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Ensuring access to affordable, sustainable and clean household energy for all in Ghana

Aba Obrumah Crentsil
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Preface

Southern Voice's flagship initiative on the State of the Sustainable Development Goals (SVSS) has generated country-level, evidence-based analysis to enrich the global dialogue on the 2030 Agenda. SVSS is neither a typical data-driven analysis of progress nor a traditional monitoring exercise of Sustainable Development Goals (SDGs). Instead, through this research initiative, we seek to identify the 'second-generation' challenges of the global agenda along with the policy responses to address them.

Our cross-country and regional analyses show that, on the one hand, national governments have made discernible progress in designing policy frameworks aligned with the Agenda. The governments have recognised the importance of not leaving the most vulnerable behind. On the other hand, weak coordination among relevant stakeholders and lack of horizontal coherence remain as challenges in achieving the Goals. Silo approaches continue to undermine national governments' ability to address systemic problems and create the necessary conditions to end poverty for all. Paucity of financial resources, along with no changes in the allocative priorities, are symptomatic of most of the developing countries' drive towards SDGs.

With these challenges in mind, the SVSS report identifies three layers of critical action and analysis. First, we explore who is potentially excluded from deriving the benefits of SDG delivery within the country's contextual realities. Second, we recognise that the Goals are not necessarily additive (even within a holistic agenda), and delve into the links between the Goals and their interconnections, so as to maximise their synergies and protect against the trade-offs. Third, we explore the implications of the current conduct of the global institutions and policies for the national efforts to implement SDGs.

The study explores the current household energy situation in Ghana. It identifies who lacks access to clean energy, the synergies and trade-off from the use of household energy and other SDGs and targets, and how global systemic issues affect the national implementation of SDG 7 (affordable and clean energy).

We hope that this piece of Southern Voice's research will enlighten the thought process of the policy community and development practitioners in their efforts towards a fuller realisation of the 2030 Agenda.

Debapriya Bhattacharya, PhD
Team Leader, SVSS
Chair, Southern Voice and Distinguished Fellow, CPD

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Abstract

This study investigates household access to affordable energy in Ghana, assessing which groups are left behind. It considers synergies and trade-offs between other SDGs that affect equitable energy access, and how global issues affect the national implementation of SDG 7 (affordable and clean energy).

Combining quantitative and qualitative approaches to appraise access to different energy types, this paper employs a decision tree analysis to map the interplay of geographical location (urban or rural residence) and household poverty status. It illustrates that the use of clean fuels in Ghana, including electricity, is limited by both accessibility and affordability. Results from a scenario-based analysis show trade-off between SDG 7 and SDGs 2 (zero hunger), 3 (good health and well-being), 5 (gender equality), 11 (sustainable cities and communities), and 13 (climate action).

Using a transmission mechanism and causal loop analysis, this study considers how interactions between global and national issues shape access to clean energy in Ghana. Regional cooperation through research, knowledge transfer, and partnerships, can help narrow access inequalities in household energy access, if adequately funded and equitably implemented.

Authors

Aba Obrumah Crentsil is a research fellow in the Institute of Statistical, Social and Economics Research (ISSER) at the University of Ghana. She can be reached at aocrentsil@ug.edu.gh.

Ama Pokuaa Fenny is a research fellow in the Institute of Statistical, Social and Economics Research (ISSER) at the University of Ghana.

Charles Godfred Ackah is the director of the Centre for Social Policy Studies (CSPS) and a senior research fellow at the Institute of Statistical, Social and Economic Research (ISSER), both at the University of Ghana.

Derek Asuman is a research assistant at the Economics Division of the Institute of Statistical, Social and Economic Research at the University of Ghana.

Evans Otieku is currently a guest researcher at Aarhus University in Denmark and a graduate research assistant at the Institute of Statistical, Social and Economic Research (ISSER).

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Acronyms and abbreviations

BAU	Business as Usual
GHGs	Green House Gases
GLSS	Ghana Living Standard Survey
INDC	Intended Nationally Determined Contributions
LEAP-IBC	Long-range Energy Alternatives Planning System- Integrated Benefits Calculator
LPG	Liquefied Petroleum Gas
PM	Particulate Matter
SDGs	Sustainable Development Goals
UN	United Nations
WHO	World Health Organisation

Ensuring access to affordable, sustainable and clean household energy for all in Ghana

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Introduction

This study outlines the current household energy situation in Ghana. It identifies who lacks access to clean energy, the synergies and trade-off from the use of household energy and other Sustainable Development Goals (SDGs) and targets, and how global systemic issues interact with SDG 7 (affordable and clean energy) implementation nationally. Clean energy access is defined as: (1) access to electricity; and (2) primary reliance on clean fuels, in line with SDG indicators 7.1.1 and 7.1.2[1]. Aiming to identify the underlying reasons of inequal household energy access, the study utilises primary data from a qualitative field survey, and secondary data from the seventh Ghana Living Standard Survey (GLSS7).

Rationale and background

The 2030 Agenda for Sustainable Development—including 17 interconnected SDGs and 169 targets—was adopted on 25 September 2015 as a successor to the UN's Millennium Development Goals (MDGs). The Goals and targets are integrated and indivisible: therefore, they should not be seen as a list of goals to choose and pick from. Another critical feature of the 2030 Agenda is the pledge to 'leave no one behind' (LNOB). Unlike the MDGs, where national measuring of targets masked sub-national disparities, the 2030 Agenda aims to reach "the furthest behind first" using targeted interventions and data disaggregation. Achieving and monitoring the SDGs requires input from all stakeholders, and partnerships between governments, the private sector, civil society, and citizens.

The 2030 Agenda also set a historic goal to "ensure access to affordable, reliable, sustainable and modern energy for all" (United Nations, 2015). Such access is crucial to achieving many SDGs—from poverty eradication through to advancements in health, education, water supply, industrialization, and climate change mitigation.

1 Indicator 7.1.1 is the proportion of population with access to electricity. Indicator 7.1.2 is the proportion of population with primary reliance on clean fuels and technology. (See https://unstats.un.org/sdgs/metadata/).

Yet 1.1 billion people lack access to electricity, more than half of which live in Sub-Saharan Africa (International Energy Agency, 2017). About 2.8 billion people (38% of the global population), and almost 50% of the population in developing countries, rely on polluting, inefficient energy systems such as biomass, coal, or kerosene to meet daily cooking needs—both figures have remained unchanged over the last decade (World Health Organization [WHO], 2016).

In Ghana, 76% of households cook primarily with polluting fuels and technologies (Ghana Statistical Service, 2017). Across the rural–urban divide, 90% and 57% of households, respectively, rely on polluting fuels such as firewood for cooking, highlighting steep inequalities in both access and use (Ghana Statistical Service, 2017). Reliance on biomass fuels affects air quality, both indoors and outdoors. Household air pollution, primarily caused by biomass fuels and cooking technologies, causes 14,000 premature deaths per year in Ghana (WHO, 2017). Disparities in health outcomes among and within households can thus be perpetuated by unequal access to clean cooking fuels. Although progressing, Ghana's electricity development has not been consistent across the country. While access to electricity has reached 78% of Ghanaian households, approximately 58% of rural households—compared to 90% of urban ones—use electricity as their primary lighting source (Ghana Statistical Service, 2017). However, other factors, such as regularity of supply, also need to be considered when drawing conclusions.

Unequal access to clean fuel and electricity thus poses major environmental, health, and social threats, which prevent Ghana from attaining the SDGs. To address these energy inequality issues, this study takes a predictive analytical approach, using a decision tree to identify those excluded from accessing clean energy. Since the achievement of SDG 7 is intrinsically linked to other SDGs, this study also adopts the Long-range Energy Alternatives Planning (LEAP) system, to analyse Ghana's current household energy policies and alternative policy measures. This modelling tool identifies synergies and trade-offs between SDG 7 and other key SDGs. Furthermore, this study considers how global issues and perspectives affect household energy access in Ghana, and assesses how global and foreign interests interact with domestic ones to shape energy development partnerships. The specific objectives are:

- To investigate the household energy sector in Ghana to identify those the most 'left behind' and their shared circumstances.
- To examine synergies and trade-offs between the implementation of SDG 7 and other SDGs.
- To examine global systemic issues that affect the implementation of the SDG 7 in Ghana.

Only the household sector of Ghana is studied and modelled in this paper. This modelling only considers appliances and energy consuming tools of end-user households. Following the WHO Guidelines for Indoor Air Quality, clean fuels include electricity, liquid petroleum gas (LPG), natural gas, and biogas; dirty fuels burnt in open fires and leaky stoves include wood, crop wastes, charcoal, coal, and dung (WHO, 2014).

Methodology[2]

This paper's research methodology combines quantitative and qualitative approaches to study the exclusion of households from affordable energy consumption. This combined approach helps to corroborate information where possible, and balances data with in-depth discussions to determine synergies and trade-offs of other SDGs in relation to SDG 7. It seeks to unearth underlying reasons for inequalities in household energy access in Ghana. Secondary data from the latest Ghana Standard Living Survey (Ghana Statistical Service, 2017), a nationwide household survey documenting living conditions, is combined with primary data from a qualitative field survey of four communities across the four ecological zones in Ghana based on their household energy needs and use. Key documents, which included energy policies, strategic plans, environmental policy documents, published literature, unpublished documents, and media reports, were also consulted. Personal communication with experts, advocates, and government officials in the energy and other relevant sectors, broaden the applicability of this paper's findings to current implementation challenges, and to other policy areas.

Two indicators are used to identify the groups likely to be left behind in accessing clean energy: access to electricity and access to clean cooking fuels. Using a classification tree approach, an algorithm splits the value of the target indicators into groups, based on predetermined circumstances: household wealth, residence (urban and rural), educational level of household head, and household region. In each iteration, the classification tree highlights differences between groups, thereby identifying the most and least able to access electricity and clean fuels. These groups consist of households sharing common circumstances[3].

Ghana has enacted many policies aimed at developing, by 2020, an "energy economy" with reliable high-quality energy services. To identify an array of positive

2 A table of the methodological overview can be found in Appendix 1.

3 Please see Appendix 2 for a more detailed description of the methodology, as well as the selection of indicators and circumstances.

and negative consequences of these policies, the study adopts two scenarios to assess the future implications of Ghana's current energy policies using the Long-range Energy Alternatives Planning System - Integrated Benefits Calculator (LEAP-IBC)[4]. The temporal scope used in these scenarios is 2010-2030, as the SDGs are to be met in 2030. They assess synergies and trade-offs arising from interlinkages between SDG 2 (zero hunger), SDG 3 (good health and wellbeing), SDG 5 (gender equality), SDG 7 (affordable and clean energy), SDG 11 (sustainable cities and communities) and SDG 13 (climate action). The scenarios draw on previous research on household and demographic surveys conducted by the Ghana Statistical Service, the Ministry of Energy, the Energy Commission, and UN databases.

Scenario Building

The key data used in this research are:

- Macro-economic variables (nominal GDP, sector value addition, GDP projections): World Bank dataset on Ghana, Ghana Statistical Service, Bank of Ghana.
- Demographic data (total population, population growth rate, urbanisation, household structure): 2010 housing population census, Ghana Living Standards Surveys (GLSS).
- Household energy consumption patterns: Energy Commission - Strategic National Energy Plan (SNEP), Energy Statistics and GLSS, Intergovernmental Panel on Climate Change (IPCC) Emission Factor Database.

Business as Usual (BAU) with no new policies

This scenario quantitatively assesses the effect of existing and future policies on the household energy sector. Central policies analysed are the Ghana National Energy Policy, the National Action Plan to Mitigate Short-lived climate pollutants (Ghana), the Country Action Plan for Sustainable Energy for All (SE4All), the Renewable Energy Act 2011, and the Energy Sector Strategy and Development Plan[5]. This scenario takes into account current progress made in electricity access at the household level. Projections also consider population growth, economic growth, urbanisation, and fuel price and availability. This scenario is built under the assumption that policies and measures will be implemented, but they will not necessarily lead to the full accomplishment of intended objectives found in the aforementioned policies.

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4 An extensive write-up of this model can be found at https://www.energycommunity.org/default.asp?action=IBC

5 Links to the various policy documents and policy intentions can be found in Appendix 1.

The policy success scenario

This scenario projects total implementation of household energy policies in Ghana. In scenario projections, electricity access means all Ghanaian households can access grid or non-grid electricity by 2030. The analysis also recognises the need for modern stoves and fuels. It projects a 50% penetration of LPG in households by 2020, and 50,000 improved stoves by same.

Due to limitations of the LEAP-IBC model in accounting for gender, the study used focus group discussions to qualitatively analyse synergies and trade-offs between household energy use and SDG 5 (empowering women and girls). This helps incorporate household knowledge, attitudes, and practices around accessing and affording clean fuels. Primary household cooks were interviewed to understand perceptions around solid fuel and LPG use and their effects. Two researchers and a community representative conducted these focus groups.

The focus group discussions were semi-structured[6] and included prompts to elicit open-ended conversation about fuel use decision-making, barriers to exclusive LPG use, and perceptions of current stoves. Open-ended questions (see Appendix 1) were included to address economic, cultural, and psychological factors relevant to cooking practices and fuel choices.

A focus group was conducted across each of the four ecological zones in Ghana: savannah, transitional, forest, and coastal. Communities were selected to reflect the average household energy use across the country. Locations include Nkwanta, a farming community in the Asante Akim South Municipality; Nadowli, a farming and charcoal producing community in Kaleo district; Tegbui, a coastal community in Keta municipality; and Tanoso, in the Tano North district. The focus group guide was pre-tested with two community members and modified based on feedback to improve clarity. Discussions were digitally recorded using a handheld device and subsequently transcribed.

Using transmission mechanisms and causal loop diagrams, the influence of global systemic issues on household energy access is analysed. This illustrates how foreign and domestic interests and views interact to shape energy development partnerships that tackle clean energy access inequalities. A Causal Loop Diagram (CLD) is an analytical tool used to map and understand complex dynamic systems. It helps to visualize the system and analyse cause-and-effect relationships between variables (Hovmand, 2013).

6 Please see Appendix 1 for the interview guide for focus group discussions.

Diagram arrows show causal relationships: a positive "+" sign denotes a positive causal relationship: both variables are moving in the same direction. A negative "–" sign denotes a negative causal relationship: if the cause increases, the effect decreases. Intermediate factors used in this study are subjective at a certain level; however, well-cited literature is used to define and support their use. These interactions between the elements can create balancing (–) or reinforcing (+) effects (Kim, 1992). Many scholars (Naill et al., 1992; Feng et al., 2013; Robalino-López et al., 2014 & Movilla et al., 2013) have used the causal loop diagram in the energy sector.

Thus, a causal loop diagram is built using proprietary systemic dynamic modelling software called VENSIM[7] and incorporating the following elements:

i. the current Ghana household energy sector;
ii. the effects of global systemic issues on: household energy technology, support funding from development partners, energy technology and innovative practices, and global partnerships; and
iii. author perceptions on interconnections based on literature, expert interviews, and knowledge of the household energy sector.

Results

Figure 1 illustrates how interacting circumstances limit or enable access to clean cooking fuels. Approximately 76% of households sampled lack access to clean cooking fuels, instead of relying upon biomass fuels. The first split emerges regarding education: the most important predictor of access to clean fuels is the educational attainment of the head of the household. According to Rao and Reddy (2007), education improves income, altering the opportunity cost of acquiring time-saving energy sources. Household income also leads to knowledge increase, which subsequently affects cultural and consumer preferences for cleaner energy sources (Rao & Reddy, 2007). Educated household heads tend to choose cleaner energy because of its convenience, health benefits and lower opportunity cost relative to their potential labour.

In total, 60% of households with secondary or higher education use clean cooking fuels, compared to 15% of households with basic or no education. The second split is demarked by rural or urban residence. Urban households with secondary or higher education have the greatest access to clean cooking fuels. The classification tree corroborates that 1,029 urban households in the Western, Central, Greater Accra, Volta and Ashanti regions with a

7 See http://vensim.com/

secondary or higher educational level ultimately had the highest access to clean cooking fuels (see terminal node 5), compared to 112 rural households with same educational attainment (see terminal node 8) who had basic or no formal education.

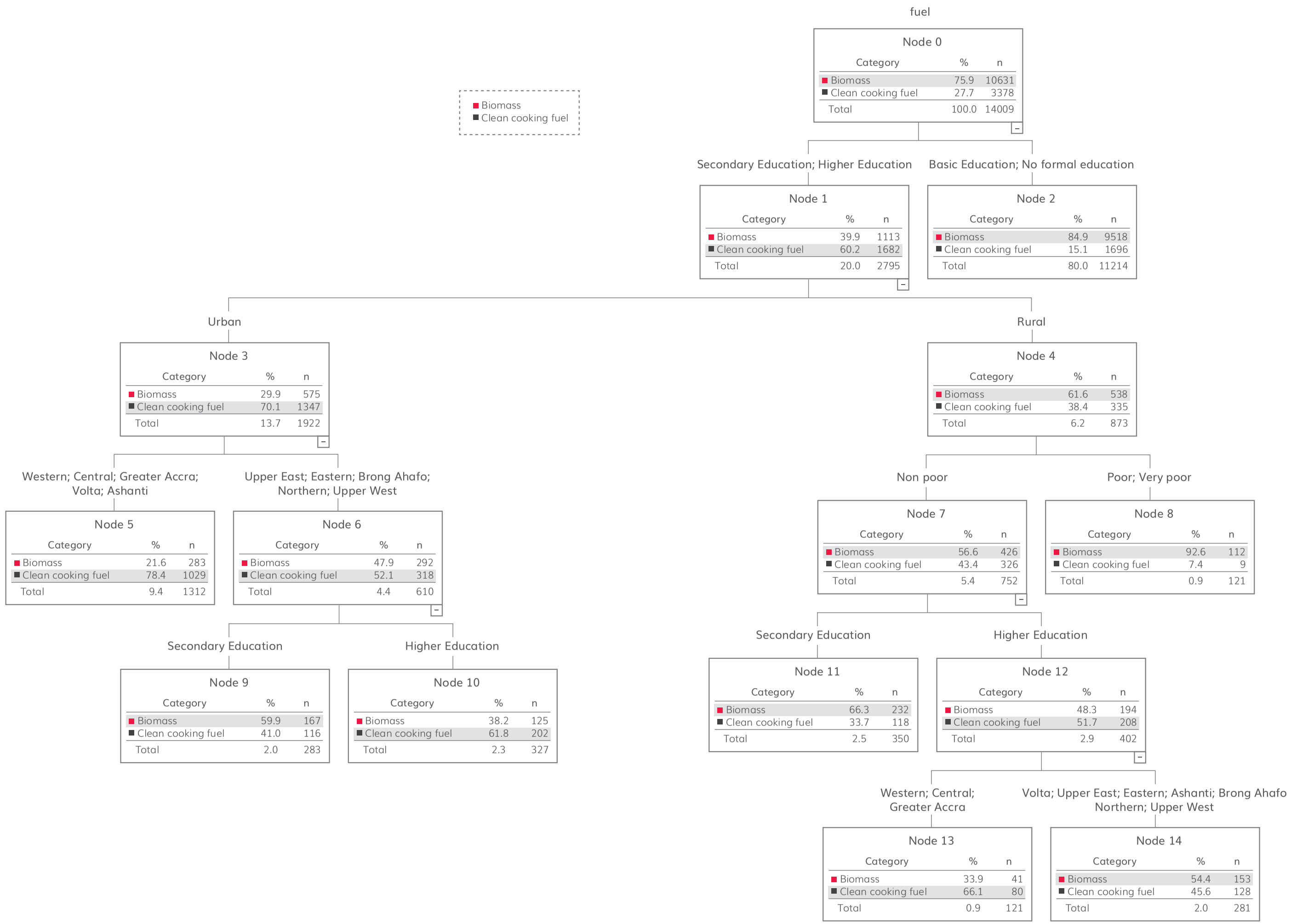
Therefore, education level is a major differentiating factor: having better jobs with higher incomes influences the type of energy households use for cooking. Similar studies (Rahut et al. 2017; Mottaleb et al., 2017) have also corroborated that education contributes to the choice of cooking fuels.

From the tree analysis, the interplay of geographical location and household poverty status illustrates that reliance on clean fuels is a question of both accessibility and affordability. In accessing electricity, 90% of urban households rely on electricity for lighting, compared to 58% of rural households (Figure 1). Rural or urban location is thus the most influential predictor of electricity access. Rural households in different regions (node 2) also had different levels of electricity access: where 73.5% of rural households in the Western, Greater Accra, Central, Volta and Ashanti regions have access to electricity compared to 48.2% of rural households in the Eastern, Northern, Upper East and Upper West regions.

> **Rural households in the Upper East Region who had no formal education are the group with the lowest access to clean energy.**

The tree shows the group with highest electricity access levels (terminal node 1), are urban households (at 91%); the group with the lowest access (terminal node 7) are rural households (at 71%) in the Upper East Region who had no formal education. Such lack of access to clean energy worsens social inequality; as Jain et al. (2015) note, households, especially rural and lowest-income ones, pay more for electricity and spend more of their income on often inferior services.

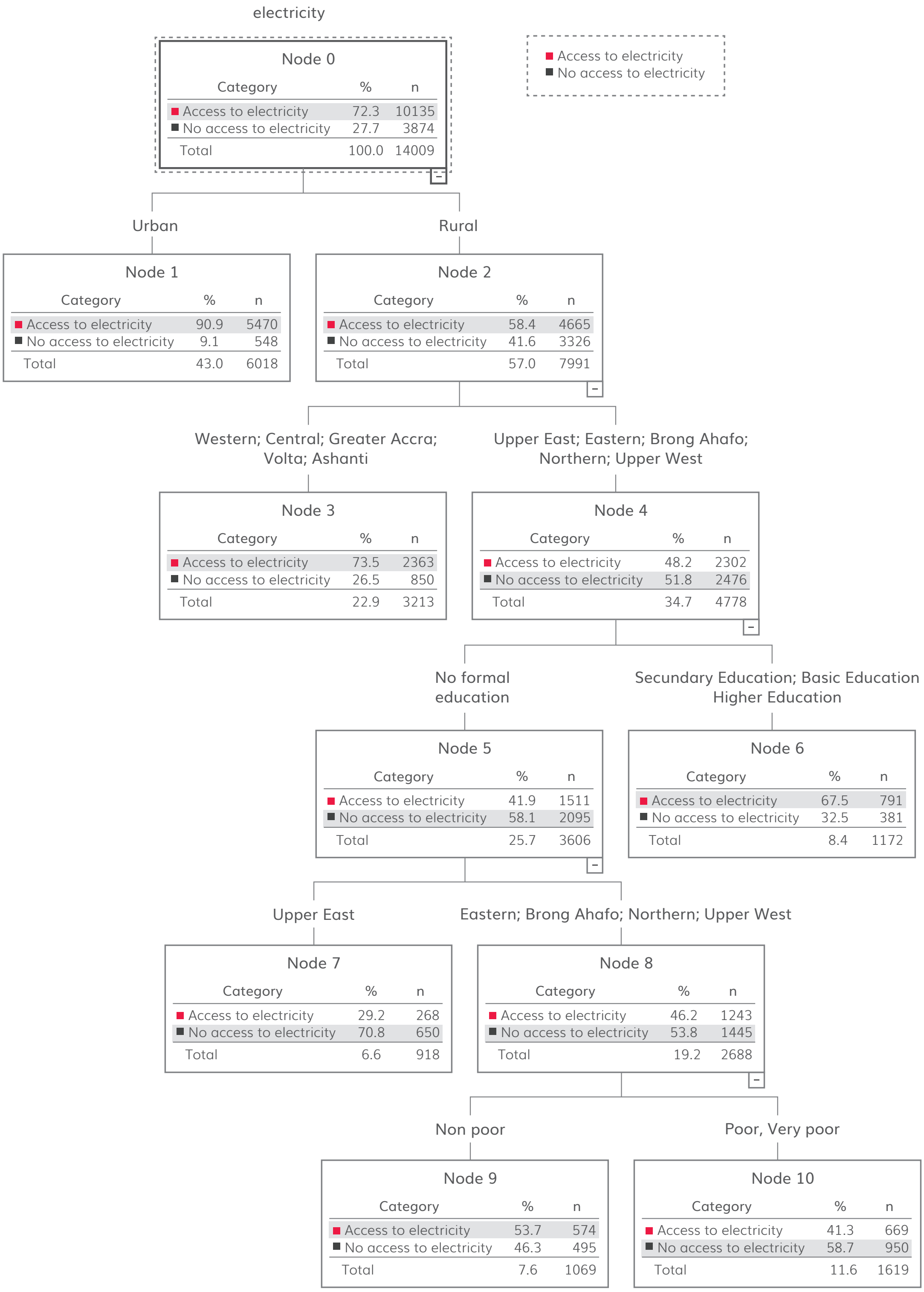
Figure 1. Decision tree highlighting difference in clean fuels access



Note. Authors' construct using GLSS 7.

Source: Ghana Statistical Service (2017).

Figure 2. Decision tree highlighting difference in electricity access



Note. Authors' construct using GLSS 7.
Source: Ghana Statistical Service (2017).

Synergies and trade-offs between SDGs are inevitable outcomes of endeavours to improve energy access. Adopting the LEAP-IBC model, this study analyses Ghana's current household energy policies and shows interlinkages between SDG 3 (good health and wellbeing), SDG 2 (zero hunger), SDG 5 (gender equality), SDG 11 (sustainable cities and communities), and SDG 13 (climate action). The current energy consumption pattern in Ghana shows negative interactions between SDG 7 and the other SDGs under consideration.

Ghana has sought to improve energy access in line with Target 13.2[8], Indicator 13.2.1[9] of the SDGs. This Target and Indicator request that states outline intended nationally determined contributions (INDC) to mitigating climate change, improving climate resilience, and lowering emissions–while not threatening food production. This aims to have countries make voluntary commitments to reducing their greenhouse gas emissions (United Nations Framework Convention on Climate Change, 2015). However, according to the International Energy Agency (2015), the energy sector accounts for roughly two-thirds of all anthropogenic greenhouse gas (GHG) emissions. Thus, most countries express their INDCs through national energy plans that reflect their natural resource and financial limitations.

> **Ghana could reduce by 30% GHG emissions by 2030, if appropriate international financial support, technology transfer, and capacity building assistance are available.**

Ghana's INDC aims to reduce GHG emissions by 15% from the projected Business as Usual (BAU) level of 73.95MtCO2e[10] by 2030. This reduction could rise to 30% if appropriate international financial support, technology transfer, and capacity building assistance are

8 Integrate climate change measures into national policies, strategies, and planning (See https://unstats.un.org/sdgs/metadata?Text=&Goal=13&Target=13.1).

9 Number of countries that have communicated the establishment or operationalization of an integrated policy/strategy/plan which increases their ability to adapt to the adverse impacts of climate change, and foster climate resilience and low greenhouse gas emissions development in a manner that does not threaten food production (including a national adaptation plan, nationally determined contribution, national communication, biennial update report or other) (See https://unstats.un.org/sdgs/metadata?Text=&Goal=&Target=13.2).

10 Million tonnes carbon dioxide equivalent.

available (Government of Ghana, 2015). Based on our analysis, total CO_2 emissions in the BAU scenario will increase from 15 million tons of CO_2 equivalent in 2010 to 24.8 million tons in 2030. In contrast, the policy success scenario shows a small decrease in GHG emissions compared to the BAU scenario. This success scenario factors in a programme to ensure all urban households, and 50% of rural ones, use LPG to cook, and the provision of 50,000 improved stoves by 2020.

Our analysis also shows that rural households emit more greenhouse gases compared to urban households. Thus, rural GHG emissions are projected to increase from 11.3 million metric tons of CO_2 equivalent in rural areas from 2010 to 13.3 million metric tons in 2030 under the BAU scenario. High utilisation of polluting fuels such as firewood, crop residues, and charcoal, in inefficient cooking devices, are important contributing factors. Alternatively, urban GHG emissions in the BAU scenario increase from 4.5 million metric tons of of CO_2 equivalent in 2010, to 8.0 million in 2030.

Emissions from energy consumption that damage health and the climate also include short-lived climate pollutants (SCLPs)[11], such as soot, methane, and ozone (WHO, 2015). The BAU scenario projects temperature levels to rise between 0.001°C to 0.015°C in Ghana through 2010-2030, with carbon dioxide and methane the two major contributors. According to the World Health Organisation (2016), the global warming potential of methane emitted from household fuels is 25 times greater than carbon dioxide. It is also precursor to ground-level ozone, a risk factor for asthma and other lung diseases. Mohajan (2012) studied the effect of methane gas, associating its presence in the human environment to the demand for biofuels. The author recognises that while lower concentrations and intakes are acceptable on health grounds, excess environmental methane gas absorbs oxygen and could thus wipe out humankind.

Additionally, consumption of wood fuels leads to ozone depletion, carbon sequestration, and has been linked to cardiovascular disease, digestive disorders, and malignant neoplasms (WHO, 2010; United Nations Environment Programme, 2016). Bunker et al. (2017) investigate the effect of heat exposure on years of life lost (YLL) from non-communicable diseases (NCDs) in Nouna, Burkina Faso, between 2000 and 2010. The authors found that exposure to moderate or extreme heat significantly increases premature mortality from NCDs. In particular, cardiovascular diseases alone accounted for 50% of YLL.

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11 Short-lived climate pollutants (SLCPs) are agents that reside in the atmosphere for a relatively short period of time—from a few days to two or so decades—and have a warming influence on climate.

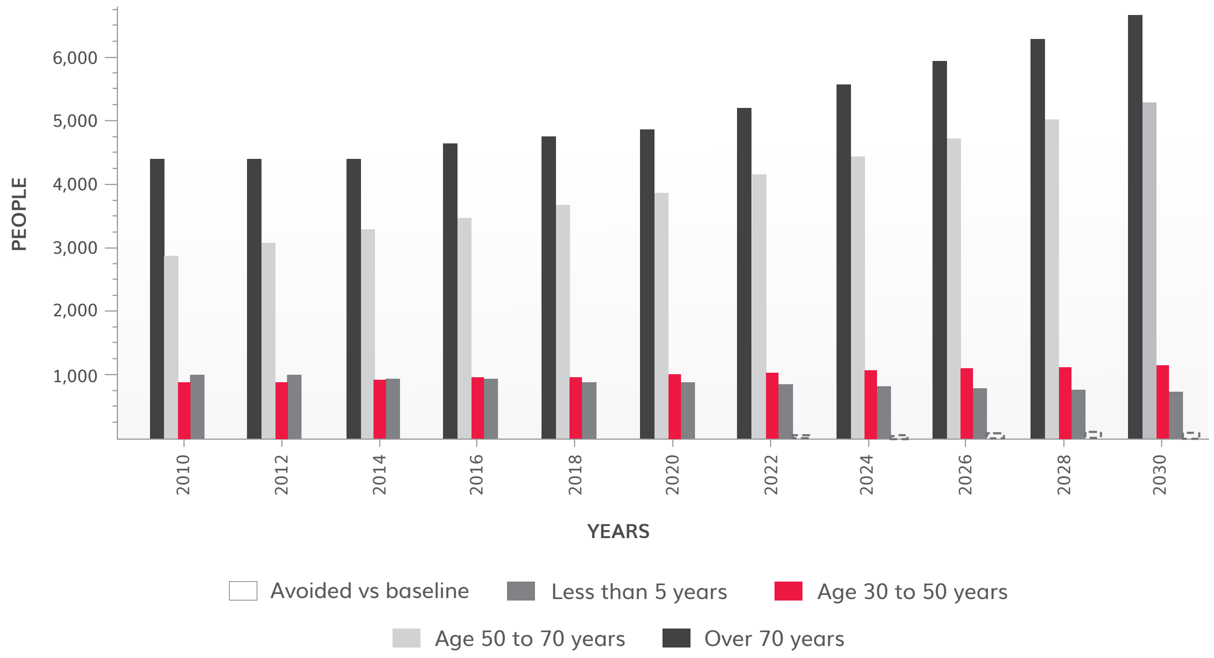
NCDs, in turn, cause substantial economic drain by reducing labour supply, productivity, investment, and education levels. Codjoe and Nabie (2014) link rising temperatures in Ghana to cerebrospinal meningitis. This illustrates that increases in temperature are particularly problematic in tropical countries like Ghana. For instance, rising temperature levels in the tropics have increased demand for air conditioners among growing middle classes (Hoegh-Guldberg et al., 2018). This increases household GHG emissions and raises the already high emissions reported in the BAU scenario.

Should the same household energy policy initiatives be implemented until 2030, Ghana's contribution to emissions will rise unabatedly. This will contravene the Paris Agreement, which requires all signatories—Ghana included—to limit global temperature increases to below 2°C. Despite a slight reduction in emissions in the policy success scenario, there remains a trade-off in current energy policies between household energy consumption and the environment. To mitigate these trade-offs and maximise synergies, the government can develop more ambitious clean energy policies and interventions. Prioritising the extension of grid electricity to the entire population is one possibility. Another is to encourage private sector participation in providing off-grid electricity—through non-polluting technologies—to supply areas beyond the reach of government at subsidised costs. This will help mitigate environmental externalities often associated with consumption of unimproved energy services.

Despite a slight reduction in emissions, there remains a trade-off in current energy policies between household energy consumption and the environment.

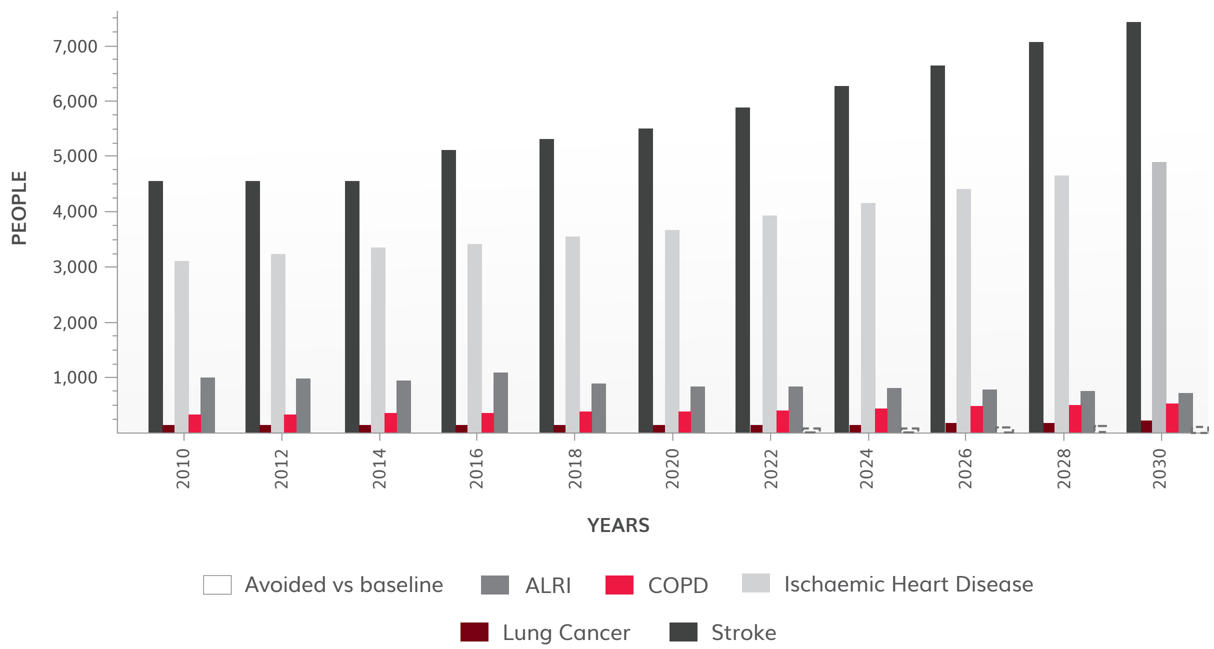
Household energy (SDG 7) targets are closely related to other Goals that promote healthy lives and wellbeing. Specifically, reducing deaths and illness from hazardous chemicals and air, water and soil pollution, and contamination are important cogent goals (SDG 3, Target 3.9). Under the BAU scenario, total Ghanaian deaths because of exposure to household energy pollution are projected to increase from 9,1038 in 2010 to 13,920.8 in 2030. The demographics most at risk are the elderly and children under 5. Our results reinforce that leading causes of death from household energy use are strokes, ischemic heart diseases (mostly in adults) and acute lower respiratory infections, (mostly in children) (see Figures 3 and 4). These findings support other studies indicating that lower respiratory infections, stroke, and ischaemic heart disease are associated with household air pollution and comprise three of the top 15 causes of disease in Ghana (WHO, 2017).

Figure 3. Age-specific deaths due to $PM_{2.5}$



Note. Authors' construct using GLSS 7 datasets.
Source: Ghana Statistical Service (2017).

Figure 4. Disease specific deaths due to household energy use



Note. Authors' construct using GLSS 7 datasets.
Source: Ghana Statistical Service (2017).

The qualitative component of these analyses also foreground the health and gender implications (SDG 5) of unclean cooking fuels. Quotes from focus groups discussions illustrate how women's household roles render them more susceptible to negative consequences of less efficient cooking fuel use. One participant remarked that:

> ...I remembered I was severely sick, at first it started with some kind of heat in my body, I thought it was just one of those things, but my head continues to ache me, and so I finally went to the hospital for a check-up, the first thing the doctor asked was if I cook and stay with huge fire for long, I said yes and so the doctor explained to me that I was sick because I always stay by firewood my blood pressure is reducing...

Another participant recalled:

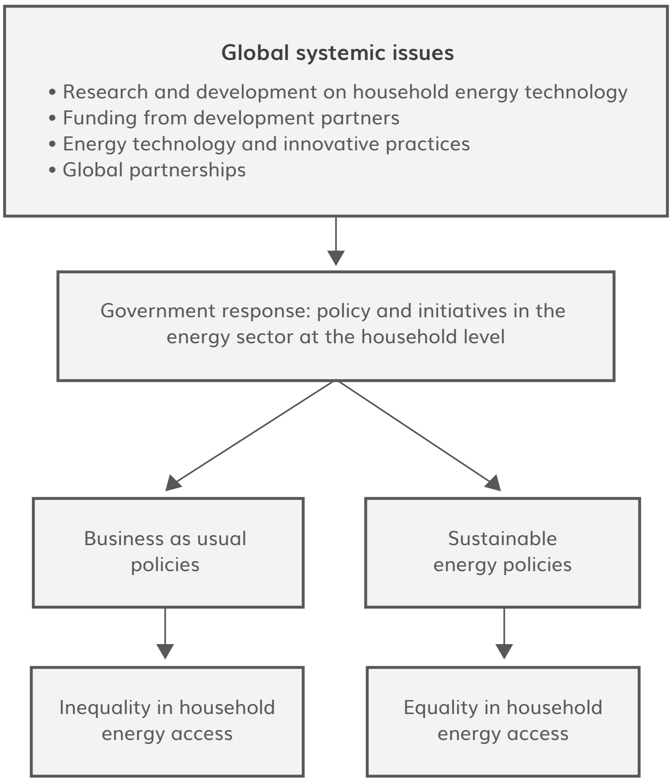
> ...as for our eyes, we have been suffering from this smoke thing, it is a problem for us, cooking everyday with firewood, look at my eyes, they are all red because of the smoke that goes into my eyes every day that I cook...

Based on analysis from the focus group discussions, we corroborate that household energy use has dire consequences on the health of women.

Trade-offs between current energy consumption and food security (SDG 2) also exist. Household energy pollutants under the BAU scenario are projected to cause crop losses, especially in staple grains like maize and rice, of 4,005.07 thousand tonnes in 2030: an increase from 1891 thousand tonnes in 2010. Maize crops will see the highest losses of 3977.8 thousand tonnes in 2030. The impact is even greater when considering interlinkages between biofuel energy consumption, acid rain formation, food production, and the agricultural labour supply. For instance, excess atmospheric carbon dioxide, methane and other GHGs will create acid rain capable of destroying food crops and contaminating natural drinking water sources (Gonzalez, C. (2011).A chain of ill-health conditions, reducing the farming population for agricultural labour in Ghana, may result, in turn decreasing productivity and raising food safety issues.

To mitigate these trade-offs and enhance synergies in SDG implementation more generally, this study considers some global systemic approaches that can improve equitable energy access. Figure 5 maps how global systemic approaches affect household energy access in Ghana. International organisations have formulated policies, research and development (R&D) agendas, and energy technologies to address the role of the energy systems in achieving development ambitions. These policies are clustered under goals relating to affordable energy, clean energy, and reliable energy. The Cookstove Alliance, for example, has globally researched and promoted improved cookstoves. Funding from development partners including the United Nations Development Programme (UNDP), the African Development Bank (AfDB), USAID, the Global Alliance for Cookstoves and other partner agencies, has helped advance these programmes. These initiatives have been adopted in Ghana and transformed into policies to provide households with clean cooking energy fuels and technologies. However, the usefulness of these policies is context-specific. As the scenarios illustrate, household energy inequalities increase if a BAU approach is taken. On the other hand, if sustainable energy policies such as the Sustainable Energy for All Acceleration Framework (SEAAF) are implemented, equality in household energy access can be achieved.

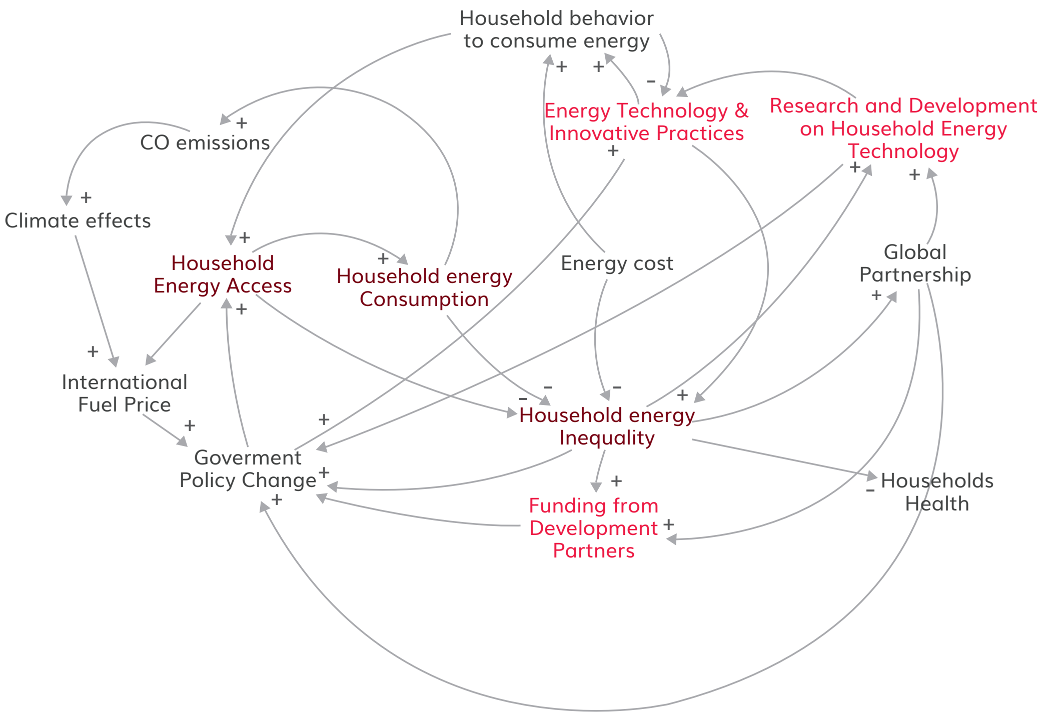
Figure 5. Transmission mechanism of the influence of global systemic issues to household energy access in Ghana



Elaborated by the authors.

Figure 6 shows the resulting Causal Loop Diagram that maps the domestic transmission of global agendas. Components in green indicate elements of Ghana's household energy system captured under SDG 7, Target 7.1. Components in red indicate global systemic issues that can affect the achievement of that goal in Ghana. The household energy inequality element reinforces the need for government policy change to improve household energy access and narrow inequality. Thus, the element 'household energy inequality' reinforces itself, creating a causal loop. In the reinforcing loops, interactions are such that each action adds to the previous. To address the main objective of this section, only causal loops associated with global systemic issues are considered.

Figure 6. Causal Loop Diagram of Ghanaian household energy access and global systemic issues



Elaborated by the authors.

Conclusions and implications

Ghana faces many challenges in providing universal household access to clean energy. While some regions and localities enjoy good access, others are struggling. For those without access to clean cooking fuels and electricity, their health and wellbeing, as well as opportunities for education and productive work, are reduced.

Large gaps exist between those with the most and least access to clean cooking fuels and electricity, degrading the aspiration of leaving no one behind. Access to clean cooking fuels is the more unequally distributed, with a gap of 71 percentage points between those with the most and least access. Similarly, although Ghana's average electricity rate is among the best in sub-Saharan Africa, the access gap between the best off and the furthest behind groups is approximately 64 percentage points. According to the Ghana Living Standard Survey (GLSS7), around 76% (10,631 households) of households in Ghana are being left behind in access to clean cooking fuels. Comparatively, approximately 28% (3,874 households) are left behind in accessing electricity.

Levels of access to clean cooking energy show that the poor or the very poor, rural households are worse off than any other group. When considering electricity as a lighting source, urban households (91%) had the highest access while rural households (71%) in the Upper East Region, with no formal education, had the lowest.

This interplay of geographical location and poverty illustrates that reliance on clean fuels is a question of both accessibility and affordability in most countries. This paper's findings have important policy implications because they reinforce the need to also focus on accessibility and affordability in policy design. In particular, cleaner fuel policies should not only increase supplies, but show how modern fuels can accelerate economic growth for households. Public education may be an effective instrument to promote a move away from more polluting fuels.

Adopting the LEAP-IBC model, this study has also scenario-tested both Ghana's current household energy policies, and alternative policy measures, to illustrate interlinkages with SDG 3 on health, SDG 2 on food security and sustainable agriculture, SDG 5 on gender, SDG 11 on cities, and SDG 13 on climate change. Current household energy consumption patterns negatively affect users' health (SDG 3), their environment (SDGs 11 and 13), livelihoods (SDG 2) and productivity (SDG 5).

Access to clean household energy (SDG 7) targets are highly intertwined with SDG 3. For instance, total deaths because of exposure to household energy pollution in Ghana are projected to increase from 9,1038 in 2010 to 13,920.8 in 2030 under the BAU scenario.

As women prepare food for their families, they inhale thick smoke for hours, negatively affecting their health. Children, the elderly, and other vulnerable people also suffer disproportionately because, like women, they spend more time at home. Both scenarios in this paper show that these negative interlinkages between the SDGs will continue if pro-poor policies are not implemented. More premature deaths and disease will result from exposure to cooking fuel pollutants.

Access to clean and affordable energy (SDG 7, Target 7.1) is a key enabler of food security and better nutrition (SDG 2). Exposure to household energy pollutants is projected to cause crop losses (maize and rice) of 4,005.07 thousand tonnes in 2030. Our analysis also mapped the relationships between urban ecosystems (SDG 11) and household energy use. Under the BAU scenario, $PM_{2.5}$ emissions in urban areas will increase from 9.9 thousand metric tonnes in 2010 to 33 thousand metric tonnes in 2030.

It is important that households have access to clean energy and technologies for health reasons, but also to advance sustainable development and reduce GHG emissions. However, solutions rely on the right technologies, commercially viable business models, supply chains that can reach remote areas, consumer information, community involvement, and innovative financing. In most cases, these are beyond the capabilities of the country.

> **Access to clean household energy (SDG 7) targets are highly intertwined with good health and well-being (SDG 3).**

Ghana needs global support—foreign aid, partnerships, and research and development assistance—to be able to achieve SDG 7 (specifically Target 7.1). This process will entail institutional reforms, coordination among key actors in the energy sector, and breaking a siloed work culture to enable cross-sectoral collaboration in mitigating trade-offs. This study has demonstrated that policymakers can no longer work in silos, developing energy plans based on assumptions from the energy sector only. To achieve SDG 7, they also need to work with local sectors and international organisations to achieve other related SDGs.

Recommendations

The following are key recommendations for policymakers:

- Explore the household energy behaviour to understand reasons for localised disparities in clean energy access. Multi-stakeholder consultations, such as community engagement and research, are needed in areas with high-energy inequalities to understand household motivations and choices. Research demonstrates that households have abandoned most cooking technologies not suitable for cooking with traditional fuels.

- Encourage collaboration among government ministries and agencies to strengthen household incentives for choosing clean energy sources. Given the impact that energy inequalities have on the other SDGs, cross-sectoral and inter-ministerial coordination is imperative since different SDGs are in the domain of different ministries in Ghana. For example, collaboration between the Ministry of Health (the custodian of SDG 3 in Ghana) and the Ministry of Energy (the custodian of SDG 7) is needed to ensure that Target 3.9 (by 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water and soil pollution and contamination), and Indicator 3.9.1 (mortality rate attributed to household and ambient air pollution) are met.

- Support global partnerships, research and development. The government can increase global cooperation to acquire appropriate energy technologies and improve knowledge transfer. This will help build trust and encourage collaboration among stakeholders to fill critical gaps in the household energy sector.

- Support data collection to understand how energy inequalities affect individual household members. Existing data do not allow for a full understanding of household choices, behaviours or inequalities arising among and within households. Disaggregated data are therefore necessary to understand impacts on particular household members. Data could be gathered periodically through specific and representative surveys.

- Improve national energy policies that are 'pro-poor'. Energy policies should advance sustainable development alternatives while ensuring energy access for Ghana's poorest people. Truly competitive and widely-used technologies must be implemented and adapted to the cultural needs of users. Energy goals should be redefined to address broader and cognate development outcomes, including health, gender equality, and access to essential services.

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Appendices

Appendix 1. Resources

Links to policy documents

Ghana National Energy Policy --- https://www.greengrowthknowledge.org /sites/default/files/downloads/policy-database/GHANA%29%20National%20Energy%20Policy.pdf

National Action Plan to Mitigate Short-lived climate pollutants (Ghana) https://www.ccacoalition.org/en/resources/national-action-plan-mitigate-short-lived-climate-pollutants-ghana

Country Action Plan for Sustainable Energy for All (SE4All) - http://energycom.gov.gh/files/SE4ALL-GHANA%20ACTION%20PLAN.pdf

Renewable Energy Act, 2011 -- http://energycom.gov.gh/files/RENEWABLE%20ENERGY%20ACT%202011%20(ACT%20832).pdf

Energy Sector Strategy and Development Plan. https://ouroilmoney.s3.amazonaws.com/media/documents/2016/06/09/energy_strategy.pdf

Checklists for key informants and focus group discussion

1. What are the major sources of energy used in the area to meet daily basic energy requirements? e.g. Cooking and Lighting
2. Is household energy (cooking and Lighting) a problem in the community ?
3. What are the major problems of using your household energy? – Health e.g. Respiratory, eye irritation , skin problems, chest pains , sore throat , headache etc.
4. Which group of people are affected most--- Women, Children, Men
5. Are these fuels expensive, are they getting scarce, what was the situation long ago-say 10 years back?
6. How does the availability and price compare to 10 years ago in the area?
7. Do fuel availability and/or price vary by season?
8. Generally how do people cope with household energy problems for both cooking and lighting?

9. Do you think people could shift more and more to commercial fuels such as LPG and electricity for cooking and lighting?
10. What are the major constraints or possible new avenues for such shift?
11. Is there a credit facility available, which organization is extending credit for household energy use?
12. What are the main uses of electricity in the household? e.g for reading at night, watching TV
13. Is electricity supply reliable in the community?
14. Which household members make use of electricity and for what purposes?

Methodological Overview

Research objective	Data sources	Indicators	Data analysis
Leaving no one behind			
To assess household energy use in Ghana to identify the "furthest behind" and their shared circumstances	Secondary Sources Ghana Living Standard Survey (6)- 2010 Housing and Population Census. Energy Policies e.g. SE4ALL Country Action Plan. National Energy Policy World Bank data sites. Ministry of Finance reports. Primary Sources Key informant interviews.	1. Number or percentage of households connected to the national grid or to an off-grid system (number of connections) by sex of household head, locality (rural and urban) and income levels 2010-2030. 2. Number of households using improved biomass cookstoves as primary cooking device by sex of household head, locality (rural and Urban) and income levels, 2010-2030.	• Descriptive analysis • Predictive analysis using the Decision tree
Leaving no one behind			
To examine the synergies and trade-offs between the implementation of SDG 7, and the other SDGs	Secondary Sources: World Health Organization (WHO) Household Energy Database 2016. Internet Primary Sources: Key – Informant interviews	1. Multiple impact assessment using the LEAP-IBC tool to estimate health (SDG 3), climate (SDG 13), air pollution (SDG 15) and crop benefits (SDG 12) and of current energy use and alternative scenarios	• Econometric Simulations using the LEAP – IBC model • Context analysis of qualitative data

World Health Organization (WHO) Household Energy Database 2016.			
To examine the global systemic issues that affect the implementation of the SDG 7 in Ghana.	Secondary sources Ministry of Finance, budget allocation to energy. International Energy Agency databases. World Bank databases Primary sources: Key Informant interviews	1. Research and Development –effect on household energy use 2. Funds from Development Partners for household related energy issues 3. Global Partnership that focus household energy related issues	• Transmission Mechanism • Causal Loop Diagram

Appendix 2. The decision tree analysis

The decision tree analysis was used to identify groups with the lowest and highest access to clean energy by using the two selected indictors. The main aim of the decision tree classifier is to build a model that predicts the target variable based on various input variables.

Target variable: Type of cooking fuel used (clean or not).
Input Variables: The input variable being considered are the following:

Residence (urban vs. rural);
Household wealth
Highest education level in the household (No Education, Primary, Secondary, Higher).
Region

To identify the groups with the highest or lowest access to clean energy, a classification tree is constructed using the classification and regression tree (CART) algorithm in SPSS software. CART constructs binary tree and splits dataset based on Gini index. It prunes the tree using minimal cost complexity, which is computed using number of leaves and percentage of data instances mis-classified by the tree.

The root node of the tree is the entire population sample. The tree method algorithm starts by searching for the first split (or branch) of the tree. It does so by looking at each circumstance and separating the sample in two groups, so that it achieves the most "information reduction." This information metric can be defined in a few ways, while the most common one – and the one used in this analysis is the "entropy".

The tree representation

A tree method is an algorithm that estimates the accessibility of clean energy by partitioning the household into different groups based on the household factors chosen:

$$P(Y_i = 1||X_{1i}\, X_{2i} \ldots\ldots X_{Li}) - \sum_{j=1}^{m} Pj \times I\, ((X_{1i}X_{2i} \ldots.X_{li}) \in\, A_j$$

Where Yi is the observed opportunity for the i-th household in the sample, X1i, ..., Xli are the household factors. In the example of clean energy, Y is the access to clean cooking energy,

X1, X2, X3, X$ (where l = 4) are residence, household poverty status and highest education level of household head. A1, A2, ... Am are the different partitions of the sample, also called end nodes, where:

$A_i \cap A_j = \emptyset$ and $\bigcup_{i=1}^{m} A_i = \Omega$

This means the end nodes are mutually exclusive and complementary, and every household belongs to one and only one of the end nodes. I () only takes value 1 when the i-th household belongs to j-th end node, otherwise, I () takes value 0. The tree algorithm generates the end nodes, according to metrics that measure the effectiveness of the partition that gives to different levels of access to clean energy.

Information theory and entropy is a very common choice for the metrics. Entropy for j-th end node can be calculated according to the definition:

$$I_E(p_j) = -(p_j \times log_2 p_j + \left(1 - p_j\right) \times log_2 \left(1 - p_j\right))$$

The aggregated entropy for the tree is

calculated by $H\,(T) - \sum_{j=1}^{m} qj \times I_E\,(p_j)$

Where qj is the sample proportion of Aj. The actual algorithm that generates the end-nodes works step-by-step, starting from the entire sample. Each time the sample is partitioned, new end-nodes are generated and the entropy is calculated and compared to the entropy before the new partition. Apart from finding groups that are significant, the operate under the algorithm that each group should have enough members.

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