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The influence of energy policy on charcoal consumption in urban households in Tanzania

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ABSTRACT

The sustainability of energy use in the residential sector has relevance for global initiatives to achieve sustainable development and limit climate change. Using the city of Dar es Salaam, in Tanzania, as a case study, we look at how national energy policy has influenced household cooking energy use between 1990 and 2018, and how energy policy could achieve further progress to realise national and global priorities. The study involved questionnaire surveys of households, retailers, transporters and producers of charcoal; semi-structured interviews with government officials and non-charcoal fuel suppliers; price data collection; a comparative analysis of prices and taxes for different cooking fuels; and policy and document review. Trends in energy policy and demand for different fuels, are compared. We find that Tanzania's national energy policies have focused on achieving an energy transition from biomass to electricity and fossil fuels, with an increasing focus on supply-side issues. Fiscal policy tools have been used effectively to reduce demand for kerosene, while increasing demand for liquefied petroleum gas. However, this has not resulted in a transition away from biomass, with most households using multiple fuels (fuel stacking). Charcoal remains the cheapest (excluding firewood) and most widely used fuel, reflecting the strong influence of price in consumer fuel choices. Energy policy needs to acknowledge the continued dominance of charcoal in urban energy use. In the context of rapid urbanisation and increased energy demand, there is a need for sustainable urban energy planning across a range of fuel types including charcoal, in ways that balance economic, social and environmental outcomes. Greater inter-sectoral coordination is needed to improve the sustainability of urban residential energy supplies.

Introduction

Background to charcoal's place in urban energy supplies and energy policy

Reducing emissions of greenhouse gases, including from residential sources and land use change, whilst '*ensuring access to affordable, reliable, sustainable and modern energy for all (SDG 7)*' are global challenges codified in the Paris Agreement (UNFCCC, 2015) and the Sustainable Development Goals (SDGs), respectively. Achieving these global ambitions requires national policies to deliver relevant outcomes. In sub-Saharan Africa, the residential sector is the largest consumer of energy, primarily as biomass energy for cooking (Ouedraogo, 2017). Despite decades of national policies attempting to transition residential consumers away from biomass, it remains the main source of energy for 2.8 billion people globally (Bonjour et al., 2013), including 780 million in sub-Saharan Africa (IEA, 2018). While many models predict a decline in the relative importance of residential biomass consumption as a proportion of total energy consumption in sub-Saharan Africa, given urbanisation and increasing populations, there is little evidence that total demand will decline (Ouedraogo, 2017).

In most countries in sub-Saharan Africa, urbanisation has resulted in charcoal gaining in relative importance, while firewood declines (Girard, 2002). Charcoal is the main cooking fuel for most urban households across sub-Saharan African countries (Makonese, Ifegbesan, & Rampedi, 2018; van der Plas & Abdel-Hamid, 2005). Charcoal has been linked to a range of environmental and social problems (Sola et al., 2017) including climate change (Bailis, Drigo, Ghilardi, & Masera, 2015; Maes & Verbist, 2012), deforestation, forest degradation (Mwampamba, 2007; Zulu & Richardson, 2013), increased morbidity due to indoor and outdoor air pollution (Bruce, Perez-Padilla, & Albalak, 2000; Butt et al., 2016; Conibear, Butt, Knote, Arnold, & Spracklen, 2018; Roy, 2016) and political violence (Branch & Martiniello, 2018). Globally,

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woodfuels generate 1.9–2.3% of global greenhouse gas emissions (Bailis et al., 2015). To help address these issues, reducing charcoal consumption has been a policy goal in many African countries (Leach, 1992; Zulu, 2010). Policy tools that have been used to reduce consumption include criminalising charcoal production and/or trade (Zulu, 2010); subsidising alternative fuels (Hosier & Kipondya, 1993); and promoting fuel-efficient stoves (Maes & Verbist, 2012). In many countries, such policies have had limited success (Girard, 2002; Maes & Verbist, 2012). Charcoal bans have generally driven the trade further into informal ways of operating (Zulu, 2010). While the use of subsidies has been found to be more effective than bans, in influencing consumers, energy subsidies are often regressive and costly (Hosier & Kipondya, 1993; Maes & Verbist, 2012), replace one non-biomass fuel for another, such as liquefied petroleum gas (LPG) replacing kerosene (Leach, 1992), and/or result in a diversification of fuel types rather than a transition (Maes & Verbist, 2012). Even in countries, including Zimbabwe and South Africa, where subsidising electricity has contributed to its widespread uptake for domestic cooking, many households retain biomass fuels in their energy mix (Campbell, Vermeulen, Mangono, & Mabugu, 2003).

Charcoal's place in Tanzania's urban energy supply and energy policy

This study looks at the influence of energy policy on urban residential energy use in Tanzania. Residential energy consumption comprised 70% of total national energy consumption in 2017, a decline from 74% in 2002 (IEA 2005, 2019). The majority of the residential energy consumption (84% in 2002, 97% in 2017 (ibid.)) comes from biofuels and waste. In 2017, 90% of all households in Tanzania were using either charcoal (21%) or firewood (69%) as their main source of energy for cooking (URT, 2019). The primacy of biomass energy has changed little since 1989 when 92% of final energy consumption came from firewood, charcoal and agricultural residues, of which 80% was used in the residential sector (URT, 1992). Given urban households' preference for charcoal over firewood, urbanisation drives a shift from firewood to charcoal. Tanzania is the fifth largest producer of charcoal in Africa and the charcoal trade in Tanzania is one of the most frequently studied charcoal trades in Africa (FAO, 2016; Sola et al., 2017).

Policy-makers in Tanzania have sought to reduce urban households' dependence on charcoal as a way of reducing deforestation (Doggart & Meshack, 2017) and air pollution, and pursuing a broader modernisation agenda. The first national energy policy was adopted in 1992, with revised policies being adopted in 2003 and 2015. All three policies have included objectives seeking to transition away from biomass energy and into electricity and fossil fuels (URT, 1992, 2003; URT, 2015). They differ in the declining emphasis placed on improving the sustainability of biomass energy production. For example, the 1992 policy includes two objectives aiming to improve biomass energy production and efficiency for residential use, whereas the 2015 policy only considers biomass in the context of electricity generation. The 2015 policy notes that despite the promotion of modern energy supplies in previous policies, they remain expensive and inaccessible to most Tanzanians. Based on these challenges, the policy prioritises improving the business environment and increasing access to modern energy supplies. However, despite three decades of aspiring to an energy transition, charcoal remains persistently popular in Tanzania's cities, a policy tension highlighted in several previous studies (CHAPOSA, 2002; Peter & Sander, 2009; CamCo, 2014) and mirroring tensions experienced in many other tropical countries (Leach, 1992).

Tanzania's policy has its theoretical roots in the 'energy transition model' (Leach, 1992). Energy policies seeking to transition households from biomass energy to fossil fuels and electricity assume that consumers perceive biomass energy, including both charcoal and firewood, to be inferior goods. Thus, with increased incomes, it is assumed that households will climb the 'energy ladder' from biomass energy, through kerosene, LPG and on to natural gas and electricity, the so-called 'modern' fuels. This pathway is known as the 'energy transition' and has been considered as, '*a basic feature of economic growth*' (ibid). Fuel availability and the price of the fuel and cooking appliances are considered to be the key obstacles to households climbing the energy ladder. While some countries have followed this transition, other countries have followed a different trajectory, in which, as households grow wealthier, they use multiple fuels in increasingly complex ways, a behaviour known as 'fuel stacking' (Hiemstra-van der Horst & Hovorka, 2008; Choumert, Combes Motel, & Le Roux, 2017; Maes & Verbist, 2012; Masera, Saatkamp, & Kammen, 2000). Instead of substituting fuels, as the energy transition predicts, households diversify fuel use. In Tanzania, there is clear evidence of households moving away from firewood with urbanisation and increasing incomes (D'Agostino, Urpelainen, & Xu, 2015), thus following the energy transition model. However, instead of transitioning to 'modern' fuels, firewood is substituted by charcoal in combination with one or more additional fuel types in a fuel-stacking pattern. The market treats charcoal as a normal good with demand positively correlated with household income (d'Agostino et al., 2015). Multiple reasons can account for this, including charcoal's relative price and availability, cultural preferences and the advantages of fuel-stacking over transitioning in terms of household energy efficiency and security (Makonese et al., 2018; Ruiz-Mercado & Masera, 2015).

Focal questions for the study

In this study, we consider four questions:

1. Is there evidence of an energy transition from biomass energy to 'modern' fuels between 1990 and 2018 in Dar es Salaam?
2. Have the policy tools that have been used to influence the urban residential energy sector, achieved the expected policy outcomes, and at what cost?
3. What are the implications for national energy policy of households diversifying rather than transitioning their cooking energy supplies?
4. How can national energy policies be more effective in achieving outcomes compatible with both national priorities and with global goals around climate change and sustainable energy supplies?

The study adds new empirical evidence of fuel-use behaviour providing additional insights into the tensions between energy policy and household practices; and proposes a re-orientation in energy policy to place more emphasis on matching demand and supply, inter-sectoral coordination and global sustainability goals. The paper is organized as follows: section 2 describes the study location and methods; section 3 presents the main results of the study; section 4 includes a discussion of how the study's results address the four questions listed above; section 5 presents recommendations for further research; and section 6 summarises key conclusions of the study.

Study location and methods

Study location

Dar es Salaam - the commercial capital and largest urban area in Tanzania with 4.3 million people, comprising 37.4% of the total national urban population at the time of the last census in 2012 - was selected as the focus for this case study. The intercensal growth rate between 2002 and 2012 was 5.6% per annum and the projected population for the study period, in 2018, was 5.96 million (NBS, 2013, 2016). Tanzania is becoming increasingly urbanised with the proportion of the population living in urban areas increasing from 19% in 1990 to 34% in 2017 (UNDESA-PD, 2018). The average household size in Tanzania is 4.6 people, with urban households being smaller, on average, (4.2) compared with rural households (4.9) (NBS, 2019).

Dar es Salaam is a coastal city, important for trade and manufacturing and was the capital of Tanzania until 1974. We selected Dar es Salaam firstly because it has the largest charcoal market in Tanzania

being home to approximately 30.3% of Tanzania's urban population, by 2015 (Worrall et al., 2017) and secondly due to the availability of historical studies (Hosier, 1993; CHAPOSA, 2002). The city is divided into 5 municipalities: Ilala, Kigamboni, Kinondoni, Temeke and Ubungo. Municipal councils are responsible for promoting social and economic development, and maintaining peace and order. A City Council, headed by the City Mayor, promotes coordination between the municipal councils and is responsible for inter-municipal issues, including transportation. A Regional Administration headed by the Regional Commissioner, provides an additional layer of government between local and central government.

The study focused on Dar es Salaam but has relevance to other urban areas in Tanzania and sub-Saharan Africa. Studies of other urban areas in Tanzania show comparable patterns of household fuel use (Hosier & Kipondya, 1993; Mwampamba, 2007). For example, the 2017/18 household budget survey found that 60.5% of all urban households use charcoal as their main cooking fuel, compared with 58.9% in Dar es Salaam (NBS, 2019). Similarly, there are many commonalities between cooking fuel use patterns, trends and policies in Tanzania, with other countries in sub-Saharan Africa (Makonese et al., 2018).

Overview and timing of data collection

The study involved interviewer-administered questionnaires with households, retailers, wholesalers, transporters and producers of charcoal; key informant semi-structured interviews with government officials and non-charcoal fuel suppliers; price data collection; and policy and document review. The data collection was carried out between October and November 2018 in Dar es Salaam Region, and, in the case of charcoal producers and transporters, in the adjacent regions of Morogoro (Mvomero and Morogoro Districts) and Coast (Kisarawe and Kibaha Districts), as well-documented sources of charcoal for Dar es Salaam (Malimbwi & Zahabu, 2008).

Household questionnaire surveys

Questionnaire interviews on domestic energy use were carried out in 100 households across the city's five municipalities. The sample size was calculated to give a margin of error ≤ 10% at a 95% confidence level).

Population and sampling

A stratified random sampling approach was used to select the households where the stratification was based on urban wards across Dar es Salaam Region. Household sampling used the 2012 census ward shapefile provided by the National Bureau of Statistics. Sampling intensity in each ward was based on the ward's relative contribution to Dar es Salaam's population. An urban ward was defined as a ward with a population density of 2000 people per sq. km. Only urban wards were included. Initial sampling locations were generated at random within the urban wards, using the random points tool in QGIS. The wards in southern Kigamboni were excluded from consideration because they did not meet the definition of urban. Twelve other wards did not receive sample points because their relative contribution to population was too low. Overall, there were no sample points in wards that cumulatively held 4.5% of the total population of Dar es Salaam Region. Table 1 compares the sampling intensity with the population of the five municipalities.

The sample points were overlaid on Google Earth high resolution imagery. The residential building closest to the sample point was selected as the sample household. Two reserve points per sample point were selected at the next two nearest residential buildings. In the event that the survey could not proceed at the original sample household, one of the reserve points was used. Finally, sample households were loaded into google maps to make it easy for interviewers to navigate to the households.

Table 1
Population distribution and sample intensity across the five municipalities of Dar es Salaam.

Municipality	Population (NBS, 2017)	% of the Dar population	Total sample points
Kinondoni	1,231,516	21%	23
Ilala	1,616,901	28%	28
Temeke	1,597,479	28%	26
Ubungo	1,119,830	19%	19
Kigamboni	215,830	4%	4
Total	5,781,556	100%	100

Data collection

A conditional branching questionnaire was developed, using the online KoBo Toolbox survey tool. The questionnaire was pre-tested with 4 households. The results from the pre-testing were included in the final survey. The survey tool included questions about: the current mix of cooking fuels used by the household; the amount of each fuel purchased, fuel prices and expenditure; reasons for using each fuel type; reasons for not using Liquefied Petroleum Gas (LPG), electricity and/or charcoal (where relevant); types of food cooked with each fuel; and energy saving techniques applied by the household. Cooking fuels that were considered in the survey included: briquettes, charcoal, electricity, ethanol gel, firewood, kerosene, LPG and an 'other' category to cover energy sources such as biogas, solar and natural gas.

Data analysis

We prepared descriptive statistics from the results of the household questionnaires to provide an overview of fuel use in 2018 and compared these with results of previous surveys including three Household Budget Surveys in 2000/1, 2007 and 2011/12, the 1990 Tanzania Urban Household Survey as reported in Hosier and Kipondya (1993) and the 2016 Energy Access Situation Report (NBS, 2017). These five earlier surveys are comparable with the current study in using household questionnaires and in using the regional boundary for Dar es Salaam as one of their sample units. All five surveys produced data on average household fuel use, albeit based on different sample sizes and sample selection methods. These five surveys provide the best available datasets from which to detect trends, relevant to the study.

The temporal gap between the historical data points ranges from 5 to 10 years. Whilst this creates a potential limitation by missing fluctuations occurring in the intervening periods, we recommend ways to improve monitoring of energy use patterns, in future.

Questionnaires with actors along the charcoal value chain

Population and sampling

The charcoal value chain involves four key steps: production, transportation, retail/wholesale and consumption (Sander, Gros, & Peter, 2013). To reflect this, the study included questionnaire interviews with actors along the value chain including producers, transporters, retailers and wholesalers.

Producers: 35 Producers were selected opportunistically from eight charcoal-producing villages in three districts (Kibaha, Kisarawe and Mvomero) within 180 km of the centre of Dar es Salaam (Table 2). We estimated that there are approximately 62,500 producers supplying charcoal to Dar es Salaam based on an annual production rate of 8 t/producer (van Beukering, 2007) and 500,000 t of charcoal consumed in Dar es Salaam annually (Peter & Sander, 2009).

Transporters: 35 transporters were included in the survey among those working within 180 km of Dar es Salaam. This included transporters in: Kibaha (19), Kinondoni and Ubungo Municipalities (14), Kisarawe (2) and Morogoro (1). Transporters were selected opportunistically from those waiting to pass through government check points on the main east-west highway coming into the city. Van Beukering (2007)

Table 2
Number of charcoal producers interviewed per village.

District	Village	Number of producers interviewed
Mvomero	Doma	4
	Mkata	4
	Mangae	4
Kibaha	Kwala	3
	Dutumi	7
Kisarawe	Panga la Mwingereza	5
	Mafumbi	5
	Kirui Chole	3
Total		35

estimated that 0.9 million person years were utilised in transporting charcoal to Dar es Salaam annually.

Retailers and wholesalers: the study was designed to include 20 retailers and 20 wholesalers. Retailers sell charcoal directly to consumers, usually from small shops close to residential areas. Shops are usually open-fronted and the charcoal is sold in small bags, tins or buckets. We estimate that there are >12,000 retailers in Dar es Salaam although precise data on the number of retailers is not available. Our estimate is based on retailers selling an average of 39 t of charcoal per year and a total trade volume of at least 500,000 t per year (Peter & Sander, 2009). Over the course of the study this was increased to 24 retailers. Wholesalers sell charcoal to retailers, usually by the sack. Over the course of the study, sampling was revised to 7 wholesalers. Reasons for the reduced sample of wholesalers are outlined in Section 3.5. The survey tools for the producers, transporters and retailers/wholesalers included questions on pricing, type and source of charcoal traded, volume and costs of trade, regulatory compliance, and trend perceptions. The margin of error (95% confidence level) for the tax compliance rates for producers, transporters and retailers were calculated based on a binomial distribution using the sample size and assumed population size.

All questionnaire data were recorded using the Open Data Kit application https://opendatakit.org and exported to Excel for analysis.

Key informant interviews with government officials and non-charcoal fuel suppliers

Semi-structured key informant interviews (KIIs) were conducted with ten Local Government Authority (LGA) staff, six Central Government staff from the Tanzania Forest Services Agency (3), the Forestry and Beekeeping Division, the Tanzania Revenue Authority and Ministry of Energy, two LPG distributors and one briquette manufacturer. Interviews with the government staff included questions on the role of the respondents' government office in planning and regulating domestic cooking fuel value chains and on the collection of taxes, royalties, fees and other government revenues from household cooking fuels. Interviews with private sector suppliers of biomass briquettes and LPG covered product pricing, the regulatory and fiscal environment and plans for the future. The interviews were designed to provide qualitative depth to the study, exploring particular issues relevant to stakeholders' role in relation to household energy supply chains.

Energy price survey

Sampling and data collection

Charcoal - Charcoal prices were collected through the retailer questionnaires described above. Weights of charcoal sold in small bags, tins, buckets and sacks were measured with spring balances to give an accurate price per kilogram.

Electricity and kerosene - Prices for electricity and kerosene are set periodically by the Government. Prices for these energy types were determined with reference to relevant government documents. Official prices were compared with prices at selling points to confirm that the official prices are those applied.

Ethanol and briquettes - Prices for briquettes were collected through the KIIs while prices for both briquettes and ethanol were surveyed by visiting two known retailers for one or other of the fuels and three other shops, in Kinondoni Municipality. As neither of the two products is widely used, the prices from these outlets were considered sufficient for the comparative price analysis.

Data analysis

On the assumption that price is a key determinant of consumers' fuel choices, we explored price differences between fuels and the contribution of indirect taxes and forest product royalties on fuel prices. As a first step in the analysis, we converted each of the prices into a price per unit of energy measured in Tanzanian shillings per megajoule (TZS/MJ) using standard conversion factors (CamCo, 2014). As a further step, considering that different fuel types convert into usable energy with different efficiencies, we then calculated the price per unit of useful energy, using values from CamCo, 2014. We repeated this for the taxes. Useful energy is defined as energy delivered to the pot, considering differences in the efficiency with which the energy contained in different fuels is transferred to the end use, in this case cooking (Bhattacharya & Abdul Salam, 2002). Firewood was not included in the comparison as the majority of firewood-using households collected firewood themselves, with no financial cost or tax.

Policy review

Policy documents were reviewed including policies, master plans, regulations and plans in the energy and forestry sectors, annual budget speeches from the Ministry of Finance and annual reports by the Energy and Water Utilities Regulatory Authority (EWURA). Data on domestic fuel use from the national budget survey and the national energy access situation reports were reviewed for comparisons (see Supplementary Materials for a list of the documents reviewed).

In our review of fiscal policies, we have only considered indirect taxes such as Value Added Tax (VAT), and royalties. Suppliers of LPG, briquettes, electricity and ethanol are also liable to pay a range of payroll taxes, as well as corporate income tax.

We prepared a timeline of key policy documents and decisions using the document review and KIIs, and compared these with the trends in household fuel use, in order to detect whether the desired policy outcomes were reflected in trends in household behaviour.

We compared policy objectives with consumer priorities to detect similarities and differences.

Definitions

We define charcoal as the '*solid residue derived from carbonization distillation, pyrolysis and torrefaction of fuelwood*,' (FAO, 2004).

We use the term 'modern fuels' to include LPG, natural gas, kerosene and electricity. This definition is adopted from Tanzania's National Energy Policy. We explore the issues around excluding biomass energy from the concept of energy modernity, in the discussion section.

Results

Household cooking fuel use status in 2018

The results of the household survey show that charcoal was the most popular household cooking fuel in Dar es Salaam in 2018, both as the main fuel (56% of households) and as part of a broader fuel mix (88% of households) (Fig. 1). LPG is the second most popular fuel, both as the main fuel (32%) and as part of the cooking fuel mix (58%). While kerosene is frequently used by households as part of the fuel mix (28%), only 3% of households use it as their main fuel. Similarly,

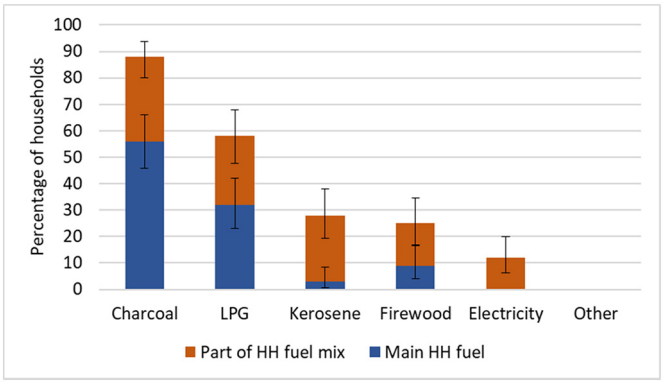

Fig. 1. Cooking-fuel types used by households in Dar es Salaam. Households list their main fuel, and other fuels as part of a fuel mix, if multiple fuels were used. Values are based on household surveys conducted in 2018. Note that there was no limit to the number of fuels that households could include when listing their fuel mix, while only one fuel could be described as the main fuel. Confidence intervals are shown calculated in r using the binom. test tool.

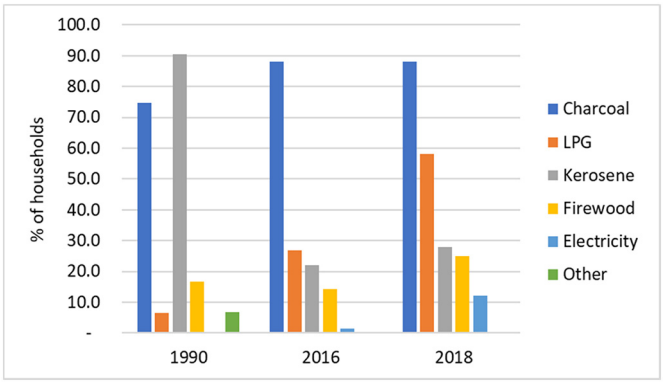

Fig. 3. Changes in the percentage of households using five cooking-fuels in Dar es Salaam between 1990 and 2018. Data sources: 1990: Hosier & Kipondya, 1993; 2016: National Bureau of Statistics Energy Access Situation Report (NBS, 2017); 2018 current survey.

firewood is only used by 9% of households as their main fuel and by 25% of households as part of the fuel mix. No household uses electricity as their main fuel and only 12% use electricity as part of the cooking energy mix.

Household cooking fuel use trends between 1990 and 2018

Fig. 2 compares results from our 2018 household surveys with Tanzania's household budget surveys that recorded the main household cooking fuel in Dar es Salaam in 2001, 2007 and 2012. Between 2001 and 2018, there has been a strong decline in kerosene use as the main fuel from 42% in 2001 to 3% in 2018. Between 2001 and 2007, charcoal replaced kerosene as the main household fuel. Between 2012 and 2018, increasing use of LPG as the main household fuel matches a decline in kerosene and charcoal as the main fuel.

Fig. 3 contrasts the results of our household survey with the 1990 Tanzania Urban Household Energy Survey (Hosier & Kipondya, 1993) and the Energy Access Situation Report 2016 (NBS, 2017). These surveys recorded all fuels used by households, in contrast to the household budget survey (Fig. 2) that only recorded the main household cooking fuel. Fig. 3 shows that charcoal has remained an important part of the fuel mix, with 75% of households using charcoal in 1990 increasing to 88% in 2018. Kerosene use has fallen dramatically, from 90% of households in 1990 to 28% in 2018. LPG was very rarely used in 1990, but increased to nearly 30% of households in 2016 and 58% in 2018. The rapid increase in LPG use between 2016 and 2018, matches national LPG imports which increased by 70% from 71,311 Metric Tonnes (MT) in 2015/16 to 120,961 MT in 2017/18 (EWURA, 2016, 2018a).

Fourteen different fuel combinations were recorded by our 2018 survey with a charcoal/LPG mix as the most frequently used combination (Fig. 4). Only 20% of households use only one fuel (i.e. 13% charcoal only, 5% LPG only and 2% firewood only), with 52% of households using two fuels, while 25% use three fuels, and 3% use four fuels. On average, households use 2.1 different fuels for cooking.

Reasons for household fuel preferences

Fig. 5 presents the reasons that households select different fuels for cooking. While having a fuel that can quickly be turned on and off was the reason cited most frequently for fuels being included in the fuel mix (Fig. 5a), affordability was the most frequent response for the selection of households' main fuel (Fig. 5b). Other reasons included a preference for LPG during the rainy season when charcoal was more expensive and it is difficult to cook outside; and having back-up fuels when the main fuel ran out within the household.

Respondents in the household surveys also stated their reasons for not using particular fuels. For both LPG and electricity, >90% of

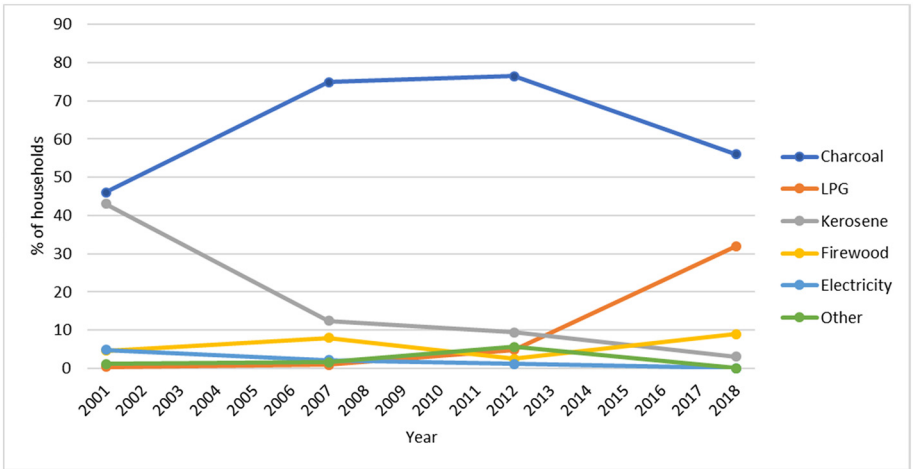

Fig. 2. Trends in the main household cooking fuel in Dar es Salaam between 2001 and 2018. The chart uses data for Dar es Salaam from Household Budget Surveys in 2000/1, 2007 and 2011/12 combined with the results of our survey in 2018.

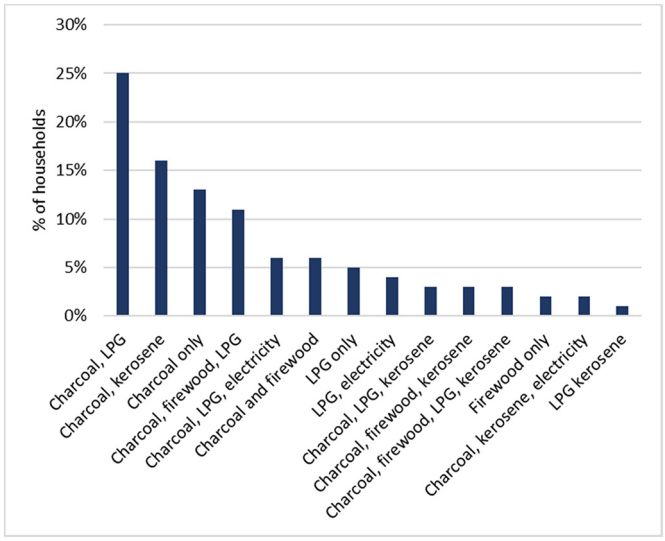

Fig. 4. Cooking fuel combinations used by households in Dar es Salaam in 2018.

households who did not use the fuel stated that the fuel was too expensive, while, in the case of kerosene, 59% of respondents who did not use kerosene, complained that it was messy, smoky or spoiled the taste of the food.

Cultural preferences can affect cooking fuel choices (Ruiz-Mercado & Masera, 2015). In order to understand the degree to which choice is influenced by cultural preferences, we asked about fuel preferences in preparing different foods. In the two-fuel LPG/charcoal households, we found that the majority (92%) of households will only prepare beans, using a charcoal stove. Meat and rice were also more likely to be cooked using charcoal, while breakfast porridge and leafy greens were more likely to be cooked using LPG. For other foods, no clear pattern emerges, and even within households the two fuels may be interchanged for preparing different food types.

In terms of fuel-efficiency measures practiced by households, 34% of households stated that they regularly soak beans prior to cooking and 10% of households sometimes use a pressure cooker. Other fuel-efficiency strategies that were mentioned by households include cooking in bulk (11%) and stopping the charcoal or firewood from burning when cooking is finished, for later re-use (16%).

Fuel prices and taxes

The household surveys highlight the importance of affordability in fuel choice-making. The results of the price survey data allow us to explore whether consumers' perceptions of affordability match with the relative price per unit of energy, of the different fuels.

The comparative price analysis indicates that the two most popular fuels, charcoal and LPG (Fig. 1), are the cheapest per unit of energy, while the least popular fuels, ethanol and briquettes, are the most expensive (Fig. 6).

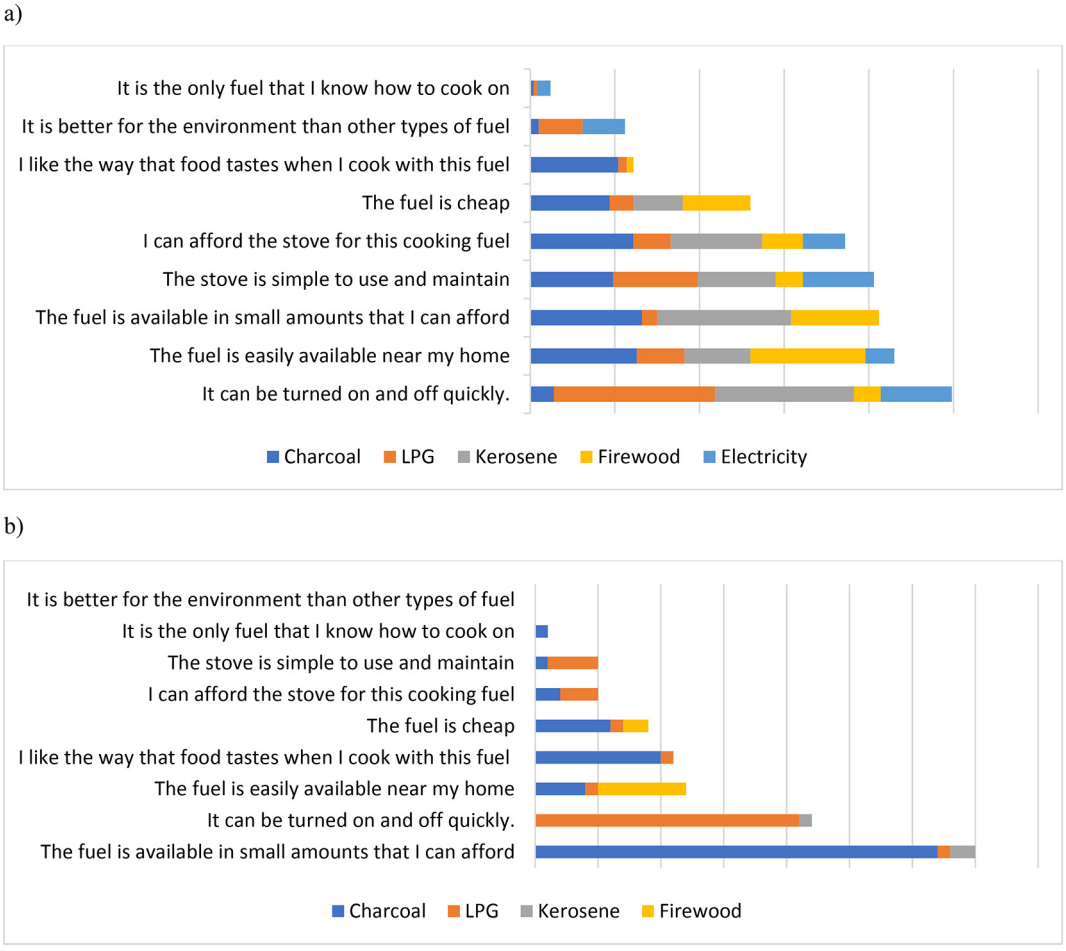

Fig. 5. Reasons for household fuel selection. a) Reasons mentioned by households for selecting fuels for use either individually or in combination with other fuels. Multiple responses were allowed. b) Households' most important reason for selecting their main fuel type. This was a follow up question to the question on main fuel type. Only one response was allowed.

From a policy perspective, Fig. 6 and Table 3 demonstrate how fiscal policies have affected the relative prices of the different fuels. The highest tax rates per unit of useful energy are for ethanol (TZS 60/MJ) and kerosene (TZS 42/MJ), while the rate for LPG is the lowest. The tax exemption for LPG has made it cheaper than electricity and kerosene. If the TZS 26/MJ in taxes on electricity were removed, it would be cheaper at TZS 116/MJ, than LPG which costs TZS 126/MJ. Similarly, in the case of kerosene, removing the TZS 42/MJ in duties and levies would make it cheaper at TZS 112/MJ, than LPG. In the case of briquettes and ethanol, both products would remain more expensive than LPG and electricity, even if they were exempted from all taxes. Charcoal, electricity and briquettes have comparable rates at between TZS 25.5–30/MJ (Table 3). However, it is charcoal's low pre-tax price that has made it the most affordable of the six fuels. If we take away the TZS 30/MJ of royalties in the charcoal price, we are left with a price of TZS 59/MJ equivalent to less than half of the LPG zero-tax price of TZS 126/MJ. This suggests that it would require a tax rate on charcoal of >100% to reach a comparable price with LPG.

While the average price of charcoal is lower than that of other sources of energy (Fig. 6), the price is highly variable. Table 4 shows that the prices of charcoal recorded during the survey ranged from 385 to 1430 TZS/kg fuel (mean ± standard deviation = TZS 776 ± 243). In general, it is cheaper to buy charcoal by large sack than by small plastic bag or by bucket (Table 4). The weight of charcoal in differently sized selling units was found to be highly variable. For example, the weight of charcoal sold in a 10-l bucket could vary from 2.8 kg to 4.2 kg. This is caused by differences in charcoal density and by the way that the charcoal is placed into the container. By using units of volume e.g. tins or buckets, as the units of sale, the price per unit of energy is highly variable given that the energy generated by charcoal will depend more on its weight than the volume of the container in which it is packaged. Charcoal's high price variability therefore suggests that, while consumers are correct in selecting charcoal for its overall affordability, it can be more expensive than LPG and electricity per unit of energy. For example, consumers who purchase a 1 kg plastic bag of charcoal for TZS 1429 will pay TZS 164/MJ of useful energy, making it more expensive per MJ, than electricity, LPG or kerosene.

Stakeholder perspectives

Local and central government

In terms of the mandate of different parts of government, for overseeing household energy supplies in Dar es Salaam, local government representatives responded that issues of urban energy supply were outside of their mandate. The Ministry of Energy respondent stated that their role is to increase supplies of modern energy for urban households pointing to the Power (electricity) Sector Master Plan (URT-MEM, 2016a), the Natural Gas Utilisation Master Plan (URT-MEM, 2016b), and the promotion of LPG. Both local government and the Ministry of Energy respondents indicated that woodfuel supplies were within the mandate of the Ministry of Natural Resources and Tourism (MNRT). Within MNRT, representatives from the Forestry and Beekeeping Division and the Tanzania Forest Services Agency described their role with regard to charcoal as including policy development, management of the charcoal trade and revenue collection. In response to questions around the regulatory challenges associated with the informal nature of the charcoal trade, TFS rejected the characterisation of the trade as being 'informal'. Instead, they described revenue collection challenges including traders avoiding checkpoints and weak coordination between different stakeholders involved in the charcoal trade. In contrast, the Tanzania Revenue Authority (TRA) explained that VAT is not collected on charcoal because it is considered to be part of the 'informal sector' business category and because annual returns of charcoal traders do not meet the income threshold required for businesses to register for VAT. TRA added that discussions are ongoing around collection of VAT on charcoal.

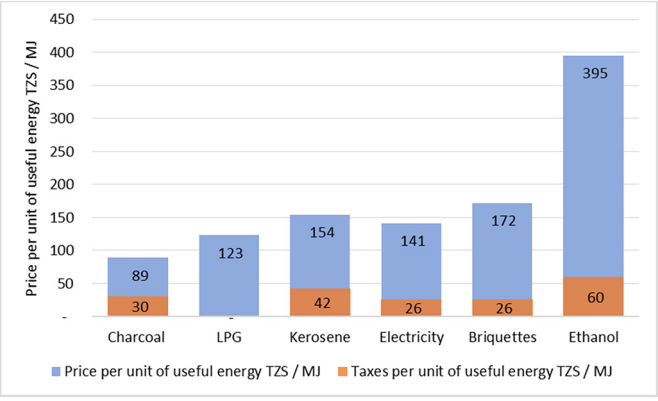

Fig. 6. Fuel price comparisons per unit of useful energy (Tanzanian Shilling (TZS)/MJ). The exchange rate at the time of the study was 1 US$ = 2284 TZS. The fraction of total fuel price that is comprised of indirect taxes is indicated.

Private sector

LPG suppliers stated that they anticipate, and are ready for, increasing demand for LPG. Investing in infrastructure and making LPG available in a broader size-range of tanks and cylinders are some of the strategies already being implemented. For example, LPG can now be bought in 3 kg cylinders making it more affordable for poorer households. Key concerns for the LPG suppliers were harmonisation of taxes and regulations; and LPG-related disaster preparedness and mitigation, including quality control for gas stoves.

Fig. 7 presents the study results on the kinds of taxes and fees that charcoal retailers, transporters and producers pay. The most frequently cited fees and tax were the TFS royalties, the wholesaler and trader licence fees also payable to TFS and the district agricultural tax payable in the district where charcoal is produced, known as 'cess'. VAT was not mentioned by any of the respondents. During the field survey, few wholesalers were identified while in some cases retailers were selling both by the sack and in smaller amounts. In the latter case, they were included in the retailer category while overall the wholesaler sample size was reduced from 35 to 7, of whom 5 paid TFS registration fees and 2 paid municipal business licence fees.

National energy policy trends between 1990 and 2018

Fig. 8 presents a timeline of key energy policies in Tanzania. Tanzania's national energy policies have consistently sought to transition the residential sector away from firewood and charcoal. *Arresting woodfuel depletion* (URT, 1992), *reversal of deforestation* (URT, 2003 and *reducing deforestation* (URT, 2015a) are cited as energy sector issues that the three policies have sought to address through this transition. While the 1992 National Energy Policy focused on transitioning to electricity, coal and biogas, the 2003 policy emphasised efficiency gains while still promoting coal as an alternative for household cooking. In 2006, LPG was exempted from the fuel levy and from VAT on gas cylinders in order to persuade urban households to transition from charcoal to LPG. The emphasis on transitioning households to LPG was then embedded in the 2015 National Energy Policy stating, '*the Government has been promoting substitution of charcoal and firewood by providing tax relief to stimulate the use of LPG in the country*,' (URT, 2015a). In 2016, master plans were published for the electricity and natural gas subsectors including long term aspirations for both energy sources to play a greater role in meeting residential sector demand, including as cooking fuels to substitute biomass energy. For example, the natural gas utilisation master plan includes the objective, '*To promote the use of natural gas as an alternative fuel to charcoal and wood for domestic use*' (URT-MEM, 2016a) while the electricity master plan states '*In the*

Table 3
Price per unit of energy of different cooking fuels used by households in Dar es Salaam in October 2018.

Fuel Type	Price	Taxes, royalties duties and levies	Conversion factor to MJ	Price per unit of energy	End use cooking efficiency	Price per unit of useful energy	Tax per unit of useful energy
	TZS per unit	TZS per unit		TZS per MJ		TZS per MJ (US$/MJ)	TZS per MJ
Charcoal	776/kg	262.5/kg	29 MJ/kg	26.76	0.3	**89.20** (0.039)	30
Charcoal price: TZS 776/kg is the average price across the different units of sale (see Table 4).							
Charcoal royalties and levies: TZS 262.5/kg is based on a royalty of TZS 250/kg (95% to the Tanzania Forest Services Agency and 5% to Local Government Authorities (LGA)) plus TZS 12.5/kg for the LGA tree-planting levy. Although charcoal is not exempted from VAT, the Tanzania Revenue Authority (TRA) confirmed that they do not collect VAT from charcoal as TRA class charcoal as an informal industry.							
LPG	3333/kg	0/kg	45 MJ/kg	74.07	0.6	**123.44** (0.054)	0
LPG price: TZS 3333/kg is the most representative price for household LPG use. The standard retail price of LPG varied from TZS 2750/kg for a 38 kg cylinder to TZS 3333/kg for the 3 kg, 6 kg and 15 kg cylinders from Oryx, in Dar es Salaam. Oryx were the largest supplier of petroleum products in 2017/18 (EWURA, 2018a). During the KII, the Oryx representative stated that the 6 kg and 15 kg cylinders were the most popular.							
LPG tax: As LPG is exempt from both VAT and the fuel levy, we considered these to be TZS 0.							
Kerosene	2247/litre	615/litre	36.3 MJ/litre	61.9	0.4	**154.75** (0.068)	42.4
Kerosene price: TZS 2247/litre was the EWURA Dar es Salaam price cap for October 2018 (EWURA, 2018b).							
Kerosene duty and levies: TZS 615/litre includes TZS 465/litre in excise duty and TZS 150/litre in petroleum duty (EWURA, 2018b Table 11).							
Electricity	356/kW·h	64.2/kW·h	3.6 MJ/kW·h	98.89	0.7	**141.27** (0.062)	25.5
Electricity price: TZS 356/kW·h is based on the 2018 TANESCO variable tariff (TZS 100/kW·h for the 1st 75 kW·h/month, thereafter TZS 350/kW·h plus VAT (18%) and EWURA (1%) and REA (3%) levies). Given the variable tariff, we calculated the average tariff by assuming that households used 10.74 kW·h per day including 6 kW·h for cooking equivalent to 4 hours of use for 1 average 1.5 kW cooking hob.							
Electricity tax and other levies: TZS 64.2/kW·h is based on an inclusive price of TZS 356/kW·h of which TZS 64.08 is VAT being charged at 18% plus 1% paid towards EWURA and 3% paid towards the Rural Energy Agency.							
Briquettes	1500/kg	229/kg	29 MJ/kg	51.72	0.3	**172.41** (0.075)	26.3
Briquette price: For the energy price comparison, we used the price of TZS 1500/kg. Based on KII with the briquette manufacturer, Mkaa Endelevu, the wholesale price for briquettes in Dar es Salaam was TZS 1000/kg, with most of their retailers selling at TZS 1500. In our survey of retailers, we found that the price of a 2 kg bag ranged from TZS 3000 to TZS 3200 inclusive of VAT.							
Briquette tax: a VAT inclusive price of TZS 1500 equates to a pre-VAT price of TZS 1271/kg with 18% VAT worth TZS 229/kg.							
Ethanol	5900/litre	900/litre	23 MJ/litre	256.52	0.65	**394.65** (0.173)	60.2
Ethanol price: The price of ethanol was recorded from two retailers in Kinondoni. In one retailer, a 1-litre plastic bottle of Moto Poa was sold for TZS 5900/litre. Moto Poa is an ethanol-based fuel imported from South Africa. The fuel was sold alongside camping equipment. In the other retailer, 190g of Hotpack fuel, was sold in tins for TZS 3000. Hotpack is a methanol-based fuel imported from the United Arab Emirates. The packs were sold as chafing fuel alongside catering equipment, for use in buffets. Ethanol was not available in the other 5 shops surveyed. In our price comparison, we have used the price of the cheaper of the two fuels i.e. Moto Poa fuel as this fuel had previously been marketed for household use.							
Ethanol tax: TZS 1500 equates to a pre-VAT price of TZS 1271/kg with 18% VAT worth TZS 229/kg.							

1 US Dollar= 2284 Tanzanian Shillings (TZS), kW·h = kilowatt-hour, MJ = Megajoule.

future, wood and charcoal will be replaced by electric power, gas and petroleum products in line with urbanization of Tanzania' (URT-MEM, 2016b).

Although the 2015 National Energy Policy is consistent with previous policies in its focus on energy transitioning, it differs in taking a more supply-side approach to policy making. While the 1992 and 2003 policies contain sections considering the '*Energy End Use*' (URT, 1992)/'*Energy Demand*' (URT, 2003), there is no equivalent consideration of energy demand in the 2015 policy which is primarily concerned with increasing the supply of, and access to, 'modern' energy sources.

Policy tools that have been used to achieve the energy transition include fiscal tools and charcoal bans. The most significant fiscal tool has been the exemption of LPG from the indirect taxes charged on other imported petroleum products including the fuel levy, excise duty and the petroleum fee. A comparable tax exemption for kerosene, introduced in the 1990s, was reversed in 2011 when excise duty was increased from TZS 52/litre to TZS 400.3/litre with the aim of reducing the price difference between kerosene and petrol which had led to dealers mixing the cheaper kerosene into diesel supplies (UNIDO, 2015).

Since 2006 there have been two attempts to use bans to force consumers to transition away from charcoal. In January 2006, a ban was announced on charcoal production and trade. This was reversed within two weeks following resistance from consumers and traders (Sander et al., 2013). In March 2017, another attempt to prohibit charcoal was made by banning the transportation of charcoal across district boundaries. As with the 2006 ban, the 2017 ban was rapidly reversed and a charcoal task force was established to assess policy options around the charcoal trade.

Comparing energy policy objectives with consumer priorities

The mission of the National Energy Policy of 2015 is '*to provide reliable, affordable, safe, efficient and environment friendly modern energy services to all while ensuring effective participation of Tanzanians in the sector*.' Comparing this with consumer prioritisation of affordability, efficiency and availability, we find that the mission of the national energy policy closely reflects consumer priorities in its focus on affordable, reliable and efficient energy supplies. However, the scope of the policy differs from consumer choices. While 90% of urban households use

Table 4
Price of charcoal sold in units of different volumes.

Unit charcoal sold in	Mean unit price	Price range (min–max)	Mean weight	Weight range (min–max)	Mean price per kg	Price range per kg (min–max)	n
	TZS/unit	TZS/unit	kg/unit	kg/unit	TZS/kg	TZS/kg	
Small plastic bag	1206	500–2000	1.50	0.7–2.60	831	455–1429	17
10-l bucket	2567	1000–4000	3.44	2.8–4.2	755	385–1071	15
20-l bucket	7500	7000–8000	8.00	8.00	938	875–1000	2
Large sack	37,857	24,000–52,000	73.04	47.5–100	561	400–947	7
Overall	N/A	N/A	N/A	N/A	776	385–1429	41

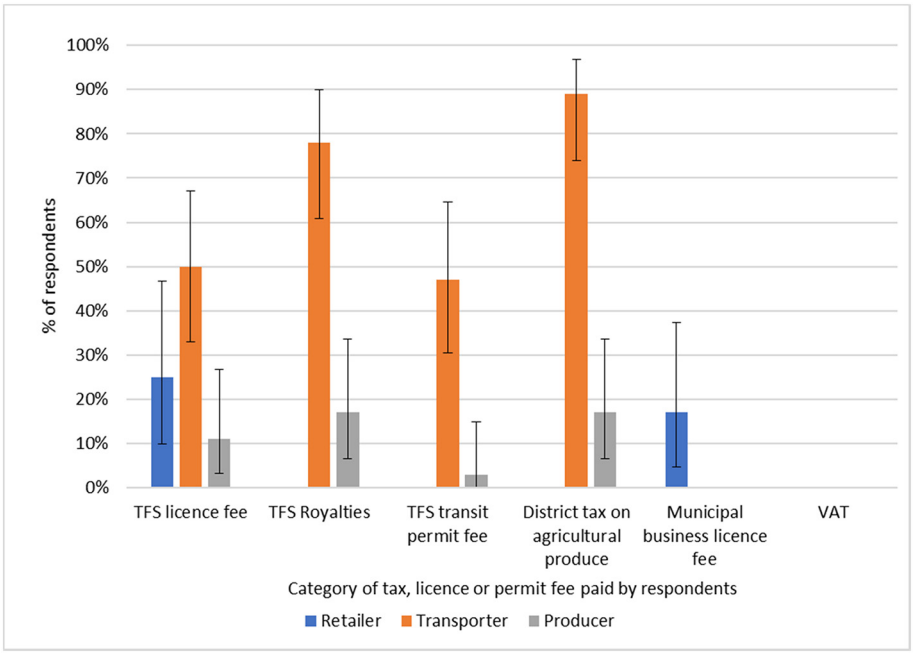

Fig. 7. Fees, taxes and royalties paid by actors along the charcoal value chain with error bars showing the 95% confidence interval.

biomass energy for cooking (charcoal and/or firewood), the scope of the National Energy Policy excludes biomass energy.

Discussion

Is there evidence of an energy transition in Dar es Salaam?

The study shows that there has not been a transition away from biomass energy in Dar es Salaam, over the period of Tanzania's three national energy policies (1992–2015) despite their consistent emphasis on achieving an energy transition. Our work shows that charcoal has remained the most widely used fuel both as the main household fuel, and within a fuel mix. Reduced use of kerosene has largely been matched by increased demand for LPG, with an increase in charcoal comprising households' main fuel between 2001 and 2012 (Fig. 2). Firewood continues to play an important role in more rural municipalities such as Ubungo, while electricity is used occasionally as part of an energy mix. Our results are consistent with previous studies showing that the energy stacking model better describes trends in Dar es Salaam's energy use, than the energy transition model (Choumert et al., 2017).

Total demand for LPG and charcoal have increased and will continue to increase with urbanisation in Tanzania (d'Agostino et al., 2015; Hosier, Mwandosya, & Luhanga, 1993). Dar es Salaam's population increased from 1.3 million in 1990 (Hosier, 1993) to 5.9 million in 2018. In the case of charcoal, if we take the average urban household size of 4.2 people (NBS, 2019), an average household consumption rate of 2.4 kg/day (Hosier & Kipondya, 1993) and 88% of households using charcoal in their household fuel mix, then total annual demand for charcoal in Dar es Salaam has increased from approximately 0.22 million tonnes in 1990 to 0.94 million tonnes in 2018. To achieve a transition in the overall energy mix, the rate of switching from biomass energy to other forms of energy needs to occur at a faster rate than the population growth rate i.e. at a rate > 5.6% per annum. This has profound implications for energy supply planning. Given that a decline in the total volume of demand for charcoal is unlikely, based on the findings of this study and previous studies, there is a need for a policy that will achieve greater social, economic and environmental sustainability around

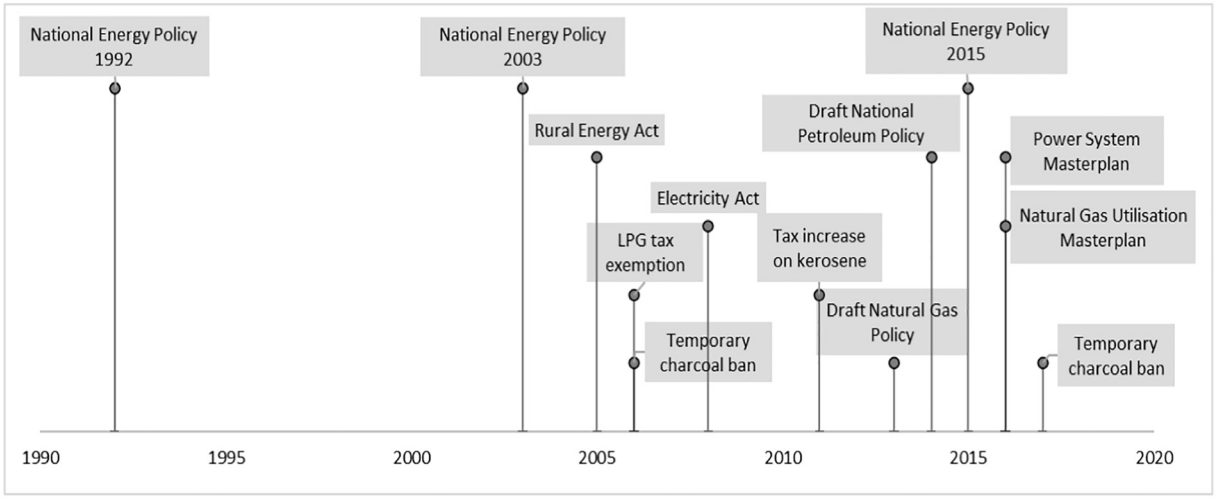

Fig. 8. Timeline of energy policy in Tanzania.

charcoal's role as the dominant source of energy for urban households in Tanzania.

One fuel that was not detected as a household cooking fuel in our surveys is natural gas. Tanzania has substantial offshore gas reserves. The Natural Gas Utilisation Plan includes the strategic objective, '*promoting the use of natural gas as an alternative fuel to liquid fuel, charcoal and wood for domestic use,*' while also stating that, '*the importance of supply of gas as an alternative energy to biomass (mainly charcoal and firewood) makes it necessary for the Government to strategically intervene and promote its implementation through appropriate policies in order to save the fast depleting natural forests*.' The plan assumes that '*10% of households in the country will be supplied with natural gas for cooking by 2045*' (URT-MEM, 2016a). The Tanzania Petroleum Development Corporation (TPDC) is piloting the provision of natural gas to households and industries in Kinondoni Municipality and Mkuranga District (URT-NAO, 2019). For natural gas to contribute significantly to household energy supplies will require the installation of an expensive distribution infrastructure. While its importance is likely to increase in some limited areas where the infrastructure is installed, it seems likely that it will diversify household fuel uses in those areas, rather than transition households away from biomass energy. Thus, while natural gas may play a greater role in decades to come, based on current plans, it is only likely to reach 10% of households, after another two or three 10-year policy cycles. Again, this reinforces the need for a policy relevant to the current situation, while laying a foundation for longer term shifts in Tanzania's energy mix.

Have the policy tools that have been used to influence the urban residential energy sector, achieved the expected policy outcomes, and at what cost?

The influence of LPG tax exemptions and their cost, in revenues foregone

Using fiscal policy tools, Tanzanian energy policies have been effective in influencing demand for kerosene and LPG. The 2011 increase in excise duty on kerosene has contributed to many consumers moving away from kerosene while tax exemptions on LPG have contributed to its growing popularity. This finding is consistent with work showing increased kerosene and electricity use in the 1990s, driven by subsidies (Hosier & Kipondya, 1993). Twenty-five years later, households are still responding to fiscal prompts, albeit away from kerosene and in favour of LPG. While the decline in kerosene use and the increase in LPG use are clear from our household fuel-use data, and fuel import statistics, there is less evidence that these changes have affected charcoal demand given an increase in the proportion of households using charcoal in their mix of fuels (Fig. 3) balanced against a decline in the proportion of households using charcoal as their main fuel (Fig. 2). One reason that LPG is still struggling to compete with charcoal is evident from the results of the fuel-price comparison (Fig. 6). Our results show that, even with the tax exemptions on LPG, LPG is still more expensive per unit of usable energy than charcoal.

The cost of the LPG tax exemptions is high, in terms of government revenues foregone. In 2017/18, 120,961 Metric Tonnes of LPG were imported (EWURA, 2018a). Had taxes been paid on that LPG at a comparable rate to taxes charged on kerosene i.e. TZS 768,750/tonne (based on TZS 615/litre converted at a rate of 1 l = 0.8 kg of kerosene with 1 kg of kerosene being roughly equivalent to 1 kg of LPG in energy content), this would have generated TZS 93 billion equivalent to US$ 40.7 million or 0.74% of the 2017/18 total tax revenue collection of TZS 12.3 trillion (URT, 2018). Using subsidies to encourage LPG adoption also tends to benefit wealthier households and businesses rather than energy poor households (Maes & Verbist, 2012). As an imported commodity, increasing use of LPG will place greater pressure on Tanzania's foreign exchange reserves.

The influence of fiscal policy on charcoal's price

Fiscal policy tools have also boosted charcoal's position in the residential energy market. TRA's decision not to collect VAT on charcoal means that it is effectively exempted from VAT. This contributes to its affordability. Assuming that VAT were charged at 18%, and that the combined retail value of charcoal is TZS 772 billion per annum (0.9 million tonnes @ TZS 776,000/tonne), the effective VAT 'exemption' is worth TZS 139 billion (US$ 61 million) per annum.

A similar pattern emerges in terms of royalties. Although TFS royalties for charcoal are charged at TZS 240/kg, equivalent to 31% of the average price to the consumer (TZS 776/kg), compliance rates may be as low as 10% given the many challenges around revenue collection raised by TFS and other stakeholders, during our interviews. Although 78% of the transporters stated that they pay royalties (Fig. 7), some transporters stated that they only pay royalties on a portion of the charcoal that they transport. Respondents from TFS also suggested that the capture rate is likely to be much lower than 78%. A lower capture rate can also be inferred from a comparison of charcoal consumption estimates and TFS revenue targets. Assuming annual demand for Dar es Salaam of 0.94 million tonnes, the total charcoal royalties for Dar es Salaam alone, should be TZS 226 billion given a TFS royalty rate of TZS 240/kg. Although TFS do not publish disaggregated annual revenue figures from charcoal royalties, the TFS overall revenue target for 2019/20, as announced in the MNRT budget speech, is TZS 153.5 billion, across all forest produce including charcoal, timber and other wood products (URT-MNRT, 2018). Even if charcoal revenues comprise as much as 50% of their total revenue, or TZS 76.7 billion, this would still comprise only one third of the expected value of royalties on charcoal consumed in Dar es Salaam alone. Mwampamba (2007) estimated that the Dar es Salaam charcoal market comprises 30% of the national charcoal market. Thus, while official figures are not available on revenues from charcoal royalties, we can infer from TFS revenue targets and our understanding of the current market size, that the current system of royalty collection only collects a small fraction of the royalties due and that this contributes to charcoal's affordability.

VAT would be an alternative way to collect revenues from charcoal, with the advantage that it is easier to govern charcoal retailers who have fixed premises, compared with transporters who have effectively evaded royalty payments for many decades. Over the last five years, TRA have been effective in broadening the tax base and rolling out electronic fiscal devices to retailers in urban areas. A transition from royalties to VAT on charcoal could build on these successes.

Environmental and health outcomes of the current fiscal policy on LPG and charcoal

While fiscal tools have been effective in promoting more LPG use, this does not equate to achieving policy outcomes around reducing deforestation and pollution. An initial impetus for the exemption of LPG from the fuel levy, was the publication of the report '*The True Cost of Charcoal*', in 2002, by the Tanzania Association of Oil Marketing Companies (Norconsult, 2002). The report argued that charcoal was a major driver of deforestation; that deforestation was costing the country 2% of its GDP; and that subsidising LPG would result in households switching from charcoal to LPG. After 13 years, more data is available to review the assumptions underpinning the decision to exempt LPG from indirect taxes.

We find that three of the key assumptions for exempting LPG from indirect taxes, are not borne out by current research. Firstly, various studies, including our findings, indicate that increased LPG adoption is not equivalent to a transition away from charcoal (Choumert et al., 2017). Research on fuel-switching behaviour indicates that households who adopt LPG rarely switch fuels entirely. Only 10% of households in our survey use LPG without using charcoal. Similarly, work by Alem, Ruhinduka, and Berck (2017) showed that households who adopted LPG maintained charcoal consumption at 75% of pre-LPG, consumption rates. This is linked to the second assumption, that LPG tax exemptions make LPG cheaper than charcoal, whereas the results of the price comparison suggest that, even with the exemptions, LPG is more expensive, on average, than charcoal per unit of usable energy (Fig. 6).

Thirdly, reduced charcoal consumption is not equivalent to reduced deforestation given increasing data showing that agriculture, rather

than charcoal, is the main driver of deforestation (Curtis, Slay, Harris, Tyukavina, & Hansen, 2018; Doggart et al., 2020). That fuel subsidies may change households' energy use, but do not result in changes in deforestation was also a conclusion of Hosier and Kipondya (1993), in the context of the kerosene tax exemption.

Similar arguments apply, in terms of public health outcomes being used as a rationale for the LPG tax exemption. If LPG adoption does not equate to reduced charcoal use, then the public health benefits of reducing air pollution, will not be achieved. Even if an impact on public health could be demonstrated, it is unclear that the health outcomes gained by foregoing TZS 93 billion in tax revenues would be the best way to achieve those outcomes, given that the total value of the LPG exemption was equivalent to 54% of the development funds spent nationally on improving health services delivery in 2016/17 (TZS 171 billion) (URT, 2017).

What are the implications for national energy policy of households diversifying rather than transitioning their cooking energy supplies?

The diversification of household cooking energy supplies between 1990 and 2018, has a range of implications for policy and planning. These issues are discussed below, in the order that they appear in the 2015 National Energy Policy:

i. **The vision of the National Energy Policy:** The vision of the policy is of '*a vibrant Energy Sector that contributes significantly to economic growth and improved quality of life of Tanzanians*.' Issues of poverty reduction, employment and economic development are central to the policy's vision. Household energy diversification has profound implications in terms of the energy sector's contribution to economic growth and improved quality of life, that are not considered in the current policy. For example, diversification implies employment and business development opportunities in supplying and trading a wide range of fuels, stoves and other cooking devices.
ii. **The scope of the National Energy Policy:** The tension between the national energy policy and the household energy market arises from the scope of the policy and its roots in the energy transition theory. Based on the energy transition theory, the policy assumes that, if modern energy supplies are provided and urbanisation and development occur, then households will automatically substitute biomass energy with modern energy. From that theoretical basis, the sustainable supply of biomass energy is excluded from the scope of the policy which focuses exclusively on electricity and fossil fuels. In this way the fuel that best meets consumer and energy policy criteria for being reliable and affordable i.e. charcoal, is transformed into 'the fuel to beat' in urban energy planning, using a combination of fiscal and regulatory policy tools. The reason for charcoal's exclusion is rooted in the energy policy mission that energy services should be '*safe and environment-friendly*' combined with policy-makers' deeply held views that charcoal is worse for the environment and public health, than the alternatives (Mwampamba, Ghilardi, Sander, & Chaix, 2013). Another way to approach energy policy development, would be to accept that charcoal is going to be a part of the energy mix for the foreseeable future, and to get behind the development of charcoal to transform it into a modern fuel supplied from well-managed woodlands providing economic development for rural areas; transported in a safe way, providing further employment opportunities; sold to consumers in ways that protect their energy rights; and used by consumers in ways that minimise exposure to pollution and maximise energy efficiency.

Energy transition theory has biased policy-makers away from promoting a more sustainable domestic biomass energy sector and has contributed to a perception of biomass as being an inferior fuel. As concluded by other authors, a policy focus on fuel-switching away from biomass energy '*stands in the way of realistic and effective programs that focus on increasing the sustainability of solid fuel use*' (Maes & Verbist, 2012). This has contributed to policy-makers overlooking the benefits of charcoal including employment creation, energy security, affordability and availability (Owen, 2013).

Households' use of two or more energy forms requires a more holistic policy approach. The policy is currently structured from a supply-side perspective with sections on the electricity sub-sector and the petroleum and gas sub-sector, with policy tools such as sub-sector master plans divided accordingly. Thus, the energy policy is disconnected from the demand side in two ways. Firstly, households are using multiple fuels, as indicated in this study. Plans to improve household energy security require a clear overview of how demand will be met in a way that connects planning for all forms of energy. Secondly, biomass is the primary source of household cooking energy and its exclusion from the national energy policy effectively recuses the Ministry of Energy from responsibility to provide affordable, reliable, sustainable and modern energy for the majority of the present population.

iii. **Capacity building, research and development:** while the current policy focuses on building capacity in the petroleum and electricity sub-sectors, household energy diversification implies the need to include policy objectives that are relevant to charcoal. This might include broadening the curricula in higher education and training institutions around the supply, use and economics of charcoal, as well as investing in training for actors along the charcoal value chain on more energy-efficient, safe and environmentally friendly production methods.
iv. **Integrated planning:** the policy promotes inter- and cross-sectoral planning and the development of sub-sector master plans. While these are highly relevant approaches, in the context of household energy diversification, the effectiveness of these approaches is limited by excluding charcoal. Charcoal requires particular attention to inter-sectoral planning given its relevance to multiple sectors including energy, forestry, land, agriculture, water and environment. Similarly, integrated planning, in the current policy, does not consider the demand side such as linkages with urban planning and the health sector.
v. **Public awareness:** the 2015 National Energy Policy focuses on public awareness on petroleum supply issues including communicating decisions in the petroleum industry and corporate social responsibility of petroleum companies. This excludes awareness on charcoal supply and energy use, including measures that household users can take to improve energy efficiency and reduce exposure to indoor air pollution. Given the primacy of household cooking in overall energy demand, awareness raising on household-level energy efficiency measures, could have profound sectoral impacts.
vi. **Cross-cutting issues of health and environment:** the 2015 National Energy Policy focuses on health and environmental issues associated with the supply of petroleum products and electricity including occupational health and safety and environmental restoration following decommissioning of energy-related installations. Environmental and health issues associated with household energy use and charcoal production are not considered. Again, this is a significant policy gap in the context of household energy diversification.

How can national energy policies be more effective in achieving outcomes compatible with both national priorities and with global goals around climate change and sustainable energy supplies?

Building on the findings from the study, we make four recommendations.

1. Embrace woodfuel, including charcoal, into national energy policy

Achieving household energy security for urban populations in the context of SDG 7, requires an energy policy that guides the sector in matching supply and demand, with special consideration for households facing energy poverty. By excluding biomass energy from the scope of the national energy policy, the policy excludes consideration of measures to improve the supply of up to 80% of the total national energy

demand. There are many steps that could be taken to improve the supply and use of biomass energy. On the supply side, interventions are needed to improve regeneration rates and the management of forests supplying charcoal (CHAPOSA, 2002); to improve kiln efficiency, particularly through increasing the skills and working conditions of charcoal producers (van Beukering et al., 2007); and to empower rural communities to benefit from a well-governed and sustainable charcoal production system, including through community-based forest management (Chidumayo & Gumbo, 2013; Maes & Verbist, 2012; Mwampamba, 2007). During transportation, interventions are needed to improve working conditions for charcoal traders including safer vehicles, reduced exposure to charcoal dust, and reducing charcoal waste. For consumers, access to the latest generation of charcoal stoves (Mitchell et al., 2019) and awareness on how to reduce indoor air pollution would reduce health risks and improve efficiency (Das, Jagger, & Yeatts, 2017; Dherani et al., 2008). For example, Maes and Verbist (2012) found that improving ventilation can reduce levels of indoor air pollution from charcoal to levels comparable to LPG stoves. Investing in campaigns to promote safer use of charcoal and to adopt the latest generation of charcoal stoves could bring greater public health benefits than the LPG exemption. These require a policy, resources and a commitment from central and local government to work together to promote a more sustainable, modern supply of biomass energy. Other advantages of embracing biomass energy into national policy include employment, rural development (Schaafsma et al., 2012; Owen, 2013), high local content and reducing pressure on foreign exchange reserves for the import of LPG.

From a climate change perspective, sustainable charcoal production has the potential to reduce net emissions of greenhouse gases from deforestation and forest degradation, thereby contributing to global climate change goals (UNFCCC, 2015). By integrating post-harvesting regeneration of biomass stocks into a sustainable charcoal production system, net emissions are reduced, compared with charcoal production that occurs as part of a transition from forest land to agricultural land (Chidumayo & Gumbo, 2013). Promoting sustainable charcoal production and use is also compatible with Tanzania's Intended Nationally Determined Contributions (INDCs) under the Paris Climate Change Agreement. Tanzania's INDCs include: enhancing efficiency in wood fuel utilisation; enhancing and up-scaling implementation of participatory forest management programmes; and enhancement and conservation of forest carbon stocks (URT, 2015b).

2. Integrate sustainable energy plans into urban planning

Energy planning can be carried out at city level (Ostojic, Bose, Krambeck, Lim, & Zhang, 2013). By calculating projected demand, cities can put in place strategies to ensure a reliable supply of energy, across multiple fuels. Recognising that households are more likely to practice fuel stacking than transitioning, strategies can be put in place to influence households to select a mix of fuels that meet their needs as well as national and global goals around health, environment, local content and other priorities. For Dar es Salaam, we estimate that 17.2 PJ of usable energy will be needed for residential cooking by a population of 11.4 million in 2030, based on current population growth rates. This assumes that the daily requirement of usable energy is 4.14 MJ/person, equivalent to 0.47 kg charcoal (based on 2 kg/household/day reported in Malimbwi & Zahabu, 2008; a household size of 4.2 people; and an energy to pot efficiency for charcoal of 8.7 MJ/kg (Table 3)). This would be equivalent to 6841 GW.h of electricity (see Table 3 for conversion efficiency rates), equivalent to 53% of the 12,870 GW.h total national residential energy demand estimated for 2030 in Tanzania's Power Sector Master Plan, or approximately 0.6 million tonnes of LPG. A sustainable urban energy plan for Dar es Salaam could provide a useful road map, including plans on how to meet the 17.2 PJ of usable energy required for household cooking, by 2030, in ways that balance economic, social and environmental considerations.

3. Evaluate fiscal tools regularly

Our study has shown that fiscal tools have been effective in influencing demand for particular fuels. However, it seems less clear that they have achieved the intended environmental and social outcomes. It is recommended that fiscal tools be re-evaluated regularly and in a more holistic way across multiple fuel-types. It is recommended that the LPG exemption be re-evaluated to examine whether there might be more effective and efficient ways to reduce deforestation and air pollution; and that consideration be given to the implications for Tanzania's foreign exchange reserves, of an increase in dependence on LPG, as an imported commodity. We also recommend evaluating the proposal to replace charcoal royalties with VAT and/or simplifying the system, with a view to increasing compliance rates.

4. Promote fuel efficiency and safer cooking techniques

Promoting energy efficiency measures along the value chain of all fuel types would generate multiple environmental, social and economic benefits (Ouedraogo, 2017, 2019) aligned with national and global priorities. Multiple strategies can be used to achieve this including improved kilns (Mwampamba, 2007) and improved cook-stoves (Bhattacharya & Abdul Salam, 2002; Mitchell et al., 2019).

Further research

With continued urbanisation in Tanzania and other sub-Saharan African countries, there is a need for research into a wide range of topics around sustainable urban energy futures, including on urban energy planning, comparative life cycle analyses for different fuels, and on the economic and social impacts of different energy scenarios for human health, employment and the environment. Given charcoal's continued dominance of the household cooking fuel market, further research around sustainable charcoal production and the role of charcoal production in deforestation, including the connections between charcoal production and agriculture are required. We also recommend that Tanzania's household budget survey add a question to cover all of the cooking fuels that are used by a household, rather than solely focusing on the main cooking fuel, given the prevalence of fuel stacking in urban Tanzania.

Conclusion

In conclusion, fiscal policy tools have been effective in influencing urban households to select LPG rather than kerosene and electricity, for cooking and to diversify fuel use. However, none of the policy tools applied so far, have succeeded in prompting a widespread transition away from charcoal. This is because affordability is a primary concern for consumers and charcoal is cheaper than LPG, electricity and kerosene. Recognising that charcoal's affordability will continue to make it the preferred fuel for many households, a new vision is needed for charcoal that magnifies the positive outcomes of the trade, while mitigating its negative social and environmental impacts.

Declaration of competing interest

None.

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Data availability statement

The data that support the findings of this study are available as supplementary material.

Appendix A. List of policy documents and government reports reviewed

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2020.06.002.

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