu, E.S.H., and J.C. Jin	1992	Total energy consumption (EEC)	Industrial productionindex of manufacturing, based on 1987=100	USA	Co-integration test	Neutrality hypothesis
Asafu-Adjaye, J.	2000	Commercial energy use in kilogrammes of oil equivalent per capita	Real income, GDP at constant 1987 prices	India 1973–1995; Indonesia 1973–1995; Thailand 1971–1995; Philippines 1971–1995	Engle-Granger methodology	**Growth hypothesis:** India and Indonesia **Feedback hypothesis:** Philippines and Thailand
Soytas, U., and R. Sari	2003	Annual energy consumption in millions of metric tons of coal equivalent	GDP	G-7 countries and top 10 emerging markets	Granger causality	**Feedback hypothesis:** Argentina **Conservation hypothesis:** Italy and South Korea **Growth hypothesis:** Turkey, France, Germany and Japan
Al-Iriani, M.A.	2006	Energy consumption	Real GDP	Gulf Cooperation Council (GCC) countries	Panel co-integration and causality tests	Conservation hypothesis
Akinlo, A.E.	2008	Commercial energy use in kilogrammes of oil equivalent per capita	Nominal GDP, the GDP deflator (1985=100)	11 sub-Saharan African countries	Autoregressive Distributed Lag Bounds Test (ARDL) Granger causality	**Feedback hypothesis:** Gambia, Ghana and Senegal **Conservation hypothesis:** Sudan, Congo and Zimbabwe **Neutrality hypothesis:** Cameroon, Côte d'Ivoire, Nigeria, Kenya and Togo
Chontanawat, J., L.C., Hunt, and R. Pierse	2008	Final energy consumption in thousand tonnes of oil equivalent (TOE)	Real GDP in US dollars using purchasing power parities	30 OECD countries and 78 non-OECD countries	Granger causality with Hsiao	Growth hypothesis more common in OECD countries
Ouedraogo, N.S.	2013	TOE	Human Development Index (HDI)	15 Developing countries	Panel unit root, co-integration and error correction models	**Short-term:** Neutrality hypothesis **Long term:** Growth hypothesis

While early studies of the relationship between economic growth and energy consumption focused largely on developed countries, the more recent studies show the growing attention paid to the relationship in developing countries. The article by Asafu-Adjaye (2000) has particular significance because, while it demonstrates the existence of the feedback hypothesis in the Philippines and Thailand, the results for India and Indonesia support the third hypothesis. The growth hypothesis postulates that there exists unidirectional causality from energy consumption to economic growth. This relationship was originally challenged by Kraft and Kraft's work (1978); however, it has continued to find support in various studies, including Asafu-Adjaye (2000). Soytas and Sari (2003) found evidence of the growth hypothesis in Germany and Japan; Chontanawat, Hunt and Pierse found that the growth hypothesis is prevalent in OECD countries (2008). The growth hypothesis runs counter to the policy implications of Kraft and Kraft's conclusions, as it supposes that if causality runs from energy consumption to GDP, then policy encouraging energy conservation may harm GDP growth.

Scholars have also presented evidence for the lack of any relationship between household energy consumption and GDP (Akarca and Long 1980; Yu and Hwang 1984; Yu and Jin 1992). Akarca and Long (1980) specifically critique Kraft and Kraft, arguing that their results were generated solely due to their sample inclusion of the years 1973 and 1974. Removing these final two years, heavily influenced by the oil embargo and rapidly rising energy prices, they find no causal relationship between income and energy consumption. Supporting the results found by Akarca and Long, Yu and Choi (1985) also found no causal relationship between GNP and total energy consumption in the USA, UK and Poland. The lack of causal relationship between these variable was coined the neutrality hypothesis by Yu and Jin (1992), in their study which found no long-term relationship between energy consumption and output/employment.

The four hypotheses largely classify the literature on the relationship between energy consumption and economic growth, and the results are substantially spread. In a review of the literature, Payne (2010a) found that 31.15 per cent of the country studies support the neutrality hypothesis, 27.87 per cent support the conservation hypothesis, 22.95 per cent the growth hypothesis, and 18.03 per cent the feedback hypothesis. The variety in results is most clearly shown by more recent studies focused on developing countries (Asafu-Adjaye 2000; Akinlo 2008; Kahsai et al. 2012). Akinlo (2008) examined the causal relationship between energy consumption and economic growth in 11 sub-Saharan Africa countries and found that Granger causality found evidence for the feedback hypothesis in three countries, the conservation hypothesis in three countries and the neutrality hypothesis in five countries. Variation in causality is similarly found in studies focused on the energy–GDP nexus in developed countries (Soytas and Sari 2003; Al-Iriani 2006).

Reflecting the increasing attention to the relationship between energy and poverty, several studies have analysed the variation in relation to the country's stage of development. However, these large-scale studies have produced inconsistent results. Apergis and Payne (2011) found that the causal relationship between electricity consumption and economic growth may depend in part on the developmental stage of the country. Using data from 88 countries, they noted that low- and middle-income countries tended to show evidence of the growth hypothesis, while upper-middle- and high-income countries tend to support the feedback hypothesis. Using price elasticities, they show that in lower-middle-income countries, a 1 per cent increase in electricity consumption increases real GDP by 0.306 per cent, and that this elasticity becomes smaller as income level increases (Apergis and Payne 2011). Chontanawat et al. (2008) also found that a country's developmental stage has an impact on the energy–GDP nexus; however, their results differ from those of Apergis and Payne.

They posited that the growth hypothesis is more prevalent in Organisation for Economic Co-operation and Development (OECD) developed countries than in non-OECD developing countries. This suggests that energy is overall neutral with respect to economic growth in developing countries, countering Apergis and Payne's findings. While Chontanawat et al.'s study is significant for producing systematic analysis for 99 countries, they fail to propose an explanation for the causality they reveal. A similar critique can be made of Apergis and Payne's study; their broad study lacks specificity and thus limits its utility.

The variance in the causal relationship suggests that it is heavily context-dependent. Payne (2010b) asserted that the variation in results can be attributed to a range of country-specific factors, including heterogeneity in climate conditions, fluctuating energy consumption patterns, the structure and stages of economic development in a country, the econometric methodologies used, omitted variable bias and varying time horizons of studies. The recognition that more specific causal factors need to be identified is reflected in a number of works.

Relevant to development policy, Ferguson and colleagues (2000) made a significant contribution in correlating energy and GDP for 99 countries. They found that, rather than energy, the most accurate correlation with GDP and development is the proportion of energy used as electricity in the country as a whole. They suggest that electricity consumption should, therefore, replace energy consumption as a measure of development. This has important implications for a consideration of the relationship between energy consumption and economic growth in relation to poverty in developing countries. In particular, is shows the need for a closer focus on the variable not just of energy, but electricity specifically (Ferguson et al. 2000).

Ouedraogo (2013) produced an important study relating energy consumption to development, including a consideration of electricity consumption. His article assessed the causality between energy and electricity consumption and Human Development Index (HDI) in 15 countries. In the short term, his results supported the neutrality hypothesis; however, in the long term the evidence suggests that economic growth and the realisation of the MDGs is highly dependent on access to modern energy services. The distinction between long- and short-term trends has been identified in a select number of studies (Asafu-Adjaye 2000; Al-Iriani 2006; Apergis and Payne 2011; Ouedraogo 2013), which note that the relationship frequently changes over time. However, this topic is in need of greater attention, especially when considering the SDGs and how to measure the progress of countries.

Furthermore, Ouedraogo's attention to modern energy services links his research to development policy. The report produced in 2010 by the Secretary-General's Advisory Group on Energy and Climate Change (AGECC) placed firm emphasis on 'modern energy services'. These relate closely to the sources of fuels considered modern sources of energy—natural gas, liquified petroleum gas (LPG), diesel and biofuels—which provide clean energy to consumers. In addition to these sources, technology such as improved cooking stoves are an important component in what is considered modern energy services. This paper will discuss in detail the hierarchy of fuels and technology in a later chapter; however, it is important to note that the literature on energy consumption and economic growth has become increasingly inclusive of developmental criteria.

This is significantly demonstrated by an important article by Lenzen and colleagues (2006). In this study, they analyse sustainable household consumption and the role of income growth on the environmental impact of household energy access and consumption. Their article is significant in two respects: first, because it concludes, like the above analyses, that there is no uniform cross-country relationship between energy and household expenditure, even when controlling for socio-demographic variables. Thus showing the relationship is complex, and context-specific. Second, it is important to demonstrate the interaction of the relationship between income and energy with other factors of development, specifically the environment. The holistic impact of energy access and consumption has broad impacts relating to poverty and development, which will be investigated in more detail in the following section.

The conclusions of Ferguson et al. (2000) and Ouedraogo (2013) are reflected in SDG7, which emphasises access to *clean* and *modern* forms of energy for sustainable development. However, the literature demonstrates substantial variation in the causal relationship between GDP and energy consumption, which has particular significance for development policy. The relevance of the variation means that there is no universal policy solution; policies will need to be specific to countries, as Lenzen (2006), Akinlo (2008) and others have demonstrated. This, plus the interaction of energy and income with other developmental criteria such as the environment, adds complexity to pursuing SDG7.

3 ENERGY POVERTY

While the literature remains divided on the exact causal relationship between electricity consumption and economic growth, since the early 2000s increasing attention has been paid to energy poverty. A large number of scholars have argued that energy is vital for development (Reddy 2000; Birol 2007; Bazilian et al. 2010; Sovacool 2012; Ouedraogo 2013). However, today 1.1 billion people lack electricity to light their homes, and nearly 40 per cent of the world's population relies on biomass products for their basic needs (Sovacool et al. 2016). These figures underpin SDG7 and contribute to the shifting perception of poverty and development as a broader assessment of quality of life. Energy poverty is vital, because as the former Executive Director of the International Energy Agency (IEA), Fatih Birol (2007), argued, the reduction of energy poverty can help to reduce social development obstacles. The multifaceted role than energy plays in development, demonstrated by this literature, places the analysis beyond the scholarship on income and economic growth.

While the exact definition is somewhat debated, there is general consensus that energy poverty refers to "the absence of sufficient choice in accessing adequate, affordable, reliable, high quality, safe and environmentally benign energy services to support economic and human development" (Reddy 2000). Reddy (2000) provided one of the first comprehensive overviews of the development implications of energy poverty, including inequality, gender, urbanisation and consumption. Similar reviews in recent years have been produced by Kaygusuz (2011), Sovacool (2012) and Bazilian et al. (2014). These and other scholars have reiterated Reddy's argument that energy has the ability to solve many of the current development challenges (Cecelski 2003; Birol 2007; Kemmler and Spreng 2007; Bazilian et al. 2010; Bhide and Monroy 2011; Nussbaumer et al. 2012; Sovacool 2012; 2016; Ouedraogo 2013; Rasul 2016).

As scholars have noted, energy poverty is multifaceted. A study by Kemmler and Spreng (2007) demonstrated through regression analysis that an energy-access measure has a strong correlation with the majority of poverty measures. Notably, it correlates as well as the expenditure measure of poverty. Numerous scholars have reviewed the number of ways in which a deprivation of energy exacerbates poverty (Reddy 2000; Cecelski 2003; Kaygusuz 2011; Sovacool 2012; 2016). Sovacool (2012, 275) notes that poverty and energy deprivation go "hand-in-hand". Reddy (2000) observes in his broad review that access to energy services are a "crucial input" to numerous primary development challenges, including productivity, education, housing and health care.

Thus, a lack of access to modern energy places numerous limitations on households, and their development potential. Reddy (2000), Kaygusuz (2011) and Sovacool (2012) note that energy deprivation restricts the hours of productivity available to the household to daylight hours, limiting economic activity, the hours available for schooling and homework and other activities. Furthermore, access to energy allows for the development of communication services (Bazilian et al. 2010). Contributing to the restrictions on productivity, a number of reviews have shown that energy access is also necessary for safe drinking water, refrigeration and efficient food preparation (Reddy 2000; Birol 2007; Sovacool 2012). These have direct impacts on the healthy growth and development of both children and adults. As these reviews demonstrate, the lack of access to energy services which defines energy poverty places significant limitations on households (Kaygusuz 2011; Sovacool 2012).

A distinguishing feature of energy poverty in the developing world is the household reliance on biomass fuels to meet basic needs (Clancy, Skutsch and Batchelor 2003; Hiemstra-van der Horst and Hovorka 2008; Kaygusuz 2011; Sovacool 2012; Ouedraogo 2013). This is closely associated with the correlation between high income and increased use of modern fuels, especially electricity, which will be discussed in the following section (Barnes and Floor 1996). In addition, reliance on biomass can be a result of rural isolation and a lack of infrastructure (Pachauri and Spreng 2004; Kaygusuz 2011; Rasul 2016). Biomass, which can be either collected or purchased, consists of dung, crop residues, wood and charcoal (Sovacool 2012). Its use affects many aspects of life, playing a significant role in energy poverty. It is largely used for cooking, which constitutes approximately 80 per cent of rural energy needs in developing countries (Kaygusuz 2011). Biomass and woodfuel stoves are hugely inefficient, due to incomplete combustion, thus limiting the amount of useful energy that the stoves can produce (ibid.).

In addition to being inefficient in combustion, the collection of biomass consumes time, effort and potential working hours, particularly for women (Reddy 2000; Clancy, Skutsch and Batchelo 2003; Sovacool 2012). The gendered aspect of energy poverty has been highlight by Clancy, Skutsch and Batchelor (2003), and also by Cecelski (2003). The impact of energy poverty on women is an important topic; however, there is still a lack of attention paid to gendered issues in energy poverty (Sovacool 2012). A reliance on biomass to address basic needs severely restricts household development.

Energy poverty is not just about access; the SDGs aim for the access to modern energy to be *sustainable*, *affordable* and *reliable*. Generating a well-being approach to energy consumption, Pachauri and Spreng (2004) argued that in addition to energy access, the sufficiency of energy supplies is central. A significant economic challenge involved in energy poverty, which has been empirically proven, is that poorer people spend a higher percentage of their income on energy (Reddy 2001; Barnes et al. 2004; Campbell 2003; Sovacool 2012). This means that although poor households consume less energy than richer households, they spend more on it. Empirical evidence for this affect is apparent in the study by Marufu and colleagues (1997) in Zimbabwe, which found that even where urban households have access to electricity, some houses choose not to use it because of its expense. Similar results have also been found in South Africa (Davis 1998) and India (Bhide and Monroy 2011).

The phenomenon is closely related to the issue of efficiency. Energy-efficient devices and supplies tend to have high start-up costs, while less efficient devices tend to be cheaper to set up. However, in the long term, due to efficiency, the former are more cost-effective (Reddy

2000). This means that "poorer people often pay more per unit of energy used because they cannot afford the initial costs of supply option that have the lowest lifetime costs" (Kaygusuz 2011). As Reddy (2000) and Kaygusuz (2011) noted in their reviews, energy efficiency is important because, for consumers, energy is most relevant for the services it can provide. In this way, energy poverty has a cyclical dynamic, restricting poor people to energy-inefficient fuels and devices, which consume more of their income. This phenomenon can also be seen in developed countries where modern energy services are unaffordable for a sector of the population (Druckman and Jackson 2008).

In addition to inefficiency and other economic costs, energy poverty and restricted access to modern fuels also has significant adverse health and environment impacts. A number of scholars have documented the health impacts of indoor air pollution from the combustion of biomass fuels (Abakah 1990; Holdren and Smith 2000; Barnes et al. 2004; Sovacool 2012). The incomplete combustion of biomass is proven to lead to the release of toxins into the atmosphere and can lead to severe health problems. Holdren and Smith (2000) in particular documented the variety of adverse health impacts that indoor air pollution can cause. They range from respiratory infections and diseases to asthma and heart conditions and adverse pregnancy outcomes. They report that indoor air pollution has caused the death of 500,000 women and children, making up 5–6 per cent of the national burden of health. This is more than the national burden of malaria, TB, HIV/AIDS, tobacco, heart disease and cancer (ibid.). Pachauri and colleagues (2013) note that improved access to modern cooking fuels can avert between 0.6 and 1.8 million premature deaths annually by 2030.

In addition to health impacts, the incomplete combustion of biomass and other fuels also contributes to broader environmental pollution and damage. This can include deforestation (Cline-Cole et al. 1990; Holdren and Smith 2000; Ouedraogo 2013), change in land use (Kaygusuz 2011; Sovacool 2012), land and soil degradation (Abakah 1990; Reddy 2000; Rasul 2016) and greenhouse gas emissions (Sathaye and Tylor 1991; Holdren and Smith 2000). However, it is important to note that a number of these trends have been debated (Marufu et al. 1997; Arnold et al. 2006; Pachauri et al. 2013). This is largely related to woodfuels, with the orthodox approach claiming that domestic woodfuel usage leads to deforestation (Eckholm 1975), whereas newer studies have disputed this, arguing instead that agriculture, lines of communication and other factors have a larger impact (Cline-Cole et al. 1990; Arnold et al. 2006). In addition, studies have shown that the 'fuelwood crisis' feared in the 1970s has not produced as dramatic results as expected (Arnold et al. 2006).

One environmental study, by Chakravarty and Tavoni (2013), is particularly relevant here. The authors investigate the impact of energy poverty alleviation on energy consumption and subsequent carbon dioxide emissions, thus explicitly relating poverty alleviation with energy consumption, focusing on its environmental impacts. Addressing this important nexus, they use a quantitative model to conclude that an energy poverty eradication policy to be met by 2030 would increase global final energy consumption by about 7 per cent and would contribute at most 0.13 degrees of additional warming. Their results are significant for considering the broad impacts of energy poverty alleviation policies. However, the study is limited by its assumption of a power law relationship between household energy consumption and income. As discussed above, the existence of a universal relationship between income and energy consumption is highly debated. In addition, this study focused purely on modern energy and did not account for the complexities of households switching from traditional to modern means of energy. This process has a significant impact on energy consumption, poverty and the environment, as the following section will demonstrate.

Energy poverty, largely defined by limited or restricted access only to inefficient fuels and services, has the ability to restrict development and the alleviation of poverty around the world. In their assessment of the aspects of energy poverty which require greater research, Sovacool et al. (2016) recognise there is a need to assess the relationship between energy and other services more closely, such as health and water, and in addition it is necessary to investigate the 'tipping points' in improving energy services. The alleviation of energy poverty will have a significant impact on removing obstacles to sustainable development, beyond pure income calculations. However, what the above literature has failed to directly address is the impact that reducing energy poverty will have on global energy consumption levels. Where Chakravarty and Tavoni (2013) engage with this relationship, they are limited by their lack of engagement with the process of energy transition. How households move out of energy poverty will have a significant impact on energy consumption, and it is this process which will be assessed next.

4 THE ENERGY LADDER

The household consumption of biomass for energy is closely related to the SDGs which emphasise the need to ensure universal access to *clean* and *modern* energy services by 2030. A central goal of the SDGs is to reduce the 2.9 billion people who cook with biomass, such as firewood (Sustainable Energy for All, undated). Therefore, it is important to assess the factors which encourage households to abandon the use of biomass, in favour of more efficient fuels. This process too will have significant effects on global energy consumption patterns. The substitution of one energy carrier for another is known as energy transition, or fuel substitution, and is widely covered in literature. Of particular significance is the concept of the 'energy ladder', which denotes the energy transition from biomass up to the most efficient carriers, LPG and electricity, coinciding with an increase in income (Hosier and Dowd 1987; Leach 1988). The energy ladder links directly to the correlation which Barnes and Floor (1996) noted, between income and increased use of modern fuels, and, therefore, can be interpreted as supporting the conservation hypothesis. Beyond this hypothesis, the energy transition, or fuel substitution process, as it is also known, has significance for a variety of developmental factors.

Attention to the process of fuel substitution was sparked by the African fuelwood crisis in the 1980s; many of the early studies are focused on the use of fuelwood in African communities (Hosier and Dowd 1987; Leach 1988; Abakah 1990; Cline-Cole et al. 1990). These studies presented support for the energy ladder hypothesis, largely through the assessment of large data, and regression models. Hosier and Dowd (1987) found evidence of the energy ladder hypothesis in Zimbabwe, and have become the classic proponents of the energy ladder hypothesis, noting that households with higher incomes tend to have access to and tend to use more effective or sophisticated energy carriers. Leach (1988; 1992) also employed the energy ladder concept to explain fuel substitution in both rural and urban areas of developing countries. The energy ladder, and the number of challenges made against it, provides an angle from which to consider the impact of poverty alleviation on energy consumption, particularly in the household sector.

Support for the energy ladder hypothesis has been provided by a number of empirical case studies (Hosier and Dowd 1987; Abakah 1990; Reddy and Reddy 1994; Davis 1998; Campbell et al. 2003). Abakah (1990) analysed the relationship between the consumption of woodfuel, real income and inflation in Ghana from 1974 to 1987, and found a close relationship between woodfuel consumption and income to support the energy ladder hypothesis. Reddy and Reddy (1994) carried out household surveys in Bangalore to assess the fuel substitution process, and also found empirical evidence to support the energy ladder, as with increasing income it was shown that households moved up the ladder away from biomass to more efficient fuels. Davis (1998) draws on a large-scale survey in South Africa to demonstrate the existence of an energy transition which is largely dependent on income. Also using households surveys, Campbell et al. (2003) found in Zimbabwe an energy transition correlated with increase income. Although none of these studies directly refer to the hypotheses developed by the literature on the relationship between energy consumption and GDP, they do provide evidence for the existence of the conservation hypothesis, as they imply that increasing income leads to increasing energy consumption.

TABLE 2

A comparison of a selection of studies examining the energy ladder hypothesis

Author	Year	Method	Case study country	Energy ladder conclusion
Hosier, R.H., and J. Dowd	1987	Case study and regression analysis	Zimbabwe	Evidence of energy ladder
Leach, G.A.	1988	Review	Global	Evidence of energy ladder
Abakah, E.M.	1990	Case study and regression analysis	Ghana	Evidence of energy ladder
Leach	1992	Review	Developing countries	Evidence of energy ladder
Reddy, A.K.N, and B.S. Reddy	1994	Case study	Bangalore	Evidence of energy ladder
Marufu, L. et al	1997	Case study	Zimbabwe	Evidence against energy ladder
Davis, M.	1998	Case study	South Africa	Partial evidence of energy ladder
Masera, O.R. et al.	2000	Case study	Mexico	Evidence against energy ladder
Campbell, B.M. et al.	2003	Case study	Zimbabwe	Partial evidence of energy ladder
Heltberg, R.	2004	Case studies	8 developing countries	Evidence against energy ladder
Hiemstra-van der Horst, G., and A.J. Hovorka	2008	Case study	Botswana	Evidence against energy ladder
Bhide, A., and C.R. Monroy	2011	Case study	India	Evidence against energy ladder

Movement up the ladder is desirable due to the increasing efficiency, cleanliness and cost-effectiveness of fuels higher up the ladder. However, the analyses by both Davis (1998) and Campbell et al. (2003) reveal a pattern which has come to challenge the energy ladder hypothesis. Both note that complete fuel switches, as denoted by the energy ladder, are rare and that the use of multiple fuels is common. The study by Campbell et al. (2003) gives stronger evidence for the fuel ladder with regards to lighting, whereas there are often multiple cooking fuels. Davis (1998) agrees with this to some extent, although little emphasis is placed on it. While neither suggest alternatives to the energy ladder, both demonstrate that it does not effectively describe the fuel substitution process.

During the 1990s, the traditional energy ladder began to be challenged by two phenomena: urbanisation failing to lead directly to fuel substitution (Barnes et al. 2004), and the household use of multiple fuel types (Hiemstra-van der Horst and Hovorka 2008). A number of classic proponents of the energy ladder found evidence that urbanisation leads to movement up the fuel ladder, in correlation with income (Leach 1988; 1992; Sathaye and Tyler 1991; Hosier and Kipondya 1993; Marufu et al. 1997). However, this is challenged in Botswana (Hiemstra-van der Horst and Hovorka 2008), more broadly in Africa, where fuelwood continues to be used in urban centres (Arnold et al. 2006), and India (Bhide and Monroy 2011). Thus, while fuel type often correlated with income, analyses recognised that other factors affected the process of fuel substitution, including accessibility (Leach 1992; Davis 1998; Barnes et al. 2004), education (Heltberg 2004), cultural preference (Marufu 1997; Bhide and Monroy 2011) and fuel security (Campbell et al. 2003; Arnold et al. 2006).

Despite being early proponents of the energy ladder, it is important to note that from their study in Tanzania, Hosier and Dowd (1987) did not claim that income is the only factor affecting fuel substitution; they state that factors including size of household and location are also important. In addition, Leach (1988) also shows that there are 'non-economic' reasons behind fuel substitution. The proposition that transition is influenced by non-economic factors is supported by a variety of case studies (Marafu 1997; Davis 1998; Masera 2000). Contrary to the energy ladder, these case studies demonstrate that there is significant variation in how households use energy and energy carriers, and, reflecting the hypotheses literature again, that there is not one single relationship between energy consumption and development. This has implications for both the design of policy and also the expected impact of poverty reduction on energy consumption. Rather than presenting a universal pattern of energy transition, the following case studies demonstrate the individuality of fuel substitution around the world.

Following a study in Zimbabwe based on biomass consumption micro-surveys, Marufu and colleagues (1997) concluded that consumption was significantly related to fuel availability and family size. In particular, they noted that all urban households in their study had access to electricity and used it as a main energy source. They found no statistically meaningful relationship between per capita income and fuel consumption rates in the study areas.

In contrast, in South Africa, Davis (1998) found that only 14 per cent of electrified households rely exclusively on electricity, thus challenging the significance of access. In Mexico, Masera and colleagues (2000) found strong evidence that fuelwood continues to be used because of cooking preferences, and households, therefore, rarely follow the energy ladder but use multiple fuel carriers. The use of multiple fuel carriers has come to be referred to as "fuel stacking" (ibid.). Fuel stacking was also found in Botswana (Hiemstra-van der Horst and Hovorka 2008) and Zimbabwe (Campbell et al. 2003).

In their study of energy consumption in Botswana, Hiemstra-van der Horst and Hovorka (2008) recognised that the energy ladder fails to account for active decision-making by households, and consumer responsiveness to aspects such as fuel prices and fuel security. They found wood to be the most widely used fuel, across all income groups, and that households often used a variety of different fuel carriers due to preference and security.

A number of scholars note that using a mixture of fuels increases the fuel security of households, in case of price fluctuations or energy shortages (Campbell et al. 2003; Pachauri and Spreng 2004; Arnold et al. 2006). Indeed, Bazilian and colleagues (2010) identified energy security as the most powerful and most neglected aspect of energy poverty that needs to be addressed. However, unfortunately, Hiemstra-van der Horst and Hovorka (2008) noted that the energy ladder has remained a linear understanding of progression.

The energy ladder has significant implications for policy concerning energy poverty. In particular, numerous countries have sought to expand rural electrification to alleviate rural poverty. China is a critical example of rural electrification policies, having achieved almost 100 per cent electrification in the early 2000s (Bhattacharyya and Ohiare 2012).

However, significantly reflecting the complexity of energy transitions, despite achieving an almost 100 per cent electrification rate, electricity counts for only 10 per cent of the energy consumed in China; the main energy carriers used being coal, oil and non-commercial products (ibid.). The low rural electricity consumption in China was also noted by an official report by the International Energy Agency (Niez 2010). In addition, Yang (2003) found that electrification had the greatest impact on the medium-developed regions, and not on the poorest.

The result of the study by Davis (1998) in South Africa similarly challenges the policy assumption that electrification will reduce energy poverty. In assessing the energy poverty situation in India, Bhattacharyya (2006) noted that the government's rural electrification plan for 2012 would be unable to solve the problem of energy access, as electricity counts for a minority of the poor population's energy mix. In a study focused on African countries, Szabó and colleagues (2013) concluded that there would be no one-size-fits-all approach to rural electrification. Instead, they found that rural electrification would rely on a combination of technologies. This conclusion is also supported by the Chinese experience, which relied on bottom-up local approaches to achieving rural electrification (Bhattacharyya and Ohiare 2012).

The critique of the energy ladder largely rests on its normative linearity. A number of studies provide clues for how the energy ladder may be reconceptualised to address this challenge. As mentioned above, while studies such as Davies (1998) and Campbell et al. (2003) concluded that there is little evidence for the traditional energy ladder, their results imply that there may be different ladders for different end uses/appliances. Campbell et al. (2003) noted that all households in the study that had access to electricity used it for lighting, with the majority saying it was the main or only fuel for this end use. Electrified houses, however, still used other fuels on occasion for cooking.

The difference in transition between lighting and cooking has also been observed elsewhere (Sathaye and Tyler 1991; Barnes et al. 2004). Sathaye and Tyler (1991) concluded that the two most popular end uses of electricity in developing-world households are lighting and refrigeration. In addition, Barnes and colleagues (2004) noted that lighting is also the first use of electricity in urban households. The above review has shown that this is not the case for cooking. A particularly important study here is Masera et al. (2000), who use their case study to suggest that rural transitions can be more accurately understood as a 'multiple fuel' model, with fuel stacking. While these studies prove the inaccuracy of the energy ladder hypothesis in many cases, there are rarely suggestions of how it can be improved or adapted.

The evidence provided by these various studies suggests that there is the potential to consider the existence of more than one energy ladder, or multiple ladders, relating to different end uses/appliances. This paper suggests from the above review of the energy ladder literature that there is potential utility in developing separate energy ladders for lighting and cooking. It will allow for variation which accompanies fuel transition processes, including access, cost, fuel security, and cultural factors which come to play in household decision-making. The multiple models would allow for a more accurate depiction of household fuel transitions, and the application of these models may illuminate where the opportunities for encouraging the use of clean and modern fuels most realistically lie from culture to culture. This would assist with achieving the SDGs and with understanding how changing poverty rates may affect energy consumption around the world. However, the specificity of these ladders would not allow for a macro design but, rather, would depend on empirical evidence and experiences of individual households themselves.

The challenges posed by the transitional energy ladder model are particularly relevant for SDG7. As this goal aims to ensure access to clean and modern energy services for all, the lack of empirical consensus on the energy ladder suggests that that there is no global trend of energy transition, and thus the progression to access to clean and modern energy will not be universal. In addition, the role of cultural preferences as seen in the above studies suggests that access to electricity does not equal automatic consumption. The case of South Africa (Davis 1998), the role of cooking preferences in Mexico (Masera 2000) and active decision-making in response to external situations (Hiemstra-van der Horst and Hovorka 2008) all challenge the inherent assumption in SDG7 that the pursuit of universal access to electricity and other modern energy carriers will necessarily lead to the eradication of biomass and other harmful fuels. This is evident in the continued use of biomass fuels in several urban studies (Arnold et al. 2006; Hiemstra-van der Horst and Hovorka 2008; Bhide and Monroy 2011).

The failure of a general model such as the energy ladder also poses a challenge to the observation of energy access and transition in the light of the SDGs. In particular it means that the assessment of household consumption in relation to poverty cannot be accurately carried out at the macro level. The existence of four hypotheses, in addition to the proposal of developing multiple energy ladders, reiterates this, as the current model is unable to capture the reality of fuel decision-making in households. Therefore, further research is necessary to accurately assess household energy usage and transitions on a micro scale, at the household level itself.

5 HOUSEHOLD CONSUMPTION

The energy ladder literature demonstrates that there is significant variation in how households use energy and energy carriers. The lack of general energy consumption patterns challenges the accuracy of macro approaches to both research and policy. Therefore, it is important to look more directly at the consumption of energy, in particular electricity, at the household level, to emphasise the trends which occur relating to inequality and development. The study of household consumption, however, faces significant methodological challenges: namely, the assessment of household consumption without access to direct data. The metering of household appliances is the simplest way to analyse household consumption; however, metering is both expensive and inconvenient. In addition, when aiming to focus on developing countries, the prevalence of energy meters is extremely low. Thus the majority of studies use models to predict the energy consumption of households and individual appliances.

In their comprehensive review on the topic, Swan and Ugursal (2009) identified two distinct approaches to the modelling of household consumption: top-down and bottom-up. The top-down approach treats the household as an energy sink, whereas the bottom-up uses the estimated energy consumption of a set of households and scales them up. The bottom-up models allow for recognition of the differing usage of individual appliances, rather than assuming a blanket household consumption. This reiterates the challenges presented by the energy ladder, with the need for the disaggregation of energy consumption tends. The interest here is with the specific consumption of households in relation to poverty levels; therefore, this article will focus on the bottom-up approaches, to demonstrate how they may be integrated into social policy. To do so, there are two categories of methods: engineering methods and statistical methods.

Engineering methods are based on theoretical considerations from the power ratings and characteristics of the appliances (Parti and Parti 1980; Aigner et al. 1984; Aydinalp-Koksal and Ugursal 2008; Swan and Ugursal 2009). Swan and Ugursal (2009) provide a comprehensive review of the engineering methods in literature, and show that it can be applied in a number of different ways, including using actual data from a household sample (it can be regionally or nationally representative) as the input information, and distributions of appliance ownership. Most relevant here is that engineering methods can be applied to a representative set of houses to produce archetypes.

These archetypes are selected to broadly classify houses into groupings, which can then be used as the input data for energy modelling. Parekh (2005) details the process of producing these archetypes, which first draw on housing stock surveys, particularly concerning geometric and thermal characteristics, and are then correlated to reveal various groups within the housing stock. Parekh outlines the three criteria for producing representative housing archetypes: geometric configurations, thermal characteristics and operating procedures. The outcome of producing archetypes is generating minimum, average and maximum values for building simulation platforms (Parekh 2005). The archetype approach has been used in a variety of ways, including assessing the environmental sustainability of buildings (Jones et al. 2001) and residential consumption on the city scale (Shimoda et al. 2004).

The engineering method requires an extensive database, requiring a high level of input; however, it is weak when it comes to examining socio-economic characteristics (Aydinalp-Koksal and Ugursal 2008). More specifically, and most problematic, as it is based on the manufacturing ratings and characteristics of appliances, the engineering method fails to account for consumer behaviour. Thus, it is limited in assessing the role of social and economic choices which concern energy consumption. A number of reviews have highlighted this challenge (Aydinalp-Koksal and Ugursal 2008; Swan and Ugursal 2009).

Drawing on the customer billing information from energy suppliers, and using a representative sample of households, statistical methods are able to account for the effect of occupant behaviour. Swan and Ugursal (2009) present three broad techniques within this method: regression, Conditional Demand Analysis (CDA) and neural network.

Regression analysis is a wide category, which determines the coefficients of the model from input parameters (Swan and Ugursal 2009). Ranjan and Jain (1999) applied linear multiple regression analysis to electricity consumption in Delhi for the period between 1984 and 1993, paying special attention to population and weather patterns. Regression analysis can also be used in comparative studies, such as by Zhang (2004), who used the method to compare the annual energy consumption per household in China, Japan, Canada and the USA. A recent article by Fumo (2015) reviews regression approaches to household energy consumption, demonstrating that regression analysis provides results accurately and simply.

CDA broadly falls into the category of regression analysis; however, it is able to simulate the influence of a variety of specific factors. Recognising the limitations of engineering methods to produce accurate estimates, Parti and Parti (1980) introduced CDA to allow for the disaggregation of the total household demand for electricity into estimated component demand functions.

The CDA method is able to estimate appliance-specific consumption without using theoretical engineering data or end-use appliance metering, which Parti and Parti showed for 5286 households in San Diego County, USA. These data are important, they state, because they can be used to inform energy policy and for forecasting capacity requirements. The method allows for the inclusion of variables including weather/temperature and house size, and can be used to model energy consumption over the course of a day. In addition, CDA analysis provides price and income elasticities of electricity consumption (Parti and Parti 1980).

The attention paid to income elasticities by Parti and Parti is significant because it is through this analysis that it may be linked to the four hypotheses for the relationship between energy consumption and GDP. For example, they find that electricity consumption is price-sensitive, and that a 40 per cent increase in the real price of electricity would lead to a 20 per cent decline in current consumption.[2] This is suggestive of the conservation hypothesis, recognising causality from income/price to electricity consumption. A similar relationship is found by Jones (1989), who finds the income elasticity of modern and total energy consumption between 0.64 and 1.1. Jones's study is particularly important because it is a rare example of integrating elasticity estimates with development criteria. He considers the role of urbanisation, which, although not directly relevant to this study, shows that there is utility in directing elasticity estimates to development studies. However, while Parti and Parti's (1980) CDA provides evidence for the conservation hypothesis, later elasticity work by Apergis and Payne (2011) finds support for the growth hypothesis. Context specificity is vital to understanding the variation in elasticity and, therefore, support for the four hypotheses.

CDA has been broadly applied to quantify household electricity consumption in developed countries, particularly in the USA (Parti and Parti 1980; Aigner et al. 1984; Caves et al. 1987) and Canada (Lafrance and Perron 1994). Aigner and colleagues (1984) used CDA to produce end-use profiles for hours during the day, including variables of temperature and house size. The CDA has also been applied to developing countries, and can demonstrate regional variation, as Lins and colleagues (2002) demonstrated with their study in Brazil. CDA allows more specific and accurate predictions to be made than engineering methods, which base consumption on power ratings and the thermodynamic relationship of appliances.

However, CDA is weakened by problems of multicollinearity, which makes it difficult to disaggregate the results (Hsiao 1995). In response to this challenge, a number of scholars have integrated a Bayesian approach, allowing for CDA and engineering methods to be combined. Caves et al. (1987) used an observed usage data (CDA) approach to modify a set of prior beliefs (engineering approach) to provide a distribution which describes appliance use patterns.

The Bayesian approach allows for the reduction of multicollinearity effects which can result in negative or unreasonable coefficients. Bauwens and colleagues (1994) integrated Bayesian analysis with CDA to attempt to eliminate negative end-use or appliance consumption estimates. However, unlike Caves et al., Bauwens et al. incorporated direct metering information to estimate electrical appliance consumption for a sample of Australian households. Similarly, Hsiao et al. (1995) incorporated metering data into CDA for more accurate estimations for households in Canada.

In an important study, Tso and Yau (2007) concluded that CDA is not the most accurate model to account for socio-economic variables, and instead argued that the neural network approach is more suited to assessing household energy consumption by considering consumer behaviour. Neural networks are simplified mathematical models of biological neural

2. It is important to note the time-frame of Parti and Parti's study. It was based on questionnaire responses in 1975 and used 1967 as the base year for electricity prices.

networks, and are used to determine causal relationships between a large number of factors. Most significantly, they can be used to incorporate socio-economic variables (Tso and Yau 2007; Aydinalp-Koksal and Ugursal 2008). Tso and Yau noted, however, that when applied to real data, both regression and neural network methods yielded accurate predictions of household energy consumption. While models are increasingly used to incorporate socio-economic variables, there is a lack of linkage between this literature and a consideration of poverty and development practices.

In recent years, a select number of studies have integrated socio-economic variables into modelling future household energy consumption. This literature has direct relevance to the SDGs and the alleviation of poverty and inequality; however, it lacks the micro-analysis of the above modelling techniques. These studies have focused on specific countries, especially India (Ekholm et al. 2010), and regions (Bazilian et al. 2012; Pachauri et al. 2013). These articles are relevant because of their attempt to integrate the variety of factors discussed in this review which implicate poverty and energy consumption at the household level.

The study by Ekholm and colleagues (2010) is written with a focus on the improvement of living standards in India, and is significant because they purposely account for heterogeneity in households. Drawing on a basic economic choice model, they construct an energy choice model, which they then implement as the MESSAGE-Access model. This modelling method allows for the assessment of possible future scenarios of household consumption, and the impact of fuel subsidies and microfinance. Their energy choice model successfully reproduced the results of national statistics and predicted the continuation of current consumption patterns. As they note, "acknowledging the heterogeneity of consumers is a step forward to a more realistic representation of the household sector in energy system models" (Erkholm et al. 2010).

Bazilian et al. (2012) and Pachauri et al. (2013) also address future consumption patterns with regards to poverty and development; in addition, both pay particular attention to the monetary cost of alleviating energy poverty. Akin to Erkholm et al. (2010), Bazilian et al. (2012) use simple modelling techniques to produce multiple projections for energy access scenarios in sub-Saharan Africa by 2030. Their study focused largely on energy policy, and on calculating the cost and feasibility of reaching universal access by 2030, as the SDGs aim to do. In particular, they found that, rather than a threefold increase, a tenfold increase in installed generation capacity would be needed by 2030 for universal access (Bazilian et al. 2012). Their article is significant for modelling future energy consumption; however, unlike Erkholm et al., it does not account for the variation and heterogeneity of households.

Lastly, Pachauri and colleagues (2013) used two integrated assessment models to investigate the investments and consequences of completing total rural electrification and universal access to clean cooking fuels by 2030. Their study, like Erkholm et al. (2010), emphasised the importance of accounting for heterogeneity in demands and paying abilities across populations. Their results suggest that the targets for electrification and clean cooking fuels can be achieved with dedicated policies and an added investment of USD65–86 billion per year (Pachauri et al. 2013). This growing area of literature is important for demonstrating both the viability and the necessity of including developmental criteria in modelling household consumption, with regards to poverty. However, these studies also draw largely on aggregate data. There is, therefore, the opportunity to develop micro-analysis of household consumption and relate this to poverty and inequality, to more accurately reveal how global energy consumption will develop in years to come.

The current approaches to modelling household consumption demonstrate that there are several ways to study energy consumption at the micro level. In addition, recent literature shows that socio-economic criteria can increasingly be incorporated into these assessments. These studies largely imply support for the conservation hypothesis, paying particular attention to the relationship between price, income and energy usage. However, unlike the hypotheses literature, the opportunity to study household consumption at the micro level means that the context- and culture-specific factors which have been found to impact energy poverty and energy transition can be accounted for. The variation in appliance and end use is shown to be particularly significant. This supports the proposed development of multiple energy ladders, considering the changes which occur within households depending on the type of end use. The limitations of macro-analysis can be overcome through modelling techniques at the micro level, so that there can be a realistic assessment of the relationship between energy poverty and consumption as progress is made towards poverty alleviation.

6 CONCLUSION

The household consumption of energy, and in particular electricity, has important connections to inequality, poverty and development. The current literature has critically assessed the relationship between energy consumption and GDP, producing results which suggest that there is no universal pattern of causality, but that country and developmental characteristics are significant. Support for the four hypotheses of the relationship between energy and income largely depends on country-specific, or even region-specific, factors.

While the causal link is debated, the relationship between poverty and development has been explored through the concept of energy poverty. In particular, this literature highlights the variety of obstacles which energy poverty presents for sustainable development, thus demonstrating the need to address energy access issues, as the SDGs aim to do.

Notably missing from this literature, however, is the direct assessment of how poverty reduction will affect global energy consumption. A key feature of analysing this process will be the ways in which households move out of energy poverty and use modern fuels. The energy transition and fuel substitution literature, in particular regarding the energy ladder hypothesis, presents varying analysis on how this occurs. Taken together, the energy ladder literature suggests that the movement out of energy poverty towards the use of more modern fuels, especially electricity, is complex and context-specific. This has implications for the modelling and investigation of the relationship, indeed demonstrating that a macro approach to the connection will not yield realistic results.

Current approaches to modelling household consumption also demonstrate the significance of context and socio-economic factors on energy consumption in the residential sector. This literature provides further support to the need to model energy consumption in relation to poverty on a micro scale to accurately assess the relationship. The design of a model which could assess the interaction of poverty with household income with accuracy would have a significant impact on development policies such as the SDGs, and also energy policy. As poverty reduces around the world, there will be a large impact on energy usage. A micro model could help to illuminate what this impact may entail.

The above analysis presents a challenging conclusion with regards to alleviating energy poverty and encouraging sustainable development worldwide. Notably, it highlights the disjuncture between global development objectives, embodied in the SDGs, and empirical support for the necessity of context-specific, bottom-up approaches to alleviating energy poverty. This disjuncture points to the need for more detailed, culturally specific analysis on the processes which can alleviate energy poverty.

It is telling that in a content analysis of the energy studies literature in 2011, D'Agostino and colleagues found that the majority of literature is written about US energy consumption, by white males and from engineering/economic perspectives. D'Agostino and colleagues (2011) concluded their content analysis by listing five areas which require greater attention in the energy studies field: energy governance; feminism and gender studies; development studies; ethnical dimensions of energy systems; and behavioural and organisational studies. In agreement with this, and more recently, Sovacool and colleagues (2016) called for greater multidisciplinary approaches to energy and development, for the field to integrate the complex array of the economic, environmental and social aspects of providing energy access. This review found the same gaps and joins the call for the successful achievement of the SDGs.

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