Cooking Energy Systems and their Effect on Environmental Sustainability in Dodoma, Tanzania: A Driver-Pressure-State-Impact-Response (DPSIR) Synthesis

Editha M. Ndunguru[1]

[1]endunguru@mzumbe.ac.tz/3ndunguru@gmail.com (+255 783833890/754 833890)

[1]Mzumbe University, Morogoro Tanzania

ABSTRACT

Consumption of energy for various uses including cooking, has various effects on the welfare of the environment. In developing countries where the majority rely on traditional biomass, cooking energy systems entail multiple disruptions to environmental sustainability. The objective of this paper is to integrate the prevailing cooking energy use systems of Dodoma region and environmental sustainability. The study uses the Driver-Pressure-State-Impact-Response (DPSIR) framework to synthesize the two circumstances. Two sites, one rural and one urban were selected for data collection. The study adopted a case study design. Mixed methods were used to gather and analyze the data. Probability and non-probability sampling techniques were employed in the selection of the respondents. The target population was the households. The sample size constitutes 210 households. Methods of data collection included survey, in-depth interview, focus group discussion and non-participant observation. Semi structure questionnaires, interview guides and focus group discussion Results reveal a significant proportion of the population (72.4%) using biomass energy for cooking. Disaggregated data expose the rural setting to have relatively higher proportions (89. %) as opposed to the urban (53.1%). The study further noted that persistent use of biomass energy is influenced by availability, accessibility, and affordability. Moreover, many households have been using inefficient stoves which lead to the consumption of large quantities of energy. A transition from firewood to charcoal in the rural area, and a thriving charcoal business in the urban have contributed to the clearance of forests and chopping off huge trees in the rural (the source area). These have led to the gradual disappearance of certain tree species. The study found no deliberate efforts at the individual or community level to restore environmental sustainability despite all the alarming indicators. Even though there are institutional frameworks, it was very hard to establish the duties and responsibilities of the institutions regarding the responses. The study concludes that there is a long way to go before biomass energy is abandoned, therefore individuals, communities and the government to take action to safeguard the environment for the benefit of the current and future generations.

Keywords: Cooking Energy, Environment, Environmental Sustainability, Driver, Pressure, State, Impact, Response

I. INTRODUCTION

Cooked food is healthier, tastier, softer, and easily digested (Hager & Morawicki, 2013). As much as cooking is compulsory for a good number of foodstuffs consumed by humans, cooking fuel is a prerequisite. In the household sector, cooking embraces substantial amounts of energy and the growing population has always stimulated the demand, thus increasing stress on energy resources.

In developing countries, the cooking sub-sector covers a larger proportion than any other end-use services (Daioglou et al., 2012). Unfortunately, the majority of the populations living in these countries do not have access to clean cooking, they rely on dirty polluting fuels, mostly solid biomass (World Health Organisation [WHO], 2023; International Energy Agency [IEA], 2014; Vitali, 2013).

The IEA reports that in 2010, about 3 billion people worldwide lacked access to clean cooking technologies (Energy Sector Management Assistance Programme [ESMAP], 2021). In 2018 more than 2.6 billion people lacked access to clean cooking (IEA, 2019a). By the year 2020, about 2.4 billion people cooked with traditional polluting fuels and technologies worldwide (WHO, 2023), and in 2022, close to 2.3 billion still relied on dirty polluting fuels (IEA, 2023).

The observed decline rate has been recorded from Latin America and Asia, and Sub Saharan Africa (SSA) has continued lagging; unfortunately, the number of people without access is on the rise (WHO, 2023). Sub-Saharan Africa has always been the most access deficit region (IEA, 2019b) with more than 80% of the population depending on traditional biomass (IEA, 2022; Philibert, 2022; Dingeto & Kalbessa, 2021; IEA, 2019b; Vitali, 2013). The impact of population pressure on the woodland as a primary source of energy is tremendous as the majority of the people in the region still adopt traditional fuels and technologies (IEA, 2019c). At the household and village level, the combustion of solid fuels produces pollution that is damaging to health and a large contributor to the global burden of disease and imposes a high time burden on those collecting fuelwood, typically women and girls. Moreover,

unsustainable ways of woodfuel contributes to the loss of forests and associated ecosystem services (Jeuland & Pitahaya, 2012).

Tanzania is among the twenty countries from SSA with lower access where less than 5% of the population uses clean fuels and technologies as primary means of cooking (IEA, 2019b). Biomass has always played a vital role in the energy mix. Households rely heavily on biomass in its traditional form for basic energy needs, essentially cooking services. Firewood and charcoal are widely used with extensive application of incompetent stoves and other cooking devices (IEA, 2022; IEA, 2019a; IEA, 2017; WHO, 2017; Lambe et al., 2015; Hooper et al., 2018). Due to that, many households are devastated by smoke from unsafe biomass burning.

Like the rest of SSA (except South Africa), the country relies heavily on traditional biomass energy for household cooking activities. Mostly, biomass is used in the form of firewood and/or charcoal (United Republic of Tanzania [URT], 2014) and is primarily from forest resources. Generally, biomass is harvested and processed in unsustainable ways (African Development Bank [AfDB], 2015) exerting pressures on the local and regional environment (Karekezi et al., 2012) and affecting biomass energy accessibility. In addition, to high population growth, the country is experiencing rapid urbanisation. Population agglomeration brings rapid economic development, but also increased consumption of resources (Fang et al., 2017). Growing population demand for natural capital, driven by anthropogenic activities, may lead to excessive demand for ecological resources. Including energy resources (Gemani et al., 2014). The growing urban populations mean a rapid increase in household cooking energy demand (United Nations Environmental Programme [UNEP], 2017; Hussein & Filho, 2012).

Unsustainable harvesting of biomass fuels not only contributes to local environmental degradation but also has the use of polluting fuel use fall inexplicably on women, adding to the existing gender inequalities (Bailis et al., 2018; Jagoe et al., 2020). Although biomass is renewable, studies have found that rapid population growth is suppressing the Majority of the urban residents who have continued to rely on traditional biomass, primarily charcoal (Doggart et al., 2020; Yonemitsu et al., 2014). Until the first half of the previous decade, about 80% of urban households in the country relied on charcoal as primary cooking energy (Lambe et al., 2015). This situation has continued to cause serious health and environmental effects. The World Health Organization (WHO) estimated that about 18,900 deaths in Tanzania were attributable to indoor air pollution annually. Wood fuel demand is estimated to contribute to 70% of deforestation and is predicted to increase up to 83% by 2030 (Pope et al, 2018).

Utilization of traditional biomass for cooking purposes has proven to have an impact on forest resources, energy scarcity, and gender parity. Aberilla et al (2020) acknowledge access to clean fuels as essential for achieving sustainable development goals, particularly in poor countries, to minimize negative effects on human health and the environment.

Shifting of the government capital from Dar es Salaam to Dodoma has resulted in rapid population growth and rapid urbanization in the new capital city, thus, intensifying energy demand. The patterns of energy utilisation suggest a gradual transition to clean cooking solutions, yet biomass has continued to be the primary cooking energy source. Studies have already established that widespread deforestation in some areas in Dodoma including Mtitaa is consequent to unsustainable biomass harvesting (Uckert et al, 2016). The nature of biomass extraction, production, and consumption patterns have serious repercussions on environmental sustainability in the medium and long term (Sarkodie., 2020). The reliance on charcoal by large shares of the population (and often rapidly growing) in the 1980s generated concerns regarding its contribution to deforestation. Recent studies suggest that fuelwood is rarely a primary source of forest removal (Arnold et al., 2006), and charcoal production has been singled out as a major cause of forest degradation and deforestation particularly in peri-urban areas (Lambe et al., 2015).

The unsustainable exploitation of traditional biomass fuels is among the top environmental challenges across developing countries (Muller & Yan, 2018; Ifegbesan et al., 2016; Jagger et al., 2017). Biomass energy production raises discussion related to the Green House Gas (GHG) emissions. Opponents of biomass utilization claim that biomass energy production could lead to overexploitation of forest resources (68) while burning of biomass generates Carbon dioxide (CO_2).

Literature acknowledges that it is impossible to separate energy consumption from environmental sustainability (Ma et al., 2021; Nathaniel et al. 2021). The concept of environmental sustainability has become topical in several platforms today (Bhattacharya, 2020; Zafar et al., 2020). Environmental sustainability is the ability to preserve natural resources for the benefit of present needs and future generations while protecting the ecological balance of the planet's ecosystem (Henderson and Loreau, 2023). It is considered as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity (Morelli, 2011). This concept is among the three pillars of sustainability in the context of sustainable development (Pavlyk et al., 2021).

Scientists and environmentalists largely agree that energy consumption stimulates CO_2 emissions (Khan et al., 2019). Energy is central to human life and social, economic, and environmental growth, without which it is difficult to generate, deliver, or use mainstream goods. However, the production of energy and day-to-day consumption have a profound impact on the environment and human life (UNEP, 2017). Its production and utilisation raise the temperature and increase weather anomalies which ultimately influence long-term climate fluctuations (Valavanidis, 2022).

1.1 Statement of the Problem

Previous studies present a growing body of knowledge on household cooking energy about the impact of traditional biomass energy, factors affecting adoption energy, clean cooking energy and technologies and energy transition. Despite the wide-ranging topics, none of the researchers has attempted to analyze indicators of sustainability alongside the growing demand for cooking energy.

1.2 Research Objectives

The main objective of this study is to assess implication of prevalent cooking energy systems on environmental sustainability. Specifically, the study dwells on:

i. Examining primary cooking energy sources in rural versus urban
ii. Estimating the impacts of biomass energy utilization
iii. Assessing current interventions for environmental protection.

II. LITERATURE REVIEW

2.1 Energy Systems and Environment

It is scientifically proven that extraction, production and utilization of energy execute serious environmental risks (Sheng, et al., 2023; Alem et al., 2016; Urmee & Gyamfi, 2014). The fact that energy utilization is ineviatable, efforts must be made to protect the environment from damage or rehabiliate the damaged areas with consideration to a series of cause-effect relationship that exists along the energy system. According to Borja et al., (2006), energy system is a chain of causal links starting from driving forces which create pressures. Pressseres determine physical, chemical and biological changes in the states of the environment. The changes can impact on targets such as ecosystems and human health, eventually requiring social, political or technical interventions to respond to to the situation. Effective responses compels for hands-on institutional and policy frameworks.

2.2 Theoretical Framework

This study uses the Driver-Pressure- State-Impact- Response (DPSIR) model to analyse the interactions between society and the environment with regard to cooking energy. The Drivers-Pressure-State-Impact-Response framework identifies and envisages, in a simplified way, cause and effect relationships between factors in society and the environment (Smaling and Dixon, 2006).

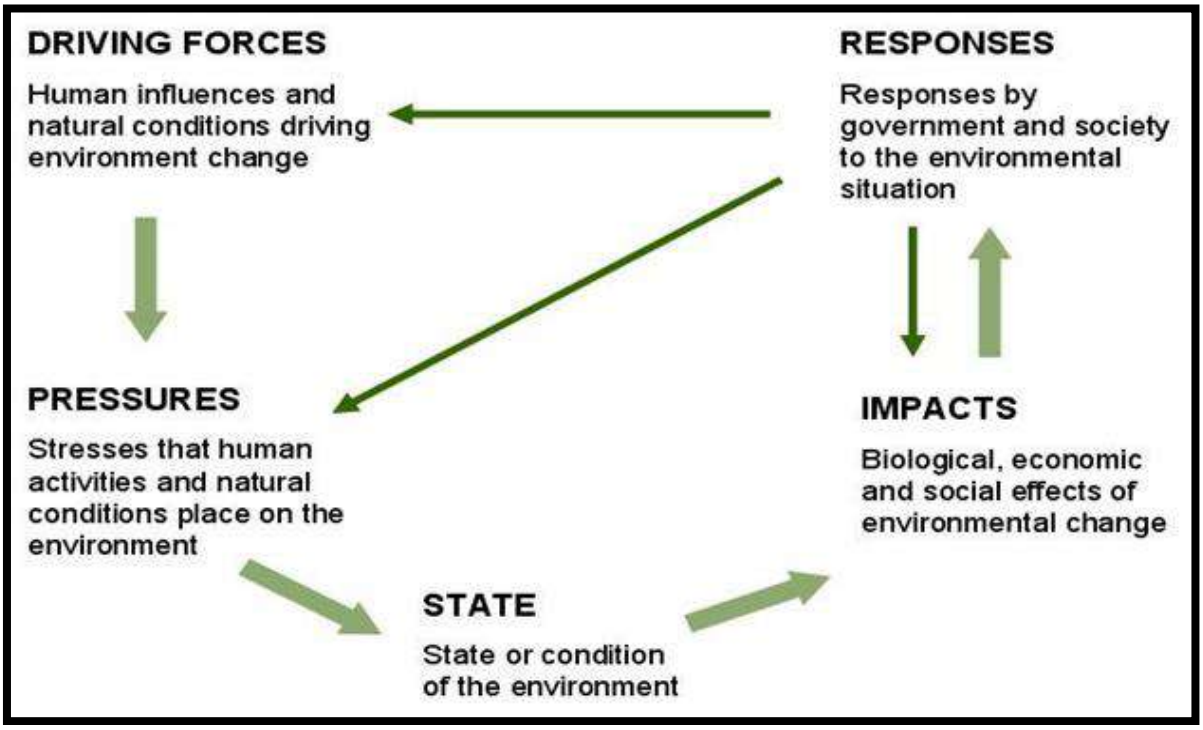

Figure 1
DPSIR Model

2.3 Driver-Pressure- State-Impact-Response (DPSIR)

Social, demographic, and economic developments have a direct impact on the environment (Martins et al., 2012). Growing populations and urban sprawl generate double impact on energy and environmental sustainability as they tend to intensify energy demand but also influence land use change, degrading the environment. On another hand, sustained uncontrolled use of biomass evoke stress on the environment which are derived from deforestation and forest degradation. These may include soil erosion, water pollution, increased insolation and increased atmospheric temperature. With such incidents, the productive and aesthetic value of the environment is incapacitated: Such disturbances lead to loss of flora and fauna, water scarcity, energy inaccessibility, and at the higher level, climate change. At this point, responses regarding the changed environment need to be put in place. Response are the measures, plans, and approaches to be taken by individuals, communities, private sector, and the government to reduce environmental risks related to cooking energy systems, specifically the use of biomass.

III. METHODOLOGY

This study was conducted in Dodoma, and it used a case study design. The study used mixed methods where both quantitative and qualitative approaches were used to collect and analyse the data. Merging the two techniques helped t to get a better understanding of the research problem.

Both probability and non-probability sampling techniques were applied to select the study area and population sample. In the first stage, purposive sampling was applied where two districts, Bahi (rural) and Dodoma urban (city) were selected. Due to its proximity to the urban, Bahi is the source area for charcoal which is used in Dodoma city. Meanwhile, Dodoma City is the principal market for charcoal produced in the Bahi district. In the second stage, simple random sampling was applied to pick one ward from each district where Mtitaa and Makole respectively were selected. In the third stage, another simple random sampling was deployed whereby Lusinde Hamlet and Makole mtaa were nominated to represent the Mtitaa and Makole respectively. Households were the unit of analysis for the study. Lusinde hamlet has a total number of 153 households whereas Makole has 131 households. Responds were the heads of households but where the heads were not available, the main household cooks were interviewed. Although the data were collected from the rural and urban settings, the DPSIR was inferred only to the rural which is the source area for biomass energy.

Population sampling was done using the Yamane (1967:886) simple formula for proportion.

$$n = \frac{N}{1+N(e)^2}$$

Where:
n = Sample size
N= Target population (total number of households)
1= Constant
e= the confidence level or margin error (0.05)

The study sample (n) was drawn from rural and urban, represented by Mtitaa and Makole wards respectively. The reason for choosing these two sites is to compare cooking energy patterns between rural and urban, but also to establish the sources of environmental degradation. Sample size (n) was obtained by calculating sample from each site then adding them i.e., sample size from rural (n_1) + sample size from urban (n_2).

(a) $n_1 = 153/ 1+153(0.05)^2$
$n_1 = 153/1+0.3825$
$n_1 = 153/1.3825$
$n_1 = 112$

(b) $n_2 = 130/ 1+130(0.05)^2$
$n_2 = 130/1+0.325$
$n_2 = 130/1.325$
$n_2 = 98$

Sample size from Rural (n_1) =112 Sample size from Urban (n_2) = 98

Total sample size $n = n_1+n_2 = 210$

A total of 210 households were involved where 112 (53.3%) were from Mtitaa (rural) and 98 (46.7%) were from Makole (urban). Heads of households were the target population, but in the absence of the head of the household, a second person in command was involved. The research methods included survey, in-depth interview, telephone conversation, Focus Group Discussion (FGD) and field observation. Instruments for data collection were semi-structured questionnaires, interview guides and focus group discussion guides. Content analysis, IBM SPSS version 26 and Excel computer programmes were used to analyse the data. Results were presented in texts, graphs, charts tables and photos.

IV. FINDINGS & DISCUSSIONS

4.1 Primary Cooking Energy Sources

Household surveys found that still there is heavy reliance on solid biomass energy for both urban and rural areas as indicates in Figure 2. Aggregated data show that close to three quarter of the study population rely on traditional biomass for their cooking needs. This is an indicator of potential environmental damage.

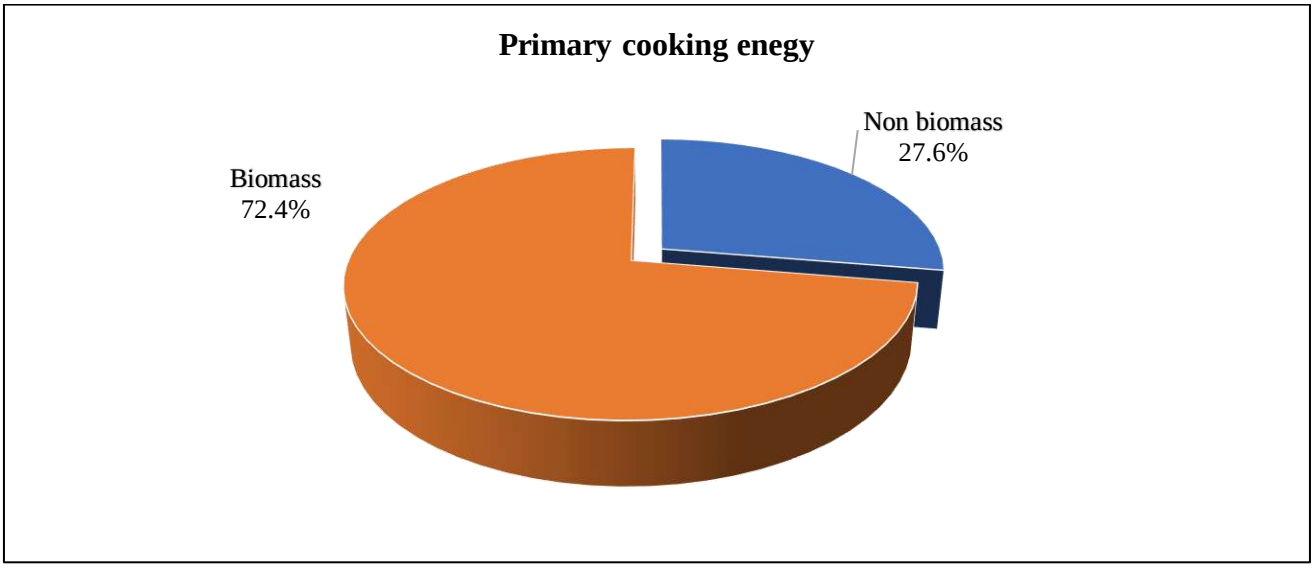

Figure 2
Primary Cooking Energy

Disaggregated data portray that the majority use traditional biomass in the form of firewood (Figure 3). In the rural setting, charcoal and firewood embraces 44.6% each. Only 10.8% use LPG. In the urban, charcoal and LPG constitute 46.9% each while firewood accounts for 6.2%. These results typically reflect the national status of primary sources of household cooking energy where biomass still dominates the household cooking energy sector (National Bureau of Statistics [NBS], 2019; IAE, 2017) as well as other sub-Saharan African countries (Philibert, 2022; IEA, 2019b; Bailis et al., 2015; Vitali, 2013).

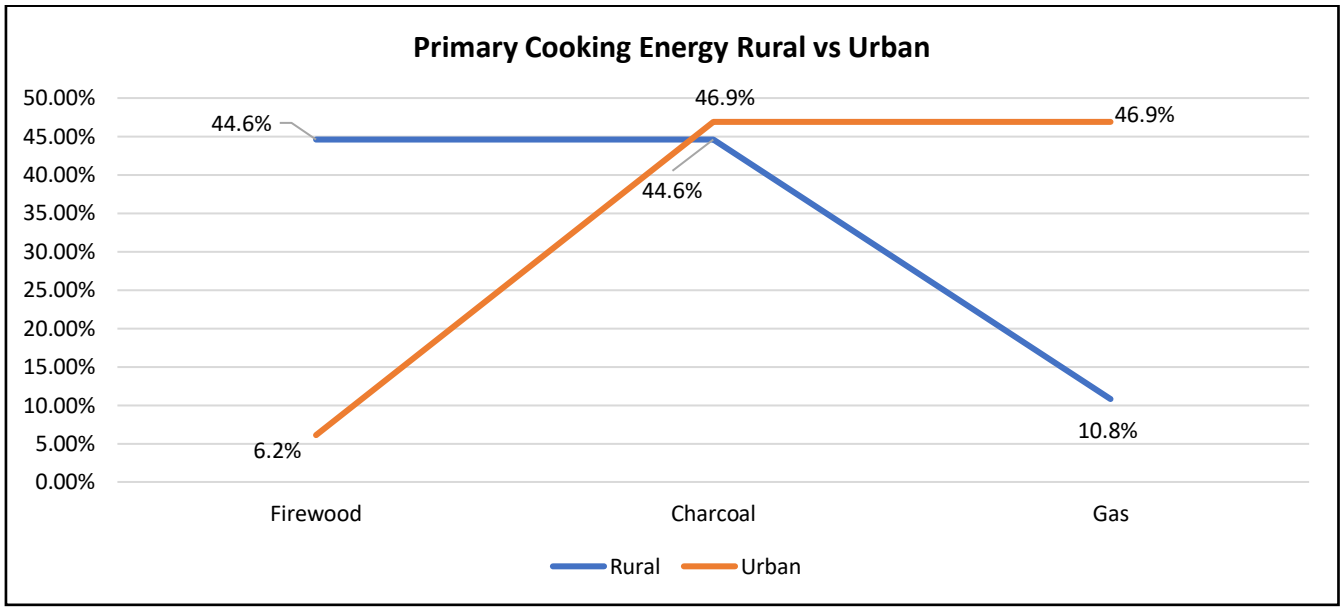

Figure 3
Distribution of Primary Cooking Energy by Type

4.2 Factors Influencing Extensive Use of Biomass Energy

Biomass energy is preferred because it is affordable to the majority. It can be observed from Figure 4 that 16% of biomass users think that the energy source is cheap; another 16% claim that it is cheap and widely available.

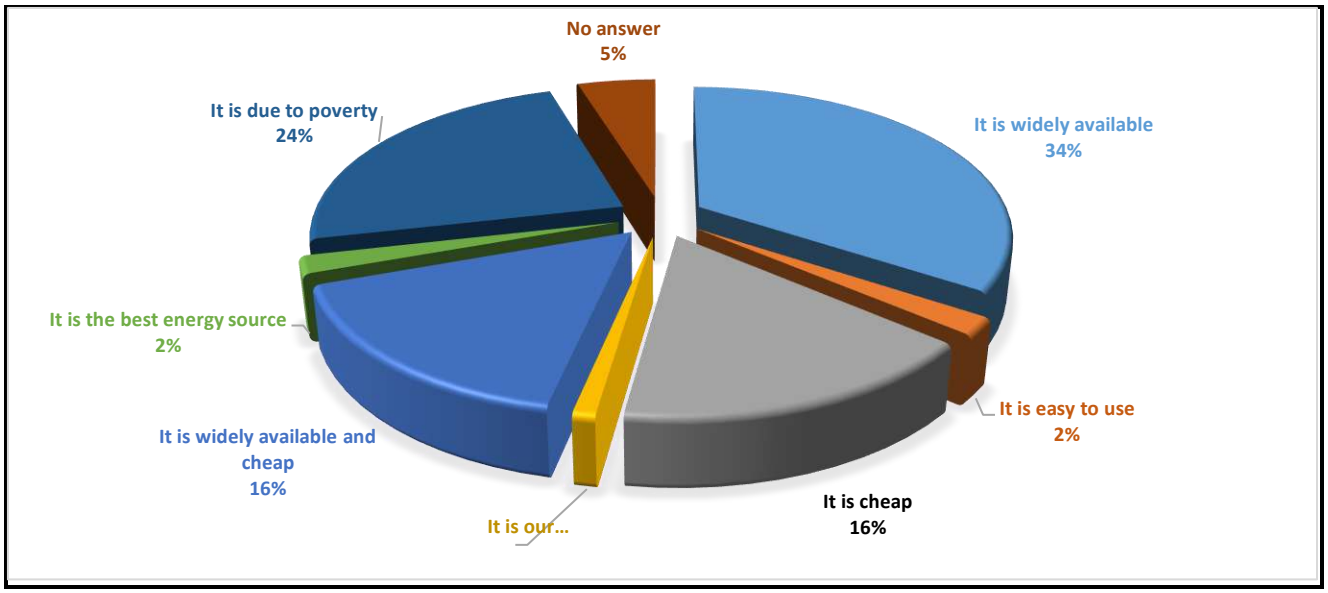

Figure 4
Factors for Preference of Biomass Energy

Evidence from the field suggests that heavy reliance on biomass energy owing to its wide availability, but also is due to poverty. Trying to explain why biomass energy is dominating the household energy sector, especially for

cooking activities, respondents had different explanations, but most of the answers revolved around availability and affordability issues as presented.

4.3 Energy Efficiency Practices

Many of the biomass users were found to be using inefficient biomass stoves. Results (Table 1) show that 26.7% of the respondents use traditional three stones. This percentage embraces all firewood users as none of them was found to have efficient (firewood) stove while 28.1% of the respondents' charcoal use traditional charcoal stoves. About 18.1% of the respondents use improved charcoal stove, however; the stoves are not efficient enough to appreciably reduce biomass consumption. These findings agree with Philibert (2022) that most of the deployed improved cookstoves in Tanzania are not efficient enough to significantly reduce biomass consumption.

Table 1

Cookstove Types

	Frequency	Per cent
Traditional three stones	56	26.7
Efficient charcoal stove	38	18.1
Traditional charcoal stove	59	28.1
Two burners gas stove	15	7.1
Small gas cylinder with cooktop	42	20.0
Total	**210**	**100.0**

Apart from producing harmful smoke and gases inefficient cookstoves require a significant amount of fuel to perform. This is persuasion to exploit considerable quantities of biomass to cater for the needs. Efficient stoves use small quantities of fuel and thus may reduce the rate of deforestation and forest degradation and their associated impacts.

4.4 Adoption of Alternative Energy Sources

The urban population is adopting alternative energy sources, predominantly LPG. Close to fifty per cent of the urban population is cooking with LPG. Nevertheless, the majority have been facing affordability challenges. High refilling costs and regular price increases are making it unaffordable to the extent that they are pushed back to traditional biomass. In rural areas, both affordability and availability challenges obstruct the adoption and consistent utilization of LPG. Meanwhile, the rural area is experiencing a rapid shift from wood fuels to charcoal. Only 10.8% of the rural population (Fig 2) has adopted LPG, yet they have been encountering availability issues as there are retailers in the village. The nearest retail outlet is located about 20km away. Each time they need to refill their cylinders they have to pay Tshs 8,000 for transportation (in most cases, motorcycles).

Increased charcoal consumption translates to increased wood harvests since the production of charcoal since charcoal perpetuates logging which in turn increases deforestation, forest degradation, and other environmental impacts such as loss of biodiversity and increased emission of climate gases (Nyamoga & Solberg, 2019; Baumert et al., 2016).

4.5 Impact of Biomass Energy

The study sought to understand respondents' views on the impacts of biomass energy utilization. Findings reveal two major categories of the impact; health and environment. Household survey (Table 2) indicate that 8.6% are of the view that biomass causes environmental degradation, 3.3% associate it with deforestation and forest degradation, 2.8% links it with climate change and a relatively small proportion, 1.4%, links it to soil erosion. About 39.5% were concerns with health issues as the major concern but could not asset any specific problem. Around 4.8% cited chest pains while 4.3% named itchy eyes. About Still, there is a significant proportion which could not link it with any social or environmental concern as 35.2% claims that biomass energy has no diverse impact.

Table 2
Impact of Biomass Energy Utilization

Identified Impacts	No	Percentage
Environmental degradation	18	8.6%
Deforestation/Forest Degradation	7	3.3%
Climate change	6	2.9%
Soil erosion	3	1.4%
Health problems	83	39.5%
Chest pains	10	4.8%
Itchy eyes	9	4.3%
There is no problem	74	35.2%
Total	**210**	**100%**

4.6 Environmental Degradation

Environmental degradation is a broad concept which involves various environmental problems including air pollution, water pollution, deforestation, soil erosion, loss of soil fertility and climate change. With that in mind, observation of some of the respondents (8.6%) is that biomass utilization a wide range on impacts.

4.7 Deforestation and Forest Degradation

Biomass energy consumption is closely linked with deforestation. This is a direct impact which can instantly be observed. Demand for cooking fuel for both rural and urban residents is among the major driving forces of deforestation and forest degradation. Although it is not the sole cause, persistent use of the same has contributed to the widespread removal of vegetation cover habitat destruction and loss of biodiversity. Data from key informant interviews reveal that forests and bushes have largely been cleared, leaving bare land and various tree species have disappeared. An elder from Mtitaa village uncovered the shrinking or disappearance of some tree species within the village land and nearby forests. The respondent mentioned *mkungugu and mtunduru* species (genus acacia*)* as among the rapidly disappearing species. These thorny, bushy trees or shrubs are commonly found in dry areas and have hardwood, thus preferred for wood fuel due to their high heat content and longer burning. Other than fuel, mkungugu and mtunduru are used for timber, pestles, club stick carvings, bee forge, poles, fodder, live fence, and dead fence.

Biomass shrinkage is likely to cause soil erosion. Due to the reduction of the forest and shortage of woody products as well as the sustainability of forests and ecosystems, the need to evaluate, monitor, and regulate the forest arose (Martine et al., 2015). The removal of trees in a particular geographical reduces the stability of the topsoil, thus increasing its susceptibility to erosion, both wind and water. Scientific evidence shows that soil erosion hampers plant growth, hence affecting crop production.

The study also discovered the disappearance of varied wild edible fruit as confirmed by one of the key informants:

> *Things have changed. In the past, we used to have big trees around the village where we could easily get poles and other building materials. We also used to hang bee hives onto the trees and harvest so much honey from them. There were also wild fruit trees such as* ***mifulu, mitundwe*** *and* ***mitumba****. When women went for firewood, they would come back with some wild fruits. All these are gone.*

This was even confirmed during a household survey where more than half of the respondents established that they have sometimes experienced difficulties in accessing fuel. Most of the reasons given by the respondents correspond to biomass shrinkage. Chopping off big trees for charcoal making is causing environmental volatility and failure to provide valuable goods and services. In a focus group discussion, it was also revealed that firewood had become scarce in recent years compared to 15 years back. Participants explained that more than 10 years back, the village had thick bushes where women and children would collect firewood.

4.8 Soil Erosion and Loss of Soil Fertility

Soil erosion plays a pivotal role in land degradation and is considered a serious environmental hazard (Poesen, 2018). The utilization of biomass for fuel is among the variable factors for Land Use/Cover Change (LUCC). The felling of trees for charcoal making has always altered land cover from vegetated or forests to bare land, exposing soils to agents of erosion. It was noted during the focus group discussion that the removal of vegetation cover has influenced the removal of the topsoil by wind during dry seasons but also by water during rainy seasons. Table 3 shows cooking energy driving forces, pressures, state and impact on the environment; and the proposed responses.

4.9 Cooking Energy Shortage

The study also wanted to find out if there is any indicator of energy storage in the study area. Results indicate that at some point, respondents mostly biomass users have had energy accessibility issues due to some reasons as indicated in figure 4. Nonetheless, many reasons could be directly or indirectly linked to biomass shrinkage. About 46.5% biomass scarcity referring to insufficient biomass stock, 23.3% reported to have limited budget to purchase the fuel, 20.9% said they could not manage to get out and fetch (firewood) due to unfavourable weather conditions (rains), but 7.0% could not tell the reason behind.

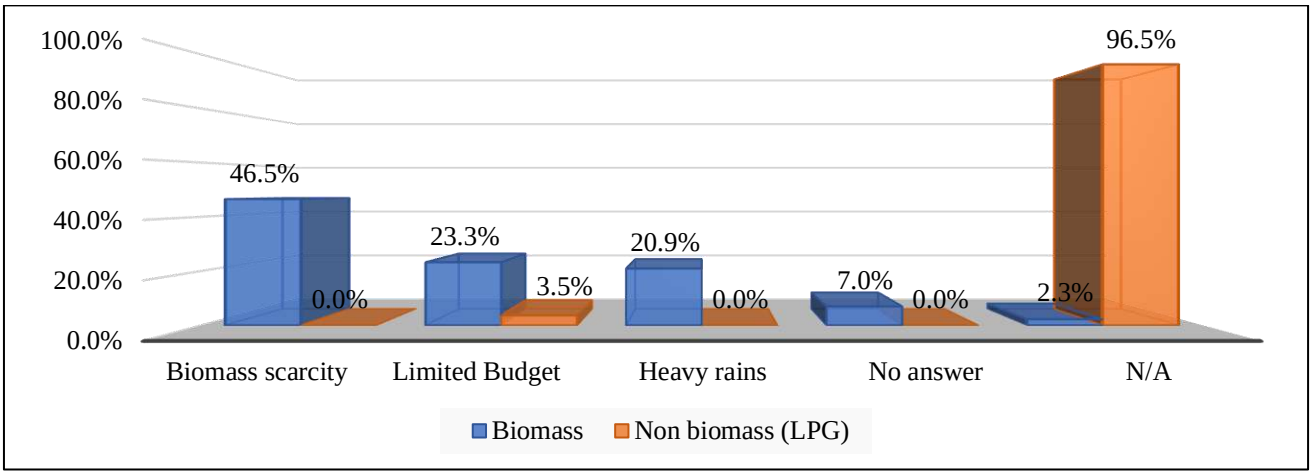

Figure 5
Factors for Energy Shortage

Biomass scarcity implies deprived environmental sustainability, thus limited biomass supply. In the urban areas the major reason is price escalation. Experience shows that price has been fluctuating from time to time, but it becomes worse in wet seasons. During this time there is low charcoal production due to shortage of labour as many of the charcoal makers engage in cultivation. Furthermore, excessive moisture prohibit charcoal making because there is incomplete combustion or kilns destruction, and poor transportation routes. Despite the high price, charcoal is mostly wet and smoky during this time.

4.10 Potential for Renewable Resources

The study area is rich in energy resources which can be developed to improve access to a variety of energy carriers. The available biomass energy stocks include forest biomass/trees, crop residues, animal dung and municipal waste. These present significant opportunities for sustainable biomass energy development. Among the opportunities for energy development include the production of efficient charcoal from biowaste, biogas from animal dung and the production of plant oils such as ethanol. The area also has favourable conditions for wind energy due to its geographical location and climatic conditions. Furthermore, there is abundant insolation for solar energy.

Normally, free access to, or low prices of biomass energy reduces the motivation to adopt alternative energy sources as long as the available energy source can meet all the cooking needs. This can be the reason why alternative fuels are not widely adopted although they are relatively available.

Sustainably managed forests play an important role in any discussion of the mitigation of climate change, with the prospect of sustainably providing essential materials and services as part of a low-carbon economy, both through the substitution of fossil-intensive fuels and materials and through their potential to capture and store carbon in the long-term (Cintas et al. 2017; Koponen et al. 2015; Lundmark et al. 2014).

4.11 Current Interventions for Environmental Protection

Although energy demand comes from both the rural and urban areas, the rural setting (supplier) is experiencing serious environmental stresses, poor environmental quality and environmental shocks that require some interventions from individuals, the community, and the government. Despite the growing number of local environmental management projects in the country, the study could not find any intervention in Mtitaa ward, Bahi district. The study found limited interventions to respond to the deteriorating environmental quality as a result of biomass energy utilization.

A local government official confirmed the village to have no environmental management projects which are community or government-led. Neither individuals nor the village government has taken any initiative for afforestation and reforestation. Tree planting projects are conducted only mainly in school, particularly during rainy seasons. Due to the semi-arid nature of the area, it is difficult to execute any tree-planting project in dry seasons. During this, even some of the trees die due to drought.

The study also could not find any guideline or bylaw which safeguards the environment concerning biomass cooking energy. It was discovered that charcoal making is highly unregulated to the extent that the natural forest is deteriorating rapidly. One of the reasons was the production of charcoal for domestic cooking as disclosed by one male participant:

> *We are uncertain about the accessibility of the biomes energy situation shortly because there is a high rate of deforestation resulting from charcoal making. Surprisingly, charcoal makers are free to feel any kind of a tree, anywhere they want to, but charcoal sellers, especially those who take it to the urban are detained and/or fined for the reason that they destroy the environment.*

This suggests that local government authorities face institutional challenges that threaten the long-term sustainability of the environment.

The factors (which act as driving forces in the DPSIR model show) tend to stimulate that the presented population is growing rapidly, showing that cylinder the DPSIR model, the cooking energy sector is the scenario, population growth.

Table 3

Cooking Energy DPSIR

Driving forces **(Demand for cooking energy)**	**Pressures** **(Environmental stresses)**	**State** **(Environmental condition)**	**Impact** **(Shocks)**	**Responses** **(Interventions)**
• Population growth • Urbanization • Access to alternative energy sources • Free access to biomass stock	• Deforestation • Forest degradation • Carbon emissions • Methane emissions • Sooth	• Outdoor Air Pollution • Indoor Air Pollution • Water pollution • Land pollution. • Soil erosion • Increased temperature • Prolonged drought	• Ecosystem disturbance • Loss of biodiversity • Energy scarcity • Water scarcity • Climate change	• Afforestation • Reforestation • Awareness creation • Environmental education • By-laws /guidelines • Promoting alternative energy sources

V. CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

Biomass energy is potentially renewable. However, this renewable energy source is rapidly diminishing following higher rates of exploitation that do not keep pace with the rate of renewal. A substantial quantity of current woodfuel consumption is unsustainable and causes declines in standing stocks of biomass (Bailis et al., 2015), requiring a switch to green and clean energy for environmental sustainability. However, the transition to green and clean energy is not easy. It necessitates substantial research and development (R&D) and a well-developed economy (Sheng et al, 2023). This being the case, traditional biomass will continue to be the primary cooking energy source to the majority of the population, both in the rural and in the urban.

Increasing biomass removals further without respect for available cautionary signs elevates a known risk and pushes the potential impacts onto future generations. This highlights the need for deploying relevant and workable precautions, proceeding in an experimental manner, and with a sound monitoring plan to address how potential impacts of biomass harvesting will be monitored effectively over time. Uncontrolled harvesting of biomass for energy reduces the forest's ability to sequester and store carbon. Removal of trees has consequences on environmental sustainability in that it ends their carbon sequestration among other things.

Environmental sustainability programs include actions such as sustainable biomass utilization, the use of efficient cookstoves, tree planting programmes and projects, and the establishment of tree plots for household energy consumption. Moreover, the government and other stakeholders need to promote research and development which can

enhance the development of green and clean energy. This includes the development and utilization of sustainable energy such as solar and wind.

5.2 Recommendations

The study recommends for effective intervention related to institutional and policy frameworks to safeguard the environment. While more attention is being paid to rural electrification (Multiconsult, 2022), the cooking energy sub-sector is bypassed. Cross-cutting policies which include the Energy Policy, Energy Subsidy Policy, Environmental Policy, Forestry Policy, Health Policy, Education Policy and Gender Policy must be implemented at the lowest level for their objectives to be achieved. Furthermore, awareness-raising campaigns should focus on educating the masses on the immediate and long-term impact of the prevailing cooking energy patterns and systems.

Acknowledgement

I would like to express my deepest appreciation to VLIR-UOS IUC P3 Research and Outreach Grants for funding field data collection. I am grateful also to the Institute of Development Studies (IDS), Mzumbe University for the approval to undertake the research. I further acknowledge the assistance I received from Dodoma Regional Administrative Office, Dodoma City Council and Bahi District Council in Dodoma, before and during research. Moreover, I thank all participants who made this research possible.

REFERENCES

Aberilla J.M., Gallego-Schmid A., Stamford L., & Azapagic A. (2020). Environmental sustainability of cooking fuels in remote communities: life cycle and local impacts. *Sci Total Environ., 713*, 136445. Wuppertal Institute for Climate, Environment and Energy.

AfDB. (2015). *Renewable Energy in Africa: Tanzania Country Profile*. Avenue Jean-Paul II 01 BP 1387 Abidjan 01, Côte d'Ivoire www.afdb.org

Alem, Y., Beyene, A. D., Köhlin, G., & Mekonnen, A. (2016). Modelling household cooking fuel choice: A panel multinomial logit approach. *Energy Economics*, *59*. https://doi.org/10.1016/j.eneco.2016.06.025

Arnold, J. M., Köhlin, G., & Persson, R. (2006). Woodfuels, Livelihoods, and Policy Interventions: Changing Perspectives. *World Development*, *34*(3), 596-611.

Bailis, R., Drigo R., Ghilardi, A., & Masera, O. (2015). The carbon footprint of traditional woodfuels. *Nat. Clim. Change, 5*(3),1. http://dx.doi.org/10.1038/nclimate2491

Baumert, S., Luz, A.C., Fisher, J., Vollmer, F., Ryan, C.M, Patenaude, G., Zorrilla-Miras, P., Artur, L., Nhantumbo, I., & Macqueen, D. (2016). Charcoal supply chains from Mabalane to Maputo: who benefits? *Energy for sustainable Development, 33*, 129–138

Borja, A., Galparsoro, I., Solaun, O., Muxika, I., Tello, E.M., Uriarte, A., & Valencia, V. (2006). The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. Estuar. *Coast Shelf Sci., 66*, 84e96. https://doi.org/10.1016/j.ecss.2005.07.021

Cintas, O., Berndes, G., Hansson, J., Poudel, B.C., Bergh. J., Börjesson, P., Egnell, G., Lundmark, T. & Nordin, A. (2017) The potential role of forest management in Swedish scenarios towards climate neutrality by mid-century. *Forest Ecology and Management, 383*, 73-84

Daioglou, V., van Ruijven, B.J. & van Vuuren D.P. (2012). Model projections for household energy use in developing countries. *Energy*, 37 (1), 601-615.

Dingeto, H. A. & Kalbessa, K. D. (2021). Ethiopia's renewable energy potentials and current state. *AIMS Energy*, *9*, 1–14.

Doggart, N., Ruhinduka, R., Meshack, C.K., Ishengoma, R.C., Morgan-Brown, T., Abdallah, J.M, Spracklen, V.D. & Sallu, S.M. (2020). The Influence of Energy Policy on Charcoal Consumption in Urban Households in Tanzania S*cienceDirect*. https://doi.org/10.1016/j.esd.2020.06.002

ESMAP. (2021). *Tracking SDG 7: The Energy Progress Report.* Washington, DC: The World Bank.

Fang, W., An, H. Z., Li, H. J., Gao, X. Y., Sun, X. Q., & Zhong, W. Q. (2017). Accessing on the sustainability of urban ecological-economic systems by means of a coupled emergy and system dynamics model: a case study of Beijing. *Energy Policy 100*, 326–337. DOI: 10.1016/j.enpol.2016.09.044

Hager, T.J., & Morawicki, R. (2013) Energy Consumption during Cooking in the Residential Sector of Developed Nations: A Review. *Food Policy, 40*, 54-63.

Henderson, K., & Loreau, M. (2023). A model of Sustainable Development Goals: Challenges and opportunities in promoting human well-being and environmental sustainability. *Ecological Modelling*, *475*, 110164.

Hooper, L.G., Dieye Y., Ndiaye, A., Diallo A., Sack, C.S., & Fan, V.S. (2018) Traditional cooking practices and preferences for stove features among women in rural Senegal: Informing improved cookstove design and interventions. *PLoS ONE 13*(11), e0206822. https://doi.org/10.1371/journal.pone.0206822

Hussein, M. A., & Leal Filho, W. (2012). Analysis of Energy as a Precondition for Improvement of Living Conditions and Poverty Reduction in Sub-Saharan Africa. *Scientific Research and Essays*, *7*(30), 2656-2666. http://www.academicjournals.org/SRE

IEA. (2014). Energy Supply Security: Emergency response of lEA Countries. OECD/IEA.

IEA. (2017). Energy Access Outlook 2017. *International Energy Agency, Paris*. https://www.iea.org/publications/freepublications/publication/WEO2017 SpecialReport_EnergyAccessOutlook.pdf

IEA. (2019a). Africa Energy Outlook - *World Energy Outlook special report*. https://www.iea.org/reports/africa-energy-outlook-2019

IEA. (2019b). SDG7: Data and Projections. *Access to Affordable, Reliable Sustainable and Modern Energy for All* https://www.iea.org/reports/sdg7-data-and-projections/access-to-clean-cooking

IEA. (2019c). *Energy Security: Ensuring the uninterrupted availability of energy sources at an affordable price.* International Energy Agency.

IEA. (2022). *Africa in an evolving global context: Africa energy outlook key findings* https://www.iea.org/reports/africa-energy-outlook-2022/key-findings

IEA. (2023). *A vision for clean cooking access for all. International Energy Agency*. World Energy Outlook Special report. www.iea.org

Ifegbesan, A.P., Rampedi, I.T., & Annegarn H.J. (2016). Nigerian households' energy use, determinants of choice, and some implications for human health and environmental sustainability. *Habit Int., 55*, 17–24.

Jagger, P., Pedit, J., Bittner, A., Hamrick, L., Phwandapwhanda, T., & Jumbe, C. (2017). Energy for sustainable development fuel efficiency and air pollutant concentrations of wood-burning improved cookstoves in Malawi: Implications for scaling-up cookstove programs. *Energy for Sustainable Development, 41*, 112–120. https://doi.org/10.1016/j.esd.2017.08.007

Jagoe, K., Rossanese, M., Charron, D., Rouse, J., Waweru, F., Waruguru, M., Delapena, S., Piedrahita, R., Livingston, K. and Ipe J. (2020). Sharing the burden: shifts in family time use, agency and gender dynamics after the introduction of new cookstoves in rural Kenya. *Energy Res. Soc. Sci., 64*, 101413.

Jeuland M.A., & Pattanayak, S.K. (2012). Benefits and Costs of Improved Cookstoves: Assessing the Implications of Variability in Health, Forest and Climate Impacts. *PLoS ONE, 7*(2), e30338. https://doi.org/10.1371/journal.pone.0030338

Karekezi, S., McDade, B.B., & Kimani, J. (2012). *Energy, Poverty and Development. In GEA, Global Energy Assessment-Towards a Sustainable Future*. Cambridge University Press, Cambridge, UK and New York, USA and the International Institute for Applied Systems Analysis, Luxemburg, Austria.

Khan, M.K., Teng, J., Khan, M.I., & Khan M.O. (2019). Impact of globalization, economic factors and energy consumption on CO_2 emissions in Pakistan. *Science of the Total Environment, 688* (2019), 424–436. Elsevier https://doi.org/10.1016/j.scitotenv.2019.06.065

Koponen, K., Sokka, L., Salminen, O., Sievänen, R., Pingoud, K., Ilvesniemi, H., Routa, J., Ikonen, T., Koljonen, T., Alakangas, E., Asikainen, A., & Sipilä, K. (2015). *Sustainability of forest energy in Northern Europe.* Technical. http://www.vttresearch.com/impact/publications

Lambe, F., Jürisoo, M., Wanjiru, H., & Senyagwa, J. (2015). Bringing Clean, Safe, Affordable Cooking Energy to Households across Africa: An Agenda for Action. *Background Paper to the Africa Progress Panel 2015 Report Power, People, Planet: Seizing Africa's Energy and Climate Opportunities.* Prepared by the Stockholm Environment Institute, Stockholm and Nairobi, for the New Climate Economy.

Lundmark, T., Bergh, J, Hofer, P., Lundström, A., Nordin, A., Poudel, B..C, Sathre, R., Taverna, R., & Werner, F. (2014). Potential Roles of Swedish Forestry in the Context of Climate Change Mitigation. *Forests, 5*(4), 557-578.

Ma, Q., Murshed, M., & Khan, Z. (2021). The nexuses between Energy Investments, Technological Innovations, R&D Expenditure, Emission Taxes, Tertiary sector development, and Carbon Emissions in China: A roadmap to achieving carbon-neutrality. *Energy Pol., 155*,112345. https://doi.org/10.1016/j.enpol.2021. 112345

Martine, S., Castellani, V., & Sala, S. (2015). Carrying capacity assessment of forest resources: Enhancing environmental sustainability in energy production at local scale. *Resources, Conservation and Recycling, 94*,11-20.

Martins, J. H., Camanho, A. S., & Gaspar, M. B. (2012). A review of the application of driving forces – Pressure – State – Impact – Response framework to fisheries management. *Ocean & Coastal Management, 69*, 273–281. doi:10.1016/j.ocecoaman.2012.07.029.

Morelli, J. (2011). Environmental Sustainability: A Definition for Environmental Professionals. *Journal of Environmental Sustainability, 1*(1), Article 2. https://doi.org/10.14448/jes.01.0002

Muller, C., & Yan, H. (2016). Household fuel use in developing countries: Review of theory and evidence. *Energy Economics, 70*, 429-439.

Multiconsult. (2022). *Clean Energy Transition in Tanzania. Powering Sustainable Development*. Norwegian Embassy, Dar es Salaam https://www.norway.no/contentassets/00c56b3642e5429fbc917d5fa42ff869/clean-energy-transition-in-tanzania-report.pdf

Nathaniel, S. P., Alam, M. S., Murshed, M., Mahmood, H., & Ahmad, P. (2021). The roles of nuclear energy, renewable energy, and economic growth in the abatement of carbon dioxide emissions in the G7 countries. *Environmental science and pollution research international*, *28*(35), 47957–47972. https://doi.org/10.1007/s11356-021-13728-6

National Bureau of Statistics. (2019). *Tanzania Mainland Household Budget Survey 2017–18, Key Indicators Report*. Ministry of Finance and Planning— Energies 2022, 15, 771 30 of 31 Poverty Eradication Division (MoFP-PED) [Tanzania Mainland] and National Bureau of Statistics (NBS): Dodoma, Tanzania.

Nyamoga, G., & Solberg, B. (2019). *Agriculture and Ecosystem Resilience in Sub-Saharan Africa, Climate Change Management*. Springer Nature, Berlin, Germany.

Pavlyk, N., Seiko, N., & Sytniakivska, S. (2021). *The concept of "environmental sustainability" in scientific and information space.* IOP Conference Series: Earth and Environmental Science 915 (2021) 012015 IOP Publishing. https://doi.org/10.1088/1755-1315/915/1/012015

Philibert, C. (2022). *Power to the Cooks! New Clean Cooking Opportunities for Sustainable Development in Sub-Saharan Africa*. Briefings DE L'IFRI. Centre for Climate Change.

Poesen, J. (2018). Soil erosion in the Anthropocene: Research needs. *Earth Surf. Process. Landforms, 43*, 64–84. https://doi.org/10.1002/esp.4250

Pope, D., Bruce, N., Higgerson, J., Hyseni, L., Stanistreet, D., Mbatchou, B., & Puzzolo, E. (2018). Household Determinants of Liquefied Petroleum Gas (LPG) as a Cooking Fuel in SW Cameroon. *Ecohealth*, *15*(4), 729-743.

Sheng W., Meng F., Akbar M.W. (2023). How institutional quality, and energy production sources, affect the environmental sustainability of bri countries: A comparison of different income groups. *PLoS ONE*, *18*(9), e0291144. https://doi.org/10.1371/journal.pone.0291144

Smaling, E.M.A. & Dixon, J. (2006). Adding a soil fertility dimension to the global farming systems approach, with cases from Africa. Agric. *Ecosyst. Environ., 116*, 15–26.

Uckert, G., Kimaro, A., Gassaya, O., Swamila M., Yustas, Y., Romuli, S., Elly, N., Mgeni, C., Munder, S., Makoko, B., Silayo, V. & Mueller J. (2016). *Final Report for Additional Biomass Utilization and UPS Implementation in WP6.3 (ZALF, ICRAF, SUA, UHOH, ARI, MVIWATA)*. Trans-SEC. https://trans-sec.zalf.de/media/upload/product/pdf/ef081586b13c56171625b71519263e30.pdf

UNEP. (2017). *Atlas of Africa Energy Resources.* Nairobi, Kenya.

United Republic of Tanzania. (2014). *Basic Demographic and Socio-Economic Profile Report Tanzania*. Ministry of Finance, Dar es Salaam.

Urmee, T., & Gyamfi, S. (2014). A review of improved Cookstove technologies and programs. *Renewable and Sustainable Energy Reviews*, *33*, 625-635.

Valavanidis, A. (2022). *Global Warming and Climate Change: Fossil fuels and anthropogenic activities have warmed the Earth's atmosphere, oceans, and land.* Department of Chemistry, National and Kapodistrian University of Athens, University Campus Zografou, 15784 Athens, Greece chem-tox-ecotox.org/ScientificReviews

Vitali, F. (2013). *Appropriate Solutions for Cooking Energy at the Household Level in the Logone Valley.* (Chad – Cameroun) (PhD thesis) University of Brescia Faculty of Engineering WB (2023). Moving the Needle on Clean Cooking for All.

WHO. (2017). *Household Air Pollution and Health.* World Health Organization. http://www.who.int/mediacentre/factsheets/fs292/en/

WHO. (2023). *Basic energy access lags amid renewable opportunities, new report shows.* World Health Organization. https://www.who.int/news/item/06-06-2023-basic-energy-access-lags-amid-renewable-opportunities--new-report-shows

Yamane, T. (1967). *Statistics: An Introductory Analysis* (2nd ed.). New York: Harper and Row

Yonemitsu, Y., Njengab, M., Iiyamab, M., & Matsushita, S. (2014). Household Fuel Consumption Based on Multiple Fuel Use Strategies: A Case Study in Kibera Slums. *APCBEE procedia*, *10*, 331-340.

Zafar, M. W., Shahbaz, M., Sinha, A., Sengupta, T., & Qin, Q. (2020). How renewable energy consumption contribute to environmental quality? The role of education in OECD countries. *Journal of Cleaner Production*, *268*, 122149.