COSTS AND BENEFITS ANALYSIS OF CLEAN AND IMPROVED COOKING SOLUTIONS IN GHANA

Voice for Change Partnership (V4CP)

March, 2020.

SNV

LIST OF ACRONYMS

ALRI: Acute Lower Respiratory Illness 20

BC: Black Carbon 58

BCR: Benefit-Cost Ratio 15

BCTs: Behaviourial Change Techniques 42

Capex: • Capital costs 20, 57

CER: Carbon Emission Reduction 20, 57

CH4: Methane 58

CO: Carbon Monoxide 58

CO_2:Carbon Dioxide 8

COPD: Chronic Obstructive Pulmonary Disease 20

CSO: Civil Society Organizations 9

DMC: • Distribution and marketing costs 20, 57

EB: Environmental benefits 20, 57

ESL: Environmental Services Lost 20, 57

FC: Fuel cost 21

FS: Final Scenario 22

GHACCO: Ghana Alliance for Clean Cookstove and Fuels 12

GHG: Greenhouse Gas 6

GHp: Ghana Pesewas 31

GHS: Ghana Cedi 59

GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit 12

GLSS: Ghana Living Standard Survey 37

GoG: Government of Ghana 12

HAP: Household Air Pollution 7

HB: Health Benefits 20, 57

hr: Hour 59

IAQ: Indoor Air Quality 20, 57

IHD: Ischemic Heart Disease 20

IS: Interim Scenario 22

Kg: Kilogram 59

LC: Learning costs 20, 57

LPG: Liquified Petroleum Gas 1, 19

MJ: Mega Joule 59

N_2O: Nitrous Oxide 58
NAMA: NATIONALLY APPROPRIATE MITIGATION ACTION 12, 21
NCCP: The Ghana National Climate Change Policy 22
OC: Organic Carbon 58
Opex: • Operation and maintenance costs 20, 57
SDG: Sustainable Development Goal 6
SE4ALL: The Ghana Sustainable Energy for All Action Plan 12, 21
SNEP: The Strategic National Energy Plan 12, 21
TCS: Traditional Cookstoves 7
TS: Time savings 20, 57
UN: United Nation 12
USAID: United States Agency for International Development 12

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EXECUTIVE SUMMARY

Household cooking, particularly in developing countries like Ghana, is mostly done using Traditional Cookstoves (TCS) technologies and unclean fuels. The costs of these high polluting cooking methods and fuels have been significant at the private and social levels. Household Air Pollution (HAP) kills at least 14,000 people prematurely in Ghana, annually (WHO, 2018). Again, the annual burden of disease in Ghana associated with HAP was over 790,000 in 2012 of which 17,500 deaths were recorded (WHO, 2015). The environmental costs of CO_2/GHG, locally and regionally, are considerable; the impact of climate change on global warming, changing weather patterns, food security, air quality, etc. is far-reaching.

Accordingly, national and international efforts have been focused on delivering cleaner cooking technologies and interventions to ameliorate, and to some extent, reverse the growing impact on the environment. While these interventions have been associated with benefits, they have also come with costs. Previous studies have sort to investigate these costs and benefits; purposely to ascertain if the benefits of these interventions justify their costs. And, to understand why in the midst of these 'benefits', the penetration of Improved Cookstoves (ICS) remain slow.

This study estimates and compares the benefits and costs of switching from TCS to improved alternatives at the household level including wood-burning, charcoal-burning, and Liquified Petroleum Gas (LPG) stoves. This was achieved utilizing country-specific averages (in some cases regional/global averages) as guided by literature and stakeholders. The assessment also includes sensitivity and Scenario analyses of net benefits.

It found that:

1. Based on the average values, using the three mentioned clean cooking technologies has more costs than benefits at the household level. This is confirmed by the simulation analysis as a huge majority of trial results delivered negative net private benefits.
2. While all three technologies witness time savings in Ghana, only wood ICS provide fuel savings. In other words, while the existing ICS in Ghana cook quicker that their corresponding TCS, not all of them cook with relatively smaller quantity of fuel.

3. All three technologies deliver benefits that outweigh their costs when social and environmental benefits are introduced i.e. the benefits driven from climatic improvements and forest restoration or decreased degredation are enormous enough to make the adoption ICS worthwhile. Indeed, the impact of such improvements on agriculture, frequency and magnitude of disasters, etc. directly affects households and national development. Specifically, LPG delivers largest positive net benefits; followed by wood and charcoal ICS, in that order.
4. The capital cost of adopting an ICS solution in Ghana constitutes the largest driver of total cost; followed by maintenance and program costs with learning cost trailing.
5. With respect to benefits, health benefits are largest driver of the total benefits for adopting charcoal ICS and LPG solutions in Ghana; ahead of time saving. For wood ICS, it is fuel savings.
6. For charcoal ICS, efficiency (time and fuel) is critical for delivering increased desirable net benefits.
7. For wood ICS, CO_2 emissions factor, amount of biomass harvesting that is (non)renewable, fuel efficiency and time efficiency, are central to achieving desired result.
8. For LPG stoves, the huge net benefit is driven by its cleanness (including its indirect contribution to non-renewable biomass harvesting), energy conversion and fuel efficiencies.
9. In all the scenarios, resultant gains outweigh the investment required in multiple folds i.e. the economic value of ICS adoption is far more beneficial at the national level and thus investments that deepens ICS penetration by the State are justified.
10. The drivers of ICS adoption are economic, social, and demographic and therefore require comprehensive understanding of the unique dynamics of different segments of the Ghanaian society to tackle.

The results—that private net benefits are not always positive—could explain why penetration of ICS solutions have been slow. This is so because whiles the capital cost of adopting an ICS solution has been found to be very significant in the analysis, the value of these solutions to the private household, in the midst of low incomes, is found to be incommensurate. As such, the awareness of households especially in the rural areas on the benefits of improved cooking on health and the climate and its impact on economic activities like farming needed to be communicated clearly during roll out of campaigns; they must be made clear to elicit a better appreciation of the social benefits of ICS solutions since our results clearly show that private benefits alone, don't cut it.

And accordingly, recommends that:

1. ICS Solution should include subsidies/incentives. As shown, the huge capital and maintenance costs of adopting and using ICS erodes all their private benefits. As such, incentives that seek to reduce these costs will be beneficial.
2. Efficiency—time and fuel—improvement should continue to be cardinal in stove design. As found, fuel and thermal efficiency are major drivers of ICS adoption in Ghana. First, because they improve the economics of such interventions and second, because the time spent in cooking is an important consideration especially for urban households. It is therefore important to continue to invest in ways to improve these efficiencies to be able to continue to make a better case for ICS.
3. Fuel availability and access should be improved to prevent the need for stove stacking. As government continues to drive the growth of ICS especially LPG, across the country, it is important to continue to create an enabling environment that will entice the private sector to invest in siting fuel distribution outlets e.g. LPG vending points, particularly in rural areas as availability and access of fuel are key drivers of ICS adoption.
4. ICS interventions should include well-coordinated promotional and educational campaigns to improve awareness of the benefits of ICS solutions. ICS solutions must be sold. Just as any new product, the benefits of these solutions both to the individual household and to the society must be well marketed. Awareness campaigns should accompany these interventions to improve their appeal.
5. ICS interventions must be based on research and accompanied by well-thought out implementation policy with in-built M&E program and measuring metric to allow for periodic review and assesement.
6. Engagement of community groups especially women peer groups and Behavioral Change Techniques (BCTs) should be factored into ICS interventions implementation. The role social groups can play in awareness campaigns and behavior modification cannot be underplayed. CSOs and program implementers should work with women groups and community influencers in the promotion of ICS solutions
7. Future studies in the clean cooking space could also include designing methods for measuring aesthetic and cultural/status change benefits as these could significantly improve net private benefits.

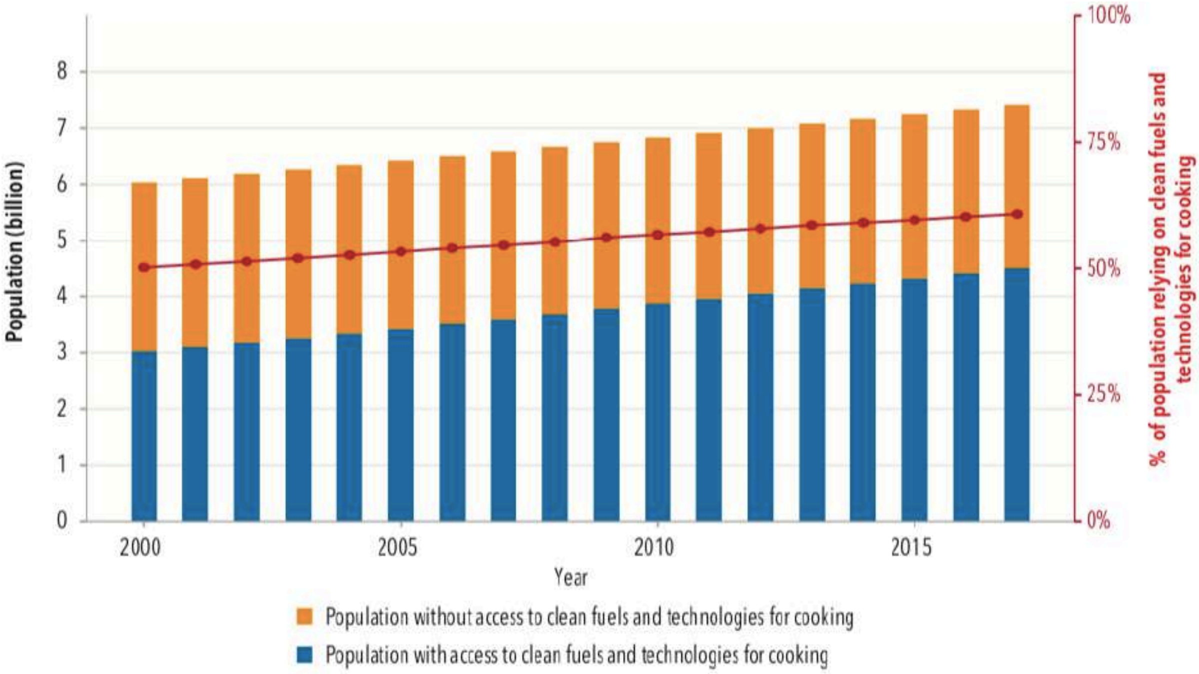
8. ICS interventions should take into consideration demographic, social, and other cultural-specific differences to enhance general acceptability. The appeal of these solutions and their ability to achieve their goals is hinged on their ability to effectively target and meet the specific needs of different segments of society. ICS solutions should not be general or come as 'one-cap-fits-all'. They should among others recognize income differential, rural-urban disparities, household composition disparities, etc. For instance, the current government 'Rural LPG Program' which involves free distribution of LPG cylinders/stoves to rural households may struggle to attain its goals. And this is why. While it is ideal to introduce rural homes to LPG stoves, the cost of running them taking into consideration the level of rural incomes in Ghana and the fact that rural households predominantly do not buy fuel, may only result in stove abandonment or stacking. Conversely, such a program may be more 'beneficial' and pragmatic if applied to urban and peri-urban Ghana. This is because the relatively higher urban household incomes will mean their ability to purchase fuel and maintain such stoves. On the other hand, government rural interventions could target the introduction of biomass ICS that are more efficient and burn more cleanly. This takes the income and fuel acquisition characteristics of the rural household into consideration and government can guarantee an improvement in environmental degradation and HAP/IAP exposure.
9. Government should use the power of the State as the biggest buyer to create a market for ICS. In this respect, it is recommended that existing government programs and institutions such as the School Feeding Program, LEAP, NADMO, boarding schools, Prisons, etc. must be utilized to create a primary market for ICS. This increased demand will not only enhance ICS penetration but will also positively affect the capacity and ultimately efficiency of stove manufacturers.
10. Stakeholders in the clean cooking space should support and/or create activities or programs that seek to develop the business and financing models of private players along the ICS value chain. This recommendation is steeped in the observation, gathered from the stakeholder engagements, that ICS manufacturers in Ghana are only commercially viable when they receive carbon credits or grants. They are therefore unable to continue production in the absence of such incentives/interventions.

Project Background

1.0 INTRODUCTION

1.1. Background

According to the 2019 Tracking SDG 7 (Energy Progress) report, in 2017, 39% of the world's population depended on unclean fuels for household cooking and heating; translating into some 3 billion people (IEA, IRENA, UNSD, WB and WHO, 2019). The report also revealed that between 2010 and 2017, average access to clean fuels and technologies grew by just 0.5% annually. Indeed, within this period, Sub-Saharan Africa actually saw an increase in the number people without access to clean fuels and technologies; from below 750 million to about 900 million people.



urce: WHO 2019.

Figure 1: Global Clean Cooking Access

Evidence shows that a huge proportion of unclean fuels are solid fuels such as wood and charcoal. Therefore, solid fuel consumption is hugely linked to air pollution. In 2014, 42% of global CO_2 emissions came from solid fuel consumption (World Bank, n.d.). And given that an enormous proportion of households cooking is done using solid fuels i.e. 89%, 77%, and 35.3% in Africa, Asia, and Latin America, respectively, it is predictable to note that households' contribution to Greenhouse Gas (GHG) emissions is very significant (WHO, n.d.).

This is explained by the fact that a huge majority of households utilize solid fuel-dependent traditional stoves (TCS) and heaters with low efficiency (Jeuland & Soo, 2016); particularly in developing countries and rural households.

There are consequences for the use of these TCS, which costs can be distinguished into private and social costs. These stoves burn poorly resulting in incomplete combustion that releases small particles and constituents proven to be injurious to human health. Household air pollution (HAP) has thus become a leading health risk factor in developing economies. In 2018, harmful exposure to smoke from cooking with polluting fuels killed around 4 million people globally (WHO, 2019). 54% of these deaths were women and children. In Africa, 739,000 deaths were attributed to HAP in 2016 (WHO, 2018). Aside the fact that the most affected from this HAP are women and children, the direct economic and environmental costs are enormous as observed in the areas of forest destruction, ill-health and the burden of disease, time and productivity loss, ambient air quality degradation and global warming consequent on the release of carbon-based greenhouse gases.

1.2. The Context and Justification for Study

Like any developing economy with a large rural population, household solid fuel consumption and emissions are significant in Ghana. 89% of Ghana's biomass consumption is from woodfuels (Energy Commission of Ghana, 2018). Similarly, the residential sector accounts for 46% of Total Final Energy Consumption (TFEC). In addition, about 68% of Ghanaian household rely on woodfuels of which some 51% are TCS i.e. about 16 million people. See Figure. 2 below for details (Ghana Statistical Service, 2019).

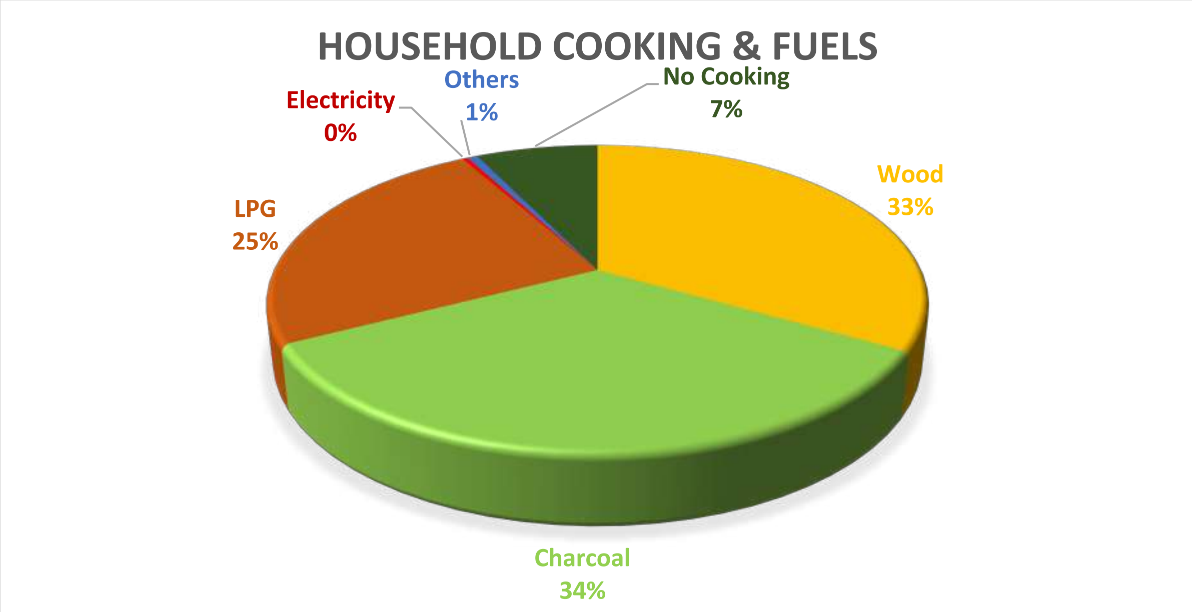


Figure 2: Household Cooking in Ghana (GLSS 7: Latest Available Data)

The remaining 49% with access to ICS including LPG is broken-down as follow; 0.6% improved firewood stoves, 12.2% improved mud stoves (wood), 11.9% improved charcoal stoves, 24.5% LPG and improved pellet/briquette (Ghana Statistical Service, 2019).

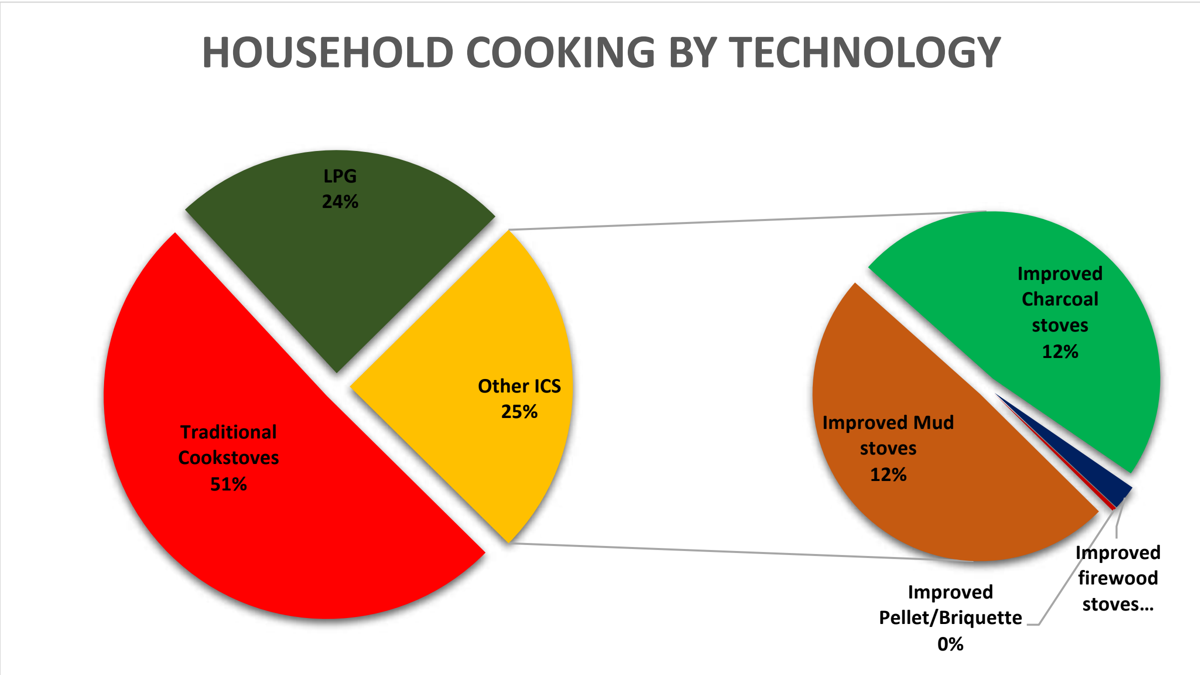


Figure 3: Household Cooking Technology

Predictably, HAP kills at least 14,000 people prematurely in Ghana, annually (WHO, 2018). Furthermore, approximately 64% or 7.7 million metric tons of the CO_2 emissions in Ghana are attributed to residential and commercial/public buildings (Trading Economics, n.d.). The environmental costs of CO_2/GHG, locally and regionally, are significant; the impact of climate change on changing weather patterns, food security, air quality, etc. is far-reaching. Scientific pronouncements on the negative impacts of the time spent collecting biomass fuel, the degradation of forest ecosystem, and the release of GHG in the atmosphere are emphatic (Lim, et al., 2013, Jeuland & S., 2012, Ramanathan & G., 2008, Jeuland, et al., 2014, Jagger & G., 2014, Bond, et al., 2013, Bailis, et al., 2015).

Following from this, there has been increased focus (1) by Civil Society Organizations (CSO) on clean cooking advocacy and engagement; and (2) by State and International Agencies on finding and funding a mix of appropriate interventions that will enhance the transition from TCS and solid fuels to enhanced technologies. Nevertheless, such interventions only make sense if they are based on studies that scientifically digest both the associated costs and benefits of such a shift. This is especially so, considering that interventions that seek to propel the uptake of ICS and cleaner fuels happen in the midst of relatively cheaper existing technologies with easily accessible fuels.

The present study seeks to unearth an understanding of the true economic and social and environmental value of adopting clean cooking technologies at the household level. In addition, through the anticipated iterative simulations, an understanding of the relative importance of various factors to the scale-up of ICS will be achieved. This is particularly important because of the spread of factors that militate against adoption and use of ICS, e.g. the cost and availability of fuel, the cost of operating and maintaining stoves, the cost of and time to learn how to use new technology, etc.

The simulations here offer a range of options that give policymakers an idea of what works. At the national level, the comparative analyses of switching from TCS to different tiers of ICS gives a Ghana-context needed for advocacy/engagement with the targeted groups.

1.3. Objectives of Study

This study generally sought to provide insights on the economic value of clean cooking interventions at the household level with the view to making a strong contribution to clean cooking policy and intervention pathways. The following specific objectives were pursued;

i. Estimate the costs and benefits of clean & improved cooking interventions at household level.
ii. Establish the social and environmental benefits of clean & improved cooking interventions at household level.
iii. Establish the level of gender and social inclusion in clean cooking interventions
iv. Analyze the risks and opportunities of the study of clean cooking interventions

Sector Players & Programs

2.0 CLEAN COOKING PROMOTION IN GHANA

The Government of Ghana (GoG) through its agencies ranging from ministries to commissions and their subsidiaries provides the overarching policy guidance for the use and introduction of clean cooking interventions and goals. The cross-cutting nature of the issue has, over the years, engendered a collaborative approach to developing policies, laws, goals, directives, and interventions. In this regard, a host of notable interventions stand out: The Ghana Sustainable Energy for All Action Plan (SE4ALL), The National LPG Promotion Programme, The Strategic National Energy Plan (SNEP), The Ghana National Climate Change Policy (NCCP), The Renewable Energy Act, The Renewable Energy Masterplan, The Ghana Forest and Wildlife Policy, The Bioenergy Policy, The Wildlife Policy, The Forestry Development Masterplan, The Energy for Poverty Reduction Action Plan, and The National Energy Policy. These interventions are geared towards the promotion of sustainable energy use including the advancement of ICS introduction and use, for the attainment of health improvements and promotion of Ghana's commitments under the NATIONALLY APPROPRIATE MITIGATION ACTION (NAMA). Indeed, the coming into force of the United Nation (UN) SDGs has brought into sharper focus, issues of sustainable energy use starting from the household level. These policies and initiatives by the State have yielded significant results in a number of areas. Principally, the share of biomass in primary energy supply dropped considerably from 62% in 2000 to 37% in 2018 (EC, 2019, 2018, 2014); well ahead of the 40% target by 2020. Also, LPG consuming households grew from 9.5% in 2006 (EC, 2012) to 18.4% in 2018 (GSS, 2018).

On the nongovernmental, bilateral, and multilateral levels, the role of Relief International and EnterpriseWorks with funding from the USAID and Shell Foundation in the design, production, and introduction of the Gyapa ICS in Ghana, in 2002, could be described as both pioneering and revolutionary. The Gyapa brand remains about the most widely known ICS in Ghana today. Also, the activities of the Clean Cooking Alliance (CCA) and its implementing partner; the Ghana Alliance for Clean Cookstove and Fuels (GHACCO), SNV Netherlands Development organisation (SNV), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), United States Agency for International Development (USAID), etc. have complemented GoG efforts in pursuing clean cooking advancement in the country. Specifically, these organizations in their advocacy, among other things, educate relevant groups and professionals on the need for clean cooking, build the capacity of agents on the value chain including the manufacturers and distributors of clean cookstoves, help state agencies in the development and implementation of policies and programs, and support and commission research into relevant issues in the area. SNV's activities in the area of cookstoves for income-generating uses and support to GHACCO in the area of institutional strengthening are worthy of note. Indeed, this study is a further contribution to the sector.

In the private sector, the role of Toyola Energy Limited, Man & Man Enterprise, Cookclean Ghana Limited, Anomena Ventures, Gyapa Enterprise among others, in the introduction, development and supply of clean cooking technology is significant. Accordingly, the clean cooking sector in Ghana is endowed with an active cookstove market with several consumer segments, local cookstove producers, and a decent government interest.

Empirical Literature

3.0 REVIEW OF EMPIRICAL LITERATURE

As noted earlier, "*biomass burning for home energy use is a major health and environmental concern*" (Piedrahita, et al., 2016). A host of literature and medical investigations have established the direct impact of HAP from cooking and heating on health and the environment (Bruce et al. (2000), Bruce et al. (2006), Smith et al. (2000), Smith et al. (2004), Hutton, et al. (2007)). Accordingly, the discussion has shifted from what the impact of HAP from biomass and other solid fuels burning is, to how stakeholders can reverse the growing incidence of solid fuel use. This shift which has occasioned the introduction of various interventions globally, especially on clean cooking at the household level has attracted a lot of literature. Most specifically, a number of studies have been conducted on the costs and benefits of these interventions; primarily to establish justification or otherwise for their introduction. These studies were propelled by the development of comprehensive guidelines by WHO for CBA analysis. (Hutton & Rehfuess, 2006)[1]. In this regard, four main studies standout; Hutton, et al. (2007), Jeuland & Pattanayak (2012), Larsen (2014) and Jeuland & Soo (2016), which are briefly discussed below.

Hutton, et al. (2007) performed cost-benefit analysis of two global interventions that sort to introduce cleaner fuels and cleaner and more efficient cookstoves. The benefit-cost ratio (BCR) was adopted as the measure. In this respect, average economic benefits per year (which include the savings from less illness, the value of productivity gains associated with reduced illness and deaths, time savings, tree savings and reduced emission) is divided by the corresponding net programatic, fuel and stove costs. The paper analysed 2 scenarios on the bases of the UN Millenium Development Goals (MDGs) entailing 50% and 100% adoption rate of cleaner fuels and ICS in 2005 and 2015 respectively. It found that for 50% and 100% reach for LPG, it will cost US$13 billion and US$34 billion, with fuel, stove and program costs accounting 85.7%, 13.5% and 0.8% of these, respectively. On the other hand, the benefits associated with 50% reach amounted to US$90 billion for LPG and US$105 billion for ICS with time savings on fuel collection and on cooking accounting for the largest gains. As such, BCR for LPG in rural

[1] The WHO guidelines present a framework for performing a CBA of household energy and health interventions. This framework presents a matrix with 10 questions that a CBA must answer to be comprehensive and consistent.

areas was 1.5≤BCR≤21.2 and for urban areas, 2.6≤BCR≤negative[2]; whiles that of ICS is negative for both. The paper therefore concludes that "*Investments in interventions to reduce indoor air pollution are potentially cost-beneficial".*

On their part, Jeuland & Pattanayak (2012) sort to find out why uptake of ICS has been slow by verifying the claim that household adoption of ICS always yield "*large and positive benefits"*. The study analysed the monthly costs and benefits attendant with switching from TCS to ICS by a household. The costs identified in this study include capex[3], opex, program, learning and fuel expense. Benefits include health improvements, time savings from cooking, improvement in social standing and environmental gains to society. These costs and benefits were estimated using about 5-dozen parameters expressed in equations. Monte carlo and one-way parameter analysis was done to test the range of parameters. The width of the parameters are determined based on literature review. The study concludes that the private net benefits[4] of adopting ICS is not always positive; indeed, it is negative in many cases. While subsidies and carbon financing are incentives for ICS adoption, they are not always suitable because the impact of capital costs on net private benefits relatively modest. The paper notes that the cost of fuel, fuel and time use efficiencies, the incidence and cost of illness (COI) of Acute Respiratory Illness (ARI) and the cost of cooking time form the principal drivers of costs and benefits. As such, subsidies on stove cost may be ineffective given that maintenance cost of using these stoves in terms fuel cost will offset the appeal to households. Indeed, even fuel subsidies may be counterproductive from an environmental point of view, in that, the wrong signal they may send to the market may result in an overuse of these stoves by the rich. It concludes that these coupled with the inconvenience of switching technologies and cultural inappropriateness could be the factors that are slowing the incidence of adoption of cleaner and improved ICS.

Larsen (2014) estimated the health benefits of reduced exposure to air pollution and the costs and benefits of air pollution mitigation. The paper calculated disease burden associated with PM2.5 exposure and found that as a key causative factor for premature death and disease, an annual cost of health burden of US$2.3 trillion is required to lower mortality risk. In addition, the paper found that benefits from mitigating househould cooking and heating PM2.5 pollution

[2] "A negative ratio means that intervention cost savings exceed intervention costs" (Hutton, et al., 2007)

[3] Capex: the capital cost of adopting an ICS. Opex: the Operational/maintenance cost of using ICS

[4] Private net benefits are based on health benefits and time savings; excluding environmental improvement and emissions reduction.

dwarfs its costs by far. It further found that the annual net benefits of reaching 50% access for ICS and LPG amounts to US$51-200 billion with 100% coverage yielding US$62-316 billion. The global BCR was estimated as 6-18 for coal and biomass ICS and 1.1-2.9 for LPG adoption. Nonetheless, whiles this is the case, the net net benefits for LPG are greater. Thus, it is recommended that "LPG should be promoted among those that can afford it".

Jeuland & Soo (2016) improved on the approach presented in Jeuland & Pattanayak (2012). These improvement were made in four main areas; valuing health improvements,climate emissions benefits, incorporation of new information and updating of data. On health valuation for instance, Jeuland & Pattanayak (2012) depended solely on the results of trials that reviewed the link between adoption of cleaner stoves and health improvements. The study found that (i) time and health benefits are the main drivers of net benefits at the average level (ii) stove, program and fuel (stoves using commercial fuels) costs drive net cost (iii) at the social level, all options are beneficial (iv) 50% of wood-burning, charcoal-burning and LPG ICS trials result in negative net benefits at household level, 36% for electric stoves and (v) outcomes range from -US$6.9 to US$7.5 per household in a month for the 10^{th} to 90^{th} percentiles. It concludes that these may be reasons behind the low incidence of adoption of ICS at the private level. At the social level however, the results are more positive albeit minimal for biomass ICS.

Overall, the journey of costs and benefits analyses of the introduction of ICS and fuel mitigations has been remarkable as shown in the literature above. These range of analysis has been wide and the focus has also been varied. Yet, the findings have been varied and, in some cases, contradictory. From the above, whiles Hutton, et al. (2007) found negative BCR for biomass ICS and positive BCR for LPG adoption, Larsen (2014) found positive BCR for both biomass ICS and LPG adoption. Again, whiles Jeuland & Soo (2016) asserts that net private benefits for biomass, charcoal and electric ICS are not always positive, Jeuland & Pattanayak (2012) notes that median net private benefits for these stoves are negative. There is therefore a need for further work in this area especially at country specific level to offer more precise findings and explanations for the trends witnessed at the country level.

Study Methodology

4.0 OUR APPROACH AND METHODOLOGY OF STUDY

4.1 Methodology

In this study, we followed the approach proposed in (Jeuland & Soo, 2016) to compare the benefits and costs of switching from TCS relying on wood and wood-product fuels to improved alternatives at the household level. The technologies included are wood-burning stoves, charcoal-burning stoves, and Liquified Petroleum Gas (LPG) stoves. Where applicable, the technologies were further disintegrated into tiers to allow for a detailed and micro level understanding of each technology's performance. The monthly household costs of switching to improved technologies is compared with the monthly household benefits. The baseline technology is the traditional wood-burning stove. The net benefit criterion was used to assess the appeal of alternative stoves to the baseline technology.

This methodology allowed us to include and examine both the private benefits and costs accruing directly to the household. In this regard, a market-reflective discount rate was adopted. Unlike other approaches that are restricted to only private costs and benefits, this method extends to the social level where all the investment and costs of using and operating various stove technologies are accounted for; including the impact of such changes on emissions and forest degradation associated with unsustainable fuel-wood harvesting. The overall costs of the intervention were then estimated by escalating the household costs taking into consideration the various scenarios adopted in this analysis.

We also utilized Monte Carlo simulation and one-way parameter sensitivity tests methods to analyze the net benefits arising from switching technologies. The Monte Carlo simulations allowed us to vary all uncertain parameters simultaneously. The one-way parameter sensitivity test on the other hand allowed for one factor movement to assess the impact of individual parameters. The variations in this regard were guided by literary positions on their distribution.

In respect of employment opportunities created and identification of the key drivers for clean cooking intervention, we engaged stakeholders in the clean cooking space through interviews and where necessary, relied on available literature to answer these questions.

4.1.1 The Costs and Benefits of Adopting Improved Cookstoves

Lately, institutional research at both local and international levels have served to enrich the information available for studies such as this. The work of agencies on making both technical and behavioral data available is remarkable. Such works have created data pools on the technical characteristics of stoves ranging from their efficiency to emissions levels as presented in the GACC catalogue (Clean Cooking Alliance, 2020). They have also exposed the usage behaviors that serve to back or undermine gains from clean cooking interventions. Even so, there remain a number of parameters that are difficult to find data on. In such cases, estimates presented in the literature are best proxies to adopt.

The costs considered by this study are the capital costs of acquiring new technologies and all accompanying set up (Capex), operation and maintenance costs (including time) spent on technology (Opex), distribution and marketing costs associated with making the technology accessible (DMC) and learning costs associated with adopting new technology (LC). LC comprises both the time spent and the reduction in the quality of food prepared. Total cost is estimated as simple aggregation of all the individual components listed above. All estimated time costs assume a fraction of the market wage for unskilled labour including time benefits.

The benefits of switching to ICS considered in this paper include health improvements arising from cleaner Indoor Air Quality (IAQ) (HB); measured through reduced morbidity (Mb) and mortality (Mt), time savings from cooking (TS), environmental benefits resulting from reduced emissions and forest loss/degradation accruing to society (EB); measured as an aggregate of carbon emission reduction (CER) and environmental services lost (ESL). Just as total costs, total benefit is an aggregate of all the components above and are directly proportional to rate of use of ICS.

HB from switching to ICS are derived from improvements in exposure to HAP. This study accordingly includes a model to compute the supposed reduction in $PM_{2.5}$ owing to the adoption of ICS. The model computes the technology-specific reductions based on usage rate. It also calculates the consequent change in relative risk for Acute Lower Respiratory Illness (ALRI), Ischemic Heart Disease (IHD), lung cancer and Chronic Obstructive Pulmonary Disease (COPD), taking into consideration the onset lag for these diseases and using the Integrated

Exposure-Response model (RR_{IER}) developed by Burnett, et al. (2014) for the estimation of disease burden from $PM_{2.5}$.

Furthermore, the model takes into consideration the proportion of biomass that is sustainably harvested as this is necessary to balance and accommodate the regenerative impact of forest replacement. In this regard, data from WHO, IPCC, GACC, EPA and similar agencies are used as well as prominent literature to serve as a guide. The advantages of this approach are well discussed in (Anon., n.d.)[5].

To address the complexities associated with the different gasses as their impact over time differ (discounting for the onset lag noted above), the present value of radiative forcing from the various gasses is adopted. With the advancement of literature and availability of data, it is now possible to undertake a complete estimation of radiative forcing[6] from a cocktail of emissions linked to each stove type, over time. In fact, emissions such as Black Carbon (BC) and Organic Carbon (OC) that hitherto were not completely understood, are now well explained; allowing for distinct treatment of their unique characteristics. As such, carbon costs are discounted to improve the consistency of valuation[7]. We also calculated the purported improvements.

Note that net change in fuel cost (FC) which comprises both the relative time spent on gathering and the money spent in acquiring fuels, can either be costs or benefits depending on the relative. All models used in this work are presented in Table 11 in the appendices. The model parameters and their ranges are also presented in Tables 12 and 13.

4.1.2 Scenario Explanation

Scenarios for access of ICS will be developed and simulations performed around them.

In line with Ghana's commitments under the Nationally Appropriate Mitigation Action (NAMA) (Atul, et al., 2016) the Ghana Sustainable Energy for All Action Plan (SE4ALL), the National LPG Promotion Programme, the Strategic National Energy Plan (SNEP), and the

[5] (Anon., n.d.; Jeuland & Pattanayak, 2012; Jeuland & Pattanayak, 2012; Jeuland & Pattanayak, 2012) presented improvements on the approach presented in (Jeuland & Pattanayak, 2012).

[6] Radiative forcing is the change in the earth's energy balance due to the presence of an agent like greenhouse gasses.

[7] See supra note 5

Ghana National Climate Change Policy (NCCP), we recommend two types of scenarios; Interim Scenario (IS) and Final Scenario (FS). IS simply refer to scenarios with targets below 100%, whiles FS are scenarios seeking universal penetration. Note that FS do not seek to build upon IS. Each is indepecdent.

Together, the study assessed five scenarios made up of three IS and two FS. The first interim scenario (IS-1) is based on stove tiers and sets 10% penetration rate for tier 3 and 4 cookstoves in rural and urban Ghana respectively. The study utilizes the Voluntary Performance Targets to segregate stoves into tiers for analysis. The International Workshop Agreement (IWA) framework based on ISO standards rates cookstoves along 6 tiers beginning 0 as the lowest performing to 5 as highest performing. 5 indicators are used for this rating: thermal efficiency, CO emissions, $PM_{2.5}$ emissions, safety, and durability. That said, it is noteworthy that the Ghanaian ICS market is dominanted by stoves below tier 3. As such, this study is based on tier 2 ICS except for the scenario IS-1 as described above.

IS-2 is based on stove type and sets a 50% penetration rate for ICS; IS-3 is based on fuel type and sets 100% increase for LPG stoves. The two FS—FS-1 and FS-2—sets 100% coverage of ICS and LPG in Ghana.

The above scenarios are broad-based enough to present a complete picture of what it will take for clean cooking interventions to achieve the general social, climatic, and environmental goals and commitments set out in the national documents mentioned above. Again, they also fall in line with Ghana's commitments internationally, especially in respect of the SDGs 3, 5, 7 and 13.

Furthermore, these assumptions have been chosen because they realistically take into consideration the vast ICS access disparity between urban and rural Ghana which in 2017 stood at 41% against 8% in favour of Urban Ghana (IEA, IRENA, UNSD, WB and WHO, 2019). The baseline scenario below presents a picture of Ghana's current position relative to the assumptions and Scenarios.

Scenario Baseline and Assumptions:

1. Baseline/Business-as-usual Scenario represents the current situation (as things stand) i.e. 51% reliance on TCS; 49% on ICS including LPG is broken-down as follow; 0.6%

improved firewood stoves, 12.2% improved mud stoves (wood), 11.9% improved charcoal stoves, 24.5% LPG and improved pellet/briquette stoves. Total number of households in Ghana are 7,299,95 with urban and rural being 4,089,330 and 3,210,595, respectively. The 24.5% LPG penetration represents 1,788,482 households with 34.8% urban and 8.7% rural household penetration as 1,423,087 and 279,322, respectively (GLSS 7)

2. All scenarios are independent of the others i.e. the scenarios are not related except for the fact that they are built from national goals. Each scenario starts from the baseline.
3. For each scenario, the technology in question at every point is assumed to be the only technology being supplied. For instance, in IS-1 below, at 10% penetration of tier 4 ICS, if the number of households to be supplied with tier 4 ICS is 1 million (representing the 10%), then the results show how much it will cost to supply 1 million wood ICS or charcoal ICS or LPG and the corresponding (net)benefits.
4. Achieve universal access by 2030 for modern energy forms
5. Achieve 50% LPG coverage by 2025
6. Reduce the average urban household woodfuel energy intensity by 50% by 2025
7. Reduce the average rural household woodfuel energy intensity by 10% by 2025
8. Reduce share of woodfuels in energy mix to 40 per cent by 2025
9. Achieve 10% penetration of ICS by 2025

Scenarios:

Scenario Control Variable	Target	Equation	Variable Identification
• IS-1	10% penetration of tier 4 ICS in urban households 10% penetration of tier 3 ICS in rural households	$TC_{si} = (TC_{hh} \times thh_{ut4}) \ldots\ldots\ldots equ(s1)$ $TB_{si} = (TB_{hh} \times thh_{ut4}) \ldots\ldots\ldots equ(s2)$ $TC_{si} = (TC_{hh} \times thh_{rt3}) \ldots\ldots\ldots equ(s3)$ $TB_{si} = (TB_{hh} \times thh_{rt3}) \ldots\ldots\ldots equ(s4)$	TC_{si}, TB_{si}, and thh_{ut4}, thh_{rt3} are total cost and benefit of scenario i and total number of urban and rural households adopting tier 4 and 3 ICS according to the scenario rate
• IS-2	50% penetration of ICS	$TC_{sii} = (TC_{hh} \times thh_{sii}) \ldots\ldots\ldots equ(s5)$ $TB_{sii} = (TB_{hh} \times thh_{sii}) \ldots\ldots\ldots equ(s6)$	TC_{sii}, TB_{sii}, and thh_{sii} are total cost and benefit of scenario ii and total number of households adopting ICS according to the scenario rate.
• FS-1	100% penetration of ICS	$TC_{siii} = (TC_{hh} \times thh_{siii}) \ldots\ldots\ldots equ(s7)$ $TB_{siii} = (TB_{hh} \times thh_{siii}) \ldots\ldots\ldots equ(s8)$	TC_{siii}, TB_{siii}, and thh_{siii} are total cost and benefit of scenario iii and total number of households adopting ICS according to the scenario rate.
• IS-3	Double LPG penetration	$TC_{siv} = (TC_{hh} \times thh_{siv}) \ldots\ldots\ldots equ(s9)$ $TB_{siv} = (TB_{hh} \times thh_{siv}) \ldots\ldots\ldots equ(s10)$	TC_{siv}, TB_{siv}, and thh_{siv} are total cost and benefit of scenario iv and total number of households adopting LPG according to the scenario rate.
• FS-2	100% LPG penetration	$TC_{sv} = (TC_{hh} \times thh_{sv}) \ldots\ldots\ldots equ(s11)$ $TB_{sv} = (TB_{hh} \times thh_{sv}) \ldots\ldots\ldots equ(s12)$	TC_{sv}, TB_{sv}, and thh_{sv} are total cost and benefit of scenario v and total number of households adopting LPG according to the scenario rate.

Table 1: Scenarios

Note: Except LPG or otherwise indicated, ICS are tier 2

4.1.3 Stakeholder Engagement

The questions on identifying the key drivers for clean cooking interventions and employment creation are as empirical as they are hypothetical. Performing a desktop review of appropriate literature will answer questions of this nature but such approach alone, will provide global-level answers which are inadequate for the specific purposes of this research. Accordingly, a stakeholder review of country-specific interventions is an appropriate complementary approach in this case. These engagements were in the form of brief interviews with stakeholders or players along the clean cooking chain. The study engaged stakeholders in the policy and regulation space, CSOs, Manufacturer and Distributors. Attached in the appendices are the sample interview questions.

Study Results

5.0 RESULTS OF STUDY

The results are presented in two sets including; the net private benefits for the uptake of ICS and the net benefits representing an aggregation of both private and social (environmental) costs and benefits of ICS uptake (exceptions should be noted in the discussions). As shown in the parameters earlier, this study makes use of a gamut of GHG in CO_2, CH_4, N_2O, CO, BC, OC. The addition of the three extra gasses to the three Kyoto protocol gasses is due to the growing understanding of the importance of these other gasses especially relative to the amount of these gasses produced from household biomass burning.

5.1 Composition of Benefits and Costs for Average Values

This section presents results, including graphical representations, on the composition of costs, benefits, and net benefits for each of the 3 ICS technologies; wood, charcoal and LPG using the mean values presented in Table 13. The mean parameter values are, to a large extent, country-specific averages. While the use of some regional or global averages, to some extent, generalizes the results, the sensitivity and simulation results presented subsequently, allows for an elastic assessment of each parameter and the safe adoption of conclusions made herein.

The results as presented in Figure 4 below reveal that the capital cost (Capex) of ICS acquisition and Operations and maintenance cost (Opex) form the principal costs in the total cost. Specifically, whiles the Capex of wood and charcoal ICS are almost similar at GHS3.54 and GHS3.22 per household per month respectively, that for LPG is almost double these at GHS6.50. This is not particularly surprising given that while the purchase of a stove is all that is needed for both wood and charcoal, LPG setup requires the purchase of a burner and a gas cylinder. Distribution and marketing cost and learning cost follows in that order.

While net fuel savings is positive for wood ICS at GHS2.69, it is negative for charcoal ICS and LPG. The principal explanation underlining this, is both practical and simple. Wood fuel consumption is predominantly a rural phenomenon compared to charcoal and LPG which are more urban. In rural areas, wood is more collected than purchased. Charcoal and LPG, on the other hand, are purchased and from the results, at a cost that is above the benefit derived from fuel saving. In addition, a typical 14.5kg gas cylinder that costs about GHS80 will likely last 1 month in a typical household of 4. Conversely, about two (2) 50kg bags of charcoal that costs at over GHS50 each will be required for that same period of time (UNDP, 2015). In addition to fuel savings, time savings and health benefits make up the rest of the benefits under private benefits. Charcoal ICS enjoys the largest time savings followed by LPG; with wood ICS trailing as expected.

The figure shows that LPG followed by charcoal ICS offer the biggest health benefits. As to be expected, LPG delivers the lowest IAP/HAP during cooking. At the household level, costs such as medical bills, time spent at the hospital, discomfort associated with illness and hospitalization as well as deaths have been found to be associated with exposure to pollution during meals preparation. This result confirms that switching to ICS especially LPG offer higher health benefits. Practically, it is easier to see why. Wood ICS releases more smoke and other gasses that are injurious and discomforting including watery and painful eyes, respiratory diseases, cancers, etc. than charcoal and LPG.

The results obtained are consistent with empirical literature as shown in Isihak, et al. (2012) and Jeuland & Soo (2016).

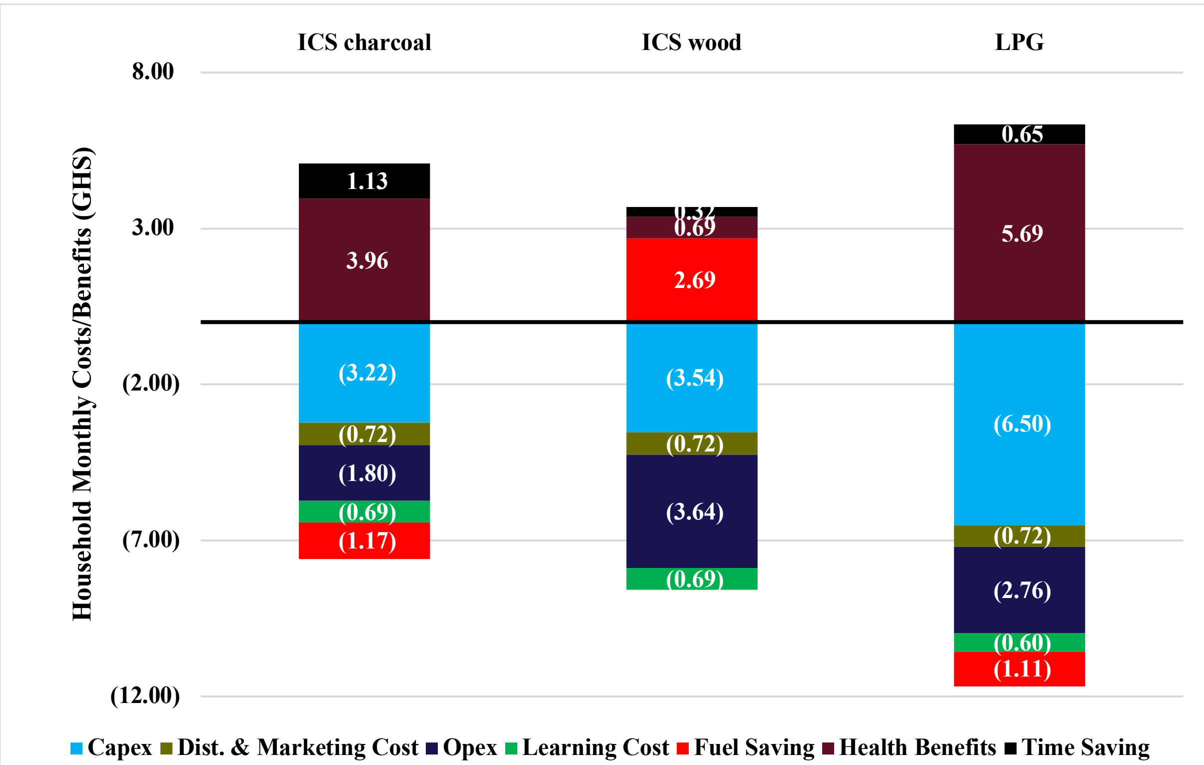


Figure 4: The Composition of Costs & Benefits for Mean Parameter Values

The results as presented in Figure 5 below indicates that Carbon Emissions Reduction constitutes the greatest environmental benefit driven from the adoption of ICS. Expectedly, LPG offers the greatest benefits in this regard. In fact, even with the inclusion of environmental benefits from tree savings to the benefits of the two biomass stoves, they stil remain behind LPG.

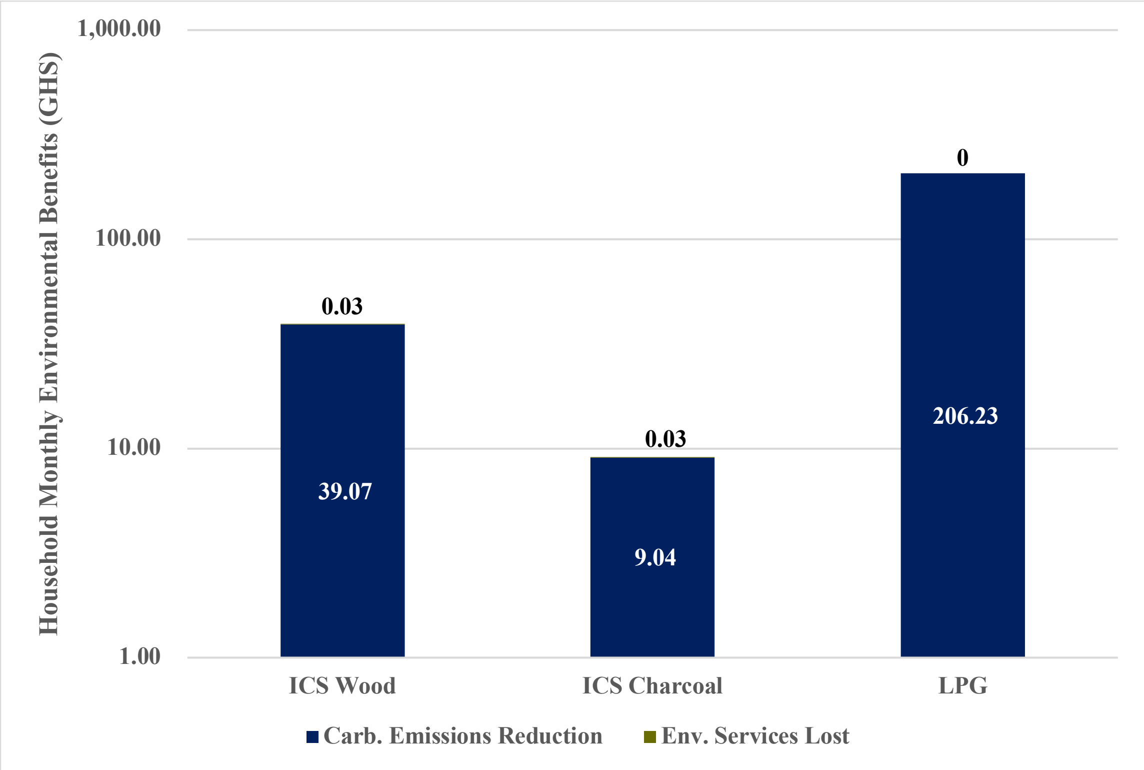


Figure 5: The Composition of Environmental Benefits for Mean Parameter Values

As shown in Figure 6, Net Private Benefits for all three stoves, at the mean values, are negative. In other words, at the household level, cost incurred in procuring, setting up, running, and maintaining ICS is higher than the benefits associated with reduced illnesses and deaths, time, and fuel savings concomitant with their use. Whiles this finding, except for LPG, is inconsistent with the results of Jeuland & Soo (2016), it is consistent with Pinto (2016). Pinto (2016) found highly negative private benefits for improved biomass cookstoves in India. It is, to some extent, also consistent with Jeuland & Pattanayak (2012) that found negative outcomes for all three stove types at the 10th percentile of simulations and negative median net private benefits for biomass and charcoal ICS. Similarly, Hutton, et al. (2007) found less than unitary BCR for biomass ICS. This is attributable to the inability of health benefits and time savings, and in the case of wood, fuel savings, to compensate for the high capital cost of stoves.

The above notwithstanding, at the national level i.e. when social and environmental benefits associated with ICS use is brought on as in the net social benefits and net benefits (defined above), the benefits are highly positive—completely outweighing the costs—for all three stove types. LPG delivers the highest net (social) benefits; followed by wood ICS. First, this is expected as ICS are known to be more efficient and deliver more reduced emissions. Second, LPG is a cleaner fuel and thus offer the largest emissions reductions. Third, the fact that net benefits of wood ICS is greater than charcoal ICS is surprising as it is expected that charcoal should mostly deliver larger emissions reduction than wood. That said, this may be attributable to the fact that OC emissions factor for wood is higher than charcoal. Note that Keita, et al. (2018) found that while wood fuel burning emits 11.05g/kg of OC, charcoal burning emits just 1.78g/kg. Indeed, Zhang, et al. (2014) also found 2.69g/kg OC emissions from wood burning; even this is still greater the 1.78g/kg for charcoal. It is also important to note that Organic Carbon (OC) emission has a net cooling effect and thus, in the calculation of emissions forcing, offset other global warming GHG such as BC. Again, note that Zhang, et al. (2014) found that wood fuel burning generates 0.57g/kg of BC. "*The implication is that greater combustion and fuel efficiency produces far greater gains than stove type, at least from a climate perspective"* Jeuland & Soo (2016). Hence, the efficiency of charcoal ICS must be quite higher than wood ICS to deliver net benefits that outweigh wood ICS. Also, it is important to note that the net benefits are driven, almost exclusively, by social benefits. As such, the difference between the two is marginal.

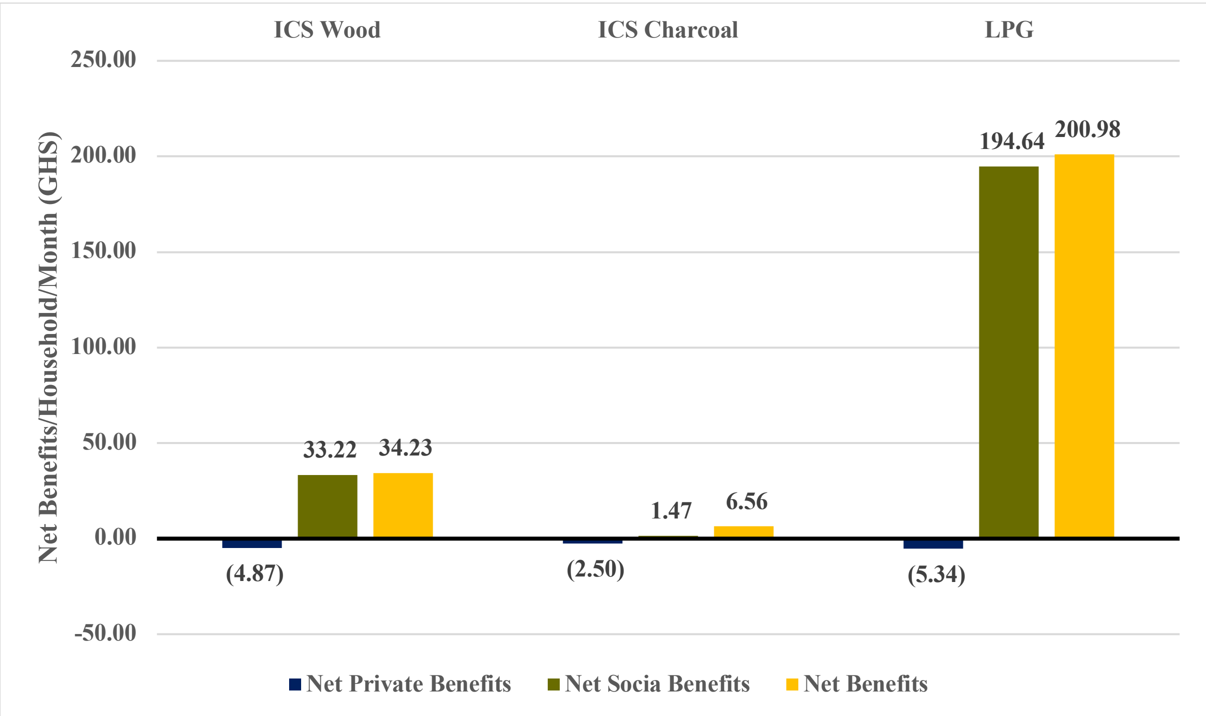


Figure 6: Net (Private) Benefits

BENEFIT-COST RATIO (BCR)		
	Private BCR	**Total BCR**
ICS wood	0.17	6.82
ICS charcoal	0.67	1.86
LPG	0.54	18.21

Table 2: Benefit-cost ratio of ICS adoption

Table 2 above, confirms the results of the net benefits shown above. The private BCRs for all three stoves are below 1; meaning for every GHS1 spent in acquiring, installing, and using an ICS, the benefits returned are less than GHS1 i.e. GHp17, GHp67 and GHp54 for wood, charcoal, and LPG stoves, respectively. However, the introduction of the social and environmental benefits improves the accruing benefits significantly to GHS6.82, GHS1.86 and GHS18.21, respectively.

5.2 Simulation Results

Having presented the results for the mean parameter values above, it is important to analyse the impact of variabilities in our parameters, together, on our earlier outcome. The Monte Carlo simulation results are presented in Figures 7 and 8.

Figure 7 shows that wood ICS yields positive private benefits in 34.5% of the simulation trials, charcoal ICS in 9.1% and LPG in 4.8%. In other words, the likelihood of a household that has adopted an ICS witnessing negative net private benefits is 90.9%, 65.5% and 95.2% for charcoal, wood and LPG, respectively; if all existing variables affecting the costs and benefits of adoting these ICS change at the same time. As expected, this is directly consistent with the results presented earlier. As explained above, this is attributable to cost of the stoves (Capex) and, in the case of wood ICS, the huge fuel savings. The results here are more negative relative to Jeuland & Pattanayak (2012) because of the cost of stoves; which is more modest than adopted here.

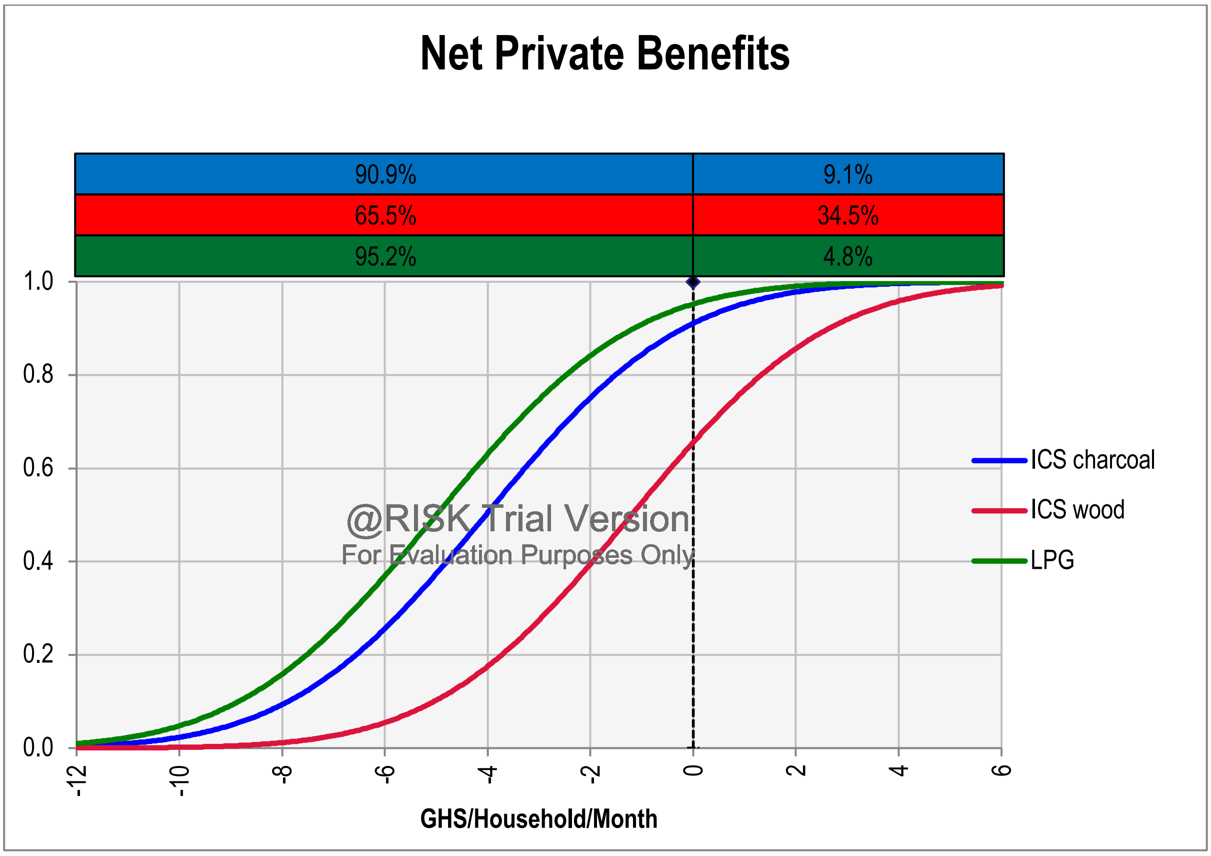


Figure 7: Cumulative Distribution (Monte Carlo Analysis) for Net Private Benefits

Figure 8, unlike Figure 7, reveals that LPG delivers positive net benefits in 92% of the trials. Wood ICS and charcoal ICS however deliver relatively lower positive net benefits in 65% and 62% of the trials. Net benefits are more positive than the private benefits mainly because of the valuation of carbon (cost of carbon) which has direct impact on the value of carbon emissions reduction. As such, pricing carbon more punitively increases net gains to households and society as shown in Figures 7 and 8. Again, interventions that target cleaner fuels and more efficient stoves are germane as they are more beneficial in the end. Lastly, it is significant to note that the Global Warming Potential (GWP) of the GHG utilized here have been discounted to take into consideration the lag in forcing. Even so, the results as can be seen, are significantly positive.

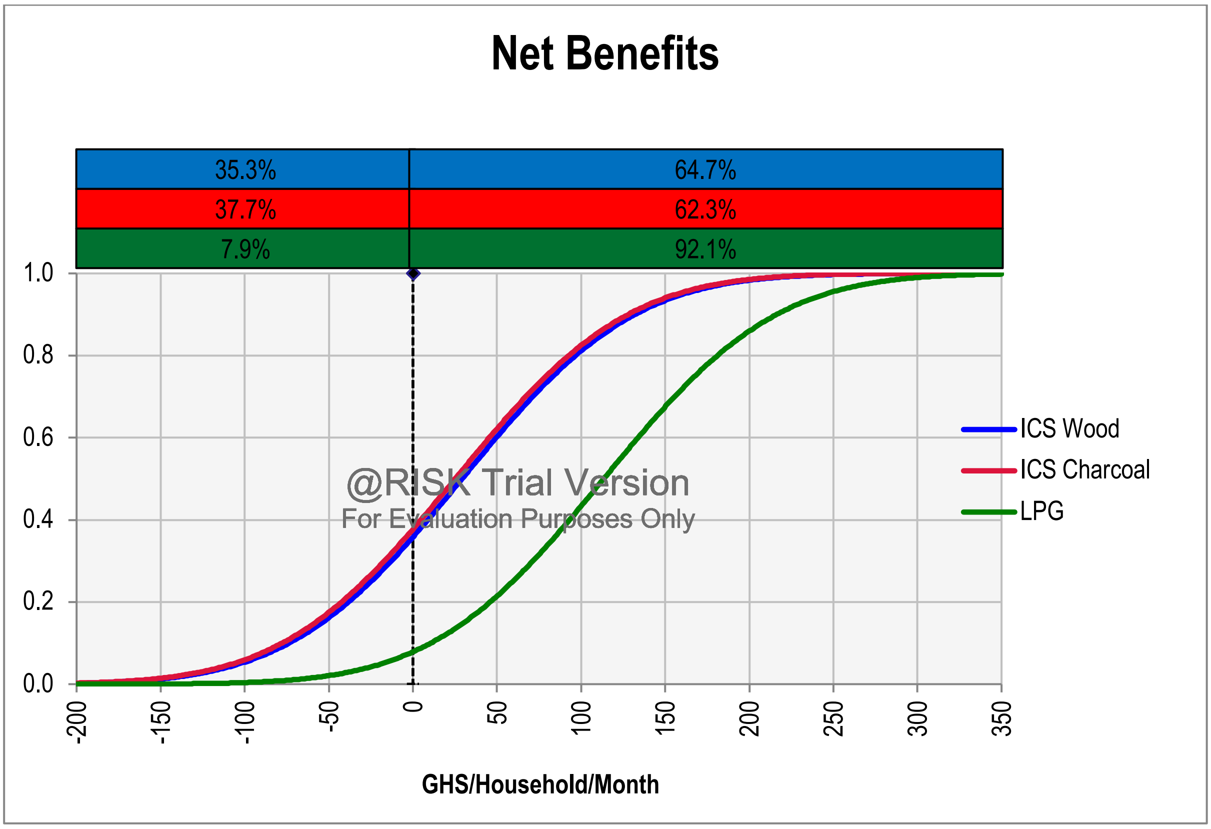


Figure 8: Cumulative Distribution (Monte Carlo analysis) for Net Benefits

5.3 Sensitivity Analysis

In this section, further variations of parameters are undertaken to assess the impact of each on net benefits. This one-way parameter sensitivity analysis simply allows the investigator to hold all parameters constant except one so as to determine the impact of such variable on the outcome. Hence, the drivers of the changes in the simulations conducted in section 5.2 above for each technology are ascertained here.

From Figure 9, Cost of stove, fuel efficiency of ICS, usage rate, time efficiency and VSL impact net private benefits of wood ICS adoption, significantly. A cursory look at these parameters, except VSL, show that they are all directly related to either Capex or Opex. In other words, aside the setup cost for wood ICS, fuel and time efficiencies are paramount in the determination of private benefits.

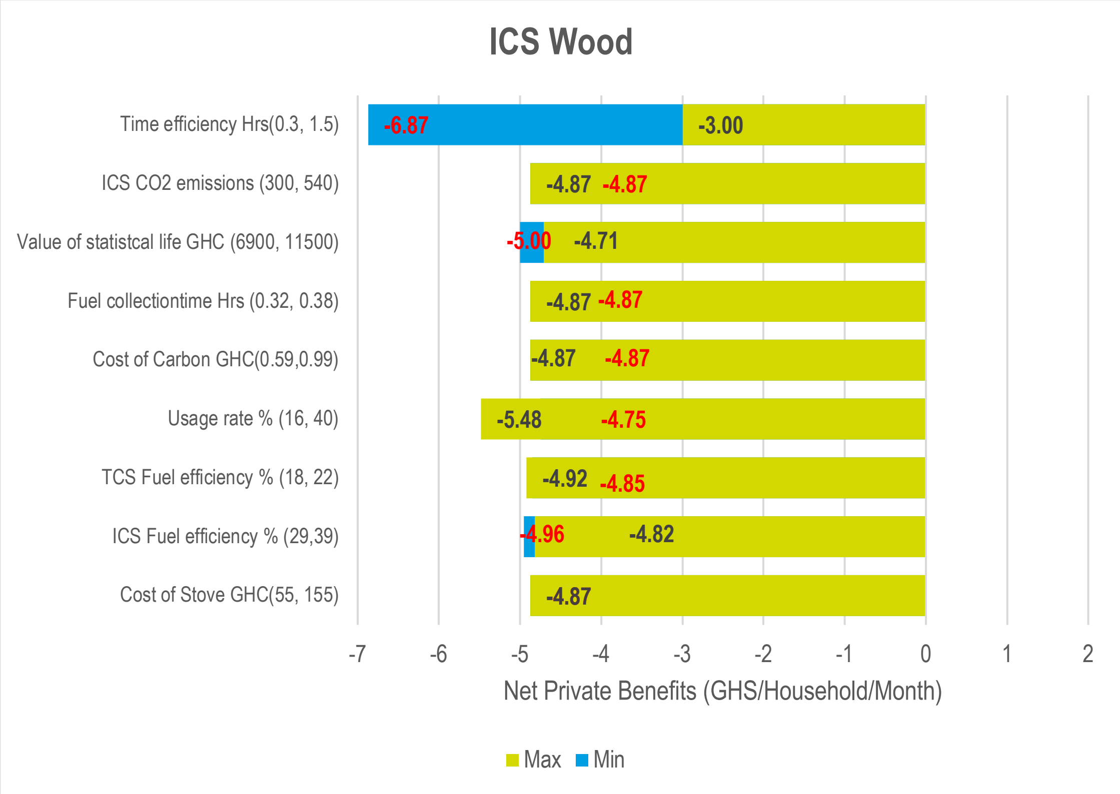


Figure 9: One-way Sensitivity Analysis for Net Private Benefits for ICS Wood

Figure 10 shows that Cost of stove, VSL, usage rate, fuel efficiency. time efficiency and CO_2 emissions offer the biggest impact in respect of charcoal ICS. Usage rate, just as above, plays a relatively significant role in the determination of net private benefits. As such, usage characteristics and issues should, among others, occupy the centre of consideration for program implementers. In other words, stove improvements that affect thermal and fuel efficiencies are more impactful and must thus receive considerable attention from both manufacturers and policymakers, even as the cost of stoves is addressed.

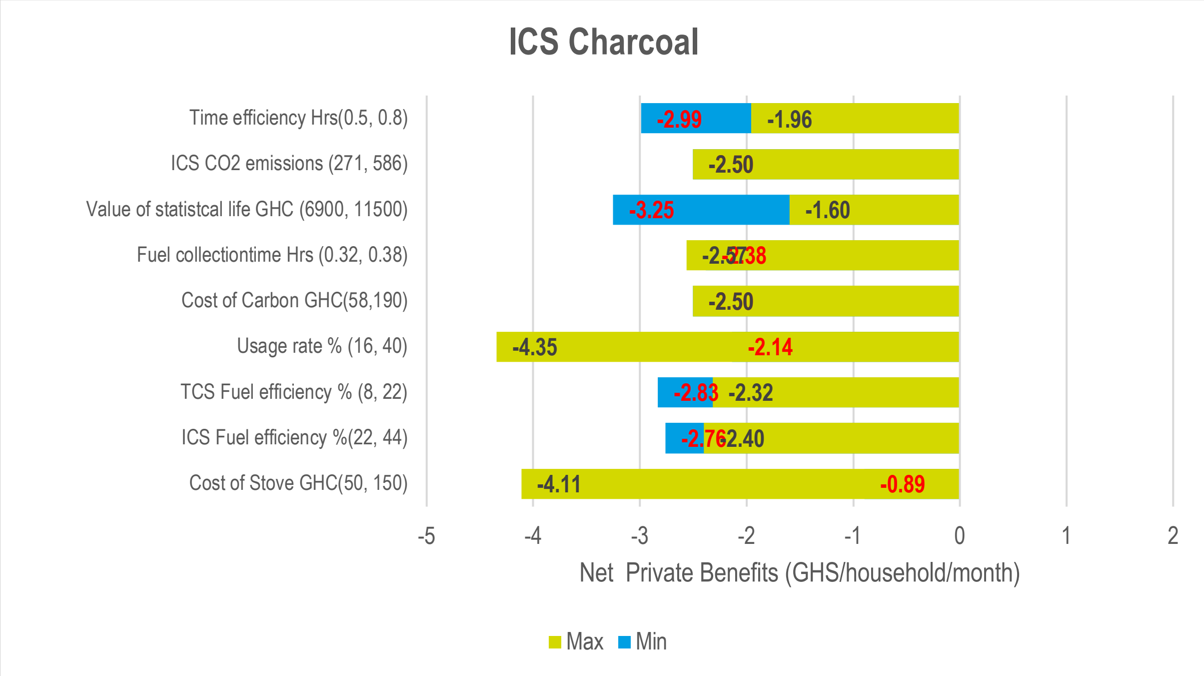


Figure 10: One-way Sensitivity Analysis for Net Private Benefits for ICS Charcoal

Figure 11 reveals that Cost of stove, VSL, usage rate and time efficiency play the biggest part in respect of LPG. Just as the above, usage characteristics are relevant for LPG adoption, as well. Indeed, for all three technologies the value that is placed on life by consumers is cardinal to the determination of gains.

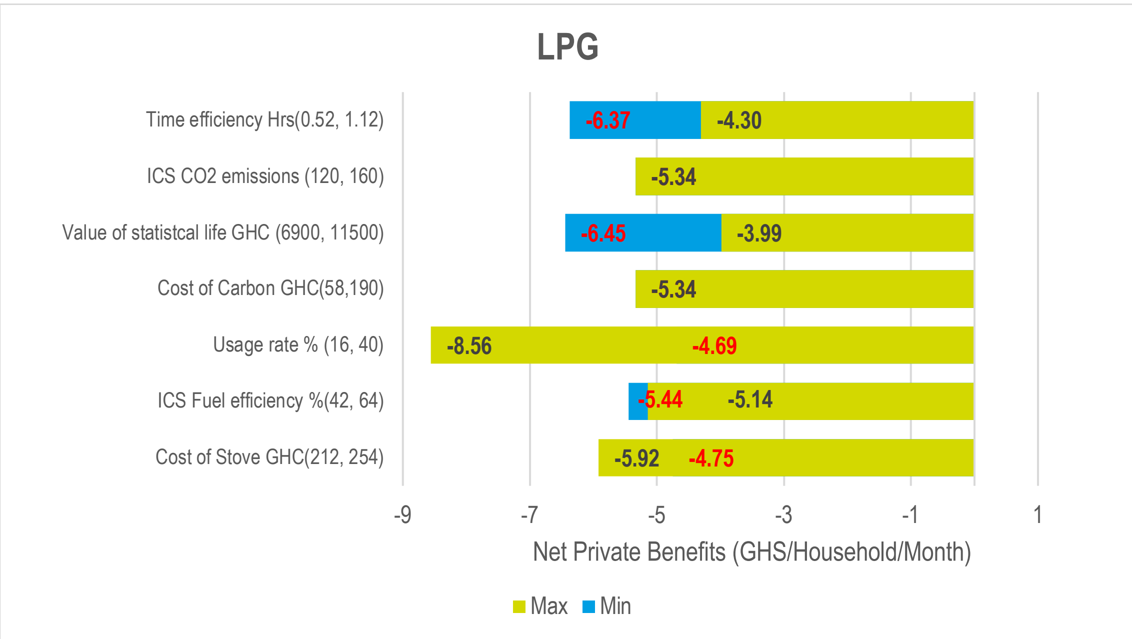


Figure 11: One-way Sensitivity Analysis for Net Private Benefits for LPG

As shown in Figures 12-14, cost of carbon, usage rate, CO_2 emmisions and proportion of biomass harvesting that is non-renewable play huge role in the determination of net benefits for all three technologies. Specifically, with regards to charcoal ICS however, efficiency of the ICS is a key driver of net benefits, just as the cost of the stove. This fits very well with the results noted in 5.1 above. The results must be read holistically taking into consideration, also, the result in Figures 4, 5 and 6.

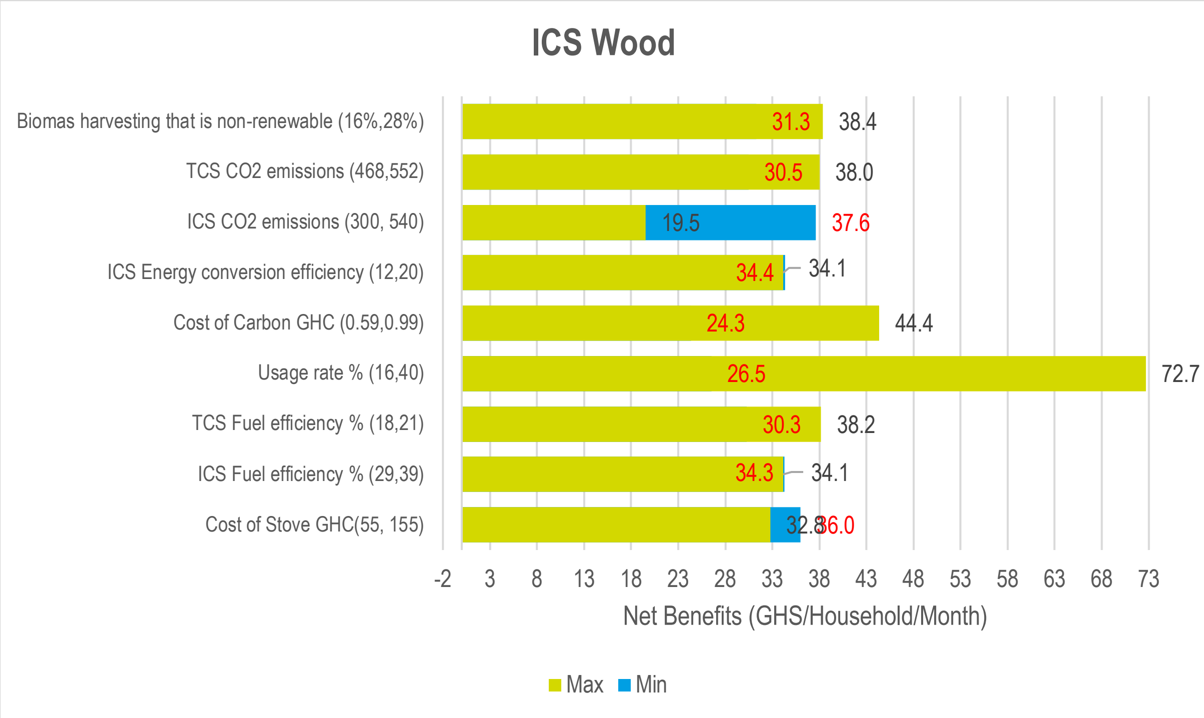


Figure 12: One-way Sensitivity Analysis for Net Benefits for ICS Wood

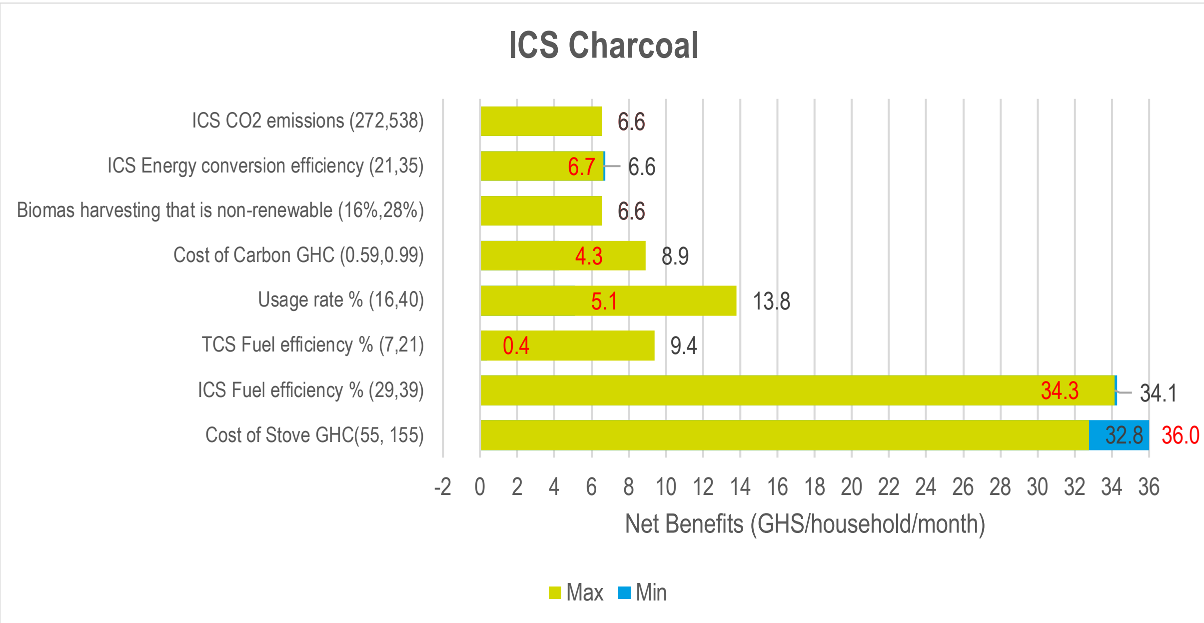


Figure 13: One-way Sensitivity Analysis for Net Benefits for ICS Charcoal

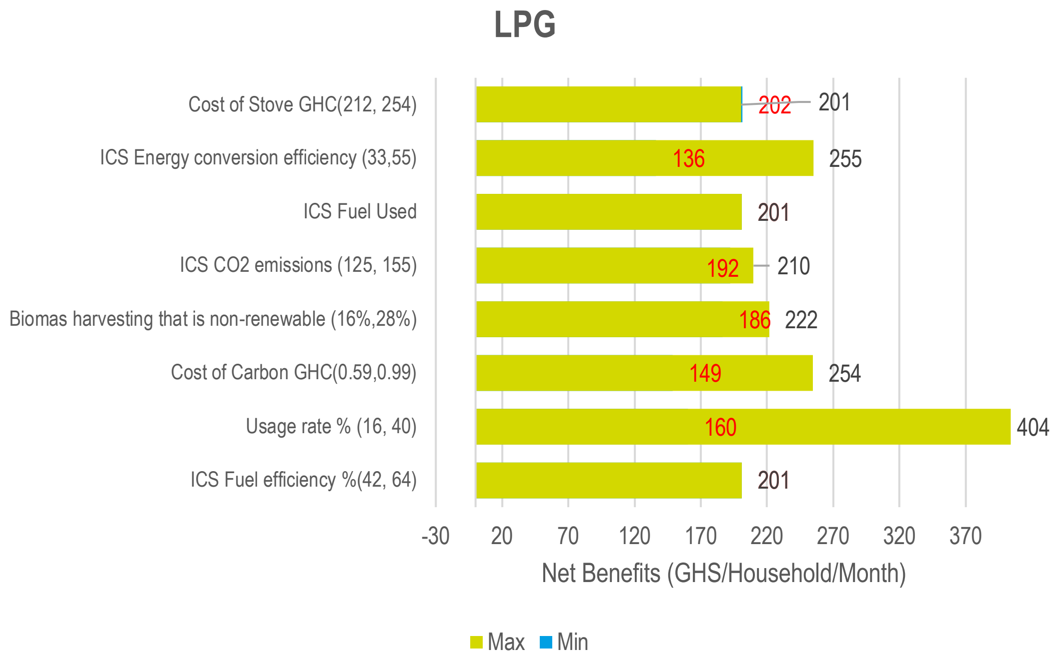


Figure 14: One-way Sensitivity Analysis for Net Benefits for LPG

5.4 Scenario Results

To provide an understanding of what it will take to meet some of the national goals outlined in the assumptions in 4.1.2 and the estimated benefits, the results of the various scenarios outlined in that section, are presented here. As mentioned earlier, the scenarios presented in this analysis are broadly categorized into two; interim and final scenarios. Secondly, the total number of households was obtained from the Ghana Living Standard Survey (GLSS) 7; reported to be 7,299.925 of which 4,089,330 were urban and 3,210,595 being rural. Thirdly, of these households, 49% or 3,576,963 (2,003,772 and 1,573,192 for urban and rural respectively) are reported to cook with ICS. Fourthly, 24.5% or 1,788,482 households use LPG. These statistics have been factored into the scenarios as base case for ascertaining the units of each stove needed for the required jump or to meet each scenario target. In addition, it is important to note that the costs and benefits presented in this section are a simple product of the unit cost and unit benefit per stove and the total units of stoves required under each scenario. These costs include only the Capex, DMC, and LC of adopting a stove i.e. it excludes the running and maintenance costs.

As shown in Table 3, to increase urban penetration of tier 4 ICS by 10%, minimum investment of GHS8.3 million, GHS8 million, and GHS19 million and maximum investment of GHS17 million, GHS16.7 million, and GHS21 million for wood ICS, charcoal ICS, and LPG, respectively, will be required. For 10% penetration of tier 3 ICS in rural areas, GHS6 million, GHS5.7 million and GHS15 million at the minimum for wood, charcoal ICS, and LPG, respectively and GHS13 million, GHS12.9 million and GHS17 million each at the maximum, is required. The net benefits of the mean investments as shown in the table are very positive at GHS216, GHS100 and GHS335 in the first instance and GHS117, GHS69 and GHS233 in the second.

IS-1	10% penetration of tier 4 ICS in urban households		
$TC_{si} = (TC_{hh} \times thh_{ut4}) \ldots \ldots \ldots equ(27)$			
	Min (GHS million)	**Mean (GHS** million)	**Max (GHS** million)
ICS wood	8.3	14	17
ICS charcoal	8	13	16.7
LPG	19	20.7	21
	Cost (GHS million)	**Benefits (GHS** million)	**Net (GHS** million)
ICS wood	14	231	216
ICS charcoal	13	113	100
LPG	21	355	335
IS-1	10% penetration of tier 3 ICS in rural households		
$TC_{si} = (TC_{hh} \times thh_{rt3}) \ldots \ldots \ldots equ(29)$			
	Min (GHS million)	**Mean (GHS** million)	**Max (GHS** million)
ICS wood	6	11	13
ICS charcoal	5.7	10	12.9
LPG	15	16	17
	Cost (GHS million)	**Benefits (GHS** million)	**Net (GHS** million)
ICS wood	11	128	117
ICS charcoal	10	79	69
LPG	16	250	233

Table 3: Interim Scenario 1-10% Penetration of tier 4 & 3 ICS in Urban and Rural Areas

Table 4 reveals that to achieve 50% penetration of ICS from the current base, it is found that interventionists will need to expend between GHS65 million and GHS146 million, GHS60 million and GHS143 million, and GHS168 million and GHS189 million for wood ICS, charcoal ICS, and LPG respectively. It is also found that at the mean spending of GHS119 million, GHS112 million, and GHS185 million, the net benefits are expected to be worth GHS777 million, GHS205 million and GHS4.6 billion for the three stoves, respectively. As can be seen, even though LPG requires the largest investment under the scenario, it also offers the largest returns owing principally to the enormous environmental benefits associated with LPG as a very clean fuel. In fact, while the investment requirement of LPG under this scenario is less than a double of either of the other stoves, the net benefits generated are many folds that of any of those. Conversely, charcoal ICS requires the least investment but also returns the least net benefits. As noted in the earlier sections, significant efficiency improvements in charcoal ICS over wood are necessary to exploit the potential increased benefits associated with the relatively cheaper option offered by charcoal ICS.

IS-2	50% penetration of ICS		
$TC_{sii} = (TC_{hh} \times thh_{sii}) \dots \dots \dots equ(31)$			
	Min (GHS million)	**Mean (GHS** million)	**Max (GHS** million)
ICS wood	65	119	146
ICS charcoal	60	112	143
LPG	168	185	189
	Cost (GHS million)	**Benefits (GHS** million)	**Net (GHS** million)
ICS wood	119	896	777
ICS charcoal	112	316	205
LPG	185	4,750	4,566

Table 4: Interim Scenario 2-50% ICS penetration

Table 5 shows that to double LPG penetration from its current 49%, the investment required is from GHS162 million to GHS182 million. At the mean investment level, expected net benefits should exceed GHS4.4 billion.

IS-3	Double LPG penetration		
$$TC_{siv} = (TC_{hh} \times thh_{siv}) \ldots\ldots\ldots equ(35)$$			
	Min (GHS million)	**Mean (GHS million)**	**Max (GHS million)**
LPG	162	177	182
	Cost (GHS million)	**Benefits (GHS billion)**	**Net (GHS billion)**
LPG	177	4.6	4.4

Table 5: Interim Scenario 3-Double LPG Penetration

Tables 6 and 7 present the final scenarios i.e. 100% penetration of ICS and of LPG in Ghana. For FS-1, total investment requirement is GHS130 million, GHS122 million, and GHS336 million at minimum and GHS293 million, GHS287 million, and GHS379 million at the maximum for wood, charcoal, and LPG ICS, respectively. At mean investment, net benefits are expected to be extremely positive as witnessed in the IS.
For FS-2, minimum investment required is GHS336 million and maximum, GHS379 million. Mean investment of GHS369 million will yield GHS9 billion in net benefits.

All scenarios return very positive net benefits. As such, there is enough economic basis for rolling out interventions with targets ranging from partial to complete ICS adoption in Ghana. Clearly, the emissions reduction impact, the health benefits, time, and fuel savings, put together, far outweigh the associated costs for such interventions.

FS-1	100% penetration of ICS		
$$TC_{siii} = (TC_{hh} \times thh_{siii}) \ldots\ldots\ldots equ(33)$$			
	Min (GHS million)	**Mean (GHS million)**	**Max (GHS million)**
ICS wood	130	237	293
ICS charcoal	122	223	287
LPG	336	369	379
	Cost (GHS million)	**Benefits (GHS billion)**	**Net (GHS billion)**
ICS wood	237	1.8	1.6
ICS charcoal	223	0.6	0.4
LPG	369	9.5	9.1

Table 6: Final Scenario 1-100% Penetration of ICS

FS-2	100% LPG penetration in urban households		

$$TC_{sv} = (TC_{hh} \times thh_{sv}) \ldots\ldots\ldots equ(37)$$

	Min (GHS million)	**Mean (GHS million)**	**Max (GHS million)**
LPG	336	369	379
	Cost (GHS million)	**Benefits (GHS billion)**	**Net (GHS billion)**
LPG	369	9.4	9.1

Table 7: FInal Scenario 2-100% Penetration of LPG in Urban Households

5.5 Drivers of Improved Cookstoves Adoption

To start with, it is essential to reecho that penetration of clean and efficient cooking solutions has been low or modest (Lewis & Pattanayak, 2012). This notwithstanding the prior existence of *"the basic theory of technology adoption–applied to environmental health behaviors–suggests that factors like information campaigns, supply chain support, trust between the supplier and consumer apart from household socioeconomic characteristics determine household choice (*Pattanayak & Pfaff, 2009; Jeuland, et al., 2015*; Jeuland, et al., 2015* as stated in Samaddar, 2017*)*. As such, several researchers have explored this area to ascertain the factors aside those captured in the above theory responsible for the drag in adoption rate. Several drivers have been found.

Jagger & Jumbe (2016) investigated these drivers with respect to Malawi and found that fuel access, knowledge of the environmental effects of using woodfuels, wood collection time by the primary cook and local peer effects are cardinal to choosing ICS. This study notes that the ease with which households are able to access fuel, expressed basically through the availability of the fuel and the number of hands available to help the primary cook with fuel-wood collection, cannot be overlooked; supply-side factors are thus far more important in the consideration for ICS adoption than demand-side factors.

Samaddar (2017) studying India found that intervention promotion, level of education especially of the household head, and occupational type were the key drivers. In other words, villages where program implementers promoted the ICS solutions, made follow ups and households with heads that are more educated adopted ICS more. However, households that are primarily agrarian or with large farms were less inclined to adopt ICS because they were oblivious of their impact on welfare.

Vulturius & Wanjiru (2017) also worked on Kenya to examine the impact behaviourial change techniques (BCTs) can have on ICS adoption. While acknowledging the impact of post-sales follow ups on the rate of use and adoption, the study also found that BCTs including working through community groups and social networks are powerful for ICS adoption. The study alludes to the impact of peer influence and social status as lures to ICS uptake.

Furthermore, Kapfudzaruwa, et al. (2017) studied 14 African countries and concluded that income and literacy level are the key drivers for ICS uptake. The paper notes the impact of (i) moderately good income levels in South Africa, Senegal and Lesotho on awareness of the assocaited benefits of ICS adoption and (ii) low literacy levels on rural individuals' ability to comprehend the impact of associated benefits.

In Ghana, Owusu, et al. (2015) found that household composition (measured by size and number of adult females), employment type of head of household, and household wealth were the principal drivers of ICS uptake. The study concluded that household size and ICS adoption are negatively correlated, the number of adult females in a household is positively correlated with ICS adoption, formal employment status and the income related factors including educational level and ICS adoption are positively correlated.

Again, literature alludes to the issue of stove stacking (Ruiz-Mercado & Masera, 2015; Jewitt, et al., 2020; Piedrahita, et al., 2016). "*These results may partly explain why adoption and usage of ICS is often low even when distributed freely (Hanna et al., 2012 as stated in Jeuland & Soo, 2016)".* It is important to note that cost of fuel is a major factor in the Opex; which has been identified by this analysis as the second most important cost driver. Situating this in the context of stove use and stacking is obvious. There is no denying the fact that fuel efficiency and saving are a major consideration for ICS adoption and use. That said, there are so many other factors that literature has identified to be responsible for the stove stacking phenomenon; ranging from availability, price and reliability of fuel/alternative fuels, taste preferences, cultural factors, etc.

Harper (2017), a short but beautiful report of observations from a market survey conducted in Accra by Envirofit Ghana, notes that time efficiency (households prefer cooking on coalpot because it was faster relative to their LPG stove), change in the taste of food (some households prefer to prepare certain foods on coalpot because it retained the traditional flavour of the food), and fuel availability and ease of access (families stack stoves for emergency backup for when the run out of gas) as the important factors that cause stove stacking. Apart from the cultural factors i.e. food taste changes which is very difficult to measure scientifically and hence not included in this analysis, the results of the one-way sensitivity analysis presented above are consistent with the rest of the variabiles—time efficiency, fuel efficiency and collection time—identified by Harper (2017).

In sum, the above literature highlights the following as the main drivers of ICS adoption.

- information campaigns,
- supply chain support or post-sales follow ups,
- availability of the fuel,
- intervention promotion,
- level of education and occupational type especially of the household head,
- BCTs achieved by working through community groups and social networks,
- peer influence,
- social standing,
- income levels,
- fuel efficiency and saving,
- availability, price, and reliability of fuel/alternative fuels,
- taste preferences, and
- cultural factors.

In addition, the sensitivity analysis results presented in section 5.3 above also identified three drivers:

- cost of ICS
- fuel and time efficiencies, and
- usage rate

After consolidating all the drivers as identified through literature review and sensitivity analysis, stakeholders including industry practioners, academics and researchers in the clean and improved cooking space in Ghana were engaged to rank the identified drivers in order of importance based on their practical, academic and research experience of the sector; as presented in Table 11 in the appendices. The paper thus, concludes that the following are the major drivers of ICS adoption in Ghana, in order of importance (see Fig. 15 below):

- Cost of ICS
- Fuel availability and ease of access
- Awareness of the benefits of using ICS
- Income levels
- Availability, price, and reliability of alternative fuels/stoves
- Peer influence
- Level of education especially of the household head
- Occupational type and employment status of head of household
- Time and fuel efficiencies of ICS
- Household composition

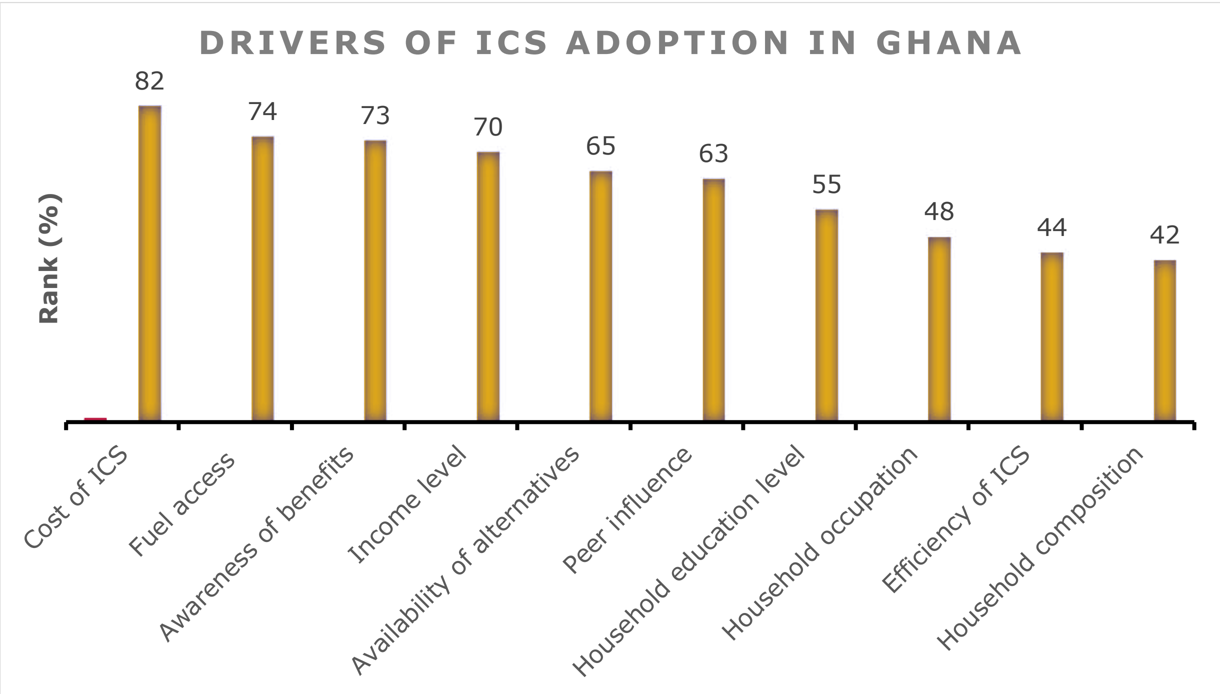


Figure 15: Drivers of ICS Adoption in Ghana

5.6 Gender and Social Inclusion Consideration of Improved Cookstoves Interventions

First, it is crucial to understand that women and girls are distinctly and disproportionately affected by energy poverty (Mahat, 2006). It is fundamental role of girls and women to collect fuel wood and prepare meals, most predominantly in Ghana and the developing world at large. Aside this, two of the main trades of women in Ghana are preparing and selling of food and smoking of fish. As to be expected, women and girls are more exposed to HAP/IAP from biomass burning.

As such, the first consideration of gender and social inclusion in ICS intervention roll out is on the importance of women inclusion in the design and manufacturing process of ICS. Women's input in the design of ICS is necessary because of their unique understanding of what is likely to meet the requirement of fellow women (UNDP, 2003 as stated in Mohammed & Oyeniyl, 2012). In this regard, the role of women as energy managers at the household level places them at the centre of household energy decision making (Bolton, 2015). Indeed, it is important to note the predominant role of women in meals preparation in the specific case of Ghana. The GLSS 6 reveals that 68.5% of women in Ghana cook compared to just 15.7% of men. As such, the impact of women in the design and production of these stoves cannot be overlooked.

The second consideration is looked at from the angle of behavioral change. As already identified in the drivers, peer influence and social standing should be important considerations for ICS interventions. Cardinal to this consideration is the role women and women groups should play. It is found that awareness campaigns and distributional promotions that utilizes women and social groups are more effective (*see Vulturius & Wanjiru, 2017*). Proponents of this argument assert that it is easier to change societal behavior more easily by working through social groups (predominantly women groups). This they note is because the strategic role play in society affords them a unique sense of the cultural and social position of their communities and hence are better placed to influence behavioral changes. They also note that peer socialization is more pronounced in women than in men, in this respect i.e. a woman is far more easily swayed by testimony from fellow woman on the impact of an ICS on their life, especially if that testimony links to social standing. The inclusion of 'status symbols or social queens' in the promotion of ICS solutions has therefore been noted to be very effective.

Also, in the roll out of ICS solutions, it is important not to lose sight of the disparity between households headed by men and those headed by women, particularly in the rural areas. The fact remains that in rural areas in developing countries like Ghana, women and households headed by women grapple with challenges related to high poverty levels, access to affordable credit due to non-ownership of assets for collateralization, high illiteracy, etc. It is thus necessary to always factor these gender-specific disparities into the development of interventions.

Conclusion

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion and Discussion

As noted earlier, solid fuels constitute a chunk of unclean fuels and as such their consumption especially at the household level accounts immensely for air pollution. Household cooking, particularly in developing countries like Ghana, is predominantly done using TCS technologies and unclean fuels. The costs of these high polluting cooking methods and fuels have impacted at the private and social levels. The associated health and environmental injuries not only affect productivity but also burden private and national resources and infrastructure.

Accordingly, national and international efforts have been focused on delivering cleaner cooking technologies and interventions to ameliorate and to some extent reverse the growing effects on the environment. While these interventions have been associated with benefits, private and social, they have also come with costs. Literature has sort to investigate these costs and benefits; purposely to ascertain if the benefits of these interventions justify their costs. Whereas most of these prior literature—referred to by Jeuland & Soo (2016) as simplified and deterministic—seems to confirm positive net benefits at household level, uptake of cleaner cooking interventions have been anything but impressive. "*Such analyses thus likely miss critical aspects of the household decision problem, perhaps due to miscalculation of costs and benefits, a lack of appreciation for the variability of private benefits across locations and households, and a misalignment of realized private benefits and those achieved under ideal (trial) conditions" (ibid).* It is therefore not out of place that further research in the area, using more comprehensive methods have emerged. In addition, while Ghana through public and private efforts has roll out some of these interventions, there has been no study of this sort, to the best our knowledge. This research seek to fill the void using the more comprehensive approach explained above.

The analyses found that:

1. Based on the average values, using the three mentioned clean cooking technologies has more costs than benefits at the household level. This is confirmed by the simulation analysis as a huge majority of trial results delivered negative net private benefits.

2. While all three technologies witness time savings in Ghana, only wood ICS provide fuel savings. In other words, while the existing ICS in Ghana cook quicker that their corresponding TCS, not all of them cook with relatively smaller quantity of fuel.
3. All three technologies deliver benefits that outweigh their costs when social and environmental benefits are introduced i.e. the benefits driven from climatic improvements and forest restoration or decreased degredation are enormous enough to make the adoption ICS worthwhile. Indeed, the impact of such improvements on agriculture, frequency and magnitude of disasters, etc. directly affects households and national development. Specifically, LPG delivers largest positive net benefits; followed by wood and charcoal ICS, in that order.
4. The capital cost of adopting an ICS solution in Ghana constitutes the largest driver of total cost; followed by maintenance and program costs with learning cost trailing.
5. With respect to benefits, health benefits are largest driver of the total benefits for adopting charcoal ICS and LPG solutions in Ghana; ahead of time saving. For wood ICS, it is fuel savings.
6. For charcoal ICS, efficiency (time and fuel) is critical for delivering increased desirable net benefits.
7. For wood ICS, CO_2 emissions factor, amount of biomass harvesting that is (non)renewable, fuel efficiency and time efficiency, are central to achieving desired result.
8. For LPG stoves, the huge net benefit is driven by its cleanness (including its indirect contribution to non-renewable biomass harvesting), energy conversion and fuel efficiencies.
9. In all the scenarios, resultant gains outweigh the investment required in multiple folds i.e. the economic value of ICS adoption is far more beneficial at the national level and thus investments that deepens ICS penetration by the State are justified.
10. The drivers of ICS adoption are economic, social, and demographic and therefore require comprehensive understanding of the unique dynamics of the different segments of the Ghanaian society to tackle.

The results as summarized offer many important insights to some of the gaps that exist in the policy space with respect to clean cooking interventions.

The results—that private net benefits are not always positive—could explain why penetration of ICS solutions have been slow. This is so because whiles the capital cost of adopting an ICS solution has been found to be very significant in the analysis, the value of these solutions to the private household, in the midst of low incomes, is found to be incommensurate. As such, the awareness of households especially in the rural areas on the benefits of improved cooking on health and the climate and its impact on economic activities like farming needed to be communicated clearly during roll out of campaigns; they must be made clear to elicit a better appreciation of the social benefits of ICS solutions since our results clearly show that private benefits alone, don't cut it.

In the 1980s/90s when the earliest clean cooking programs were rolled out, program implementers sort to justify adoption with moral suasion in respect of how that impacts forest and environmental restoration, positively. While this was morally right to do, most consumers did not classify this as a personal benefit that warrants incurring the expenditure for adopting these solutions. Until lately, the private household benefits, in terms of the economics associated with savings from reduced fuel consumption, time and sickness, and even the impact of climate and environmental degradation on the economic life of households were not highlighted. The public campaigns, therefore, were mostly ineffective and accounted for slow penetration.

Again, systematic implementation of interventions backed by research is necessary and its absence has been identified as a cause for the drag in adoption and stove stacking (informed by the stakeholder engagement). For instance, the earlier LPG cylinder distribution program was not based on consumer-needs assessment. Consumers have different requirements; not all consumers need a 14.5kg cylinder, for instance. But, the earlier programs came with cylinders that were the same size. Secondly, the programs did not take into consideration access to LPG especially in rural areas. Previously, it made little business sense for private business people to set up LPG vending points in rural areas. As such, rural household using LPG had to travel to the nearest city or major town to refill, thereby increasing their cost of running the solution. This, in the midst of low incomes and inadequate awareness of the full benefits of these solutions, was always going to result in poor uptake or usage. Furthermore, the absence of an effective monitoring metric to assess the impact (success/failure) of these interventions did not help. Indeed, the presence of such a metric was necessary to alert implementers of need for post-sales issues. These initial interventions did not come along with after sale servicing. The absence of this discouraged further penetration of these stoves after the pioneer buyers, as negative feedback from these people due to breakdowns and usage challenges gets across.

6.2 Recommendations

From reviewing previous and current interventions and targets in this area especially the government ones, it is important to be realistic and to introduce pragmatism by retuning current programs and designing future ones to meet the unique characteristics of the Ghanaian consumer. For instance, income differential of the different market segments must be factored into the solutions as identified in the drivers. To this end, the current government 'Rural LPG Program' which involves free distribution of LPG cylinders to rural households may struggle to attain its goals. And this is why. While it is ideal to introduce rural homes to LPG stoves, the cost of running them taking into consideration the level of rural incomes in Ghana and the fact that rural households predominantly do not buy fuel, may only result in stove abandonment or stacking.

Conversely, such a program may be more 'beneficial' and pragmatic if applied to urban and peri-urban Ghana. This is because the relatively higher urban household incomes will mean their ability to purchase fuel and maintain such stoves. In addition, the living environment of urban Ghana means no fuel is free. Models such as the Envirofit SmartGas Pay-As-You-Cook program has been able to prove that household utilization of LPG may be cheaper than biomass use. And so, urban households with LPG stoves will most certainly be capable of maintaining such stoves.

On the other hand, government rural interventions could target the introduction of biomass ICS that are more efficient and burn more cleanly. This takes the income and fuel acquisition characteristics of the rural household into consideration and government can guarantee an improvement in environmental degradation and HAP/IAP exposure.

Specifically, the following recommendations should be considered:

1. ICS Solution should include subsidies/incentives. As shown in the results in section 5, the huge capital and maintenance costs of adopting and using ICS erodes all their private benefits. As such, incentives that seek to reduce these costs will be beneficial. Such incentives can: (i) come in the form of supports that pushes down the cost of domestic ICS production as a way of reducing the price at which stoves are delivered to users. (ii) be direct subsidy on sales price of ICS, and/or (iii) be on the fuel such as LPG—in this regard, gas pricing could be categorized, just as utility tariffs, to allow for cross subsidization of the residential sector.

2. Efficiency—time and fuel—improvement should continue to be cardinal in stove design. As found, fuel and time efficiencies are major drivers of ICS adoption in Ghana. First, because they improve the economics of such interventions and second, because the time spent in cooking is an important consideration especially for urban households. It is therefore important to continue to invest in ways to improve these efficiencies to be able to continue to make a better case for ICS.
3. Fuel availability and access should be improved to prevent the need for stove stacking. As government continues to drive the growth of ICS especially LPG, across the country, it is important to continue to create an enabling environment that will entice the private sector to invest in siting fuel distribution outlets e.g. LPG vending points, particularly in rural areas as availability and access of fuel are key drivers of ICS adoption.
4. ICS interventions should include well-coordinated promotional and educational campaigns to improve awareness of the benefits of ICS solutions. ICS solutions must be sold. Just as any new product, the benefits of these solutions both to the individual household and to the society must be well marketed. Awareness campaigns should accompany these interventions to improve their appeal.
5. ICS interventions must be based on research and accompanied by well-thought out implementation policy with in-built M&E program and measuring metric to allow for periodic review and assesement.
6. Engagement of community groups especially women peer groups and Behavioral Change Techniques (BCTs) should be factored into ICS interventions implementation. The role social groups can play in awareness campaigns and behavior modification cannot be underplayed. CSOs and program implementers should work with women groups and community influencers in the promotion of ICS solutions
7. Future studies in the clean cooking space could also include designing methods for measuring aesthetic and cultural/status change benefits as these could significantly improve net private benefits.
8. ICS interventions should take into consideration demographic, social, and other cultural-specific differences to enhance general acceptability in line with the drivers identified. The appeal of these solutions and their ability to achieve their goals is hinged on their ability to effectively target and meet the specific needs of different segments of society. ICS solutions should not be general or come as ‘one-cap-fits-all’. They should among others recognize income differential, rural-urban disparities, household composition disparities, etc.

9. Government should use the power of the State as the biggest buyer to create a market for ICS. In this respect, it is recommended that existing government programs and institutions such as the School Feeding Program, LEAP, NADMO, boarding schools, Prisons, etc. must be utilized to create a primary market for ICS. This increased demand will not only enhance ICS penetration but will also positively affect the capacity and ultimately efficiency of stove manufacturers.
10. Stakeholders in the clean cooking space should support and/or create activities or programs that seek to develop the business and financing models of private players along the ICS value chain. This recommendation is steeped in the observation, gathered from the stakeholder engagements, that ICS manufacturers in Ghana are only commercially viable when they receive carbon credits or grants. They are therefore unable to continue production in the absence of such incentives/interventions.

7.0 BIBLIOGRAPHY

Agyemang, F., 2018. *BASELINE REPORT- COOK STOVES TECHNOLOGY USE IN 6 SELECTED COMMUNITIES IN GAMA1/25/2018,* Accra: sdi./PD/GHAFUP.

Anon., n.d.

Atul, S., Bhaskar, J. N., Pallavee, K. & Arindam, K. B., 2016. *ACCESS TO CLEAN ENERGY THROUGH ESTABLISHMENT OF MARKET-BASED SOLUTIONS IN GHANA,* Accra: United Nations Development Programme (UNDP).

Bailis, R., Drigo, R., Ghilardi, A. & Masera, O., 2015. The carbon footprint of traditional woodfuels. *Nature Climate Change,* 5(3), pp. 266-272.

Bolton, S., 2015. Establishing a women-driven clean cookstove distribution network in Eastern Indonesia. *Boiling Point,* Issue 66, pp. 14-17.

Bruce, N., Perez-Padilla, R. & Albalak, R., 2000. Indoor air pollution in developing countries: a major environmental and public health challenge. *Bulletin of the World Health Organization,* 78(9), pp. 1078-1092.

Bruce, N. et al., 2006. Indoor air pollution. In: D. Jamison, et al. eds. *Disease Control Priorities in Developing Countries (eds.).* Oxford: World Bank and Oxford University Press.

Burnett, R. T., Pope III, C. A. & al., e., 2014. An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. *Environmental Health Perspectives,* 122(4), pp. 397-403.

Clean Cooking Alliance, 2020. *Stoves.* [Online]
Available at: https://www.cleancookingalliance.org/technology-and-fuels/stoves/
[Accessed 13 February 2020].

Dagnachew, A. G., Lucas, P. L., van Vuuren, D. P. & Hof, A. F., 2018. *Towards Universal Access to Clean Cooking Solutions in Sub-Saharan Africa: An integrated assessment of the cost, health and environmental implications of policies and targets,* The Hague: PBL Netherlands Environmental Assessment Agency.

Daniel, J. S. & Solomon, S., 1998. On the climate forcing of carbon monoxide. *JOURNAL OF GEOPHYSICAL RESEARCH,* 103(11), pp. 13,249-13260.

Darko, O. B., Owusu-Afriyie, K., E., K. & E., N., 2015. *uel Wood Value Chain Report. The USAID/Ghana Sustainable Fisheries Management Project (SFMP).,* Accra: Narragansett, RI: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island and SNV Netherlands Development Organization. GH2014_SCI011_SNV. 157 pp.

DeAngelo, B., 2013. *Black Carbon and Other "Short-Lived Climate Forcers": Climate change science.* Washington DC: EPA.

EC, 2012. *Ghana: Sustainable Energy For All Action Plan,* Accra: Energy Commission of Ghana.

EC, 2014. *NATIONAL ENERGY STATISTICS 2000 - 2013 ,* Accra: ENERGY COMMISSION OF GHANA.

EC, 2018. *NATIONAL ENERGY STATISTICS 2008 - 2017,* Accra: Energy Commission of Ghana.

EC, 2019. *NATIONAL ENERGY STATISTICS 2009 - 2018,* Accra: ENERGY COMMISSION OF GHANA.

ENERGICA, 2009. *Pre-feasibility study for an improved cook stoves project in Northern Ghana,* Accra: CARE Denmark.

Energy Commission of Ghana, 2018. *NATIONAL ENERGY STATISTICS 2008 - 2017,* Accra: s.n.

ENERGY COMMISSION, 2018. *NATIONAL ENERGY STATISTICS 2008 - 2017,* Accra: ENERGY COMMISSION.

Ghana Statistical Service, 2014. *Ghana Living Standard Survey Round 6 (GLSS 6),* Accra: GSS.
Ghana Statistical Service, 2019. *Ghana Living Standard Survey 7,* Accra: s.n.
GSS, 2018. *Ghana Living Standards Survey Round 7 (GLSS7),* Accra: Ghana Statistical Service.
Hanna, R., Duflo, E. & Greenstone, M., 2012. Up in smoke: the influence of household behavior on the long-run impact of improved cooking stoves. *National Bureau of Economic Research.*
Harper, N., 2017. *Stove Stacking – Problem or Challenge?.* [Online]
Available at: https://envirofit.org/stove-stacking-problem-or-challenge/
[Accessed 3 January 2020].
Hutton, G. & Rehfuess, E., 2006. *Guidelines for conducting cost–benefit analysis of household energy and health interventions,* Geneva: World Health Organization (WHO) Press.
Hutton, G., Rehfuess, E. & Tediosi, F., 2007. Evaluation of the costs and benefits of interventions to reduce indoor air pollution. *Energy for Sustainable Development,* XI(4), pp. 34-43.
Hutton, G., Rehfuess, E., Tediosi, F. & Weiss, S., 2006. *Evaluation of the costs and benefits of household energy and health interventions at global and regional levels,* Geneva: WHO.
IEA, IRENA, UNSD, WB and WHO, 2019. *TRACKING SDG7: THE ENERGY PROGRESS REPORT 2019,* Washington DC: International Bank for Reconstruction and Development / The World Bank.
Interagency Working Group on Social Cost of Carbon , 2015. *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866,* Washington, USA: EPA, United States Government.
IPCC, 2018. *Radiative Forcing of Climate Change.* [Online]
Available at: https://www.ipcc.ch/site/assets/uploads/2018/03/TAR-06.pdf
[Accessed 14 October 2019].
Isihak, S., Akpan, U. & Adeleye, M., 2012. Interventions for Mitigating Indoor Air-Pollution in Nigeria: A Cost-Benefit Analysis. *International Journal of Energy Sector Management,* 6(3), pp. 417-429.
Jagger, P. & Jumbe, C., 2016. Stoves or Sugar? Willingness to Adopt Improved Cookstoves in Malawi. *Energy Policy,* Volume 92, pp. 409-419.
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).
Jeuland, M., Bluffstone, R. & Pattanayak, S. K., 2015. The economics of household air pollution. *Annual Review of Resource Economics,* Volume 7, pp. 81-108.
Jeuland, M. & Soo, T. J., 2016. Analyzing the costs and benefits of clean and improved cooking solutions.
Jewitt, S., Atagher, P. & Clifford, M., 2020. We cannot stop cooking": Stovestacking, seasonality and the risky practices of household cookstove transitions in Nigeria. *Energy Research & Social Science,* Volume 61 101340, pp. 1-10.
Kapfudzaruwa, F., Fay, J. & Hart, T., 2017. Improved cookstoves in Africa: Explaining adoption patterns. *Development Southern Africa ,* 34(5), pp. 548-563.
Keita, S. et al., 2018. Particle and VOC emission factor measurements for anthropogenic sources in West Africa. *Atmos. Chem. Phys.,* Volume 18, pp. 7691-7708.
Larsen, B., 2014. *Benefits and Costs of the Air Pollution Targets for the Post-2015 Development Agenda: Post-2015 Consensus.* Copenhagen, Denmark: Copenhagen Consensus Center, Working Paper.
Leon, G. & Miguel, E., 2011. *Transportation Choices, Fatalism and the Value of Life in Africa,* California: Unplublished.

Lewis, J. J. & Pattanayak, S. K., 2012. Who Adopts Improved Fuels and Cook-stoves? A Systematic Review. *Environ Health Perspect Environmental Health Per-spectives,* 120(5), pp. 637-645.
Mahat, I., 2006. Gender Roles in Household Energy Management: Issues and Implications. *Mountain Forum Bulletin.*
Mohammed, N. & Oyeniyl, B., 2012. ROLE OF RURAL WOMEN IN HOUSEHOLD ENERGY MANAGEMENT IN TOFA L.G.A OF KANO STATE. *SAVAP International,* 3(2223-994), pp. 417-425.
OECD, 2018. *Effective Carbon Rates 2018: Pricing Carbon Emissions Through Taxes and Emissions Trading,* Paris: OECD.
Olmer, N. et al., 2017. *GREENHOUSE GAS EMISSIONS FROM GLOBAL SHIPPING, 2013–2015,* Washington DC: International Council on Clean Transportation.
Owusu, E. S. et al., 2015. Adoption and Utilization of Improved Cookstove in Ghana. *international Journal of Innovative Research & Development,* 4(9), pp. 305-311.
Pattanayak, S. K. & Pfaff, A., 2009. Behavior, Environment, and Health in Developing Countries: Evaluation and Valuation. *Annual Review of Resource Economics ,* Volume 1.
Pennise, D. et al., 2009. Indoor air quality impacts of an improved wood stove in Ghana and an ethanol stove in Ethiopia. *Energy for Sustainable Development,* 13(2), pp. 71-76.
Piedrahita, R. et al., 2016. Assessment of cookstove stacking in Northern Ghana using surveys and stove use monitors. *Energy for Sustainable Development,* Volume 34, pp. 67-76.
Piedrahita, R. et al., 2016. Assessment of cookstove stacking in Northern Ghana using surveys and stove use monitors. *Energy for Sustainable Development,* Volume 34, pp. 67-76.
Pinto, A., 2016. *A Hard Bargain? A cost benefit analysis of an improved cookstove program in India,* s.l.: The Sanford School of Public Policy/Duke University.
Ramanathan, V. & Carmichaek, G., 2008. Global and regional climate changes due to black carbon. *Nature geoscience ,* 1(4), pp. 221-227.
Ruiz-Mercado, I. & Masera, O., 2015. Patterns of Stove Use in the Context of Fuel–Device Stacking: Rationale and Implications. *EcoHealth, DOI: 10.1007/s10393-015-1009-4.*
Samaddar, S., 2017. *Adoption and Short-term Impacts of Improved Cookstoves in Rural India,* s.l.: Sanford School of Public Policy, Duke University.
Smith, K., Mehta, S. & Maeusezahl-Feuz, M., 2004. Indoor air pollution from household use of solid fuels. In: M. Ezzati, A. Lopez, A. Rodgers & C. Murray, eds. *Comparative Quantification of Health Risks: Global and Regional Burden of Disease Due to Selected Major Risk Factors (eds.).* Geneva: World Health Organization, pp. 1435-1493.
Smith, K., Samet, J., Romieu, I. & Bruce, N., 2000. Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax,* 55(6), pp. 518-532.
Trading Economics, n.d. *Tradingeconomics.* [Online]
Available at: https://tradingeconomics.com/ghana/co2-emissions-metric-tons-per-capita-wb-data.html
[Accessed 26 July 2019].
UNDP, 2003. Gender and Energy: how is gender relevant to Sustainable energy policies, in sustainable energy strategies: materials for decision makers, United National Development?.
UNDP, 2015. *NAMA Study for a Sustainable Charcoal Value Chain In Ghana,* New York, USA: UNDP.
Vulturius, G. & Wanjiru, H., 2017. *The role of social relations in the adoption of improved cookstoves,* Stockholm, Sweden: Stockholm Environment Institute, Working Paper 2017-01.
WHO, 2015. *Household air pollution attributable deaths in 2012. Global Health Observatory data repository. Geneva.* [Online]
Available at: (http://apps.who.int/gho/data/node.main.BODHOUSEHOLDAIRDTHS?lang=en
[Accessed 1 July 2017].

WHO, 2018. *Opportunities for transition to clean household energy: Application of the WHO Household Energy Assessment Rapid Tool (HEART) in Ghana,* Geneva: World Health Organization. Licence: CC BY- NC-SA 3.0 IGO..
WHO, 2018. *Burden of disease from household air pollution for 2016 Description of method.* [Online]
Available at: https://www.who.int/airpollution/data/HAP_BoD_methods_May2018.pdf
[Accessed 14 October 2019].
WHO, 2018. *Burden of Disease from Household Air Pollution for 2016 v3.* [Online]
Available at: https://www.who.int/airpollution/data/HAP_BoD_results_May2018_final.pdf
[Accessed 13 August 2019].
WHO, 2019. *Household air pollution and health: Key facts.* [Online]
Available at: https://www.who.int/en/news-room/fact-sheets/detail/household-air-pollution-and-health
[Accessed 13 August 2019].
WHO, n.d. *IARC Publications (IARC MONOGRAPHS VOLUME 95).* [Online]
Available at: http://publications.iarc.fr
[Accessed 16 February 2020].
World Bank, n.d. *Global CO2 emissions.* [Online]
Available at: https://data.worldbank.org/indicator/EN.ATM.CO2E.KT
[Accessed 26 July 2019].
Zhang, H. et al., 2014. Indoor Emissions of Carbonaceous Aerosol and Other Air Pollutants from Household Fuel Burning in Southwest China. *Aerosol and Air Quality Research,* Volume 14, pp. 1779-1788.

8.0 APPENDICES

8.1 Models

Description		Equations
Switching costs	Capital costs of acquiring new technologies and all accompanying set up (Capex)	$Capex = (CoS_i \times \frac{Cap_r}{12}) \ldots \ldots \ldots \ldots \ldots equ(1)$
	Distribution and marketing costs associated with making the technology accessible (DMC)	$DMC = \frac{CoP}{12} \ldots \ldots \ldots \ldots \ldots equ(2)$
	Operation and maintenance costs (including time) spent on technology (Opex). Cost of maintaining TCS is assumed to be Zero.	$Opex = CoM_i \times \Re \ldots \ldots \ldots \ldots \ldots equ(3)$
	Learning costs associated with adopting new technology (LC). It comprises both the time spent and the reduction in the quality of food prepared.	$LC = Lt \times \text{Vot} \times \frac{Cap_r}{12} \ldots \ldots \ldots \ldots \ldots equ(4)$
	Net Change in fuel cost	$FS = (CF_{ics} - CF_{tcs}) \times \Re \ldots \ldots \ldots \ldots \ldots equ(5)$
	Total cost	$TC_{hh} = Capex + DMC + Opex + LC + FS \ldots \ldots \ldots .. equ(6)$
switching benefits	Time savings from cooking (TS)	$TS = Act_{tcs} \times \Re \times (1 - \sum t_i) \times Vot \times 30 \ldots equ(14)$
	Health improvements arising from cleaner Indoor Air Quality (IAQ) (HB). HB is measured through reduced morbidity (Mb) and mortality (Mt).	$Mb = \sum_k \left(\sum_{t=1}^{5} C_{kt} \times COI_k \times {}^{(Mb_k)}\big/_{(1+\text{Đ})^{t-1}} \right) /12 \ldots equ(15)$
		$Mt = \sum_k \left(\sum_{t=1}^{5} C_{kt} \times \text{VSL} \times {}^{(Mt_k)}\big/_{(1+\text{Đ})^{t-1}} \right) /12 \ldots equ(16)$
	Environmental benefits resulting from reduced emissions and forest loss/degradation accruing to society (EB). EB is an aggregate of carbon emission reduction (CER) and environmental services lost (ESL)	$CER = Ccarb \times \Re \times (ffCook_{tcs} \times GWP_{i,m} \times \Pi_{tcs} \times \Sigma \text{f}_{tcs} - ffCook_{ics} \times GWP_{i,m} \times \Pi_{ics} \times \Sigma \text{f}_{ics}) \ldots equ(17)$
		$ESL = TRC \times \Re \times (1 - \vartheta) \times (ffCook_{tcs} - ffCook_{ics}) \ldots equ(18)$
	Total benefits	$TB_{hh} = TS + Mb + Mt + CER + ESL \ldots \ldots equ(19)$
Other equations	Capital recovery factor	$Cap_r = {}^{\text{Đ} \times (1+\text{Đ})^t}\big/_{(1+\text{Đ})^t - 1} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. equ(7)$
	Cost of fuel used in traditional cookstoves	$CF_{tcs} = ffCook_{tcs} \times \beta \times wood_p + 30 \times \text{fColt}_0 \times (1 - \beta) \times Vot \ldots \ldots \ldots \ldots equ(8)$

	Cost of fuel used in wood-burning ICS. $Wood_p$ is the price of wood (GHS/kg).	$CF_{ics} = ffCook_{ics} \times \beta \times Wood_p + 30 \times \left({fCook_{ics}}/{fCook_{tcs}} \right) \times fColt_0 \times (1-\beta) \times Vot + 30 \times fPrept \times Vot \ldots\ldots\ldots\ldots\ldots\ldots equ(11)$
	Cost of fuel used in ICS that use fuels that do not require preparation like charcoal and LPG. f_i is price of the fuel	$CF_{ics} = ffCook_{ics} \times \beta \times f_i \ldots\ldots\ldots\ldots\ldots equ(12)$
	$ffCook_{tcs}$ is monthly quantity of fuel used using TCS (kg/month)	$ffCook_{tcs} = 30 \times (Act_{tcs} \times \text{fCook}_{tcs}) \ldots\ldots\ldots\ldots\ldots equ(9)$
	Shadow value of time spent cooking. Measured as fraction of market wage. K_t is time parameter, W is minimum wage rate	$Vot = K_t \times W \ldots\ldots\ldots\ldots. equ(10)$
	$ffCook_{ics}$ is monthly quantity of fuel used using ICS (kg/month)	$ffCook_{ics} = ffCook_{tcs} \times \left({\Sigma f_0 \times \Pi_0}/{\Sigma f_i \times \Pi_i} \right) \ldots\ldots\ldots\ldots\ldots equ(13)$
	$PM_{2.5}$ Exposure	$PM_{2.5} = \Re \times \acute{E}PM_i + (1-\Re) \times \acute{E}PM_0 \ldots\ldots\ldots\ldots\ldots. equ(20)$
	Mb of disease k	$Mb_k = Nhh \times (PAF_0 - PAF_i) \times \eta_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. equ(21)$
	Mt of disease k	$Mt_k = Nhh \times (PAF_0 - PAF_i) \times \Omega_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots. equ(22)$
	Global Warming Potential. J is CO, BC, N_2O, CH_4 and OC	$GWP_{i,m} = \acute{E}CO_{2,i,m} \times \vartheta + \sum_{j \in K} \acute{E}CO_{2,i,m} \times GWP_j \quad where\ j = CO_2 \notin K \ldots\ldots equ(23)$
		$GWP_{j \in K} = {\sum_{t=1}^{\infty} \left({1}/{(1+Đ)^{t-1}} \right) \times RF_{j,t}} / {\sum_{t=1}^{\infty} \left({1}/{(1+_Đ)^{t-1}} \right) \times RF_{CO2,t}} \ldots\ldots.. equ(24)$
	Population Attributable Factor	$PAF_i = {hh_{sf} \times (Rr_k - 1)}/{hh_{sf} \times (Rr_k - 1) + 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots. equ(25)$
Net benefits per household	NB_{hh}	$NB_{hh} = TB_{hh} - TC_{hh} \ldots\ldots. equ(26)$

Table 8: Models

8.2 Model Parameters

Parameter	Description
CoS_i	Cost of stove i in GHS. i is the type of stove
CoP	Cost of promoting new stoves in GHS
CoM_i	Maintenance cost of stove i in GHS
L_i	Lifespan of stove i in years
$\Re$	Rate of use of non-traditional stove in percent (%)
Act_{tcs}	Average cooking time in a day using traditional stove. Measured by hours/day
Σt_i	Time efficiency of stove i relative to TCS. A ratio
Σf_i	Fuel efficiency of stove i. ratio of Mega Joules (MJ) of useful energy to MJ of heat produced for hr of cooking
ΠI	Energy conversion factor for stove i. ratio of MJ to Kg of fuel used
$fCook_{tcs}$	Quantity of fuel utilised in cooking by traditional cookstove in an hour
$fCook_{ics}$	Quantity of fuel utilised in cooking by ICS in an hour
β	Proportion of wood bought in %
$fColt_0$	Average time (hrs) spent collecting wood fuel in a day
Vot	Shadow value of time spent cooking. Measured as fraction of market wage
ρ	Market wage for unskilled labour in GHS/hr
fPrept	Average time (hrs) spent preparing fuel for ICS in a day
CF_i	Cost of fuel type i in GHS/Kg
Lt	Learning hours for ICS
ηk	Incidence of prevalence of disease k in cases/100 persons/year
Ωk	Mortality rate of disease k in deaths/10000 persons
COI_k	Cost-of-Illness of disease k in GHS/case
Ccarb	Cost of CO_2 emission in GHS/ton
ϑ	Fraction of biomass harvesting that is non-renewable

Nhh	Household size measured by number of persons
µ5hh	Children under 5 in a household
hh_{sf}	Fraction of households using solid fuels
Đ	Discount rate
VSL	Value of a statistical life in GHS/life lost
TRC	Tree replacement cost in GHS/Kg
Rr_k	Relative risk of Mb and Mt for disease k
C_{kt}	Proportion of health benefits from IAP improvements
$É_{PM,i}$	$PM_{2.5}$ emissions by stove type i in a day 24hr µg/m^3
$É_{co2,i}$	CO_2 emissions by stove i in g CO_2/MJ
$É_{CH4,i}$	CH_4 emissions by stove i in g CH_4/MJ
$É_{N2O,i}$	N_2O emissions by stove i in g N_2O/MJ
$É_{CO,i}$	CO emissions by stove i in g CO/MJ
$É_{BC,i}$	BC emissions by stove i in g BC/MJ
$É_{OC,i}$	OC emissions by stove i in g OC/MJ
$GWP_{j\in K}$	Global Warming Potential of gas j

Table 9: Model Parameters

8.3 Parameter Range

The range values assumed for each variable is obtained from various data sources including the Global Alliance for Clean Cooking Catalogue and various studies. These studies have established distributional ranges for these variables based on assumptions grounded in literature and empirical test results. As much as possible, this study utilized country-specific data for each variable. In cases where this is not available, regional or global level estimates have been secured as presented in previous studies on the subject.

Parameter	Unit	Value				Source
			Min.	Mean	Max.	
CoS_i	GHS	TCS (3 stones)	0	0	0	(Agyemang, 2018)
		TCS Charcoal	25	37.5	50	GACC catalogue
		ICS wood	55	110	155	
		ICS charcoal	50	100	150	
		LPG	212	233.2	254.4	
CoP	GHS	annual	6.45	8.6	10.75	(Hutton, et al., 2006)
CoM_i	GHS	ICS wood	17.649	18.179	19.239	(Jeuland & Soo, 2016)
		ICS charcoal	3.975	9.01	17.649	
		LPG	2.809	13.78	22.737	
L_i	Years	TCS Charcoal	2	3	4	(ENERGICA, 2009)
		ICS wood	3	4	5	GACC catalogue
		ICS charcoal	3	4	5	
		LPG	4	5	6	
$\Re$	Percent (%)		16%	20%	40%	(Jeuland & Soo, 2016)

Act_{tcs}	Hours/day		0.65	0.69	0.74	GLSS 6 Min-Urban Max-Rural, Mean-Ghana
Σt_i		ICS wood	0.3	0.9	1.5	(Jeuland & Soo, 2016)
		ICS charcoal	0.5	0.65	0.8	
		LPG	0.5	0.8	1.1	
Σf_i	MJ of useful energy/MJ of heat produced for hr of cooking	TCS (3 stones)	18%	20%	21%	(Jeuland & Soo, 2016)
		TCS Charcoal	7%	17%	21%	(Dagnachew, et al., 2018)
		ICS wood	29%	32%	39%	
		ICS charcoal	23%	26%	43%	GACC catalogue
		LPG	42%	54%	64%	
Π	MJ/Kg of fuel used	TCS (3 stones)	13.28	17.70	22.13	GACC catalogue
		TCS Charcoal	23.78	31.70	39.63	
		ICS wood	12.00	16.00	20.00	
		ICS charcoal	21.15	28.20	35.25	
		LPG	33.53	44.70	55.88	
$fCook_{tcs}$	Kg/Hour		0.4	0.6	0.7	(Jeuland & Soo, 2016)
$fCook_{ics}$	Kg/Hour		0.3	0.4	0.5	(Jeuland & Soo, 2016)
β	%		23%	35%	47%	(Jeuland & Soo, 2016)
$fColt_0$	Hrs/day		0.32	0.36	0.38	GLSS 6
Vot	fraction of market wage		0.35	0.78	1.2	(Jeuland & Soo, 2016)
ρ	GHS/hr		0.58	1.17	3.4	GLSS Min-Lowesr Max-Highest, Mean-Ghana total
fPrept	Hrs/day		0.5	0.7	0.9	(Jeuland & Soo, 2016)

f_i	GHS/Kg	Wood	0.5	0.8	1.1	(ENERGY COMMISSION, 2018)
		Charcoal	0.72	0.96	1.2	Market survey
		LPG	4.0275	5.37	6.7125	
Lt	Hrs		15	27.5	40	(Jeuland & Soo, 2016)
ηk	Cases/10000 persons/year	ALRI	20.50	63.80	71.00	(Jeuland & Soo, 2016)
		COPD	1.20	4.50	7.70	
		Lung Cancer	1.73	2.30	2.88	
		IHD	75.00	100.00	125.00	
Ωk	Deaths/10000 persons/yr	ALRI	14.80	15.40	16.00	(Jeuland & Soo, 2016)
		COPD	1.36	1.81	2.26	
		Lung Cancer	0.81	1.27	1.73	
		IHD	9.20	10.70	12.20	
COI_k	GHS/case	ALRI	91.43	121.90	152.38	(Hutton, et al., 2006)
		COPD	337.88	450.50	563.13	(Jeuland & Soo, 2016)
		Lung Cancer	4014.75	5353.00	6691.25	et al
		IHD	4014.75	5353.00	6691.25	
Ccarb	GHS/ton		0.59	0.79	0.99	EPA ($:GHS5.3)
ϑ	Fraction (%)		16%	21%	28%	(Bailis, et al., 2015)
Nhh	Persons/household		3.6	4	4.5	GLSS 6 Min-Urban Max-Rural, Mean-Ghana
µ5hh	Children/household		0.45	0.5	0.6	Est. GLSS 6 Min-Urban Max-Rural, Mean-Ghana
hh_{sf}	Fraction		0.58	0.73	0.92	GLSS 6 Min-Urban Max-Rural, Mean-Ghana
Đ		Social	5%	3%	2.5%	EPA

		Private	20%	16%	12%	
VSL	GHS/life lost		6,901	9,201	11,501	(Leon & Miguel, 2011) at US$: GHS5.3
TRC	GHS/Kg		0.0106	0.053	0.106	(Jeuland & Soo, 2016) at US$:GHS5.3
Rr_k		ALRI	1.8	2.3	2.8	WHO
		COPD	1.7	2.3	3.1	
		Lung Cancer	2	2.4	2.8	
		IHD	1.3	1.6	1.9	
C_{kt}		ALRI	0.7	0.1	0.1	(Jeuland & Soo, 2016)
		COPD	0.3	0.2	0.2	
		Lung Cancer	0.2	0.1	0.2	
		IHD	0.2	0.1	0.2	
ÉPM,i	24hr μg/m^3	TCS (3 stones)	501	650	799	(Pennise, et al., 2009)
		TCS Charcoal	501	650	799	(Dagnachew, et al., 2018)
		ICS wood	110	305	610	
		ICS charcoal	35	52.5	70	
		LPG	5	20	35	
Éco2,i	g CO_2/MJ	TCS (3 stones)	468.2	510	551.8	(Jeuland & Soo, 2016)
		TCS Charcoal	300	525	750	GACC catalogue
		ICS wood	300	345	390	
		ICS charcoal	271.9	479.4	537.9	
		LPG	125	140	155	
ÉCH4,i	g CH_4/MJ	TCS (3 stones)	0.63	1.71	2.79	(Jeuland & Soo, 2016)

		TCS Charcoal	1.5	1.9	2.8	GACC catalogue
		ICS wood	0.3	1.6	2.5	
		ICS charcoal	1.08	1.24	2.57	
		LPG	0.002	0.049	0.1	
ÉN2O,i	g N_2O/MJ	TCS (3 stones)	0.058	0.114	0.17	(Jeuland & Soo, 2016)
		TCS Charcoal	0.04	0.09	0.15	GACC catalogue
		ICS wood	0.03	0.09	0.14	
		ICS charcoal	0.03	0.075	0.12	
		LPG	0.033	0.214	0.395	
ÉCO,i	g CO/MJ	TCS (3 stones)	16.3	24.2	32.1	(Jeuland & Soo, 2016)
		TCS Charcoal	7	17	27	GACC catalogue
		ICS wood	12.7	21.8	30.9	
		ICS charcoal	7.1	16.7	26.3	
		LPG	0.1	0.6	1.1	
ÉBC,i	g BC/MJ	TCS (3 stones)	0.28	0.29	0.31	(Jeuland & Soo, 2016)
		TCS Charcoal	0.007	0.015	0.03	GACC catalogue
		ICS wood	0.02	0.14	0.27	
		ICS charcoal	0.005	0.0135	0.022	
		LPG	0.003	0.0035	0.004	
ÉOC,i	g OC/MJ	TCS (3 stones)	0.25	0.675	1.1	(Jeuland & Soo, 2016)
		TCS Charcoal	0.4	0.45	0.6	GACC catalogue
		ICS wood	0.02	0.46	0.98	
		ICS charcoal	0.345	0.395	0.445	

		LPG	0.001	0.002	0.003	
$GWP_{j\in K}$		CO_2	1	1	1	UNFCCC (Min-20yrs, Mean-100yrs, Max-500yrs)
		CH_4	9	21	33	(IPCC, 2018)
		N_2O	238	298	348	(Olmer, et al., 2017)
		BC	414	460	506	(DeAngelo, 2013)
		OC	-62.1	-69	-75.9	(Daniel & Solomon, 1998)
		CO	3.96	4.4	4.84	

Table 10: Parameter Range

8.4 Ranking of Drivers of ICS adoption

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	TOTAL	RANK
Cost of ICS	9	9	9	9	9	6	10	9	3	9	**82**	**1**
Fuel availability and ease of access	5	8	8	8	8	3	8	8	8	10	**74**	**2**
Awareness of the benefits of using ICS	10	5	7	7	6	10	7	5	10	6	**73**	**3**
Income level	8	10	7	6	7	5	5	10	2	10	**70**	**4**
Availability, price, and reliability of alternative fuels/stove	3	6	10	10	3	4	9	3	7	10	**65**	**5**
Peer influence	7	4	9	8	5	7	2	4	9	8	**63**	**6**
Level of education especially of the household head	2	3	8	3	10	9	4	6	4	6	**55**	**7**
Occupational type and employment status of head of household	6	2	8	3	2	8	3	1	5	10	**48**	**8**
Thermal and fuel efficiency of ICS	4	7	5	7	1	2	6	2	1	9	**44**	**9**
Household composition	1	1	9	2	4	1	1	7	6	10	**42**	**10**

Table 11: Expert Ranking of Drivers

8.5 Interview Questions for Policy Makers

1. What are some of the clean cooking interventions by government (both fuel and clean cookstoves)?
2. How do you assess their impact?
3. What were the key drivers of the success/failure of these interventions?
4. What were the gender and social inclusion considerations for these interventions?
5. What factors do you think inhibited their overall impact?
6. If a new intervention was proposed, what factors will you proffer to make it successful (remember to consider gender and social inclusion)?

8.6 Interview Questions for CSOs

1. What are some of the clean cooking interventions you have been involved with (both fuel and clean cookstoves)?
2. Who were the drivers of these interventions?
3. What role did you play in the implementation of the said interventions?
4. How do you assess their impact?
5. What were the key drivers of the success/failure of these interventions?
6. What factors do you think inhibited their overall impact?
7. What to you were the gender and social inclusion considerations for these interventions?
8. If a new intervention was proposed, what factors will you proffer to make it successful (remember to consider gender and social inclusion)?
9. What role do you think CSOs can play to make such an intervention successful?

8.7 Interview Questions for Stove Manufacturers/Distributors

1. What are some of the clean cooking interventions you have been involved with (both fuel and clean cookstoves)?
2. Who were the drivers of these interventions?
3. What role did you play in the implementation of the said interventions?
4. How do you assess their impact?
5. What were the key drivers of success/failure of these interventions?

6. How many jobs, by your estimates, were created through each intervention? (could you disaggregate this on gender basis)
7. What factors do you think inhibited their overall impact?
8. If a new intervention was proposed, what factors will you proffer to make it successful (remember to consider gender and social inclusion)?
9. What role do you think stove manufactures can play to make such an intervention successful?
10. Are your stoves tested? If yes, do you have the following information on them: a. Time efficiency b. Fuel efficiency c. Energy conversion factor d. $PM_{2.5}$, CO2, CH4, N2O, CO, BC, OC emissions?
11. What is the price range of your stoves?

8.8 Stakeholders/Experts Engaged

1. Dr Ishmael Ackah—Energy Commission
2. Mohammed Lukumanu—Ghana Alliance for Clean Cookstoves and Fuels (GHACCO)
3. Lovans Takyi—Institute for Sustainable Energy and Environmental Solutions (ISEES)
4. Prof Francis Kemausuor—Kwame Nkrumah University of Science and Technology (KNUST)
5. Adwoa Etsiwaa Sey—World Education Inc.
6. Edem Cudjoe Bensah—Kumasi Technical University (KTU)
7. Michael Abrokwaa—SNV (also formerly of Energy Commission)
8. Gloria Theresa Addo-Aryitey—Sustainable Development & Relief Associates (SUDRA)
9. Dr Julius C. Ahikpor—Kumasi Technical University (KTU) and Centre for Energy Environment and Sustainable Development (CEESD)
10. Albert Morrison—Morrison Energy Consult