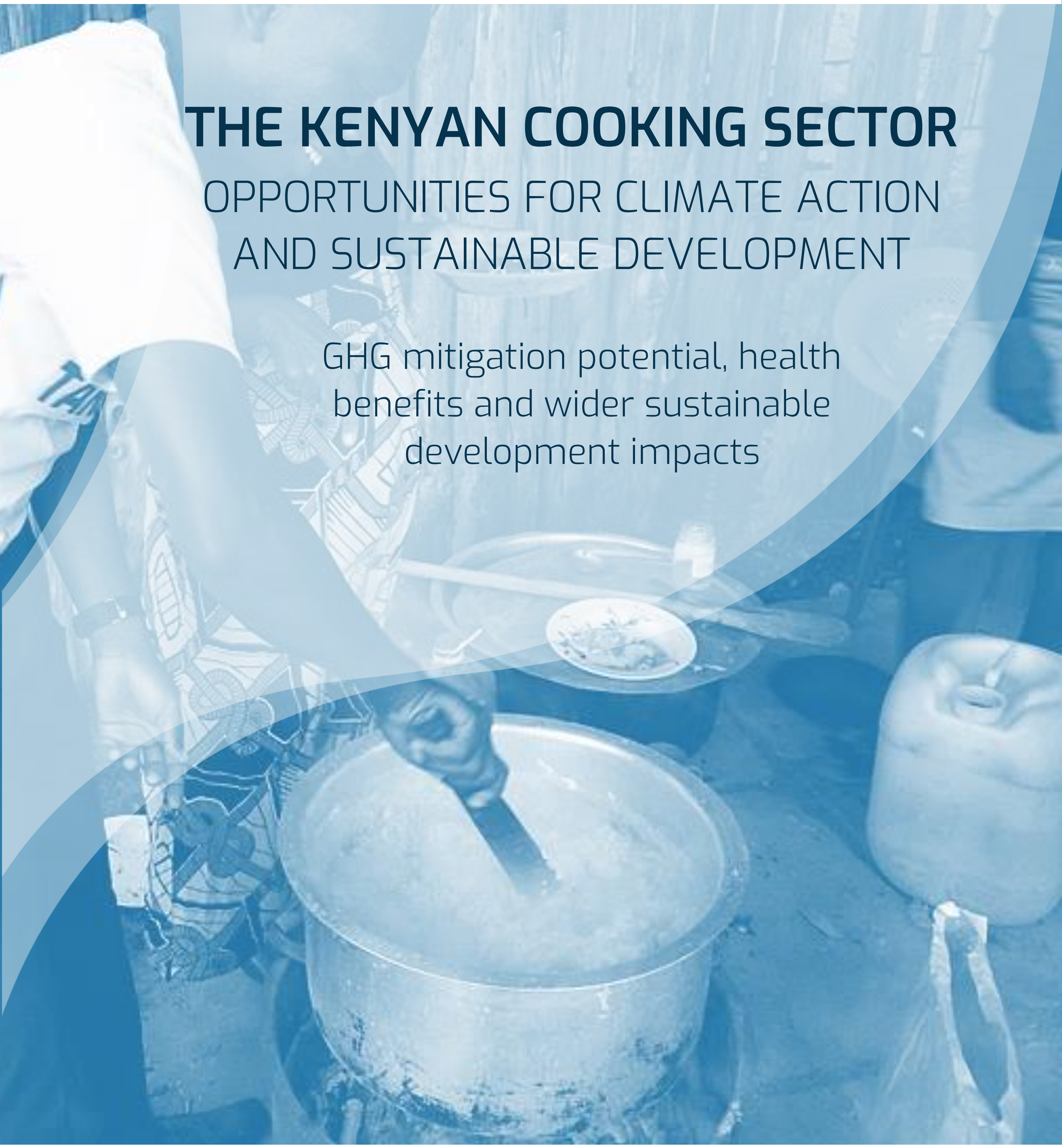
Ambition to Action

THE KENYAN COOKING SECTOR

OPPORTUNITIES FOR CLIMATE ACTION AND SUSTAINABLE DEVELOPMENT

GHG mitigation potential, health benefits and wider sustainable development impacts



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THE KENYAN COOKING SECTOR - OPPORTUNITIES FOR CLIMATE ACTION AND SUSTAINABLE DEVELOPMENT

GHG mitigation potential, health benefits and wider sustainable development impacts

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Cover picture: "Boy cooking as women oversee" by Tommilanso, edited / CC0

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EXECUTIVE SUMMARY

Kenya's residential cooking sector is at crossroads. On the one hand, rapid population growth and swift urbanisation are likely to drive emissions up in the coming years. On the other hand, clean technologies are emerging, and many actors and initiatives are working on bringing the sector onto a low-carbon development pathway. Even though Kenya has made significant progress over the past decades, solid biomass is still the primary cooking fuel used in the country. Over 90% of the rural population and around 75% of all Kenyan households still cook with wood or charcoal. Only about 20% of all households use liquefied petroleum gas (LPG) as their primary cooking fuel. The number of electric cookstoves is extremely low, with around 3% of all households owning an electric appliance [Chapter 1.1].

Kenya is one of the fastest growing economies in Sub-Saharan Africa. The country strives for rapid socio-economic development while meeting its climate and sustainable development objectives. However, cooking fuels and technologies used for residential cooking still contribute significantly to national greenhouse gas (GHG) emissions and to premature deaths from household air pollution (HAP) [Chapter 1.2.1]. While sector-specific policies, programmes and initiatives are being implemented to mitigate these adverse effects of residential cooking, there is a knowledge gap on how to ensure a sustainable transition towards a safe and clean cooking sector, which balances the need to increase access to modern cooking solutions with climate and sustainable development considerations [Chapter 1.2.2].

This study aims to address this knowledge gap by providing new and additional insights on the specific link between residential cooking solutions, climate change, health impacts and associated sustainable development objectives in Kenya. It builds on the 2019 National Cooking Sector Study and uses scenario modelling to present different possible development pathways for the Kenyan residential cooking sector, estimating their respective impact on GHG emissions and human health [Chapter 2].

Based on several scenarios (Table 1), this study:

i) quantifies GHG emissions and mitigation potentials [Chapter 3.1],
ii) estimates the fuel mix and energy demand [Chapters 3.2 and 3.3],
iii) determines the average fuel expenditure per household [Chapter 3.4],
iv) estimates the impact on deforestation [Chapter 3.5],
v) evaluates the type and level of exposure to household air pollutants [Chapter 4.2], and
vi) assesses the impact on human health [Chapter 4.3].

The findings from this combined modelling exercise can contribute to planning and policy making in three relevant national institutions: The Climate Change Directorate within the Ministry of Environment and Forestry, the Ministry of Energy, and the Ministry of Health. Modelling results can inform progressive policy making and improve overall policy outcomes in each of these institutions and provide information for a comprehensive, sector-wide strategy for reducing GHG emissions and HAP from residential cooking in Kenya. This would enable the country to swiftly forge ahead and meet its mid- and long-term climate and sustainable development objectives.

Table 1. Scenario overview.

Scenario		Description	Objective
BAU	**Business-As-Usual Scenario**	Based on historical data. Displays a future in which historic trends in the Kenyan residential cooking sector continue in a similar manner.	Present baseline scenario.
NDCU	**NDC Update Scenario**	Based on expert input from the modelling of Kenya's *updated NDC*. Assumes that a similar rate of change is maintained post-2030.	Present existing national policies and targets and a realistic development pathway for the residential cooking sector in the short- to medium-term.
IP	**Implemented Policies Scenario**	Based on policies and targets set for the mid-term (pre-2030) in the *2016 SE4All Kenya Action Agenda.* Assumes that a similar rate of change is maintained post-2030.	
GF	**Gas Focused Scenario**	Scenario with a focus on gas as cooking fuel, based on the *2020 IEA Africa Case*.	Speculative scenarios to analyse enhanced ambition and explore the requirements for decarbonising the residential cooking sector.
NZ	**Net Zero Scenario**	Scenario with a focus on electricity as cooking fuel, based on regional best practices and top-down assumptions to reach net zero by 2050.	

Results

GHG emissions and mitigation potential: Kenya ratified the Paris Agreement and set itself the target to reduce total national GHG emissions by 32% until 2030. Following a development pathway that is fully aligned with the Paris Agreement also implies that global emissions from the energy sector must reach net-zero by the mid of this century. In the model developed in this study, total GHG emissions from residential cooking are estimated to amount to 24.8 $MtCO_2e$ annually in 2019.

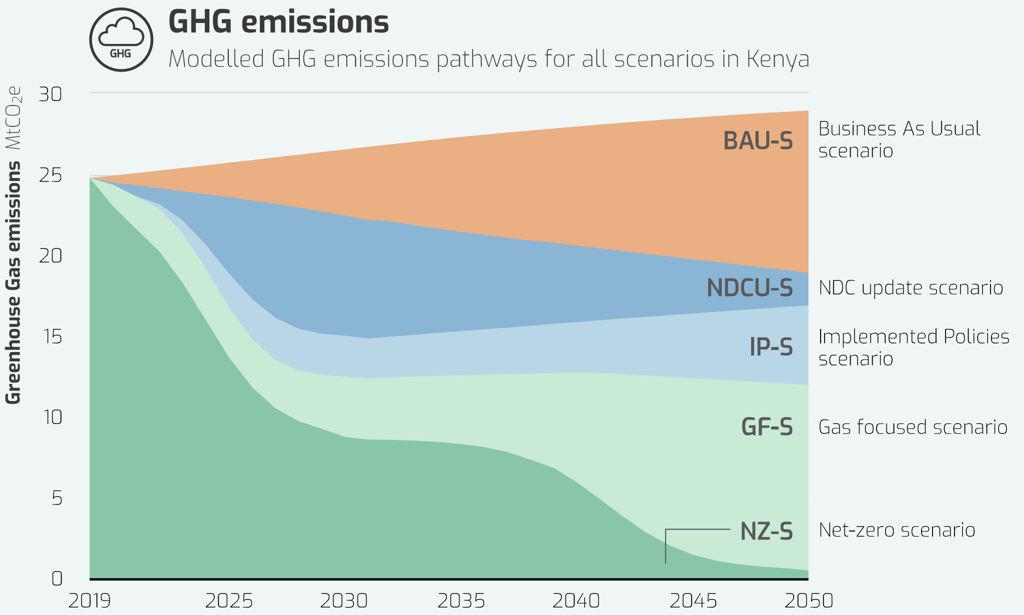

Figure 1. Modelled GHG emissions pathways for all scenarios.

The 2018-2022 NCCAP estimates that the uptake of alternative fuels and efficient cookstoves has a mitigation potential of 7.1 $MtCO_2e$. The scenarios developed in this study show that more can be achieved if the focus is shifted from modern cooking (LPG, improved biomass stoves) to clean cooking solutions (electric, biogas, bioethanol stoves). In the GF-S, which assumes increased access to LPG and a scale up of electricity, biogas and bioethanol, emissions could be almost halved by mid-century. The most ambitious NZ-S, which assumes a phase out of solid biomass and a substitution with electricity, biogas and bioethanol, brings emissions down to net-zero by mid-century, showing the strongest alignment with the quest of the Paris Agreement to decarbonise the energy sector (Figure 1).

Fuel use, energy demand and fuel expenditure: Many households which switch to more efficient fuels are expected to continue stacking incumbent technologies in the near- to mid-term. In all scenarios, except the NZ-S, the number of multiple user households increases throughout the study period along with a gradual shift to cleaner fuels. The higher the share of clean fuels and the more rapid the shift to improved solid biomass cookstoves, the lower is the resulting energy demand. The electricity focussed NZ-S scenario is the only scenario with a continuously decreasing energy demand, while a shift to gas and biofuels in the GF-S cannot compete with an increasing population and the overall energy demand increase until 2050, as is the case for the IP-S. Reduced fuel demand not only reduces emissions and air pollution but can enable considerable cost savings. As fuelwood supply is expected to decrease in the future, prices are likely to increase. The price of LPG may be subject to oil-price related fluctuations and a potential carbon price. Biogas and bioethanol still have high technology upfront costs, while the fuel costs for energy production are low. The price of electricity depends on the evolution of the electricity sector; however, there is huge potential to produce cheap electricity from renewable sources in Kenya. Against this background, the NZ-S performs best with a view to fuel expenditure in the future.

Deforestation: Along with agriculture and urbanisation, fuelwood and charcoal production is one of the major driving factors of deforestation in Kenya. The assessment of the exact impact of solid biomass consumption on deforestation is complex, as it involves the biomass supply source, the fraction of non-renewable biomass (fNRB), and the projected biomass demand. First order estimates suggest that in between 26% (BAU-S) and 8% (NZ-S) of current forest covered area risk being lost by 2050.

Air pollution and health impacts: The fuel and technology with which households prepare their food is one of the main sources of HAP. Each scenario has significant benefits in terms of avoided air pollution and premature deaths compared to the BAU-S (Figure 2). If the NZ-S was to be fully implemented, almost half a million premature deaths could be avoided over the timeframe of 30 years. The IP-S and GF-S show health benefits in the order of 250,000 to 300,000 saved lives, respectively, and the NDCU-S about 145,000. However, these are conservative figures, since a range of indicators – including morbidity-related factors, health impacts from other pollutants, effects on children, and workdays lost – were not accounted for in the analysis.

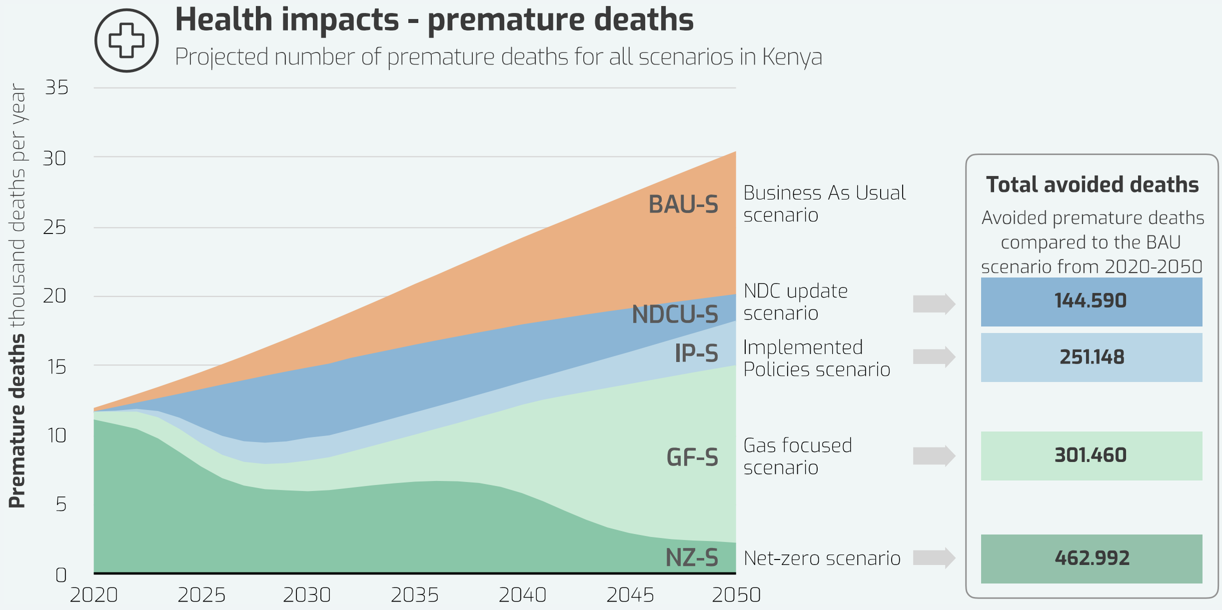

Figure 2. Estimated premature deaths for all scenarios and total avoided premature deaths compared to the BAU scenario between 2020 and 2050.

Key takeaways

The careful analysis of the scenarios offers five key takeaways [Chapter 5.1]:

1. There is significant **mitigation potential** in the residential cooking sector in Kenya.
2. Mitigation in the residential cooking sector contributes to **climate, health, and other sustainable development benefits**.
3. Clean cooking is already being recognised as a **transversal issue** in Kenya's policy landscape.
4. Rural areas still record **ultra-low access rates** and risk being left behind in the transition.
5. There are **opportunities** to promote renewable biofuels and electric cooking in Kenya.

Challenges

These key takeaways are set against three challenges that currently hamper the transition to a safe and clean residential cooking sector in Kenya [Chapter 5.2]:

Economic/financial: High upfront technology costs and expected fuel costs, paired with underdeveloped infrastructure for technology and fuel distribution, impede an increased uptake of cleaner cookstoves.

Cultural: The important cultural aspects of cooking and the practice of fuel stacking can considerably slow down the transition to cleaner cooking.

Political: While several policies and strategies exist that refer to the residential cooking sector, there is a lack of one comprehensive, sector-wide strategy to guide the transition to safe and clean cooking.

Recommendations

Based on these findings, the following recommendations can guide the future development of Kenya's residential cooking sector [Chapter 5.3]:

1. The establishment of a **permanent responsible institution and coordinated planning process** for the cooking sector could ensure that policies, strategies, and data are better aligned between the various stakeholders, including the Ministries of Environment and Forestry, Energy and Health, local authorities, and key non-state actors

2. A **dedicated, comprehensive long-term strategy** for the transition of the cooking sector could provide guidance for policy makers and all relevant stakeholders. Such a strategy ideally defines clear and realistic targets for the sector's future development in line with other relevant national planning documents.

3. It is important to **clearly prioritise clean solutions and the gradual phase out of improved cookstoves** in the longer term. Considering the global impetus towards a net zero carbon future, LPG and improved biomass should be considered as transition solutions, avoiding lock-in effects in terms of market and infrastructure developments.

4. The enormous potential of clean cooking can be harnessed to effectively support the **achievement of climate targets and other sustainable development objectives**. Awareness of these links among stakeholders and the population, particularly with regards to health benefits, can be an important driver of the transition.

5. An **improved system for data collection** and analysis in the cooking sector could be developed to improve the accuracy of projections and the quality of policy formulation in the future.

6. **Innovative infrastructure** solutions can further accelerate and enhance the transformation of the cooking sector.

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ABBREVIATIONS

ABPP	Africa Biogas Partnership Programme
AIRPOLIM	Air Pollution Impact Model
ATAR	Adaptation Technical Analysis Reports
BAU	Business As Usual
BMZ	German Federal Ministry for Economic Cooperation and Development
CCAK	Clean Cooking Association Kenya
CO_2	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
CPA	Charcoal Producer Association
EPRA	Energy and Petroleum Regulatory Authority
fNRB	Fraction of Non-Renewable Biomass
GBD	Global Burden of Disease
GCF	Green Climate Fund
GHG	Greenhouse Gas
GIZ	German Corporation for International Cooperation
HAP	Household Air Pollution
KES	Kenyan Shilling
KOSAP	Kenya Off-grid Solar Access Project
LPG	Liquefied Petroleum Gas
MJ	Megajoule
MoE	Ministry of Energy
MoH	Ministry of Health
MTAR	Mitigation Technical Analysis Reports
$MtCO_2e$	Megaton Carbon Dioxide Equivalent
MTP	Medium Term Plan
MW	Megawatt
NCCAP	National Climate Change Action Plan
NDC	Nationally Determined Contribution
NO_x	Nitrogen Oxides
PJ	Petajoule
$PM_{2.5}$	Particulate Matter of a diameter less than 2.5 micrometres
RBF	Results-Based Financing
REA	Rural Electrification Authority
REREC	Rural Electrification and Renewable Energy Corporation
SCAN-tool	SDG Climate Action Nexus tool
SDG	Sustainable Development Goals
SEI	Stockholm Environment Institute
SE4All	Sustainable Energy for All Initiative
SNV	Netherlands Development Organisation
SO_2	Sulphur Dioxide
SSA	Sub-Saharan Africa
USD	US Dollar
VAT	Value Added Tax
WHO	World Health Organization

1 INTRODUCTION

1.1 BACKGROUND

An estimated 900 million people in Sub-Saharan Africa (SSA) still rely on traditional forms of cooking such as wood, charcoal, dung, and unprocessed agricultural residues as part of their energy mix (IEA, 2018). Due to this widespread use, 390,000 deaths annually in SSA - 35% of which occur among children under five years of age - are attributable to Household Air Pollution (HAP) associated with cooking (Gakidou *et al.*, 2017). Access to clean cooking solutions in SSA is at a very low level of 15%, compared to the global average of 63% (ESMAP, 2021).

Kenya is one of the fastest growing countries in SSA and considered one of the newly emerging economies in the world (World Bank, 2015). This is also reflected in Kenya's long-term development plan *Vision 2030*, which states the objective to become a "newly industrialising, middle-income country [by 2030] providing high quality of life to all its citizens in a clean and secure environment" (Government of Kenya, 2007). Through joining the Sustainable Energy for All (SEforALL) initiative in 2016, the Kenyan government corroborated the objective to provide universal access to clean energy by 2030, in line with Sustainable Development Goal (SDG) 7. Access to clean cooking energy will simultaneously enhance the achievement of SDG 3 (good health and well-being), reducing deaths of children under five years of age as well as air pollution related deaths. In 2015, Kenya ratified the Paris Agreement on Climate Change and set itself the target to reduce total national greenhouse gas (GHG) emissions by 32% until 2030 (Government of Kenya, 2020b). Following a development pathway that is fully aligned with the Paris Agreement implies that global emissions from the energy sector must reach net-zero by the mid of this century (IPCC, 2018).

Residential cooking is central to the transition towards clean energy and a low-emissions economy. The fuel and technology with which households prepare their food is the main source of HAP, alongside heating and lighting, and a significant source of GHG emissions. Wood fuel (fuelwood and charcoal) remains Kenya's primary cooking fuel used by about 75% of all Kenyan households and more than 90% of the rural population (Ministry of Energy, 2019). In the model developed in this study, total GHG emissions originating from residential cooking fuels are estimated to amount to 24.8 $MtCO_2e$ annually in 2019.[1] Contrasted with Kenya's total GHG emissions of 93.7 $MtCO_2e$, this makes up a significant share (Government of Kenya, 2020b). In terms of health impacts, the Kenyan Ministry of Health estimated that 21,500 premature deaths per year result from diseases caused by air pollution from cooking (Ministry of Energy, 2019).

Given these significant adverse climate and health effects, air pollution from cooking is being addressed through several government policies, programmes and initiatives. In urban areas, the uptake of liquified petroleum gas (LPG) based solutions has increased significantly, while in rural areas, air pollution from

[1] Different estimations about emissions from the combustion of fuels in the residential cooking sector can be found in literature. The 2019 National Cooking Sector Study assumes annual emissions of 13.6 $MtCO_2e$ in the residential cooking sector, excluding carbon oxide, black carbon and organic carbon. When these three gases are included, the value increases to 20.5 $MtCO_2e$ (Ministry of Energy, 2019a). Another report assumes annual emissions from household biomass fuel use in Kenya's residential cooking sector to amount to in between 22-35 $MtCO_2e$, with the upper bound also considering emissions from fuel production (Dalberg, 2018). The base year emissions assumed in the model that is used in the present study are thus broadly in line with the figures that can be found in literature.

cooking is tackled mostly through the promotion of improved biomass cookstoves. Other programmes foster the adoption of biogas and bioethanol. Fully electrified stoves, on the other hand, make up only 3% of cooking appliances in Kenya (Ministry of Energy, 2019).

Remarkably, the most prominent cooking solutions based on LPG and improved biomass still emit considerable amounts of GHG emissions and air pollutants during use and production, while the cleaner solutions, including those based on biogas, bioethanol and electricity, are not yet significantly scaled up. This is problematic with a view to achieving Kenya's climate targets but also when considering the national development agenda. In addition to substantial climate and health benefits, the transition to a clean cooking sector can maximise the synergies with many other SDGs.

Against this background and recognising the lack of a comprehensive strategy for the transition of the residential cooking sector in Kenya to safe and clean cooking solutions, an estimation of the mitigation potential of different sector development pathways can provide valuable insights on the specific link between residential cooking solutions, climate change, health impacts and sustainable development objectives. Thus, in this study, the mitigation potential of various residential cooking technologies and fuels is analysed in a modelling exercise and associated socio-economic impacts are evaluated, with a focus on human health. A comparison of the results of these scenarios can help identify existing gaps and inform future-oriented development of laws, policies and regulations as well as initiatives that support a sustainable development of the Kenyan residential cooking sector in the future.

1.2 SECTOR OVERVIEW

1.2.1 Cooking fuels and technologies

The residential cooking sector in Kenya is the most developed in the East African region, both in terms of the number of people having access to improved cookstoves and in terms of the variety of cleaner cooking solutions available in the market. Improved cookstoves emerged in in Kenya the 1980s and since then the country has been viewed as a pioneer for the East African region. However, even though uptake rates are constantly increasing, several challenges remain, particularly with regards to the distribution and uptake of clean and improved cookstoves in rural areas (Stevens *et al.*, 2020).

Even though Kenya has made significant progress over the past decades, solid biomass is still the primary cooking fuel used in the country. Over 90% of the rural population and around 75% of all Kenyan households still cook with fuelwood or charcoal. Only about 20% of all households use LPG as their primary cooking technology. The number of electric cookstoves is extremely low, with around 3% of all households owning an electric appliance, including mixed LPG-electric stoves, electric coil stoves or microwaves (Ministry of Energy, 2019). The 2019 National Cooking Sector Study provides the most recent overview of the status of the residential cooking sector and serves as a main reference document in this context (Ministry of Energy, 2019).[2]

There are several terms and concepts that need to be taken into account when discussing the residential cooking sector in Kenya. The most important ones for the purpose of this study include fuel types, cooking technologies and the concept of fuel stacking.

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[2] For a detailed description of the status quo of the Kenyan cooking sector, the reader is asked to read the 2019 National Cooking Sector Study, which is available here: https://eedadvisory.com/wp-content/uploads/2020/09/MoE-2019-Kenya-Cooking-Sector-Study-compressed.pdf.

Fuel types

Fuel types considered in this study are fuelwood, charcoal, LPG, kerosene, electricity and gaseous or liquid biomass. Solid biomass (fuelwood and charcoal) can be sourced from sustainable or unsustainable biomass and is applied in either a traditional or improved cooking technology. Gaseous and liquid biomass refer to biogas and bioethanol produced from sustainable biomass and are hence categorised as clean fuels. An overview of the different types of biomass and their respective technology applications is provided in Figure 3.

In the scenarios developed in this study, lifecycle emissions, that is, emissions from the production and transportation of fuels, is not accounted for. However, the required biomass supply for the production of charcoal, gaseous and liquid biomass is estimated.

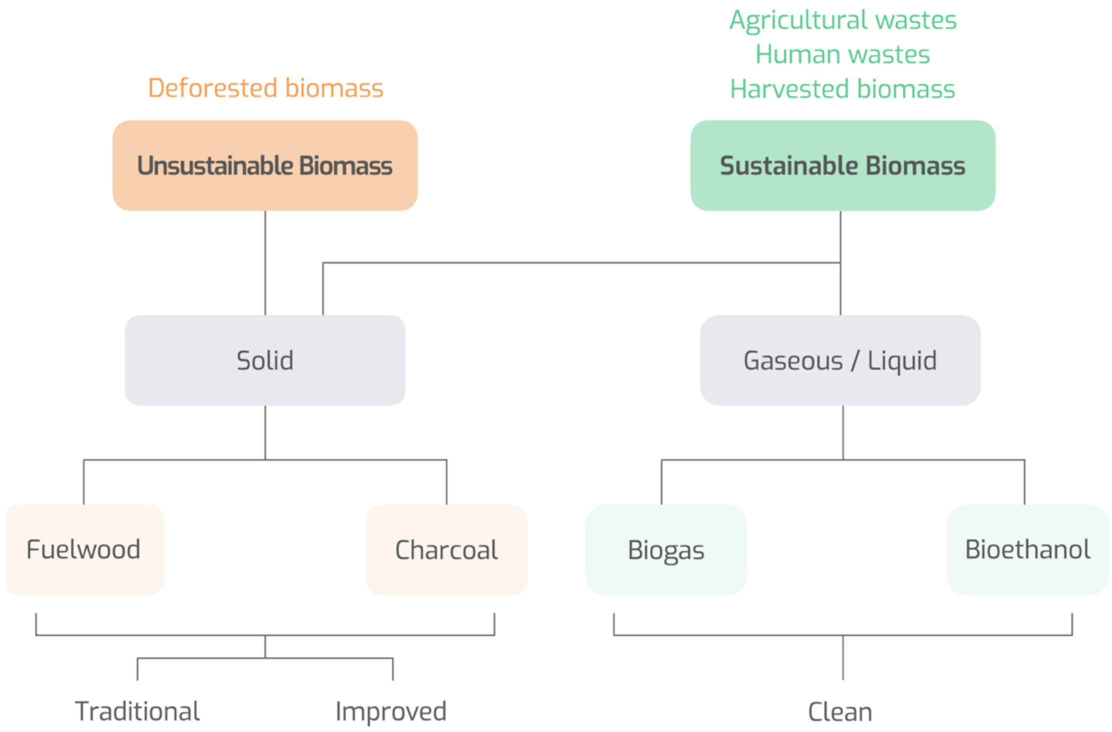


Figure 3. Overview of the sources and categorisation of biomass types.

Cooking technologies

In alignment with the different fuel types this study differentiates between three technology categories that include the main cooking technologies currently in use. Traditional cookstoves include kerosene stoves as well as traditional fuelwood and charcoal stoves. LPG cookstoves, which emit less GHGs and non-GHGs than traditional cookstoves but are not emissions free, as well as improved biomass stoves can be categorised as modern cookstoves. Gaseous and liquid biomass stoves together with electric stoves are considered clean cookstoves.[3] The categorisation of traditional, modern and clean cookstoves is presented in Table 2.

[3] Sustainable biomass used in a traditional or improved stove is not considered clean despite the fact that such an approach would be GHG-emissions neutral, i.e. GHG emissions emitted from the combustion of the biomass would be recycled in the regrowth of the new biomass. Although GHG emissions would not appear in the official accounting, the GHG emissions are still emitted. In addition, non-GHG emissions would remain the same, even though in reduced quantities in the case of improved cookstoves. In addition, the fuel consumption is not affected further than to the highest efficiency of an improved cookstove.

Table 2. Definition of modern and clean cookstoves.

Traditional	Modern	Clean
○ Kerosene ○ Traditional wood stove ○ Traditional charcoal stove	○ LPG stove ○ Improved wood stove ○ Improved charcoal stove	○ Electric stove ○ Biogas stove ○ Bioethanol stove

Fuel stacking

More than half of all Kenyan households use more than one type of fuel and technology for cooking – a practice that is known as stacking – with some even relying on three or more cooking solutions (Ministry of Energy, 2019). In rural areas, 93% of the population rely on fuelwood or charcoal as their primary fuel (Ministry of Energy, 2019). While in urban areas, a large number of households (46%) relies on LPG as their primary fuel, still around 33% have a second stove fired with charcoal or fuelwood. Clean cooking solutions, including biogas, bioethanol and electric stoves, are only used by 0.4% of the urban population as a primary cooking technology, and by 0.8% of the urban population as a secondary technology (Ministry of Energy, 2019).

Substantial effort is needed to drastically scale up the adoption of modern and – in particular – clean cooking solutions across the country in the coming years. A necessary condition is the provision of a favourable political and regulatory framework that incentivises the production, distribution and use of modern and clean cookstoves. In addition to that, several socio-cultural and economic factors play a key role that must be carefully assessed and addressed to overcome potential barriers.

1.2.2 Policy landscape

The existing policy landscape with regards to residential cooking is extensive in Kenya. In the following, relevant laws, policies and regulations in the four sectors that are closely linked to the cooking sector are briefly outlined, namely the forestry sector, the energy sector, the climate policy area and the health sector. Furthermore, existing public and private initiatives as well as relevant fiscal policies are described. This overview is meant to provide the necessary background information on existing policies and targets for the subsequent modelling exercise, as they can play an important role in planning a successful transition to a truly clean cooking sector.[4]

Forestry related laws, policies and regulations

The choice of cooking technologies and fuels has specific implications for the forestry sector. Cooking based on solid biomass can contribute significantly to forest degradation and local deforestation. This is particularly the case where large amounts of fuelwood are collected for direct consumption or charcoal production (ESMAP, 2015). Hence, policies that protect forests from unsustainable fuel collection and production practices are important. The policy landscape in the forestry sector in Kenya is still developing (Table 3).

[4] More details on the policies are included in Annex I.

Table 3. Summary of forestry related laws, policies and regulations.

Policy	Highlights	Targeted outcomes
2005 Forest Act	○ Promotes participatory forest management ○ Establishes the Kenya Forest Service ○ Places an emphasis on sustainable forest management and sustainable biomass production systems	○ Improve provisions for sustainable charcoal production, transportation and marketing
2009 Forest (Charcoal) Regulations	○ Sets rules for licensing charcoal production and transportation ○ Requires the formation of charcoal producer associations (CPAs) ○ Provides for the creation of a Forest Conservation Committee	○ Establish provisions for reforestation, conservation and for protection of endangered plant species
2016 Forest Conservation and Management Act	○ Classifies producing or possessing charcoal in a forest without a permit as an offence ○ Recognises need to develop a national forest policy which is to be accompanied by a national forest strategy	○ Provide guidance and regulations for sustainable production, transportation and trade of charcoal and fuelwood ○ Conserve forests and reduce charcoal burning
2020 Draft National Forest Policy	○ Provides basis for governance-related, administrative and legislative reforms ○ Emphasises rehabilitation and restoration of degraded forest ecosystems ○ Led to gazettement of National Strategy for Achieving and Maintaining 10% Tree Cover in 2019	○ Effectively address continuing deforestation, forest degradation and governance challenges

Energy related laws, policies and regulations

The institutional framework in the Kenyan energy sector is very dynamic, with several laws and policies having been passed in the last decade. Overall development in the energy sector is currently guided by the 2019 Energy Act and the 2018 National Energy Policy. Besides these two landmark documents, several other regulations and strategies exist in the Kenyan energy sector that target the cooking sector directly or indirectly (Table 4).

Table 4. Summary of energy related laws, policies and regulations.

Policy	Highlights	Targeted outcomes
2009 Energy (LPG) Regulations	○ Establishes licensing requirements for LPG business ○ Prescribes standardisation of LPG cylinders and valve sizes to allow for interchangeability between brands ○ Establishes "LPG cylinder exchange pool" among LPG companies	○ Promote LPG as a modern energy source and cooking fuel
2013 Energy (Improved Biomass Cookstoves) Regulations	○ Provides rules on licensing, installation, record keeping, warranty and disposal of improved biomass cookstoves ○ Provides basis to develop standards for biomass cookstoves to monitor emissions, ensure performance, safety and durability	○ Promote usage of improved biomass cookstoves ○ Enhance performance, safety and durability of improved biomass cookstoves
2018 Energy Policy	○ Shows clear link to climate change policy ○ Reiterates mitigation targets set in climate change planning documents ○ Prioritises mitigation actions in the energy sector	○ Ensure affordable, competitive, sustainable and reliable supply of energy to all Kenyans ○ Promote transition towards cookstoves running on modern and clean fuels in households and institutions
2019 Energy Act	○ Acknowledges role of MoE to provide overall guidance through policy formulation ○ Guides country's energy transition ○ Institutionalises Rural Electrification and Renewable Energy Corporation (REREC) with mandate to promote and manage renewable energy ○ Tasks County governments with development of County Energy Plans and regulation of biomass production and distribution	○ Consolidate all energy-related laws ○ Pave the way for new institutions and mandates in the energy sector ○ Devolve certain functions to the County governments, e.g., the right to identify which forms of energy to promote

2019 Energy (LPG) Regulations	○ Replaces 2009 Energy (LPG) Regulations ○ Establishes that all LPG retailers must acquire a license from EPRA for each business location (specific to the authorised cylinder brands only)	○ Resolve the issues from earlier regulations and ensure the safety of all LPG users
2020-2027 National Bioenergy Strategy	○ Provides guidelines, approaches and strategic interventions to promote sustainable production and consumption of bioenergy ○ Sets out commitment to meet clean cooking targets by 2028	○ Meet clean cooking targets, i.e., 100% access to improved biomass cookstoves, by 2028 ○ Achieve 100% access to modern bioenergy services by 2030

Climate related laws, policies and regulations

It is widely recognised that the use of inefficient and polluting cooking fuels and technologies contributes to environmental degradation and climate change. Thus, lately, the Kenyan cooking sector has been addressed more explicitly in climate related policies and guiding documents which aim at curbing national emissions, amongst others from energy demand (Table 5).

Table 5. Summary of climate related laws, policies and regulations.

Policy	Highlights	Targeted outcomes
2015 First NDC	○ Provides national contribution to the global goal of limiting global warming to 1.5°C as stipulated in Paris Agreement (without specifying sector-specific contributions)	○ Achieve economy wide emissions reductions of 30% relative to a BAU scenario by 2030
2017 NDC Sector Analysis	○ Examines options to deliver total mitigation contribution as committed to in First NDC through sector-specific contributions ○ Suggests that the energy demand sector reduces emissions of 6.1 $MtCO_2e$ relative to BAU by 2030 ○ Outlines two mitigation options in the cooking sector: “LPG Stove Substitution” and “Improved Cookstoves” ○ Ascribes the cooking sector a mitigation potential of 7.3 $MtCO_2e$	○ Assess mitigation potentials and provide options for sectors to implement sector-specific emission reductions

2018-2022 National Climate Change Action Plan (NCCAP)	○ Developed based on predecessor, 2013-2017 NCCAP ○ Identifies transition to clean cooking as priority climate action in energy demand sector ○ Ascribes the uptake of alternative fuels and efficient cookstoves in the energy demand sector a mitigation potential of 7.1 $MtCO_2e$ ○ Outlines concrete mitigation actions and targets in the cooking sector	○ Encourage uptake of cleaner cooking fuels, especially LPG and ethanol in urban areas and improved biomass cookstoves in rural areas ○ Achieve following targets by 2022: ○ 2 million households use LPG, ethanol or other cleaner fuels ○ Additional 4 million households use improved biomass cookstoves ○ 6,500 bio digesters for domestic use and 600 biogas systems for schools and public facilities are built
2020 Updated NDC	○ Provides an update to the national contribution to limiting global warming to 1.5°C as required by the Paris Agreement (without specifying sector-specific contributions)	○ Achieve economy wide emissions reductions of 32% relative to a BAU scenario by 2030

Health related policies and initiatives

Apart from the adverse environmental and climate impacts, the use of solid biomass and other harmful fuels such as kerosene is one of the world's major public health challenges, causing more premature deaths than HIV/AIDS, malaria, and tuberculosis combined (ESMAP, 2015). However, in Kenya – as is the case in many other African and Asian countries – regulation in this sector is only starting to address the issue of cooking more directly. In this context, the Ministry of Health has recently started to work on a Community Health Volunteer Handbook (Table 6).

Table 6. Health related initiatives.

Policy	Highlights	Targeted outcomes
Community Health Volunteer Handbook	○ Seeks to improve household energy use for lighting, heating, and cooking ○ Raises awareness about Household Air Pollution	○ Create demand for cleaner lighting, heating and cooking fuels ○ Reach over 100,000 communities in Kenya

Public and private sector initiatives in the cooking sector

Beyond laws, policies and regulations, Kenya witnesses a growing number of public and private sector initiatives that aim at promoting the transformation of the energy sector in general and the cooking sector more specifically. These initiatives are often technically and financially supported by international organisations (Table 7 & Table 8).

Table 7. Summary of public sector initiatives in the cooking sector.

Policy	Highlights	Targeted outcomes
2013 Kenya Country Action Plan	○ Developed with support of the Clean Cooking Alliance ○ Outlines 24 priority actions to remove barriers to the widespread adoption of clean cookstoves and fuels in Kenya ○ Proposes creation of the Clean Cooking Association of Kenya (CCAK)	○ Catalyse the clean cookstove and fuel market and contribute an estimated 7 million clean cookstoves by 2020
2016 Kenya Action Agenda	○ Developed in the framework of the Sustainable Energy for All (SE4All) Initiative ○ Presents a long-term vision for energy sector development 2015-2030 ○ Outlines how Kenya will achieve the SE4All goals, including 100% access to electricity and 100% access to modern cooking solutions by 2030 ○ Identifies existing gaps towards these targets	○ Increase access to modern and clean cooking through high impact initiatives
2016 Kenya Investment Prospectus	○ Developed in parallel with 2016 Kenya Action Agenda ○ Presents the current investment environment and priority investment areas ○ Identifies opportunities to operationalise the SE4All targets in Kenya	○ Increase distribution and uptake of clean cookstoves and fuels through prioritising specific projects

Mwananchi Gas Project (2016-2018)	○ National LPG enhancement project funded by the Treasury with KES 3 billion ○ Was planned to help distribute gas cylinders at a discounted price to poor households ○ Distribution stalled in 2018 due to fraud	○ Limit usage of firewood through distribution of 6kg complete gas cylinders at a discounted price of KES 2,000 to poor households ○ Enhance LPG penetration from 10% to 70% within three years
Kenya Off-grid Solar Access Project (KOSAP) (2017-2023)	○ Project funded by World Bank with USD 150 million ○ Targets electricity supply and cooking sector specifically	○ Provide electricity and clean cooking solutions to 14 underserved areas until 2023 ○ Provide incentives to private sector companies to disseminate solar-based and clean cooking solutions
Promotion of Climate-Friendly Cooking in Kenya (2020-2025)	○ Project funded by the GCF, implemented by GIZ in collaboration with SNV, MoE and MoH ○ Promotes the creation of an innovative and strong market in Kenya for the production and sales of improved cookstoves	○ Increase penetration of improved cookstoves in rural and remote areas ○ Advance achievement of the NDC

Table 8. Summary of private sector initiatives in the cooking sector.

Policy	Highlights	Targeted outcomes
Kenya Biogas Programme (2009-present)	○ Public-private partnership between Hivos, SNV and Dutch government ○ Implements the Africa Biogas Partnership Programme (ABPP) in Kenya ○ Distributes bio digesters to individual households ○ Establishes credit partnerships with rural micro finance institutions and saving cooperatives to reduce costs ○ Certifies emissions reductions through Gold Standard and sells carbon credits	○ Develop a commercially viable and sustainable biogas sector in Kenya ○ Raise funds for further support of biogas users (incl. after-sales support, bioslurry training, other services) through carbon credits
National Biomass Briquette Programme (2016-2022)	○ Multi-stakeholder initiative between Hivos, Greening Kenya Initiative, African Centre for Technology and Practical Action and Kenyan government ○ Promotes development of innovative briquette technologies, policies and practices in the energy sector ○ Develops supply chain ranging from production of briquettes to establishing standards for domestic and industrial use	○ Establish sustainable briquette manufacturing sector in Kenya ○ Increase adoption and usage of briquettes as cleaner fuel

Fiscal policies affecting the cooking sector

In addition to sector specific policies and initiatives, there are a few fiscal policies and banking bills in Kenya that do not target the cooking sector directly but have significant impact on it. The most relevant of these are summarised in Table 9.

Table 9. Summary of fiscal policies affecting the cooking sector.

Policy	Highlights	Targeted outcomes
Import duty on cookstoves (2016 – 2020)	○ Import duty on solid biomass stoves is first reduced from 25% to 10%, then increased from 10% to 35%, before being reduced again to 25% ○ Import duty on energy efficient cookstoves is reduced from 25% to 10%	○ Encourage purchase of modern and clean cookstoves, with a focus on energy efficient cookstoves (that use gas, electricity or other clean fuels)
2016 Finance Act	○ Removes 16% VAT on LPG and clean cookstoves ○ Introduces excise duty on kerosene of KES 7.20 ○ Removes excise duty on ethanol for cooking and heating	○ Spur the use of cleaner fuels and stoves and help achieve progress on the country's objectives to improve health, livelihoods, and the environment
2018 Finance Act	○ Further increases excise duty on kerosene from KES 7.20 to KES 10.30 ○ Introduces 8% VAT on petroleum products, including kerosene ○ Introduces an anti-adulteration levy on kerosene imported for home use, at KES 18 per litre	○ Discourage use of kerosene especially in households
2020 Finance Bill	○ Reintroduces 16% VAT on LPG and clean cookstoves ○ Contradiction of government efforts to promote clean cooking	○ Increase the price of clean cooking for consumers again

It becomes clear from this overview that current policies, programmes and initiatives focus mostly on the deployment of modern cookstoves, with much less attention being paid to truly clean cooking solutions. While the promotion of modern cookstoves can present an important intermediate step towards a clean cooking sector, it does not present a fully sustainable solution in the long-term. In order to push both the climate and the national development agenda and prepare Kenya for a sustainable future, more attention in planning and policy making must be given to the significant synergies between climate action and sustainable development in a low-emission residential cooking sector.

2 STUDY DESIGN AND APPROACH

This chapter outlines the relevance and objectives of this study in the context of Kenya's climate and sustainable development aspirations and provides a detailed description of the methodologies used for scenario modelling and the quantification of health impacts. The results of the analysis are presented and discussed in Chapter 3 and Chapter 4.

2.1 RELEVANCE

Climate change and sustainable development cannot be considered in isolation. Mitigating global warming, adapting to climate change, and responding to the risks of climate-related loss and damage have all been anchored as objectives in the 2015 Paris Agreement on Climate Change. Global emissions must be reduced by 45% from 2010 levels by 2030 in order to limit global temperature rise to the desired 1.5°C by the end of this century (UN, 2019). At the same time, the 2030 Agenda for Sustainable Development puts the spotlight on 17 SDGs and highlights the need to ensure, amongst others, universal access to affordable and reliable energy to all by 2030, as stipulated in SDG 7, and healthy lives and well-being for all at all ages, as declared in SDG 3 (UN, 2015).

Kenya has set itself ambitious climate targets and defined concrete development objectives which are laid down in different key policy and planning documents. These targets and objectives have direct or indirect implications for the country's residential cooking sector.

Kenya's climate targets

Kenya ratified the Paris Agreement in 2016 with the submission of its first Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC). In December 2020, Kenya submitted an updated NDC in which the country increased its mitigation ambition from a 30% reduction by 2030 (as in the first NDC) to a 32% reduction in the same target year, compared to a business and usual (BAU) scenario. Achieving this target will require collective efforts to move all sectors on a low-carbon pathway without jeopardising Kenya's development goals. The national climate targets set in the NDC are backed by the 2016 Climate Change Act and implemented through the 2018-2022 National Climate Change Action Plan (NCCAP), both of which highlight the importance to align the country's climate change policy with its national development objectives.

The residential cooking sector contributes significantly to Kenya's total national GHG emissions. Total GHG emissions originating from residential cooking fuels are estimated to amount to 24.8 $MtCO_2e$ in 2019. Contrasted with Kenya's total GHG emissions of 93.7 $MtCO_2e$ in that same year, this makes up a significant share (Ministry of Environment and Forestry, 2020a).

Against this background, the 2018-2022 NCCAP identifies the transition to clean cooking as a priority climate action in the energy demand sector. This transition is expected to happen through the uptake of LPG, ethanol and other alternative fuels in urban areas, and through the uptake of improved biomass cookstoves and use of briquettes in rural areas. The plan furthermore outlines concrete mitigation actions with respective targets in the cooking sector, estimating that total GHG emission reductions through the uptake of alternative fuels and efficient cookstoves in the energy demand sector can amount to 7.1 $MtCO_2e$ (Ministry of Environment and Forestry, 2018).

Kenya's (sustainable) development objectives

With regards to national development, Kenya launched its Vision 2030 in 2008. Vision 2030 is the country's long-term development plan which pursues the objective to transform Kenya into a newly industrialising, middle-income country by 2030 (Government of Kenya, 2007). The plan is being implemented through a series of 5-year Medium-Term Plans (MTPs). The latest MTP III, which covers the period from 2018-2022, focuses on the most pressing development issues of the country, recognising energy as a key driver of development, especially with regard to energy access and economic growth (Government of Kenya, 2018).

The need for sustainable development, including in the cooking sector, is indirectly anchored in the MTP III. One of the specific development objectives stated in the plan is to provide a high quality of life to all Kenyan citizens in a clean and secure environment, as well as to target improvements to health and healthcare (Government of Kenya, 2018). Even though air pollution is not mentioned explicitly, it invariably forms part of a clean and healthy environment, as anchored in SDG 3: the Kenyan Ministry of Health estimated that 21,500 premature deaths per year result from diseases caused by air pollution from cooking (Ministry of Energy, 2019). Another objective stated in the MTP III is the achievement of universal electricity access by 2020, which could further improve the access to clean cooking solutions. This objective is directly in line with SDG 7. Finally, the document refers to "greening initiatives", including the distribution of energy efficient cookstoves (Government of Kenya, 2018).

Potential for further synergies between climate and sustainable development in the cooking sector

There is a growing body of scientific analysis that shows how climate action can positively contribute to the achievement of other sustainable development-related objectives that are important to society, such as food security, human health, energy access and security, employment creation, and environmental services (IPCC, 2014). The impacts of climate-related policies which go beyond those directly related to their original purpose of climate mitigation (sometimes referred to as "co-benefits") are increasingly considered in international policy making and are gaining political and economic momentum. The integration of multiple objectives in policies can strengthen the support for such policies and increase the cost-effectiveness of their implementation (Schiefer, Roeser and Fearnehough, 2019).

Decarbonising the residential cooking sector can thus contribute, directly and indirectly, to a number of additional SDGs. According to the SDG Climate Action Nexus Tool (SCAN-tool), climate mitigation action in the cooking sector can contribute to the achievement of seven SDGs[5], including a total of 15 potential synergies between climate action in the cooking sector and the SDG targets. Figure 4 illustrates these linkages.

[5] SDG 13 (Climate Action) and SDG 17 (Partnerships for the Goals) are not included in the SCAN-tool.

Figure 4. Linkages between mitigation actions in the cooking sector and SDGs.

The SDG Climate Action Nexus tool (SCAN-tool) developed by NewClimate Institute is designed to provide high-level guidance on how climate actions can impact achievement of the Sustainable Development Goals (SDGs). The tool is available at https://ambitiontoaction.net/scan_tool/

This means that mitigation action in the residential cooking sector not only contributes to achieving Kenya's climate targets but has positive synergies with several other national development objectives.

In close relation to the SDGs, six relevant socio-economic impacts that can be ascribed to a transition of the cooking sector to clean and secure cooking solutions should be considered in future planning and policy making:

Health

Transitioning to clean cooking reduces household air pollutant emissions and has significant benefits for human health. Chapter 4 outlines this relationship in detail and estimates the specific health impacts for different cooking sector development pathways.

Biodiversity

The continuously high dependency on biomass energy for cooking exerts high pressure on indigenous forests. Stringent forest sector reforms that promote sustainable forest management and governance are thus essential to preserve forest resources for present and future generations, including the range of benefits that these offer for local and national development. Chapter 3 provides more information on the biodiversity impacts of different cooking sector development pathways, with a specific focus on deforestation.

Fuel savings

With regards to costs, a reduced fuel demand can benefit consumers as it allows for fuel cost savings. A shift to cleaner fuels can lead to lower fuel demand and cost savings, not taking capital expenditures for the stove purchase into account. More specifically, compared to the current (2019) estimated average annual fuel expenditures of USD 530 per household, this could be decreased to 20%-50% by 2030 and to 40%-60% by 2050 depending on the cooking sector development pathway chosen, as is shown in Chapter 3.

Jobs

In Kenya, the clean cooking sector provided about 19,000 direct, formal jobs and between 15,000 to 35,000 informal jobs in 2019 (Shirley and Lee., 2019). However, the level of compensation and retention is mostly low. With regards to LPG and electric cooking, sales and distribution make up the biggest part of the workforce, while for bioethanol and biogas, manufacturing and assembling are most important (Lee *et al.*, 2019). Management, finance and legal, as well as product development and research are the most difficult positions to fill. To maximise job opportunities from clean cooking, targeted trainings and local capacity building are key.

Time savings

One key benefit of transitioning away from biomass-based cookstoves is the time saved for both fuel collection and the cooking process itself. A study presenting evidence from Kenya showed that an average of 12 hours per week and per household is spent on collecting fuelwood, mostly by women (Jagoe *et al.*, 2020).

Gender equality

Clean cooking efforts contribute to gender equality and female empowerment. Women are typically responsible for both fuel collection as well as cooking, which perpetuates gender inequalities (Jagoe *et al.*, 2020). “Time poverty” restricts women's involvement in paid work, as well as in educational, political, and social activities. Further, being responsible for cooking, women and girls are disproportionately exposed to air pollution and its harmful health impacts.

2.2 OBJECTIVES

Kenya aims to balance the need for rapid socio-economic development and climate concerns through various policy documents and legal measures. While the Vision 2030, the 2018 National Energy Policy and the 2020-2027 National Bioenergy Strategy aim to ensure access to modern cooking solutions, the 2018-2022 NCCAP and the updated NDC guide the country towards a low-carbon development pathway, in line with the Kenya's climate targets. Although residential cooking contributes significantly to national GHG emissions, there is a knowledge gap on how to ensure a sustainable transition that balances the need to increase access to cooking solutions with climate considerations. This study aims to address this knowledge gap by providing new and additional insights on the specific link between residential cooking solutions, climate change, health impacts and associated sustainable development objectives in Kenya.

The main objective of this study is to present a comparative analysis of different potential residential cooking sector development scenarios which assesses the GHG emissions and human health impacts. Based on several scenarios, this study will:

i) quantify GHG emissions and mitigation potential,
ii) estimate the fuel mix and energy demand,
iii) determine the average fuel expenditure per household,
iv) estimate the impact on deforestation,
v) evaluate the type and level of exposure to household air pollutants, and
vi) assess the impact on human health.

This study builds on the 2019 National Cooking Sector Study which was commissioned by the Ministry of Energy and the Clean Cooking Association of Kenya (CCAK) in 2019 and researched by EED Advisory and the Stockholm Environment Institute (SEI), establishing a baseline for cooking sector performance indicators in Kenya (Ministry of Energy, 2019).

The findings from this combined modelling exercise can contribute to planning and policy making in three relevant national institutions, namely in the Climate Change Directorate within the Ministry of Environment and Forestry, the Ministry of Energy, and the Ministry of Health. Modelling results can inform progressive policy making and improve overall policy outcomes in each of these institutions individually, for example, through influencing climate target setting in the country's NDC process. Equally important, they can provide information in an effort of these institutions to jointly develop a comprehensive, sector-wide strategy for reducing GHG emissions and HAP from residential cooking in Kenya. This would enable the country to swiftly forge ahead and meet its mid- and long-term climate and sustainable development objectives.

2.3 METHODOLOGY

2.3.1 Overview of scenario modelling

This study uses scenario modelling to develop future scenarios for Kenya's residential cooking sector based on cooking technology deployment, fuel use and policy choices. Results from these scenarios provide insights on GHG and non-GHG emissions, fuel use, fuel expenditure, energy demand, deforestation, and human health. By means of the modelling exercise, this study illustrates different possible development pathways for the Kenyan residential cooking sector, estimating their respective impact on climate and sustainable development objectives.

For the modelling exercise, an excel-based tool built by NewClimate Institute is used to develop bottom-up projections under different policy circumstances, based on historic data. The aim of the exercise is to let the long-term scenarios inform and facilitate the discussion around different policy options and the respective outcomes that could be expected from the implementation of those. The timeframe of the quantitative analysis is from 2019 through 2050.

Baseline for fuel types and technologies

Based on data collected from the 2019 National Cooking Sector Study, a baseline is defined in terms of the type of fuel and cooking technology used per household in urban and rural areas at the time of the study. Fuel type usage is categorised as single or multiple fuel type usage. In the latter case, multiple fuel type usage is further disaggregated into primary and secondary fuel type usage, given that more than 50% of Kenyan households use more than one type of cooking fuel.

The fuel types considered in the tool include fuelwood, charcoal, LPG, kerosene, electricity and gaseous/ liquid biomass. Technologies considered are traditional cookstoves (kerosene, traditional wood, traditional charcoal); modern cookstoves (LPG, improved fuelwood, improved charcoal); and clean cookstoves (electric, biogas, bioethanol).

Time dependent and constant input parameters

The current distribution of the different fuel and technology types are used as inputs to the tool. This defines the baseline for the start year of the projections. Other **time dependent** driving factors including population projections, urbanisation rate and thermal efficiency are also included as inputs to the tool. The thermal efficiency of each individual technology changes over time as the technology is further developed.

The cooking energy demand refers to the amount of energy that is needed to cook a standard meal and is a **constant** input parameter. The household size is also constant over time but varies across urban and rural households. The average household sizes are assumed to be 3.5 and 4.7 people per household in urban and rural areas, respectively (Kenya National Bureau of Statistics, 2014). Finally, the current fuel prices present a constant input parameter, included to derive fuel expenditures for each scenario.

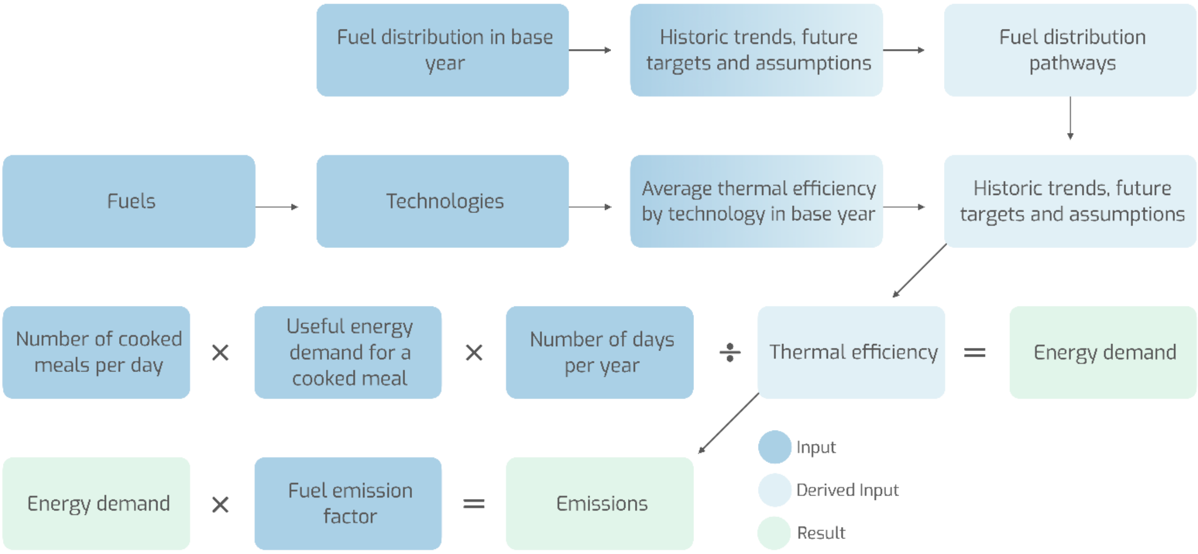


Figure 5. Mathematical logic of the scenario modelling tool.

An imperative parameter to determine GHG and non-GHG emissions is the energy demand for cooking. That is, the energy needed to deliver the heat required to cook a meal, taking into consideration fuel conversion factors[6] and the thermal efficiency of the stove. Figure 5 gives an overview of the mathematical logic of the scenario modelling tool in estimating the energy demand. Fuel and thermal efficiency pathways are developed based on historic trends and future targets, deriving the energy demand based on the energy required to cook a standard meal. The energy demand helps to derive emissions for air polluting gases and greenhouse gases, based on fuel combustion emission factors. The considered air polluting gases include $PM_{2.5}$, NO_X and SO_2 emissions, while GHGs are expressed as CO_2 equivalents (CO_2e).

Policies and targets for scenario definition

Based on these input parameters, the scenarios are developed through the consideration of selected policies and targets. Targets may refer to specific shares of a certain fuel or technology type to be achieved by a certain year but could also refer to the uptake of improved or clean technologies more generally. The result of that exercise is expressed in terms of fuel demand, fuel expenditures, energy demand (and deforestation), GHG emissions, and non-GHG emissions in respective scenarios. A simplified overview of the input and output parameters is presented in Figure 6.

[6] The fuel conversion factor refers to the process of transforming fuel input to useful heat output that can be used for cooking. As an example, energy is lost in the process of converting woody biomass into charcoal.

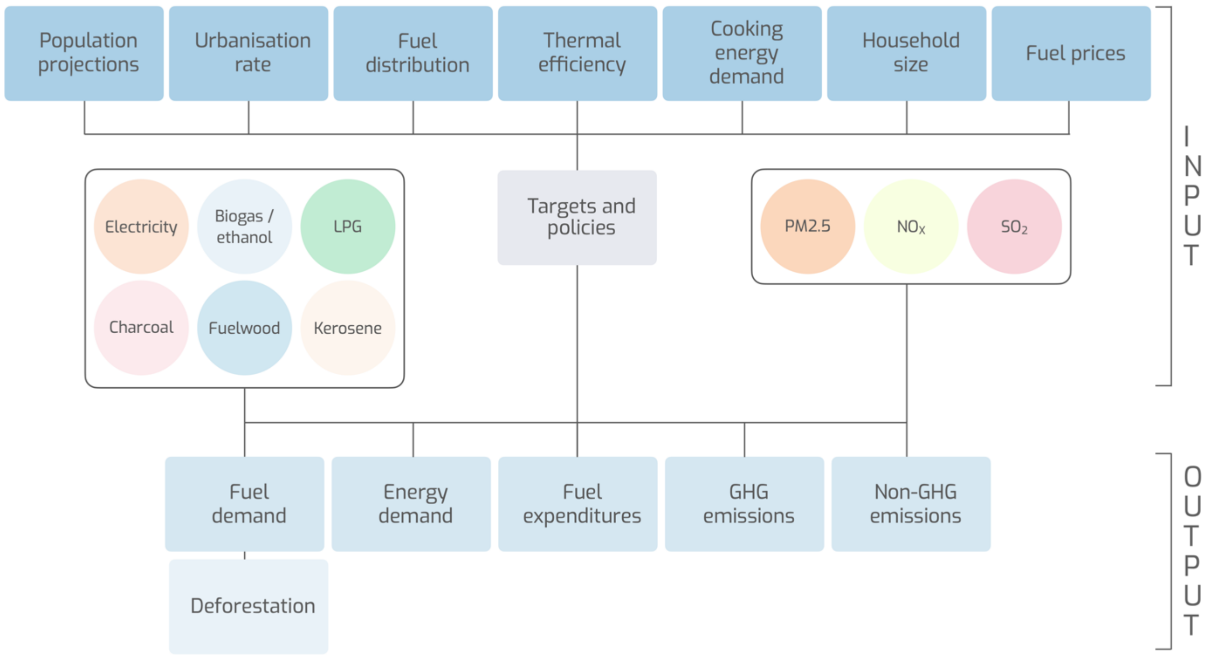


Figure 6. Overview of input and output parameters in the modelling exercise.

The round, coloured shapes refer to GHG and non-GHG emission factors.

Scope and limitations

Data availability in the residential cooking sector is often constrained. There are data gaps as well as inconsistencies between different data sources. These uncertainties present limitations to the modelling exercise and must be considered when interpreting the results. The most relevant data limitations for this study were found with regards to population and urbanisation growth; inconsistent data on fuel and technology use; a lack of data on the fraction of renewable energy use (fNRB); and a discrepancy of non-GHG emission factors in the literature. For a detailed depiction of these limitations see Annex II.

2.3.2 Modelling GHG emissions and mitigation potential

A set of six scenarios is developed which reflect existing targets and recommendations compiled from the current literature (Table 10). The *business-as-usual* scenario (BAU-S) represents a future in which **historic trends** in the Kenyan residential cooking sector continue in a similar manner. Furthermore, **existing national policies and targets** are represented in two different scenarios: the *implemented policies* scenario (IP-S) and the *NDC update* scenario (NDCU-S). Based on expert consultation, the updated NDC documentation is the most realistic development pathway for the sector compared to the original (more ambitious) NDC documentation in terms of the deployment rate of improved cookstoves. As the IP-S and NDCU-S are based on policies and targets set for the mid-term (pre-2030), it is assumed that a similar rate of change is maintained post-2030. Lastly, **enhanced ambition** is speculatively analysed in two scenarios informed by existing literature and regional best practices. Those include one scenario in which an emphasised focus on gas is observed, the *gas focussed* scenario (GF-S), and another scenario which explores the requirements for the residential cooking sector to reach net-zero emissions by 2050, the *net-zero* scenario (NZ-S).

The scenarios are developed through the modification of two main parameters:

- **Fuel type and usage**
  This parameter refers to the share of the population which uses a certain fuel as a single, primary or secondary fuel and is modified according to policies and targets. The overall sum of the shares can exceed 100% as many households use more than one type of cooking fuel.

- **Technology thermal efficiency**
  This parameter refers to the thermal efficiency of a particular technology. For example, if the uptake of improved fuelwood stoves increases, the average thermal efficiency of all fuelwood stoves will also improve. Further, it is assumed that new purchased cookstoves will have a performance similar to the maximum efficiency for that technology available at the market. Therefore, the average efficiency per technology gradually improves over time.

Table 10. Detailed descriptions of the characteristics of each scenario.

Scenario	Based on	Characteristics	Reference
BAU	Continued historic trends	o Continued moderate uptake of LPG o Slow decrease in solid biomass consumption o 50% of solid biomass users have access to improved cookstoves by 2050 o Kerosene is phased out by 2030	(Ministry of Energy, 2019)
NDCU	Expert input[7]	o Distribution of: ∗ 4.55 million improved biomass cookstoves ∗ 1.4 million LPG cookstoves ∗ 0.7 million biogas cookstoves ∗ 0.3 million ethanol cookstoves ∗ 1.4 million electric cookstoves between 2020 and 2030 o Overall solid biomass consumption (as share of households) is similar to share in the BAU-S	Expert input
IP	2016 SE4All Kenya Action Agenda	o 100% access to improved solid biomass cookstoves by 2030 o Traditional cookstoves phased out by 2030 o Primary focus on modern cookstoves (LPG and improved biomass) (35% access by 2030) o Smaller focus on clean cookstoves (biogas/bioethanol and electric) (5.3% and 2.3% by 2030, respectively)	(MOEP and SE4ALL, 2016a)

[7] The data for the NDC update scenario was shared by an expert involved in the development of Kenya's updated NDC.

GF	IEA Africa Case	○ 40% access to LPG ○ 14% access to electric cookstoves ○ 5% access to biogas and bioethanol cookstoves ○ 100% access to improved biomass cookstoves[8] by 2030[9]	(IEA, 2020a)
NZ	Regional best practices and top-down assumptions	○ Strong focus on electrification (urban) and biogas (rural): * 35% access to electric cookstoves by 2030 * 42% access to biogas and bioethanol by 2030 ○ LPG serves as a transitioning fuel in urban areas; 27% access by 2030 ○ Overall solid biomass use is reduced to 77% by 2030 of which 100% has access to improved cookstoves by 2030. Solid biomass use for cooking is phased out by 2050. ○ Traditional biomass use is completely phased out in 2050	(IEA, 2020b; Lambe, Nyambane, & Bailis, 2020; Ministry of Energy, 2018a; Expert judgement)

In the case that targets are missing for specific technologies or fuels in the respective sources for these scenarios, it is assumed that those will evolve similarly as in the BAU-S. For example, if a roadmap does not explicitly mention measures to reduce the overall use of solid biomass, this parameter is expected to stay unaffected and grow according to historic trends. Furthermore, different targets affect the amount of improved cookstoves that need to be distributed: if combined with a target of 100% access to improved cookstoves by 2030, the required amount of distributed improved cookstoves will be higher compared to a scenario which includes measures to reduce the overall solid biomass use.

The modelling of the six scenarios provides insights with regards to GHG emissions, non-GHG emissions, fuel usage, fuel expenditure, energy demand and deforestation. The results are discussed in Chapter 3.

2.3.3 Modelling human health impacts

To evaluate the impacts of residential cooking on human health, the results of the scenario analysis are fed into a separate excel-based tool to quantitatively assess the impacts of different cooking sector development pathways on diseases from air pollution and the number of avoided premature deaths.

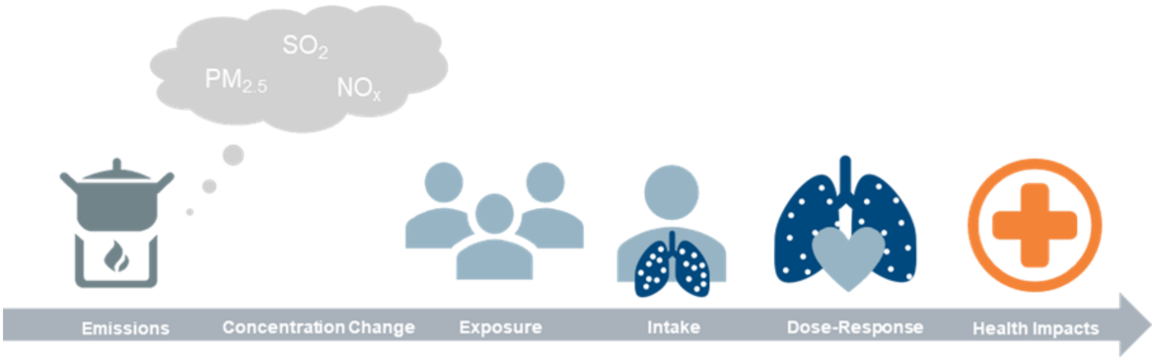
The calculations follow the structure of the Air Pollution Impact Model for Electricity Supply (AIRPOLIM-ES), which is simplified and adapted to the residential cooking sector in Kenya. AIRPOLIM is a spreadsheet-based model that uses an accessible methodology for quantifying the health impacts of air

[8] Universal access among solid biomass users

[9] Similar growth rates are assumed beyond 2030.

pollution from different sources of electricity generation and other fuel combustion. It calculates the impacts on mortality from adulthood diseases including respiratory diseases, lung cancer, chronic obstructive pulmonary disease (COPD), ischemic heart disease, and stroke, the prevalence of which is increased through exposure to air pollution.

The health impact assessment for the cooking sector is based on emissions of particulate matter ($PM_{2.5}$), NO_X, and SO_2. Emissions are estimated in line with the GHG emissions modelling, using technology-specific emission factors for each of the pollutants. Table 16 in Annex II gives an overview of emission factors and sources used.



The model then uses the intake fraction concept to estimate the change in $PM_{2.5}$ concentration in the air based on the estimated pollutant emissions. Intake fractions indicate the grams of $PM_{2.5}$ inhaled per ton of $PM_{2.5}$, NO_X, and SO_2 emissions. These fractions - drawn from literature and available for specific countries – enable the estimation of the change in $PM_{2.5}$ concentration via a backwards calculation (Fantke *et al.*, 2017).

To calculate the increased mortality risk per additional ton of pollutant emissions, the estimated change in $PM_{2.5}$ concentration is multiplied with the respective exposure-response function (Burnett *et al.*, 2014). Exposure-response functions are estimated based on long-term medical cohort studies and indicate the increase in cause-specific mortalities per 10 micrograms per cubic metre increase in $PM_{2.5}$. The Global Burden of Disease (GBD) project provides mortality rates by disease for different age groups at the country level (GBD Collaborative Network, 2020). Based on that, the AIRPOLIM obtains age-weighted mortality rates by disease using the share of the country's population in each age class based on the UN world population prospects (2020). The risk estimates, age-weighted mortality rates, and exposed population are combined to calculate the number of premature deaths and years of life lost by pollutant and for each cause of death. Premature death refers to deaths that are attributed to exposure to a risk factor, e.g., air pollution, and could be delayed if the risk factor was eliminated.

3 GHG MITIGATION POTENTIAL

The results of the scenario modelling for future development pathways for Kenya's residential cooking sector provide valuable information about GHG emissions, fuel use, energy demand, fuel expenditure and deforestation, which will be presented and further discussed in this chapter. The subsequent Chapter 4 assesses the impact of these scenarios on human health.

3.1 GHG EMISSIONS

A common factor among the *implemented policies* scenario (IP-S), the *gas focussed* scenario (GF-S) and the *net-zero* scenario (NZ-S) is their target to achieve 100% access to modern cooking technologies by 2030, in line with SDG 7. This improvement in efficiency has an outstanding impact on the overall GHG emissions of Kenya's residential cooking sector. As a result, GHG emissions and fuel demand decrease rapidly towards 2030 in a similar manner across those scenarios (Figure 7). Beyond 2030, however, further GHG emission reductions are fully reliant on the phase out of unsustainable solid biomass and its replacement with cleaner fuels. The effects of a rapid shift to improved cookstoves pre-2030 is further emphasised when comparing with the *business-as-usual* scenario (BAU-S) and the *NDC update* scenario (NDCU-S) in the same years, where less ambitious targets result in a slower introduction of improved cookstoves and thus in higher energy demand and overall GHG emissions.

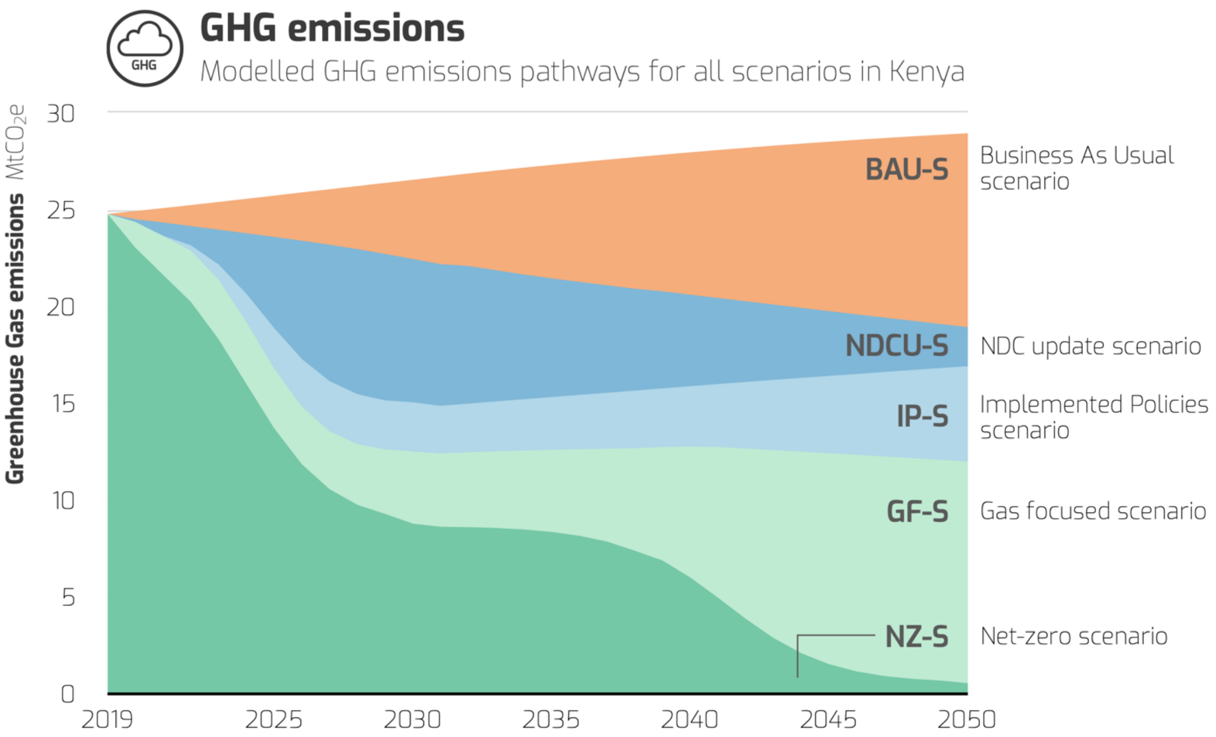


Figure 7. Modelled GHG emissions ($MtCO_2e$) pathways for all scenarios.

Once all solid biomass consuming households have gained access to improved cooking technologies, a maximal technical efficiency is achieved and cannot be further pushed. In order to further reduce GHG emissions at that state, households with improved cookstoves will need to switch to cleaner technologies. This also means that, albeit the use of traditional cookstoves has been phased out, GHG emissions will not remain constant as the continuous population growth will increase the absolute number of improved cookstoves, which still emit GHGs. This effect is observed in both the IP-S and NDCU-S, where the absence of sufficient fuel switch measures away from solid biomass leads to an increase in GHG emissions post-2030, when universal access to improved cookstoves has been achieved. More significant emission reductions in the long-term are only observed in the two speculative scenarios, GF-S and NZ-S, where the effects of a more dedicated fuel switch towards cleaner fuels are assessed. The key factor behind these improvements is the overall reduced consumption of solid biomass, including in improved biomass cookstoves, and the subsequent shift to more efficient technologies.

Implications for a net-zero residential cooking sector

To be consistent with the Paris Agreement, the global energy sector must achieve net-zero emissions by 2050 (IPCC, 2018). The NZ-S thus demonstrates where the Kenyan cooking sector would need to go to be Paris Agreement compatible. The achievement of a net-zero emission cooking sector which would bring maximum climate and sustainable development benefits could only be materialised through a complete switch to electricity and sustainable biomass. In addition, the electricity used for cooking purposes would have to be supplied from clean energy sources. Such a transition would require significant efforts in terms of infrastructure development, particularly in rural areas. In its Vision 2030, the Kenyan Government has set a target to achieve universal access to electricity by 2022, which requires timely technology rollout and financial support. These challenges pose major barriers in the short- to mid-term. Accordingly, observed regional practices in neighbouring Ethiopia show that electric cooking primarily accelerates in urban areas during the first period. Electric cooking in some urban areas of Ethiopia increased substantially in recent years, rising from 6% in 2011 to 32% in 2018, with low electricity tariffs as one of the key drivers (Scott, Jones and Batchelor, 2020). Such progress in electric cooking deployment has been applied as a best practice for the NZ-S where similar growth rates are applied to the urban sector for Kenya (IEA, 2020b).

To push down the emissions trajectory as much as possible in the short- to mid-term in the NZ-S, LPG serves as a transitioning fuel in urban areas, while biogas and bioethanol (as the only sustainable biomass fuels considered in the NZ-S) are scaled up in rural areas. The sustainable bioethanol expansion in Kenya is dependent on a reliable production industry and the development of supply chains, as well as on technology uptake. Bioethanol can be generated from sustainably produced biomass and wastes. One promising candidate for that purpose in Kenya is the use of sugar wastes, which is produced at large scales in the country (UNEP, 2019b). With regards to biogas, which can be produced from agricultural and human wastes, the user must be equipped with a biodigester and sufficient livestock, or produce sufficient amounts of waste, in order to satisfy the cooking energy demand. While fuel expenditures in that case will be negligible, the technology investment costs are high and present one of the major barriers to such transition.

Sensitivity analysis to the timely transition to improved cookstoves

As previously discussed, the rapid uptake of improved cookstoves – pursued in the target to reach 100% access by 2030 – could contribute to significant emission reductions in the short- to mid-term. However, looking at the results of previous efforts and considering key barriers, there are reasons to believe that the achievement of this target could be challenging to materialise. The current high reliance on fuelwood, and the fact that most fuelwood is collected for free, suggests a potential lack of interest among consumers to invest in improved cookstoves. To get a clearer picture of how a delayed uptake of improved cookstoves could affect emissions, a simple sensitivity analysis[10] is conducted. In the sensitivity analysis, a five-year delay is assumed for the start and end year of the target. Hence, the target of 100% improved cookstoves is achieved in 2035 in the IP-S, GF-S and NZ-S, and beyond 2050 in the NDCU-S (Figure 8). The coloured area in the charts represent the additional emissions that would be caused by a delay in reaching the targets for improved solid biomass cookstoves distribution. As can be noted, those mitigation scenarios which are less dependent on solid biomass cookstoves are less sensitive to such a delay, as are those scenarios with more ambitious targets.

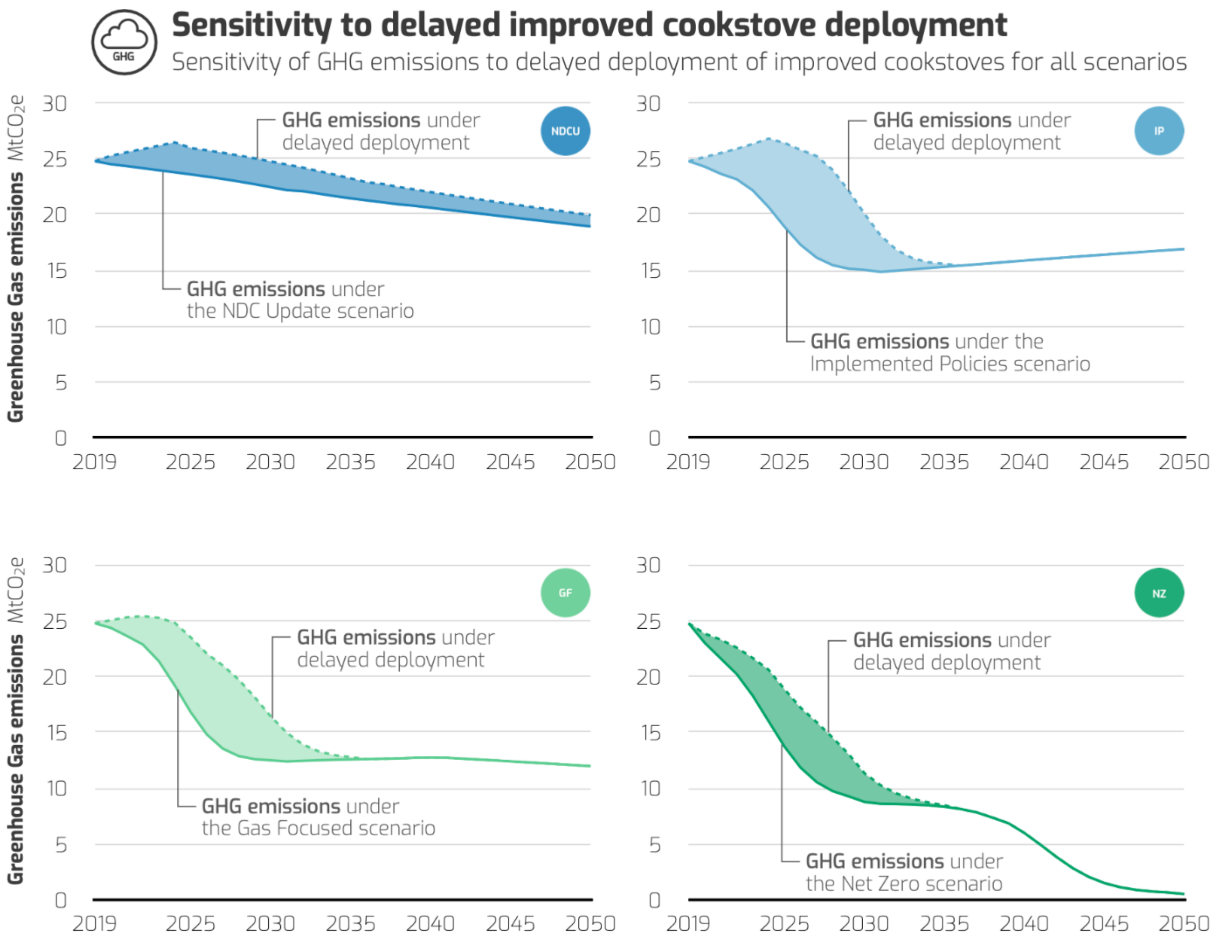


Figure 8. GHG emissions sensitivity to a delayed deployment of improved solid biomass cookstoves.

[10] In a sensitivity anaysis, a single parameter is leveled up and/ or down in order to assess how sensitive the output result is to that particular parameter. In this case, the year in which the transition to modern cookstoves is completed is adjusted.

Required number of distributed cookstoves to achieve 100% access to improved cooking

Table 11 presents the estimated amount of distributed cookstoves by technology and scenario. Given the variations in fuel and technology pathways across scenarios, similar targets may require different amounts of distributed cookstoves to achieve those targets. For instance, universal access to improved cookstoves by 2030 requires a higher number of distributed improved wood stoves in the IP-S scenario compared to the NZ-S, since the number of households using fuelwood is lower in the NZ-S. Similarly, the required distributed improved cookstoves are lower in the three first scenarios since these do not achieve universal access to improved cookstoves by 2030. Moreover, the results suggest that the target of distributing 4.55 improved biomass cookstoves by 2030 in the NDCU-S would not be sufficient to achieve universal access to improved cookstoves by that year and would only do so beyond 2050 if a similar rate of deployment was maintained.

In scenarios such as the IP-S, GF-S and NZ-S, where a direct shift to cleaner technologies is prioritised – particularly in urban areas – charcoal is phased out and replaced by fuels such as LPG and electric cookstoves, allowing for the required number of improved charcoal cookstoves to be distributed to decrease. In the NDCU-S, a phase out of charcoal is not pushed, leading to a higher number of households stacking with charcoal, resulting in a higher need for the distribution of improved charcoal cookstoves.

Since the tool used in this study does not include a stock turnover model, the numbers provided are rough estimates. The lifetime of various technologies is not accounted for and would likely have an impact on some of the numbers. Nevertheless, the estimates can serve as a basis for policymakers to inform decision making and target setting.

Table 11. Estimated number of distributed cookstoves by technology and scenario between 2020-2030 (million cookstoves).[11]

Scenario	Improved wood	Improved charcoal	LPG	Electric	Biogas and bioethanol
BAU	1.2	1.3	1.1	0.0	0.0
NDCU	2.3	2.3	1.4	1.3	0.9
IP	8.0	1.3	3.4	0.3	0.8
GF	8.3	1.3	5.8	1.0	2.1
NZ	7.1	0.8	2.1	5.5	6.7

[11] The estimated number of distributed cookstoves does not account for the lifetime of each individual technology.

3.2 FUEL USE

Figure 9 presents the share of households using a certain fuel across the analysed scenarios. As many households use multiple fuels for cooking, the total accumulated percentage may exceed 100%. That is, percentages beyond 100% represent multiple fuel user households. This study assumes that households use a maximum of two fuels, hence the overall aggregated percentage does not exceed 200%. The rather high share of households stacking fuels, in particular solid biomass stoves, contributes to continued high shares of solid biomass use in 2030 in most scenarios. Many households which switch to more efficient fuels are expected to continue to stack incumbent technologies in the near- to mid-term. In all scenarios except the NZ-S, the number of multiple user households therefore increases throughout the analysis period along with a gradual shift to cleaner fuels. In the NZ-S, that shift takes place earlier, hence, the number of multiple user households peaks earlier. By 2050, the supply chains for biogas, bioethanol and electricity are assumed to be sufficiently robust to allow for most households to depend on one single cooking fuel.

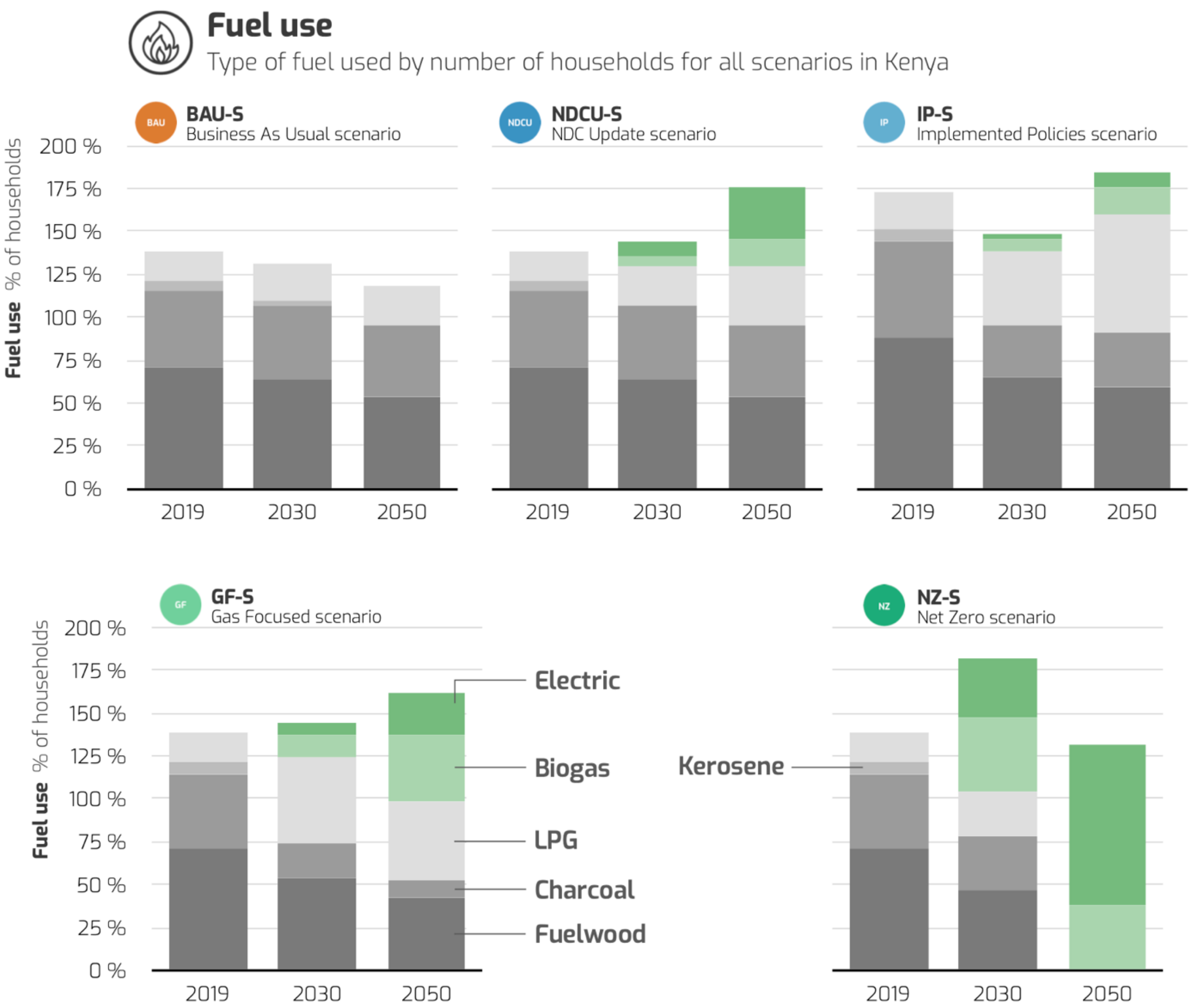


Figure 9. Type of fuel used by number of households for all scenarios.

3.3 OVERALL ENERGY DEMAND

The overall energy demand follows a similar trend as observed in the emission pathways – the higher the share of clean fuels and the more rapid the shift to improved solid biomass cookstoves, the lower is the resulting energy demand. The shift to improved solid biomass cookstoves contributes to substantial energy demand reductions, but without a shift to more efficient fuels, overall fuel demand will continue to rise in the long term, due to population growth (Figure 10). Being the most efficient technology, electricity brings the highest energy savings. The electricity focussed NZ-S scenario therefore is the only scenario with a continuously decreasing energy demand throughout the timeseries, while a shift that is more focussed on gas and biofuels in the GF-S cannot compete with an increased population and the overall energy demand increases between 2030 and 2050, which is also the case for the IP-S. The impact of only focusing on full access to improved cooking is demonstrated in Figure 11, where the BAU-S is attributed with a shift to 100% access to improved cookstoves by 2030. Energy savings are significant in the mid-term, albeit a lack of further efforts to shift to cleaner technologies in the long-term causes the overall energy demand to rise again.

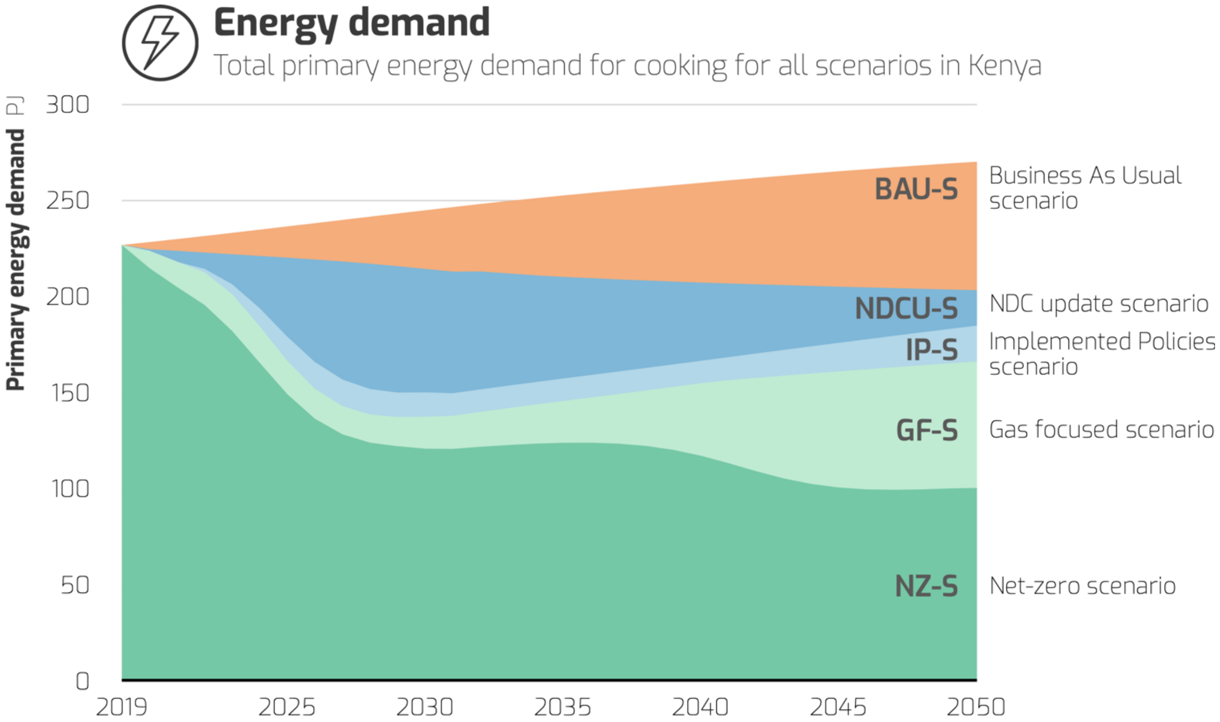


Figure 10. Total primary energy demand (PJ) for residential cooking for all scenarios.

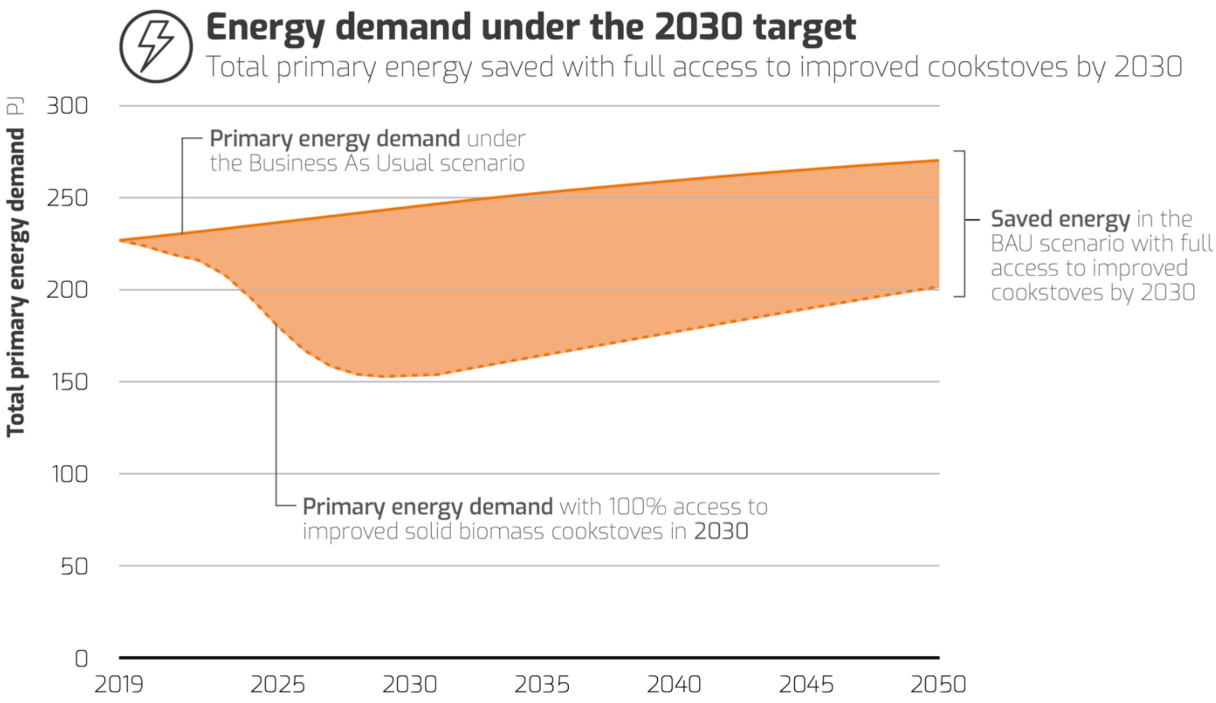


Figure 11. Total primary energy demand (PJ) in the BAU-S, applying full access to improved cookstoves by 2030.

The relevance of thermal efficiencies for overall energy demand.

As the overall thermal efficiency of the technologies for the cleaner fuel options is generally higher (see Table 12), a shift to those will result in lower fuel consumption. That is, the higher the thermal efficiency of a cookstove, the less input fuel is required to deliver the final energy demand, making thermal efficiency an important factor when looking at economic savings for the consumer as well as with a view to climate change impacts and forest degradation.

Table 12. Thermal efficiencies per fuel type.

Fuel type	Maximal thermal efficiency	Source
Fuelwood	30%	(CTCN, 2020)
Charcoal	43%	(Burn Design Lab, 2020)
Kerosene	57%	(Habib *et al.*, 2004)
Biogas	50%	(Putti *et al.*, 2015)
Ethanol	55%	(Benka-Coker *et al.*, 2018)
LPG	62%	(Habib *et al.*, 2004)
Electric	90%	(Sweeney *et al.*, 2014)

3.4 FUEL EXPENDITURES

With regards to costs, a reduced fuel demand can benefit consumers as it allows for fuel cost savings. Not taking capital expenditures for the cookstove purchase into account, the results show that a shift to cleaner fuels could lead to lower fuel demand and cost savings (Figure 12). Overall average fuel expenditures per household are calculated based on current market prices (see Table 17 in Annex II) and are kept constant throughout the time series. Commodity prices are, however, likely to change. At present, fuelwood is most commonly collected for free, but as the unsustainable harvesting of fuelwood continues and spurs deforestation, fuelwood supply can be expected to decrease, which would affect prices. Such is already the case in certain regions of Kenya, where around half of urban and rural fuelwood users lack fuelwood in desirable quantities (Ministry of Energy, 2019). Besides, it can be expected that additional measures will be implemented to counteract deforestation, which would further decrease supply and cause the fuelwood price to increase. Any measure in the forestry sector should thereby not only account for externalities in the fuelwood price but also promote sustainable biomass production.

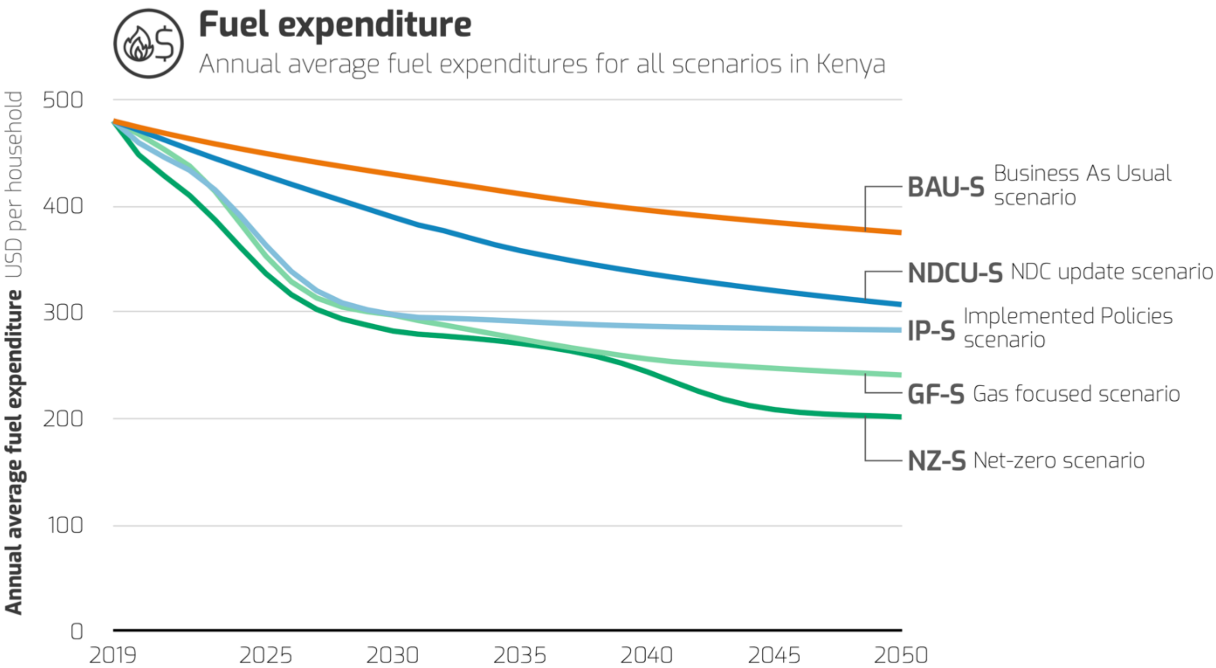


Figure 12. Annual average fuel expenditure per household (in USD).[12]

Similarly, the price of LPG may, in the future, be subject to price fluctuations. Not only due to volatile oil prices and an overall decrease in oil supply as oil investments are increasingly restricted, but also considering future carbon pricing. In a net zero future, carbon prices are likely to have an increasingly important role in limiting the use of fossil fuels and facilitating the deployment of low-carbon technologies. For these reasons, LPG might be considered a suitable bridging fuel in the near- to mid-term but would - from and emissions- as well as cost perspective – not be a favourable long-term option.

[12] Household expenditures are calculated as the weighted average of the total fuel expenditures needed to satisfy the residential cooking energy demand and may vary depending on the specific fuel combination a household is using. Projections are based on current commodity prices (2020).

The price for biogas is expected to be negligible as it is produced from agricultural and human wastes, while the price for bioethanol also contributes to the average price of the biogas/ bioethanol group. Nevertheless, compared to purchased fuelwood, bioethanol would still be a more cost-efficient fuel. The consumer price of electricity over time will depend on the evolution of the electricity sector as well as potential policy measures to reduce costs for consumers. As the fuel price is an important factor in consumers' choice of technology, such measures could have a substantial impact on the uptake of cleaner cooking solutions. Instead of incentivising a shift to cleaner fuels through measures like subsidies, another option could be the taxation of high emitting fuels.

3.5 DEFORESTATION

Since 1963, the forest covered land in Kenya has decreased from 10% to the estimated current 6-7% (Figure 13). In the National Strategy for Achieving and Maintaining over 10% Tree Cover developed in 2019, Kenya aims to restore the forested land back to 10% by 2022 (Republic of Kenya, 2019). Through such restoration, the strategy aims to contribute to Kenya's NDC objectives by reducing GHG emissions and to achieve land degradation neutrality by 2030. Along with land clearance for agricultural purposes and increased urbanisation, fuelwood and charcoal production is one of the major driving factors of deforestation in the country and can thus be directly linked to the residential cooking sector. On this backdrop, the residential cooking sector scenarios developed in this study are further analysed based on their potential implications on deforestation, looking specifically at the role of solid biomass supply and demand.

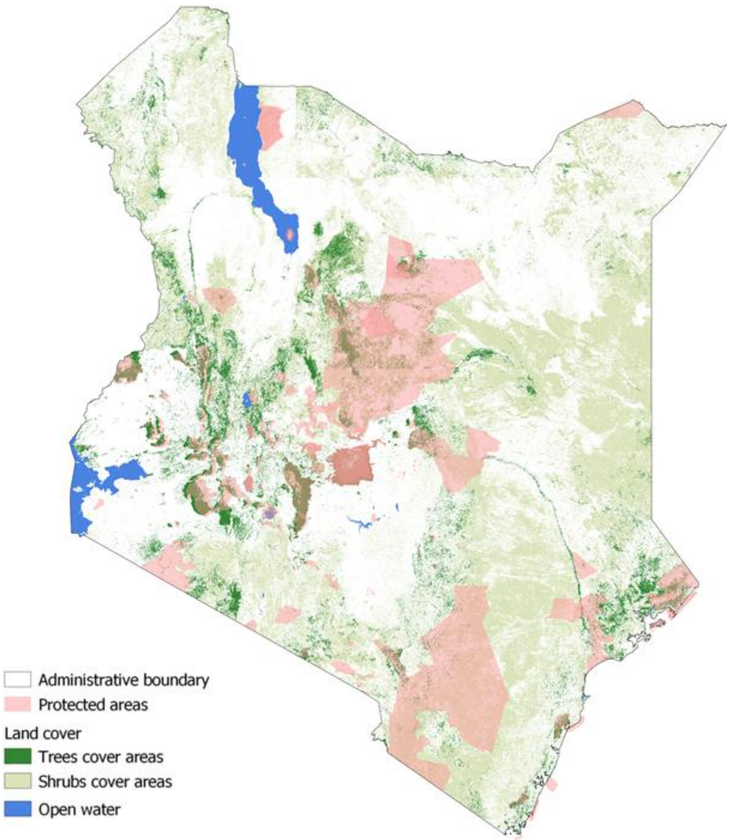


Figure 13. Protected land, tree and shrub covered land in Kenya

(European Space Agency, 2016; OCHA, 2019; UNEP-WCMC and IUCN, 2020).

Solid biomass supply

Biomass is yielded from a wide variety of sources including closed forests, woodlands, bushlands, wooded grassland, farms with natural vegetation, industrial fuelwood plantations and from agricultural and industrial residues (Mugo and Gathui, 2010). The biomass demand for cooking can thus not be directly translated to deforestation without taking into account the different supply sources. Estimates from 2002 suggest that in Kenya, the majority of the biomass supply (45%) is sourced from closed forests, woodlands, bushlands and wooded grasslands and can thus be attributed to deforestation, if harvested unsustainably. About 39% of the biomass supply is attributed to farmlands consisting of exotic tree species while an estimated 16% is sourced from plantations and residues, both of which would not count towards deforestation (Mugo and Gathui, 2010). In order to estimate the implications solid biomass consumption could have on deforestation, the concept of the fraction of non-renewable biomass (fNRB) is imperative, yet complex. The fNRB estimates the share of the total solid biomass supply that is produced unsustainably. Historically and presently, there is a general disagreement in the literature with respect to the fNRB in Kenya. Estimated fNRB levels from various sources are presented in Figure 14, demonstrating the difference among the estimates available from these sources – ranging from 30%-92%. Ultimately, and as discussed above, the expected impact solid biomass consumption could have on deforestation will therefore be dependent on two key factors: the biomass supply source and the estimated fNRB. In addition, the core parameter influencing those effects will be the projected solid biomass demand.

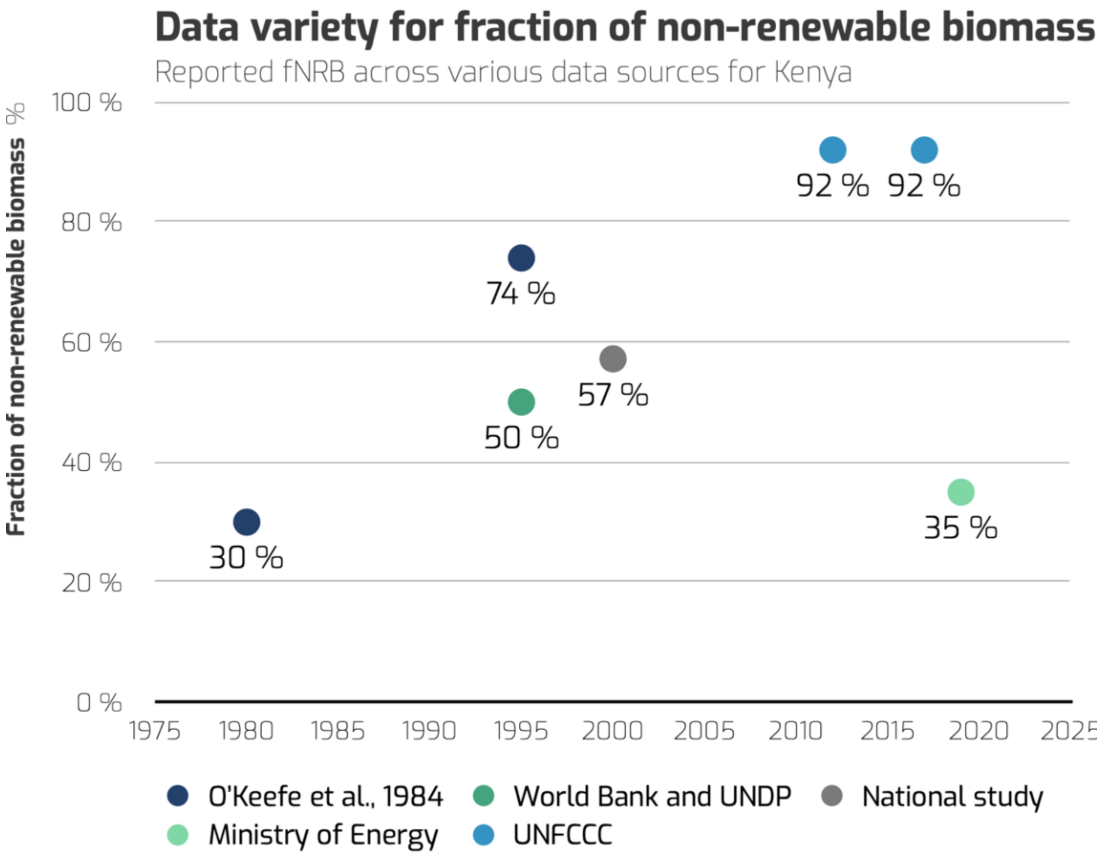


Figure 14. Reported fNRB across various sources (in %).

Projected solid biomass demand

The results of this study suggest an initially decreasing demand for solid biomass as improved cookstoves are taken up, yet a remaining demand in the mid- to long-term persist – mainly driven by population growth and a continuously growing solid biomass technology ownership (Figure 15). In order to reduce the environmental impacts from the continuously growing consumption of solid biomass, measures to ensure its sustainable production need to be considered. In the absence of any additional restoration of forest area, the results of this study imply that a maintained fNRB of 92%, as suggested by the UNFCCC, could cause significant forest losses in the long term. In the BAU-S, the cumulative demand between 2019 and 2050 would correspond to a required forest land of 11,290 km^2, representing about 26% of currently existing forest land cover in Kenya (Figure 16). The corresponding estimates for the other scenarios are notably lower except from in the lowest performing mitigation scenario, NDCU-S, which follows fairly close after the BAU-S at 22% of current forest covered area lost by 2050. The gap is thereafter relatively significant to the IP-S, reaching close to 16%, followed by the GF-S at 14%. As could be expected, the scenario with the least dependence on solid biomass for cooking, the NZ-S, will also contribute the least to deforestation of about 8% by 2050. These cumulated shares do not consider any annual re- or afforestation which could add further precision to the figures.

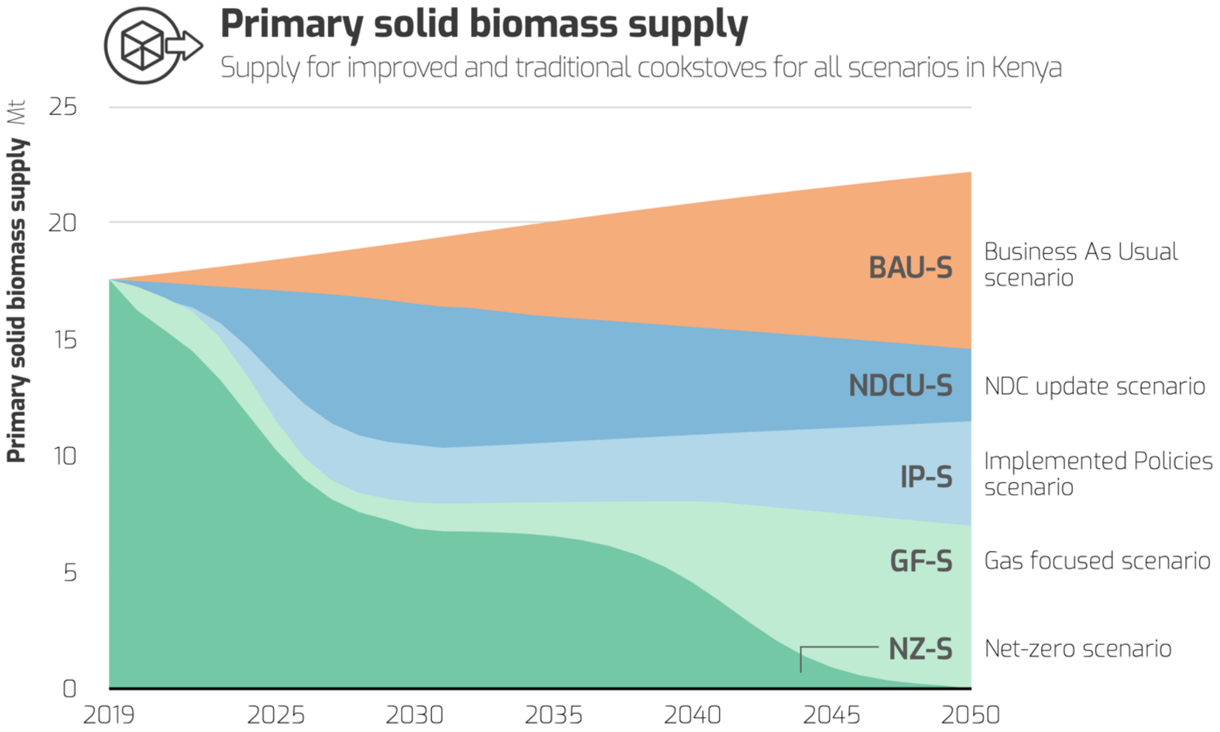


Figure 15. Primary solid biomass[13] supply (Mt) for improved and traditional cookstoves for all scenarios.

[13] The demand includes the amount of input biomass required for the production of charcoal.

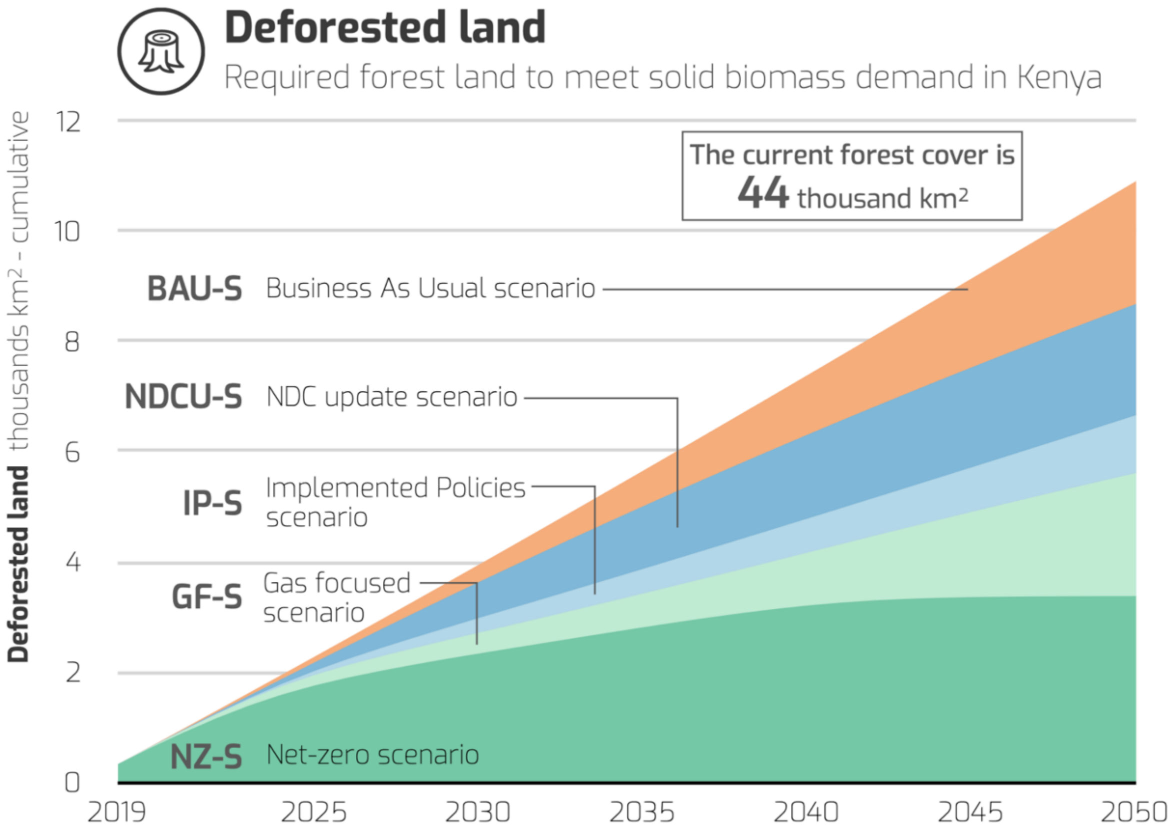


Figure 16. Required cumulative forest land (thousands km²) to meet solid biomass demand.

The left-hand axis represents the current forest covered area in Kenya, while the axis on the right-hand side represents the required forest area. The estimated land requirements do not take into account any re- or afforestation and assume a constant fNRB of 92%.

Projected deforestation rates

Studying the annually deforested land from solid biomass use in the residential cooking sector across scenarios (Figure 17), the impacts of introducing improved cookstoves, and in the longer term phasing out solid biomass cookstoves, are more obvious. Achieving universal access to improved cookstoves by 2030 leads to a 54%-75% decrease in annual deforested land in the IP-S, GF-S and NZ-S. Beyond 2030, that rate is dependent on the continuous phasing out of solid biomass cookstoves, as demonstrated by the respective scenario pathways.

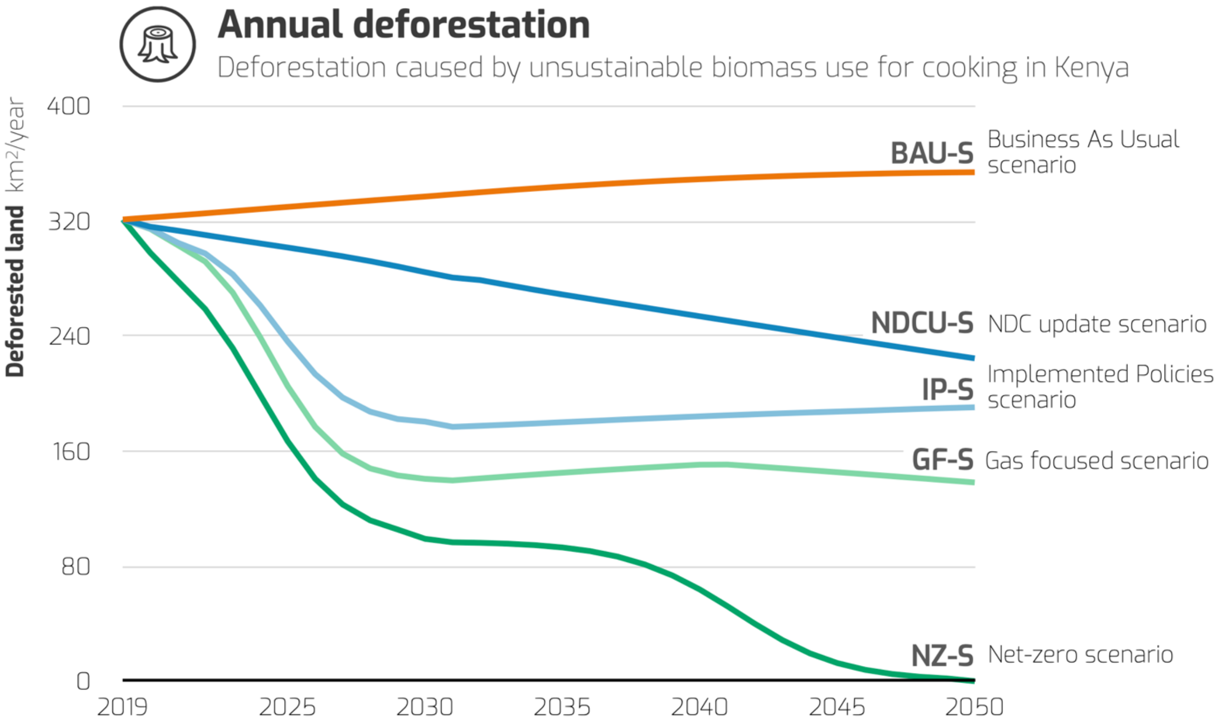


Figure 17. Annual deforested land (km^2/year) caused by unsustainable solid biomass use for all scenarios.

The deforestation estimates in this study are under the assumption that 45% of solid biomass consumed in the residential cooking sector is sourced from forests, while the remaining 55% is assumed to be sourced from farmlands and residues. This means that, should a higher share of the solid biomass supply be sourced from forest land in the future, the corresponding deforested land could increase significantly. From a GHG emissions perspective, ensuring that more solid biomass is sourced sustainably could help reduce emissions. However, doing so would not reduce the amount of non-GHG emissions. Therefore, increased efforts to phase out the overall use of solid biomass technologies would be preferable.

Sensitivity analysis to the fNRB

Due to the uncertainties with regards to the actual fNRB in Kenya, the results of the implications for deforestation are analysed with sensitivity to the fNRB. In this analysis, four different levels of fNRB (30%, 50%, 70% and 90%) are considered based on the collected data. As can be expected, the impacts on deforestation are significantly stronger in scenarios with higher overall use of solid biomass technologies, as presented in Figure 18, where the absolute gap is larger than in scenarios with a lower dependence on solid biomass cooking technologies. Overall, the results of the sensitivity analysis demonstrate the importance of access to high quality data to accurately estimate implications on deforestation from residential cooking. The same holds true for the GHG emission estimates which are significantly affected by the fNRB.

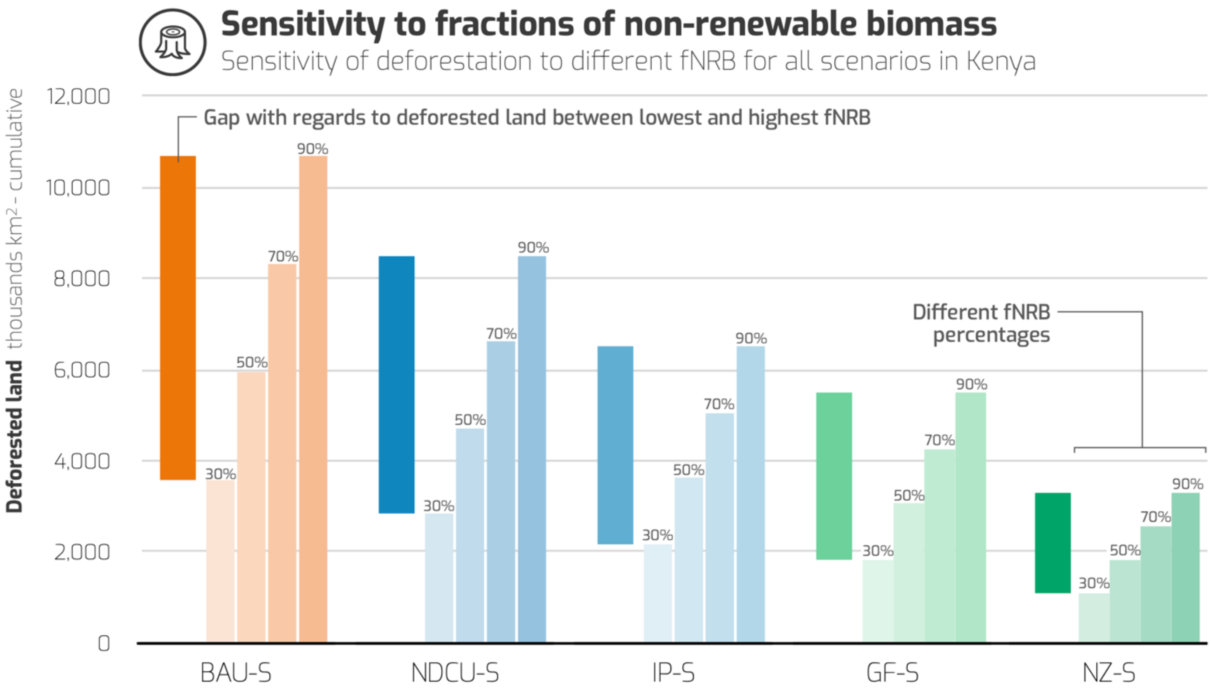


Figure 18. Estimated deforested land by 2050 with sensitivity to the fNRB.

4 IMPACT ON HUMAN HEALTH

This chapter uses the results from the scenario modelling exercise with regards to GHG and non-GHG emissions in Kenya's residential cooking sector to assess the impact of these scenarios on human health.

4.1 COOKING AND HUMAN HEALTH

Air pollutant emissions released through energy-related fuel combustion have negative impacts on human health and the environment. In 2018, exposure to particulate matter from fossil fuel emissions across sectors accounted for 18% of deaths worldwide (WHO, 2018). Energy, including both production and use, is the largest source of anthropogenic air pollutant emissions, being responsible for the production of 85% of primary particulate matter ($PM_{2.5}$ or PM_{10}) and almost all of the sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emitted worldwide (IEA, 2016; Watts *et al.*, 2017). GHG emissions and air pollutant emissions often come from the same sources, such as fossil fuel-fired appliances including power plants, industry and vehicles, but also cookstoves. Consequently, mitigation measures that reduce fossil fuel consumption typically have great potential to also cut non-GHG emissions of other air pollutants.

Household air pollution (HAP) from cooking, lighting and heating represents the single largest environmental risk to human health in the world being associated with an increased risk of a range of adverse health effects, with the strongest association recorded for respiratory diseases such as chronic obstructive pulmonary disease (COPD) and lung cancer (Simkovich *et al.*, 2019). The highest prevalence of these negative health impacts is observed among the poorest communities in low- and middle-income countries, with women and children at highest risk from exposure (WHO, 2018; Vohra *et al.*, 2021). In 2019, 4% of deaths worldwide and more than 10% of deaths in the East African region were caused by HAP from solid biomass fuels (GBD Collaborative Network, 2020). There is a variance in estimating the impact of household air pollution. While the WHO estimates that exposure to air pollution from cooking with solid biomass is associated with over 4 million premature deaths worldwide every year, including half a million children under the age of 5 years, the Global Burden of Disease (GBD) study estimates 2.31 million deaths from household air pollution in 2019 (WHO, 2018; GBD Collaborative Network, 2020).

In Kenya, HAP from solid biomass led to an estimated 22,000 premature deaths and more than one million disability adjusted life years (DALYs)[14] in 2019 (GBD Collaborative Network, 2020). The Kenyan Ministry of Health estimated that 21,500 people died prematurely in 2018 from cooking-related air pollution exposure alone (Ministry of Energy, 2019). In addition, the vast majority of the Kenyan population is exposed to ambient air concentrations of particulate matter that exceeded the threshold values set by the WHO (Roy, 2016; WHO, 2016).

[14] The measure disability adjusted life years combines years of life lost due to premature mortality and years of life lost due to time lived in states of less than full health, or years of healthy life lost due to disability.

From air pollution to health effects

The pollutants considered in the quantitative analysis include primary particulate matter $PM_{2.5}$, as well as SO_2 and NO_x, which produce secondary particulate matter formed from chemical transformations in the atmosphere. Particles of $PM_{2.5}$ have a diameter of less than 2.5 micrometres and are therefore small enough to enter the airways and alveoli. Thus, the micro-particles can reach the blood and different organs and negatively impact the cardiovascular system or directly cause respiratory illnesses (Cifuentes *et al.*, 2001).

Further physiological changes due to the pollutants include tissue damage and inflammation, plaque formation in arteries, the narrowing of blood vessels, and sometimes even permanent damage to cell DNA (Jones *et al.*, 2016). These changes can eventually lead to serious health issues such as a heart attack, stroke, or cancer.

Overall, the human health impacts caused by exposure to air pollutants are expressed through several morbidity and mortality indicators. The most common health effects reported in relation to air pollution are: a) reduction in life expectancy due to chronic diseases and acute mortality, b) an increase in chronic morbidity due to diseases such as bronchitis or asthma, and c) acute effects on morbidity, including respiratory and cardiovascular hospital admissions, asthma episodes, and restricted activity or work days lost (Markandya and Wilkinson, 2007).

4.2 IMPLICATIONS FOR NON-GHG EMISSIONS

In terms of particulate matter emissions ($PM_{2.5}$) a similar pattern compared to the previously estimated GHG emissions can be observed (Figure 19). Towards 2030 emission are rapidly decreasing across the IP-S, the GF-S and the NZ-S. This is due to the fact that all three scenarios assume that universal access to modern or clean cooking technologies will be achieved by 2030, in line with SDG 7. In the period after 2030, $PM_{2.5}$ emission reductions depend very strongly on the phase out of unsustainable solid biomass and its replacement with cleaner fuels. Therefore, significant reductions for particulate matter emissions in the long term are only observed in the NZ-S. The key factor behind this improvement is the overall reduced consumption of biomass and the subsequent shift to more efficient technologies.

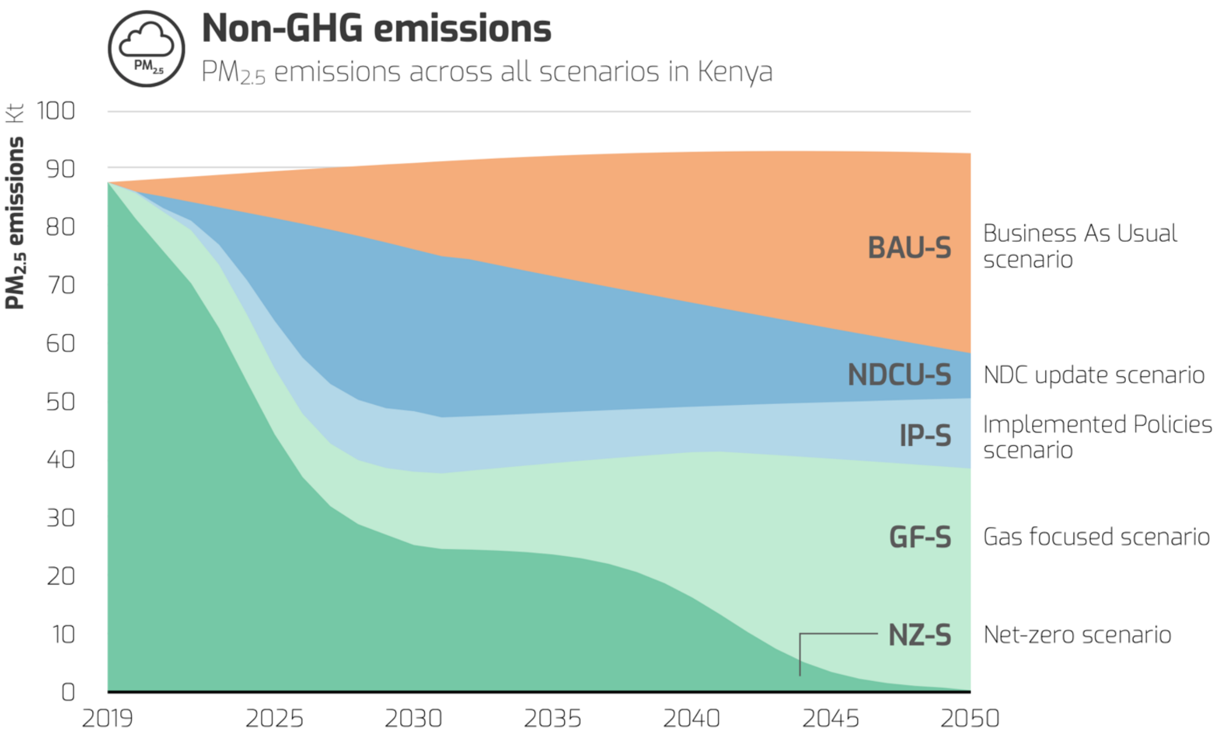


Figure 19. $PM_{2.5}$ emissions for residential cooking across all scenarios.

In terms of SO_2 and NO_x emissions the picture is somewhat differnt (Figure 20 & Figure 21). The limited decrease in SO_2 emissions across scenarios is due to the fact that even improved biomass cookstoves and biogas still emit a considerable amount of the pollutant. However, emission factors for biomass and particularly bioethanol and biogas remain the biggest source of uncertainty in this modelling exercise. Future research and data collection on country- and stove-specific emission factors would be highly beneficial and improve the accuracy of the estimations. However, research suggests that even the highest SO_2 concentration in biogas kitchens are lower than the SO_2 concentration in fuelwood kitchens, and that biogas systems can therefore offer air quality improvements if sized properly for energy demands (e.g. IRENA, 2017; McCord et al., 2017).

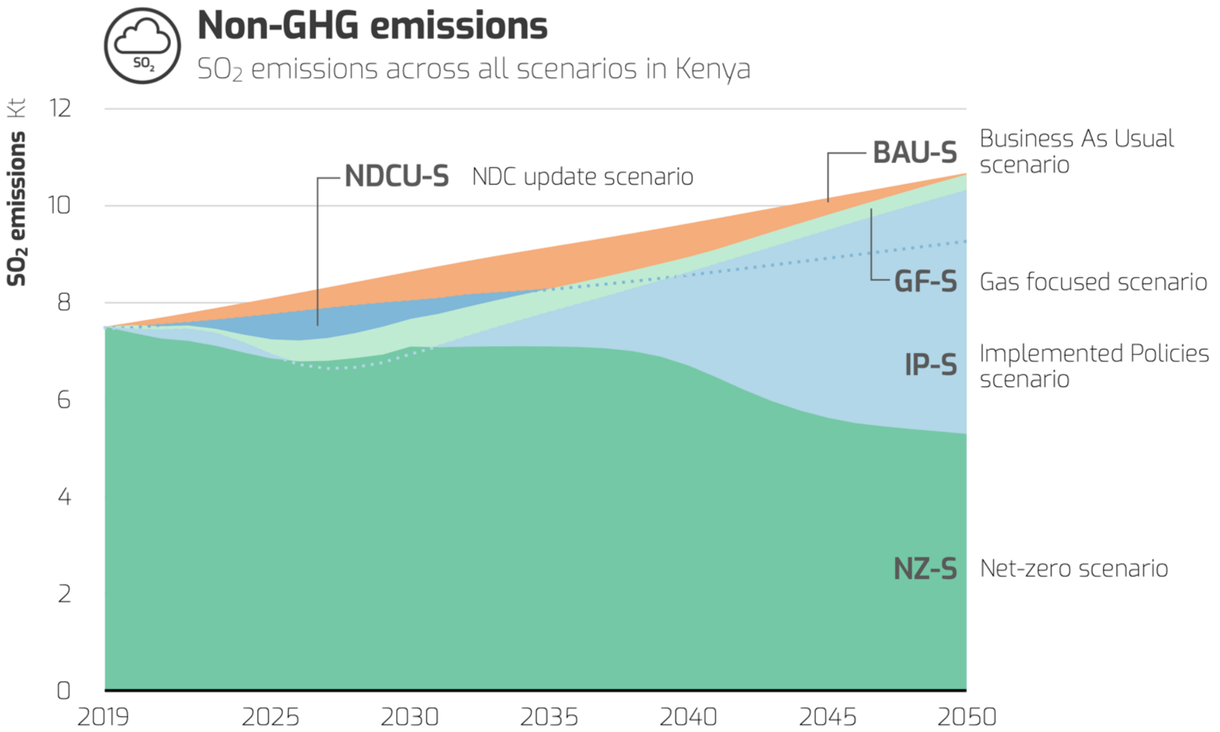


Figure 20. SO_2 emissions for residential cooking across all scenarios.

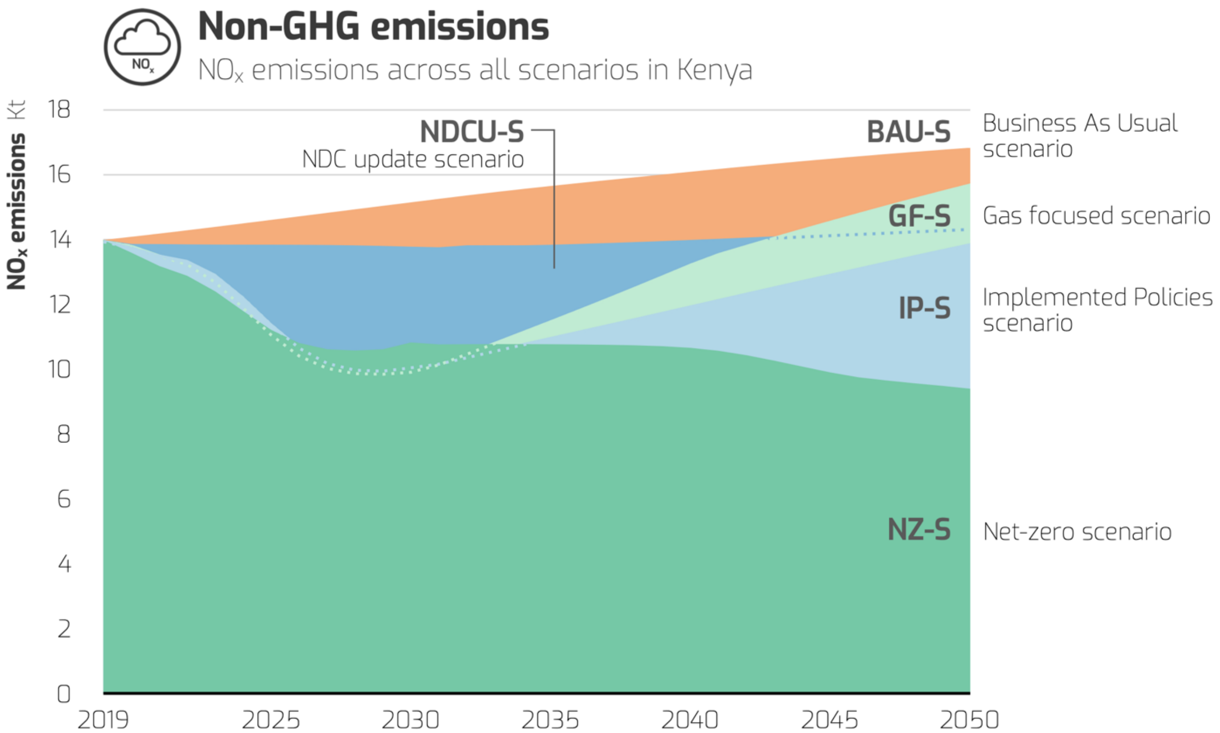


Figure 21. NO_x emissions for residential cooking across all scenarios.

4.3 IMPLICATIONS FOR HUMAN HEALTH

The number of premature deaths follows a somewhat similar trend as observed in the pollutant emission pathways – the higher the share of clean fuels and the more rapid the shift to efficient solid biomass cookstoves, the lower the number of estimated premature deaths (Figure 22). Looking at the period beyond 2030, an increase of premature deaths can be observed across all scenarios except the NZ-S. On the one hand, this is driven by population growth, and therefore increased exposure, and on the other hand by increased NO_x and SO_2 emissions from sustainable biomass, biogas and bioethanol as discussed above. In the BAU-S the number of premature deaths rises from about 14,600 in 2020 to about 28,000 in 2050, which is almost double, while in the NZ-S premature deaths decrease from about 14,000 in 2020 to 2,300 in 2050.

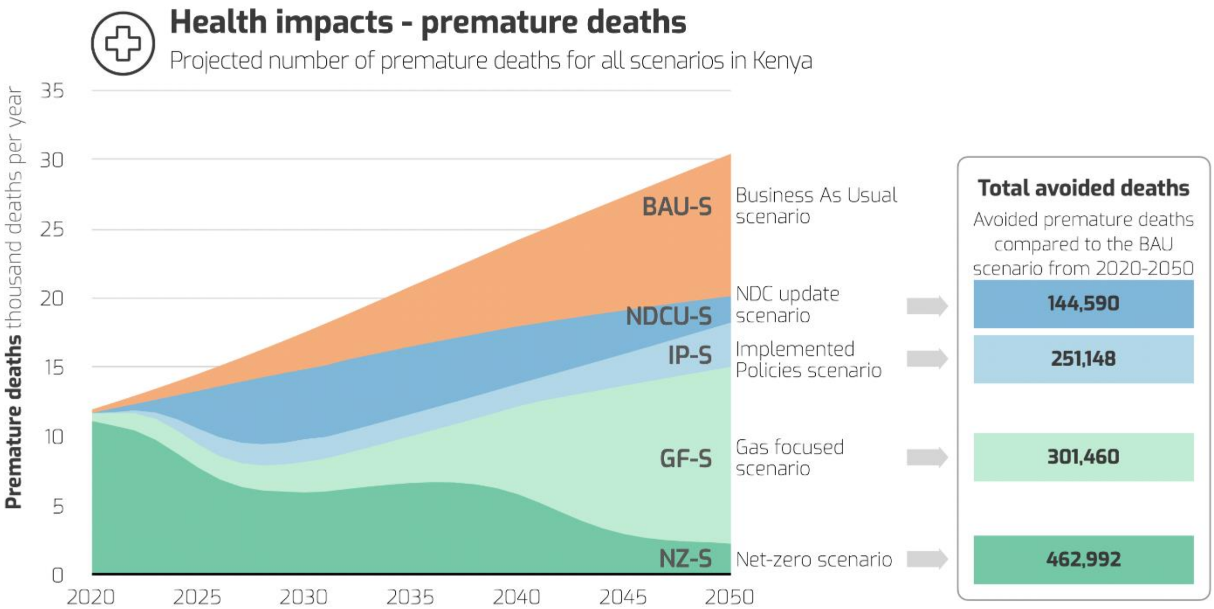


Figure 22. Estimated premature deaths for all scenarios and total avoided premature deaths compared to the BAU scenario between 2020 and 2050.

Table 13 shows that each scenario has significant benefits in terms of avoided premature deaths compared to the BAU-S. If the NZ-S was to be fully implemented, almost half a million premature deaths could be avoided over the timeframe of 30 years. The IP-S and GF-S show health benefits in the order of 250,000 to 300,000 saved lives, and the NDCU-S about 145,000. However, these are conservative figures, since a whole range of indicators – including all morbidity-related factors, health impacts from other pollutants, effects on children, and workdays lost – were not accounted for in the analysis.

Table 13. Number of premature deaths per year and scenario.

	2020	2025	2030	2035	2040	2045	2050
BAU	11,957	14,536	17,539	20,871	24,200	27,338	30,426
NDCU	11,708	13,303	14,862	16,513	17,957	19,118	20,144
IP	11,703	10,569	9,814	11,640	13,810	15,977	18,238
GF	11,681	9,430	8,174	10,044	12,180	13,683	15,037
NZ	11,125	7,750	5,967	6,651	5,837	2,955	2,262

That the annual numbers presented in this study are considerably lower than the 21,500 premature deaths presented by the Ministry of Health in 2018, is mainly due to the fact that health impacts on children and, therefore, also the number of deaths among this age group is not accounted for in this study, given limitations of the modelling approach. In addition, both the approach taken by the Ministry of Health as well as the one taken in this study need to rely on a number of assumptions as emissions and exposure are not actually measured, which of course comes with considerable uncertainties. Therefore, any of such health impact assessments should be understood as an order of magnitude estimation that gives an impression of the scope of potential negative impacts or benefits rather than the accurate number of premature deaths.

5 CONCLUSIONS

Many opportunities exist that can help guide the transition of Kenya's residential cooking sector to a truly clean and sustainable sector in the long-term. The country's ambitious climate and development targets, combined with an increased awareness of respiratory health in light of the COVID-19 pandemic, provide strong momentum for enhanced action.

The scenario modelling carried out in this study provides a first idea of what is possible and necessary to achieve significant GHG emission reductions and sustained health benefits. The analysis can feed into the stakeholder discussion around short-, mid- and long-term targets and respective measures for the cooking sector that can lead to the desired and agreed results.

5.1 KEY TAKEAWAYS

The Kenyan residential cooking sector is at crossroads. On the one hand, rapid population growth and swift urbanisation are likely to drive emissions up in the coming years. On the other hand, clean technologies are emerging, and many actors and initiatives are working on bringing the sector onto a lower carbon development pathway.

The modelling of different sector development scenarios leads to the following conclusions:

There is significant mitigation potential in the residential cooking sector.

The 2018-2022 NCCAP ascribes a mitigation potential of 7.1 MtCO_2e to the energy demand sector, through the uptake of alternative fuels and efficient cookstoves. The different mitigation scenarios developed in this analysis show that much more can be achieved if the focus is shifted from modern cooking technologies (including LPG and improved biomass stoves) to clean cooking technologies (such as electric, biogas and bioethanol stoves). In a gas focussed scenario (GF-S) that assumes increased access to LPG but also a significant scale up of electric, biogas and bioethanol cookstoves, emissions could be almost halved by mid-century. The most ambitious net-zero scenario (NZ-S), which assumes a phase out of solid biomass by 2050 and a substitution through electricity, biogas and bioethanol, even brings emissions down to net-zero by mid-century, showing the strongest alignment with the quest of the Paris Agreement to decarbonise the energy sector.

Mitigation in the residential cooking sector contributes to climate, health, and other sustainable development benefits.

While any GHG emission reduction directly counts towards the goal of limiting global warming to 1.5°C and can, if not otherwise claimed, be counted towards Kenya's national climate target of reducing GHG emissions by 32% compared to BAU by 2030, emission reductions in the cooking sector stand out through their considerable synergies with other sustainable development objectives. There are several benefits such as increased biodiversity, fuel savings, job creation, time savings and improved gender equality that can be directly attributed to the use of cleaner cooking fuels and technologies. Most importantly though, and as shown in this study, clean cooking can save lives and significantly improve the health of those who are frequently exposed to household air pollution. Already in the less ambitious scenarios (NDCU-S or IP-S) health benefits in the order of 145,000 to 250,000 saved lives could be realised over the timeframe of 30 years. The more ambitious GF-S shows health benefits in the order of more than 300,000 saved lives and the most ambitious NZ-S could even prevent close to half a million premature deaths due to reduced household air pollution between 2020 and 2050.

Clean cooking is already being recognised as a transversal issue in Kenya's policy landscape.

There are many laws, policies and regulations that directly or indirectly affect the residential cooking sector, from different sector perspectives (in particular, the forestry, energy, climate and health sectors). There are also several public and private programmes and initiatives that aim to support a transition towards cleaner cooking fuels and technologies in Kenya. What is more, clean cooking is already mainstreamed in relevant climate and development planning documents. As such, the 2018-2022 NCCAP identifies the transition to clean cooking as a priority climate action in the energy demand sector and establishes respective targets for the plan's period. The MTP III, which provides a blueprint for national development in the same period (2018-2022) is reflected in and provides the starting point for the NCCAP.

Rural areas still record ultra-low access rates and risk being left behind in the transition.

To date, about 75% of all Kenyan households and more than 90% of the rural population still use solid biomass including fuelwood and charcoal as part of their cooking solution. About two in every three households (8.1 million) use fuelwood as their primary cooking fuel, while only about 20% use LPG as a primary fuel (mostly in urban areas). Despite years of efforts and resources dedicated to this, penetration of improved cooking technologies in rural areas remains very low, with only 3% of those who use solid biomass owning an improved woodstove and around 34% owning an improved charcoal stove. The currently most realistic NDC update scenario (NDCU-S) shows a concerning upward trend of GHG emissions in comparison to other more ambitious scenarios, due, amongst others, to population growth. In the absence of a truly transformative initiative, the state of cooking in rural areas will remain the same for several years going forward. This means that GHG emissions as well as other air pollutants are still high and can be assumed to further rise in the sector.

There are opportunities to promote renewable biofuels and electric cooking in Kenya.

Less than 1% of households use a type of biofuel stove (biogas or bioethanol) while only 3% use electric appliances. There are several efforts to promote the uptake of renewable biofuels through programmes and projects. On a positive note, the electrification rate has increased from 15% in 2001 to 75% in 2018[15], while the installed capacity has expanded to 2,840 MW against a peak demand of 1,926 MW[16]. Although there are many barriers to electric cooking, including quality of supply, upfront cost of the cooking appliances, cultural practices and others, these can be addressed through financial incentives, policy interventions and awareness creation. These challenges are similar to those that existed during the formative years of the LPG uptake. Both renewable biofuels and electric applications hold great promise towards climate change mitigation with significant health and environmental benefits. Moreover, a shift to biogas systems in rural areas could reduce the need to develop supply chain infrastructure as these allow households and/ or communities to produce the biogas themselves in a decentral setup.

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[15] Compare World Bank, 2021.

[16] Compare Kenya Power, 2020.

5.2 KEY CHALLENGES

There is a large body of scientific research about different challenges and barriers for the transition towards clean cooking. Three main challenges that are found to be of particular relevance in the Kenyan context can be attributed to the economic/ financial sphere, the cultural sphere, and the political sphere.

ECONOMIC/FINANCIAL

High upfront technology costs and expected fuel costs, paired with underdeveloped infrastructure for technology and fuel distribution, hamper an increased uptake of cleaner cookstoves in Kenya.

Technology comes at a price and the more innovative a technology is, the higher its price. Thus, technological improvements of cookstoves are usually reflected in their price. Furthermore, there is a huge difference in prices for different cooking fuels.

Most fuelwood consumers live in rural, low-income households, and have few economic incentives to invest in improved cookstoves and alternative fuels, as there are no fuel expenditure savings involved in such a transition. As for the consumer group which already purchases their fuel, fuel cost is one of the main determining factors behind fuel choice. As long as an alternative fuel is more expensive than the traditional one, there is no incentive for a fuel switch. Thus, as long as electricity prices remain high, for example, few households in urban areas will consider switching from modern to clean technologies; even though improved efficiencies of a new technology may level out the higher fuel price.

Interestingly, a study on the Ethiopian residential cooking sector, which has a comparably high rate of electric cookstove users in urban areas, shows that there is a strong link between preferred cooking fuel type, income level, educational status and urban/rural settlement[17]. Although cooking in Ethiopia and Kenya differs on several levels (including lower electricity costs in Ethiopia), there are similar socio-economic patterns that could contribute to comparable outcomes in Kenya. The apparent strong link between fuel expenditures, income level and preferred cooking technology may facilitate the discussion on policies for an enhanced uptake of improved and clean cookstoves.

Another challenge in the economic sphere is the need for infrastructure development and making available high-quality cooking appliances. In order for the transition to cleaner cooking to happen across the country, infrastructure and supply-chains need to be developed to ensure the reliable and affordable supply of cleaner cooking technologies and fuels. This can be particularly challenging and costly in rural and less populated areas, where settlements are dispersed, and infrastructure is in general underdeveloped.

[17] Compare Scott, Jones and Batchelor, 2020.

CULTURAL

The important cultural aspects of cooking and the practice of fuel stacking can considerably slow down the transition to cleaner cooking in Kenya.

Efforts to scale up access to clean cookstoves typically focus on promoting technically more efficient cooking technologies. Important socio-cultural aspects of cooking such as taste, cooking practices, cultural norms and gender roles have been given less attention. There is therefore a need to understand the behaviours, practices and perceptions of households which are part of any interventions targeted at transforming the cooking sector[18]. In general, stove and fuel stacking is a common practice in Kenya, based on a culture of using different cooking devices to fulfil different cooking needs within a household. Time, costs and practical limitations associated with the primary stove, such as the inability to accommodate large pot sizes, were identified as the major reasons for stacking in a study conducted in Kenya in 2020. These reasons were found to be even more dominant than the cultural attachment to traditional stoves or associated food tastes[19]. These barriers should be taken into account when planning future programmes and interventions.

POLITICAL

While several policies and strategies exist that refer to the residential cooking sector, there is a lack of one comprehensive, sector-wide strategy to guide the transition to cleaner cooking in Kenya.

The cooking sector in Kenya is special in the sense that responsibilities are spread across several line ministries, namely the Environment and Forestry Ministry (including the Climate Change Directorate), the Energy Ministry, and the Health Ministry. Accordingly, there are many policies and strategies that regulate certain aspects of the cooking sector and set respective targets in line with broader objectives of the issuing institution. However, it seems that to date, there is a lack of ownership with regards to guiding the transition of the cooking sector as a whole. No comprehensive strategy has been developed in an effort to tackle the various challenges and define ambitious yet realistic targets to set the cooking sector on a clean development pathway. Such a roadmap, ideally developed by one lead-institution in an inter-ministerial exercise and in consultation with a wide range of stakeholders, would not only provide orientation for future policy making in the individual line ministries but could also improve access to national and international public funds. The creation of an overarching institution or coordinating agency that is in charge of the cooking sector transition could accelerate and enhance this process.

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[18] Compare Couture and Jacobs, 2019; Lambe, Nyambane and Bailis, 2020.

[19] Compare Ochieng *et al.*, 2020.

5.3 RECOMMENDATIONS FOR FUTURE ACTION

1. **The establishment of a permanent responsible institution and coordinated planning process for the cooking sector could ensure that policies, strategies, and data are better aligned between the various stakeholders, including the Ministries of Environment and Forestry, Energy and Health, local authorities, and key non-state actors**. It could be highly beneficial to institutionalise a coordination entity in one of the Ministries, for example in the form of a Directorate, to establish clear ownership and responsibilities for the cooking sector in its entirety, facilitate long-term planning and ensure a common vision between the different actors involved. Once institutionalised, a planning process could be established with permanence. This would support the efficient development of cooking sector plans and strategies in the future, ease implementation, and maximise the use of available resources. Furthermore, permanent planning would allow for effective monitoring and evaluation of progress made against the set targets.

2. **A dedicated, comprehensive long-term strategy for the transition of the cooking sector can provide guidance for policy makers and all relevant stakeholders.** Starting point for such a strategy can be the different existing policy documents that currently regulate individual aspects of the cooking sector, such as the 2020-2027 National Bioenergy Strategy and the forthcoming Ethanol Masterplan. On this basis, a comprehensive, long-term strategy for the entire cooking sector can be elaborated which ideally defines clear and realistic targets for the sector's future development. This should be done in close alignment with other relevant planning documents, such as the NDC and NCCAP, as well as with policies and strategies in cross-cutting areas, such as general development planning, forestry, energy and health. Furthermore, the strategy ideally includes concrete measures for the achievement of the targets set. For some measures, policy-specific analysis could help to determine the best regulatory instruments, financial needs and policy design options, while for others it may be possible to directly proceed to draft policies and international climate finance proposals where necessary. This study and the modelling exercise can provide further input to any long-term strategy to be developed for the sector, with specific regards to mitigation potential and health benefits of different sector development pathways.

3. **A long-term strategy for the transition of the cooking sector ideally prioritises clean cooking solutions and promotes the gradual phase-out of improved cookstoves in the future.** In the transition of the residential cooking sector, it is important to clearly prioritise clean solutions and the gradual phase out of improved cookstoves in the longer term. Considering the global impetus towards a net-zero carbon future, LPG and improved biomass should be considered as transition fuels, with special focus laid on avoiding lock-in effects in terms of market and infrastructure developments. It must be noted that this may be difficult to implement in the short- to mid-term unless drastic measures are provided to bridge the cooking fuel gap in urban and rural areas. Feasibility studies and technical analyses can help assess the potential for the roll-out of modern and clean cooking solutions in different regions of the country. This could be conceptualised, for example, through the County Energy Plans as mandated by the Energy Act of 2019, which allocates certain functions to the county level.

4 **The enormous potential of clean cooking can be harnessed to effectively support the achievement of climate targets and other sustainable development objectives.** In the context of the Paris Agreement, Kenya has set itself ambitious targets to reduce its overall GHG emissions. Efforts to decarbonise the residential cooking sector would not only be fully in-line with the Paris Agreement's goals but also mutually reinforce other national development objectives, including the objectives of the MTP III and the achievement of the Sustainable Development Goals (SDGs). Enhanced awareness of these links amongst sector stakeholders and national development strategists can assist to identify the most constructive options for Kenya's cooking sector pathway. Awareness of these additional benefits among the population, particularly on health benefits, can be an important driver of actual uptake of new technologies and reduced stacking. Financial incentives are therefore ideally combined with specific communication activities to increase awareness.

5 **An improved system for data collection and analysis in the cooking sector would improve the accuracy of projections and the quality of policy formulation.** The scenarios developed in this report are based upon the best available data and knowledge from national experts, yet there are considerable uncertainties and knowledge gaps that compromise the accuracy of the projections. More detailed and accurate information on cooking technology used, existing infrastructure for modern and clean fuels and price developments for both technology and fuels can help assess the feasibility of planned measures and track progress and success of existing policies. The establishment of a central coordination entity responsible for the cooking sector would allow to create a data management system at the national level and advise county governments on data collection and reporting in an effort to improve the data needed for analysis and policy making.

6 **Innovative infrastructure solutions can further accelerate and enhance the transformation of the cooking sector.** Kenya already has a fairly well-developed value chain and distribution network for modern energy options such as LPG, especially in urban and peri-urban areas. Innovations, such as the use of boda boda (motorbikes) deliveries for certain fuels has increased the uptake of such solutions. Others include pay-as-you-go options for cooking fuels in low-income areas. Keeping in mind the need to transition away from improved and modern fuels to truly clean cooking solutions in the longer term, the active support of innovation-driven infrastructure development, for example through targeted Government programmes, can help transform the sector fundamentally and rapidly.

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ANNEX I - POLICY LANDSCAPE

The existing policy landscape with regards to residential cooking is extensive in Kenya. In the following, relevant laws, policies and regulations in the four sectors that are closely linked to the cooking sector are briefly outlined, namely the forestry sector, the energy sector, the climate policy area and the health sector. Furthermore, existing public and private initiatives as well as relevant fiscal policies are described. This overview is meant to provide the necessary background information on existing policies and targets for the subsequent modelling exercise, as they can play an important role in planning a successful transition to a truly clean cooking sector.

Forestry related laws, policies and regulations

In 2005, the Kenyan Government adopted the **2005 Forest Act** as the main statute governing all forests on public, community and private land. The Act introduced participatory forest management, established the Kenya Forest Service (KFS) and placed an emphasis on sustainable forest management and sustainable biomass production systems (MOEWNR, 2013).

The 2005 Forest Act gave rise to provisions on sustainable charcoal production, transportation and marketing, which were gazetted as the **2009 Forest (Charcoal) Regulations**. Specifically, these regulations set rules for licensing; require the formation of charcoal producer associations (CPAs); provide for the creation of a Forest Conservation Committee; and outline provisions for reforestation and conservation as well as for protection of endangered plant species, to be implemented by the CPAs (Ministry of Forestry and Wildlife, 2009).

In 2016, in an effort to align with the forest-related provisions of the 2010 Constitution, the 2005 Forest Act was replaced by the **2016 Forest Conservation and Management Act**. Unlike the previous document, the 2016 Forest Conservation and Management Act recognises the need to develop a national forest policy which is to be accompanied by a national forest strategy (KEFRI, 2016). With a view to cooking, the Act provides guidance and regulations for sustainable production, transportation and trade of charcoal and fuelwood. The Act furthermore states that anyone who produces or possesses charcoal in a forest without a license or permit of the forest owner commits offence (Republic of Kenya, 2016).

The **2020 Draft National Forest Policy** aims to address persistent challenges such as continuing deforestation and forest degradation as well as governance challenges. The demand for forest products, such as wood and charcoal used for cooking and heating purposes, is acknowledged as a key issue. Recognising these challenges, the policy provides the basis for governance-related, administrative and legislative reforms in the sector. It also reemphasises the necessity to implement a national strategy to increase and maintain forest and tree cover to at least 10% of the total land area and for the rehabilitation and restoration of degraded forest ecosystems (Republic of Kenya, 2020). In this context, the National Strategy for Achieving and Maintaining over 10% Tree Cover was developed in 2019 and gazetted shortly afterwards (Republic of Kenya, 2019).

Energy related laws, policies and regulations

The institutional framework in the Kenyan energy sector is very dynamic, with a number of laws and policies having been passed over the last decade. Overall development in the energy sector is currently guided by the 2019 Energy Act and the 2018 National Energy Policy.

The **2019 Energy Act** provides the overarching legal framework for the energy sector. It consolidates a number of laws relating to energy and provides for national and county government functions in the energy sector, in alignment with the 2010 Constitution. The Act furthermore paves the way for new mandates and institutions, including the renaming and broadening of the mandate for the Energy and Petroleum Regulatory Authority (EPRA – formally known as Energy Regulatory Commission – ERC) as well as for the Rural Electrification and Renewable Energy Corporation (REREC – formally known as Rural Electrification Authority – REA) and acknowledges the role of the Ministry of Energy to give overall guidance through policy formulation (Government of Kenya, 2019). While this document guides the country's transition towards renewable energy, it does not address the cooking sector specifically.

The **2018 National Energy Policy** aims to ensure an affordable, competitive, sustainable and reliable supply of energy to all Kenyan citizens in order to meet national development needs, while protecting and conserving the environment. In relation to clean cooking, the policy states the objective to promote a transition towards cookstoves running on modern and clean fuels in households and institutions. The document reiterates the targets set in climate policy related planning documents (see below) and defines prioritised mitigation actions in the energy sector, including the development and distribution of 4 million improved biomass stoves and 1 million clean energy stoves (LPG, biogas and ethanol) by 2022 (Ministry of Energy, 2018b).

Besides the 2019 Energy Act and the 2018 National Energy Policy, other regulations and strategies exist in the Kenyan energy sector that target the cooking sector either directly or indirectly.

In a first step to promote Liquefied Petroleum Gas (LPG) as a clean energy source and cooking fuel in Kenya, EPRA developed the **2009 Energy (LPG) Regulations.** These established licensing requirements for the LPG business, with a view to import, bulk storage, filling, transportation, wholesale and retail. Furthermore, the regulations prescribed the standardisation of LPG cylinders and valve sizes to allow for interchangeability between brands. The creation of an "LPG cylinder exchange pool" among LPG companies was mandated, aiming to guide the exchange of LPG cylinders among the LPG marketing companies and to drive competitiveness in the industry (Ministry of Energy, 2009).

However, due to severe problems arising from the pool system, including the development of an illegal LPG market and safety issues, the 2009 Energy (LPG) Regulations were revised and replaced by the **2019 Petroleum (LPG) Regulations**. The new regulations mandate that all LPG retailers, including shops, wholesalers and transporters, are required to acquire a license from EPRA for each business location, which shall be specific to the authorised cylinder brands only. These measures intend to resolve the issues from the earlier regulations and ensure the safety of all LPG users (EPRA, 2019).

Next to promoting LPG as a cleaner source of energy, the **2013 Energy (Improved Biomass Cookstoves) Regulations** target improved biomass cookstoves using wood or charcoal as fuels. The regulations provide rules on licensing, installation, record keeping, warranty and disposal of improved biomass cookstoves for a wide range of cookstove industry stakeholders and consumers (Ministry of Energy, 2013). In accordance with these regulations, standards have been developed for biomass cookstoves to monitor emissions and ensure performance, safety and durability (Clean Cooking Alliance, 2020).

Recognising the enormous potential of bioenergy as a renewable energy source, the Kenyan Government, together with other stakeholders, developed the **2020-2027 National Bioenergy Strategy**, which was launched in December 2020. The strategy provides guidelines, approaches and strategic interventions to promote sustainable production and consumption of bioenergy. It furthermore sets a target to achieve 100% access to modern bioenergy services by 2030, including a commitment to meet clean cooking targets by 2028. More specifically, the strategy aims to i) promote the sustainable production and consumption of bioenergy while tapping economic, environmental and health benefits; ii) provide investors with information on opportunities for bioenergy development in Kenya; iii) accelerate the transition to clean cooking technologies and fuels; and iv) serve as a framework for regional cooperation and trade in bioenergy (ACCESS, 2020).

Climate related laws, policies and regulations

Lately, the cooking sector has been addressed more explicitly in climate related policies and guiding documents which aim at curbing national emissions, amongst others from energy demand.

While **Kenya's first NDC** establishes an economy wide emissions reduction target of 30% relative to a business as usual (BAU) scenario by 2030, it does not include information on the sector split. It does not specify, for example, which contribution the energy sector can and should provide to meet the 2030 target (MENR, 2015).

To this end, the **2017 NDC Sector Analysis** examines options to deliver the total mitigation contribution in the six UNFCCC mitigation sectors (energy, transport, industry, waste, forestry, agriculture). According to this document, the energy demand sector is supposed to reduce its emissions by 6.1 $MtCO_2e$ relative to BAU by 2030 to achieve the overall mitigation target. Twelve mitigation options were developed for the energy sector, including two that directly target the cooking sector: "LPG Stove Substitution" and "Improved Cookstoves". Together, these two options are ascribed a mitigation potential of 7.3 $MtCO_2e$ (Government of Kenya, 2017). Concrete measures to realise this potential are not outlined in this document.

In order to implement Kenya's first NDC, the **2018-2022 National Climate Change Action Plan (NCCAP)** was developed based on its predecessor, the 2013-2017 NCCAP. The 2018-2022 NCCAP guides Kenya's climate action towards the achievement of its first NDC and identifies the transition to clean cooking as a priority climate action in the energy demand sector. The transition is expected to happen through the uptake of LPG, ethanol and other alternative fuels in urban areas, and through the uptake of improved biomass cookstoves and use of briquettes in rural areas. The plan furthermore outlines concrete mitigation actions with respective targets in the cooking sector. As such, the number of households using LPG, ethanol or other cleaner fuels across the country is supposed to reach 2 million by 2022. In rural areas, specifically, the number of households using improved biomass cookstoves is expected to increase by 4 million and biogas technology is meant to be scaled through the construction of 6,500 bio digesters for domestic use and 600 biogas systems for schools and public facilities. The estimated GHG emissions reductions through the uptake of alternative fuels and efficient cookstoves in the energy demand sector amount to 7.1 $MtCO_2e$ according to the 2018-2022 NCCAP (Ministry of Environment and Forestry, 2018).

In December 2020, Kenya submitted an **updated NDC** to the UNFCCC in which the country increased its mitigation ambition from a 30% reduction by 2030 to a 32% reduction in the same target year, compared to BAU. The document is informed by a more detailed and robust assessment of mitigation and adaptation measures as carried out in the Mitigation and Adaptation Technical Analysis Reports (MTAR and ATAR). These were developed after the submission of Kenya's first NDC and also inform the 2018-2022 NCCAP (Ministry of Environment and Forestry, 2020b). While the updated NDC provides guidance with a view to economy-wide emissions reductions, no details on the sector split are disclosed as was the case in Kenya's first NDC.

Health related policies and initiatives

In collaboration with partners, the Ministry of Health aims to sensitise households on the effects of household air pollution. This awareness will, in turn, promote the transition from polluting to cleaner cooking solutions at the household level. To this effect, the Ministry of Health developed a training manual targeting level one health care workers[20] and the community health volunteers (CHVs), who will create awareness among households on the health impacts of using traditional cooking solutions. The training manual was developed using World Health Organization (WHO) Household Energy Use guidelines. The manual has four units: (i) introduction to household energy uses and the WHO guidelines on air quality and household fuel combustion, (ii) health safety and impacts of household energy use, (iii) household air pollution and primary prevention strategies on cooking, heating and lighting, and (iv) monitoring, reporting and evaluation. This training manual, which will be published in the second half of 2021, aims to reach over 100,000 communities in Kenya.[21]

Public sector initiatives in the cooking sector

Beyond laws and policies, there is a growing number of public sector initiatives that aim at promoting the transformation of the energy sector in general and cooking sector more specifically. These initiatives are often technically and financially supported by international organisations.

Shortly after its foundation in 2010, the Global Alliance for Clean Cooking (now Clean Cooking Alliance)[22], together with GIZ, SNV Netherlands Development Organisation and Kenyan sector stakeholders, developed the **2013 Kenya Country Action Plan** with a focus on the cooking sector. This plan outlines 24 priority actions to remove barriers to the widespread adoption of clean cookstoves and fuels in Kenya. The implementation of these interventions was expected to catalyse the clean cookstove and fuel market and contribute an estimated 7 million clean cookstoves by 2020. As a means of support, the plan proposed the creation of the Clean Cooking Association of Kenya (CCAK), which was founded shortly after the adoption of the Plan (GACC, 2013). Monitoring and reporting on the achievement of the Plan's target has not yet been institutionalised. In 2019, it was estimated that 5.2 million clean and modern cookstoves had been distributed (Ministry of Energy, 2019).

In 2012, Kenya joined the Sustainable Energy for All (SE4All) Initiative which works in partnership with the United Nations and various stakeholders to drive faster action towards the achievement of SDG 7 on clean energy. In a comprehensive multi-stakeholder process, the **2016 Kenya Action Agenda** was elaborated, which presents a long-term vision for energy sector development, spanning the period from 2015 to 2030. The Action Agenda outlines how Kenya will achieve the SE4All goals, including 100% access to electricity and 100% access to modern cooking solutions by 2030. The document identifies existing gaps towards these targets (including regulatory issues, lack of awareness, cook stove quality and performance) and defines high impact initiatives to increase access to modern and clean cooking. The document was endorsed by the Government and integrated into the national development plan cycle and budget system (MOEP and SE4ALL, 2016a).

[20] In the Kenyan community health model, a level one care unit serves a population of approximately 5,000. Between one and two trained and certified public health officers each manage a cadre of 25 community health workers, each of who are responsible for providing services to 20 households (Aridi *et al.*, 2014).

[21] The information is based on an expert conversation with a representative of the Ministry of Health which took place in May 2021.

[22] The Global Alliance for Clean Cooking was founded in 2010. In 2018, the organisation was renamed in Clean Cooking Alliance in order to more accurately reflect its industry-building approach for cookstoves and fuels (Clean Cooking Alliance, 2018a).

In parallel with the Action Agenda, the **2016 Kenya Investment Prospectus** was elaborated, which aims at presenting the current investment environment as well as priority investment areas and opportunities to help operationalise the SE4All targets in Kenya. The Investment Prospectus includes key facts in table format on a number of priority projects, among these are ten projects[23] that specifically target the increased distribution and uptake of clean cookstoves and fuels (MOEP and SE4ALL, 2016b).

In 2016, the Government, in cooperation with the National Oil Corporation, launched the **Mwananchi Gas Project** as a national LPG enhancement project. The project, which is funded by the Treasury with KES 3 billion, was planned to help distribute 6kg complete gas cylinders (including gas, burner and grill) under the Gas Yetu brand at a discounted price of KES 2,000 to poor households, in order to prevent the use of fuelwood. However, distribution stalled in 2018, after fraudulent contractors had supplied defective gas cylinders. After a third party cylinder inspector was brought on board, distribution was resumed in May 2020 (Business Daily Africa, 2020). The original target of the project was to enhance LPG penetration from 10% to 70% within three years, with benefits for public health, economic activity, quality of life, and deforestation (National Oil, 2016).

Private sector initiatives in the cooking sector

In 2009, the **Kenya Biogas Programme** was established in order to implement the Africa Biogas Partnership Programme (ABPP) in the country. The ABPP is a public private partnership between Hivos, SNV and the Dutch Government. The overarching objective of the Kenya Biogas Programme is to develop a commercially viable and sustainable biogas sector in Kenya, through the distribution of biodigesters to individual households. Since the start of the programme, over 17,000 biodigesters have been built across Kenya. In early 2020, 88% of these were in operation and use (The Gold Standard, 2020). Given that a major barrier to install a biodigester is its high upfront cost, the programme established credit partnerships with rural micro finance institutions and saving cooperatives. Certification through the Gold Standard allows for the sale of carbon credits per tonne of carbon emissions reduced. The income from carbon credit sales benefits biogas users in form of after-sales support, bioslurry training and other services (The Gold Standard, 2020).

In a multi-stakeholder initiative between Hivos East Africa, the Greening Kenya Initiative, the African Centre for Technology and Practical Action and the Government of Kenya, the **National Biomass Briquette Programme** was launched in 2016 with the aim to establish innovative briquette technologies, policies and practices in the energy sector (Hivos, 2016). The first project phase runs from 2018 to 2022 and is funded with USD 10 million. The objective is to establish a sustainable briquette manufacturing sector in Kenya by developing a supply chain that ranges from production to establishing standards for domestic and industrial use (Hivos, 2018). In line with this programme, the establishment of a briquetting plant is mentioned as an investment opportunity in the SE4All Investment Prospectus (MOEP and SE4ALL, 2016b).

In 2017, the Government of Kenya, through its Ministry of Energy, initiated the **Kenya Off-grid Solar Access Project (KOSAP)** which aims at providing electricity and clean cooking solutions to 14 underserved areas[24] until 2023. The project is funded by the World Bank with USD 150 million and implemented through different agencies, including the Ministry of Energy, Kenya Power, REREC, and

[23] The ten projects include the following: a) LPG storage and bottling facilities in Nairobi, b) Scaling up Kenya national domestic biogas (Biogas for better life) programme; c) development of cookstove sector; d) development of standard and labelling (S&L) for cookstoves in Kenya; e) Development of a communication strategy for clean cooking in Kenya; f) Strengthening distribution of clean cookstoves and fuels in Kenya; g) Clean cookstoves market acceleration project; h) Setting up bioethanol distillers; i) Bioethanol as an alternative household fuel in Kenya; j) Establishing a briquetting plant (MOEP and SE4ALL, 2016b).

[24] In the initial phase of the project, 14 out of 47 Counties were defined as “underserved” (The World Bank, 2020).

SNV. One of the four project components (Component 2) aims at establishing Results-Based Financing (RBF) and debt facilities to provide incentives to private sector companies to disseminate solar-based and clean cooking solutions. Under this component, a Clean Cooking Solutions RBF Facility (CCS Facility) is endowed with USD 6 million to support the deployment of clean cookstoves in 150,000 households within four years. Cookstoves promoted under the project must be tier 2[25] or higher in order to qualify for financing through the CCS Facility (Ministry of Energy, 2020).

In 2020, the project **Promotion of Climate-Friendly Cooking in Kenya**[26] was set up, which is co-financed by the Green Climate Fund (GCF), the German Federal Ministry for Economic Cooperation and Development (BMZ) as well as Kenya's Ministry of Energy and the Ministry of Health. The project is implemented by GIZ, together with the Ministry of Energy and SNV, and aims at promoting the creation of an innovative and strong market in Kenya for the production and sales of improved cookstoves over a period of five years. This shall help the country to increase the penetration of improved cookstoves in rural and remote areas and to significantly advance the achievement of the NDC (GIZ, 2020).

Fiscal policies affecting the cooking sector

In addition to these laws, policies, and initiatives in the energy sector, there are a few fiscal policies as well as banking bills that do not target the cooking sector explicitly but have significant impact on it.

Importantly, there have been frequent changes in the **import duty on cookstoves**. Between 2016 and 2020, the import duty on solid biomass stoves was first reduced from 25% to 10%, then it was increased from 10% to 35%, before being reduced again to 25%. Finally, the import duty on energy efficient cookstoves was reduced from 25% to 10%, aligning them with similar cookstoves that use gas, electricity and other fuels, which currently attract a 10% import duty (Clean Cooking Alliance, 2016)

In the **2016 Finance Act**, the Government removed the 16% VAT on LPG and clean cookstoves, increased the cost of kerosene by KES 7.20, and removed the excise duty on ethanol for cooking and heating in order to spur the use of cleaner fuels and stoves and help achieve progress on the country's objectives to improve health, livelihoods, the environment, and the country's overall development (Clean Cooking Alliance, 2016).

The **2018 Finance Act** further increased the cost of kerosene through an increase of the excise duty from KES 7.20 to KES 10.30. This measure was coupled with the introduction of an 8% VAT on petroleum products, including kerosene, as well as with an anti-adulteration levy on kerosene imported for home use, at KES 18 per litre (Deloitte, 2018).

Recently, in an effort to respond to dwindling economic activity, the **2020 Finance Bill** reintroduced a 16% VAT on LPG and clean cookstoves, which will increase the price of clean cooking for consumers again and contradicts government efforts to promote clean cooking. However, LPG was given a grace period of one year in this context, with the new VAT becoming effective in July 2021 (Government of Kenya, 2020a).

It becomes clear from this overview that current policies, programmes and initiatives focus mostly on the deployment of modern cookstoves, with much less attention being paid to truly clean cooking solutions. While the promotion of modern cookstoves can present an important intermediate step

[25] In 2018, an ISO technical committee comprised of experts nominated by 45 countries and 8 liaison organisations developed voluntary performance targets to provide guidance to the benchmarking of cookstove performance. Five indicators are covered by the targets: thermal efficiency, fine particulate matter emissions, carbon monoxide emissions, safety, and durability. Each indicator is rated along 6 tiers (0: lowest performing, 5: highest performing) (Clean Cooking Alliance, 2018b).

[26] The project focusses on two project countries, Kenya and Senegal. In the context of this study, only the Kenya component is being described.

towards a clean cooking sector, it does not present a fully sustainable solution in the long-term (Couture and Jacobs, 2019). In order to push both the climate and the national development agenda and prepare Kenya for a sustainable future, more attention in planning and policy making must be given to the significant synergies between climate action and sustainable development in a low-emission residential cooking sector.

ANNEX II - METHODOLOGY

RAW AND DERIVED INPUT DATA

This section provides and overview of the input data (raw and derived) and their respective sources used for the modelling exercise.

Table 14. General modelling input parameters.

Input parameter	Unit	Value	Source
Daily cooking demand	Number of cooked meals per person	2.50	(Nerini, Ray and Boulkaid, 2017)
Average urban household size	People per household	3.50	(Kenya National Bureau of Statistics, 2014)
Average rural household size	People per household	4.70	(Kenya National Bureau of Statistics, 2014)
Final energy demand for a standard meal for four persons	MJ	3.64	(Nerini, Ray and Boulkaid, 2017)

Table 15. Biomass related input parameters.

Input parameter	Geographical boundary	Unit	Value	Source
Forest biomass intensity	Africa	tonnes/ha	163	(Garzuglia and Saket, 2003)
Current forest area	Kenya	thousand ha	4413	(UN-REDD Programme, 2017)
fNRB in the biomass supply	Kenya	%	92%	(UNFCCC, 2012)
Conversion factor, solid biomass to charcoal	Kenya	%	10%-30%	(Johnson *et al.*,18)
Conversion factor, solid biomass to biogas	India	kg biogas/kg solid biomass	0.085-0.17	(Karve, 2013)
Conversion factor, solid biomass (sugarcane) to bioethanol	Bangladesh	kg bioethanol/kg solid biomass	0.44	(Miskat *et al.*, 2020)

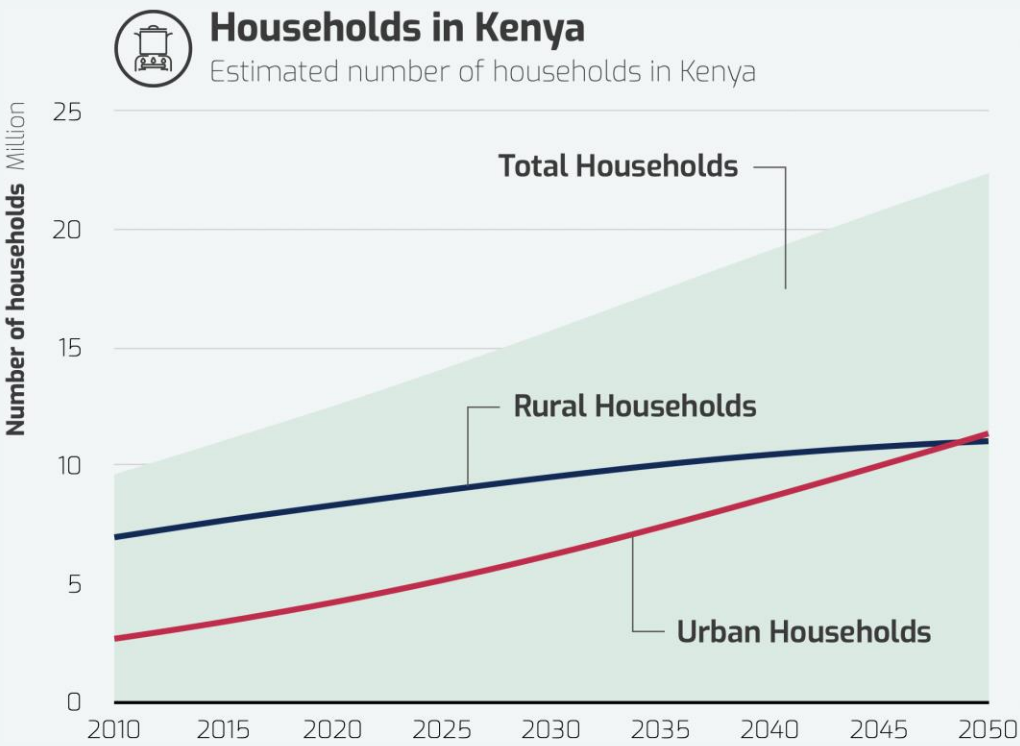

Figure 23. Estimated number of households.

Urban, rural and total, derived from UN World Population Prospects and the Shared Socio-economic Pathway 2: Middle of the road (SSP2) (UN DESA, 2019; IIASA, 2020).

Table 16. Non-GHG emission factors.

Fuel	Gas	Unit	Value	Source
LPG	NO_x	g/MJ	0.0600	(Wagner *et al.*, 2020)
Charcoal, traditional	NO_x	g/MJ	0.0700	(Vallack *et al.*, 2020)
Charcoal, improved	NO_x	g/MJ	0.0240	(Ministry of Energy, 2019; Mitchell *et al.*,2019; UNEP, 2019a)
Kerosene	NO_x	g/MJ	0.0600	(Wagner *et al.*, 2020)
Wood, traditional	NO_x	g/MJ	0.0600	(Wagner *et al.*, 2020)
Wood, improved	NO_x	g/MJ	0.0546	(Zhang *et al.*, 2000; UNEP, 2019a; SSB, 2020; Wagner *et al.*, 2020)
Gaseous/liquid biofuels	NO_x	g/MJ	0.2310	(Paolini *et al.*, 2018; UNEP, 2019a)
LPG	$PM_{2.5}$	g/MJ	0.0003	(Wagner *et al.*, 2020)
Charcoal, traditional	$PM_{2.5}$	g/MJ	0.0868	(Karnani *et al.*, 2014; Zhang *et al.*, 2000; WBG, AFREA and ESMAP, 2014; Ministry of Energy, 2019; Wagner *et al.*,2020)
Charcoal, improved	$PM_{2.5}$	g/MJ	0.0557	(Karnani *et al.*, 2014; WBG, AFREA and ESMAP, 2014; Ministry of Energy,2019; Mitchell *et al.*, 2019)
Kerosene	$PM_{2.5}$	g/MJ	0.1500	(Wagner *et al.*, 2020)
Wood, traditional	$PM_{2.5}$	g/MJ	0.6576	(Zhang *et al.*, 2000; WBG, AFREA and ESMAP, 2014; Ministry of Energy, 2019; Adhikari, Mahapatra and Pokheral, 2020; Wagner *et al.*, 2020)
Wood, improved	$PM_{2.5}$	g/MJ	0.1795	(Karnani *et al.*, 2014; Ministry of Energy, 2019)
Gaseous/liquid biofuels	$PM_{2.5}$	g/MJ	0.0074	(Weyant *et al.*, 2019)
LPG	SO_2	g/MJ	0.1160	(UNEP, 2019a)
Charcoal, traditional	SO_2	g/MJ	0.0539	(Zhang *et al.*, 2000)
Charcoal, improved	SO_2	g/MJ	0.0001	(UNEP, 2019a)

Table 17. Fuel consumer prices in Kenya. Price units are convered from KES/kg to USD/GJ.

Fuel	Type	Unit	Price	Source
Fuelwood	purchased	USD/GJ	116	(Ministry of Energy, 2019)
Fuelwood	collected	USD/GJ	4	(Ministry of Energy, 2019)
Fuelwood	weighted[27]	USD/GJ	15.2	Derived input
Charcoal	+16% VAT	USD/GJ	67.3	(Ministry of Energy, 2019)
Kerosene	general	USD/GJ	47	(Ministry of Energy, 2019)
LPG	general	USD/GJ	62	(Ministry of Energy, 2019)
Gaseous/liquid biomass[28]	biogas	USD/GJ	0[29]	
Gaseous/liquid biomass	bioethanol	USD/GJ	58	(Ministry of Energy, 2019)
Electricity	grid	USD/kWh	0.201	(GlobalPetrolPrices, 2020)

[27] The overall fuelwood price is calculated as a weighted average based on the assumption that 90% of fuelwood is collected, and 10% is purchased on the market.

[28] It is assumed that the sustainable biomass category is made up from 50% of biogas and 50% of bioethanol.

[29] It is assumed that the biomass (agricultural and human waste) to produce biogas is generated by consumers, and that it does not induce any costs for the consumer.

ADDITIONAL MODELLING RESULTS

This section presents additional results from the modelling exercise which is not specifically discussed in the report.

Table 18. Electric cooking rate[30] in 2030 and 2050 for all scenarios.

	Urban population		Rural population	
Scenario	2030	2050	2030	2050
BAU	1%	1%	0%	0%
NDCU	17%	49%	3%	8%
IP	6%	11%	0%	0%
GF	14%	42%	2%	7%
NZ	42%	100%	31%	86%

Table 19. Share of households using LPG in 2030 and 2050 for all scenarios.

	Urban population		Rural population	
Scenario	2030	2050	2030	2050
BAU	41%	41%	7%	7%
NDCU	50%	67%	5%	2%
IP	78%	100%	8%	10%
GF	92%	92%	23%	0%
NZ	51%	0%	11%	0%

[30] Refers to the shre of households using electric stoves.

Table 20. Share of households using solid biomass (charcoal and fuelwood) in 2030 and 2050 for all scenarios.[31]

	Urban population		Rural population	
Scenario	2030	2050	2030	2050
BAU	72%	68%	129%	122%
NDCU	72%	68%	129%	122%
IP	61%	61%	85%	85%
GF	37%	22%	99%	84%
NZ	52%	0%	94%	0%

Table 21. Share of households using biogas and/or bioethanol in 2030 and 2050 for all scenarios.

	Urban population		Rural population	
Scenario	2030	2050	2030	2050
BAU	0%	0%	0%	0%
NDCU	4%	11%	7%	21%
IP	3%	5%	7%	20%
GF	6%	19%	18%	57%
NZ	18%	18%	58%	58%

[31] Percentages exceeding 100% indicates to fuel stacking.

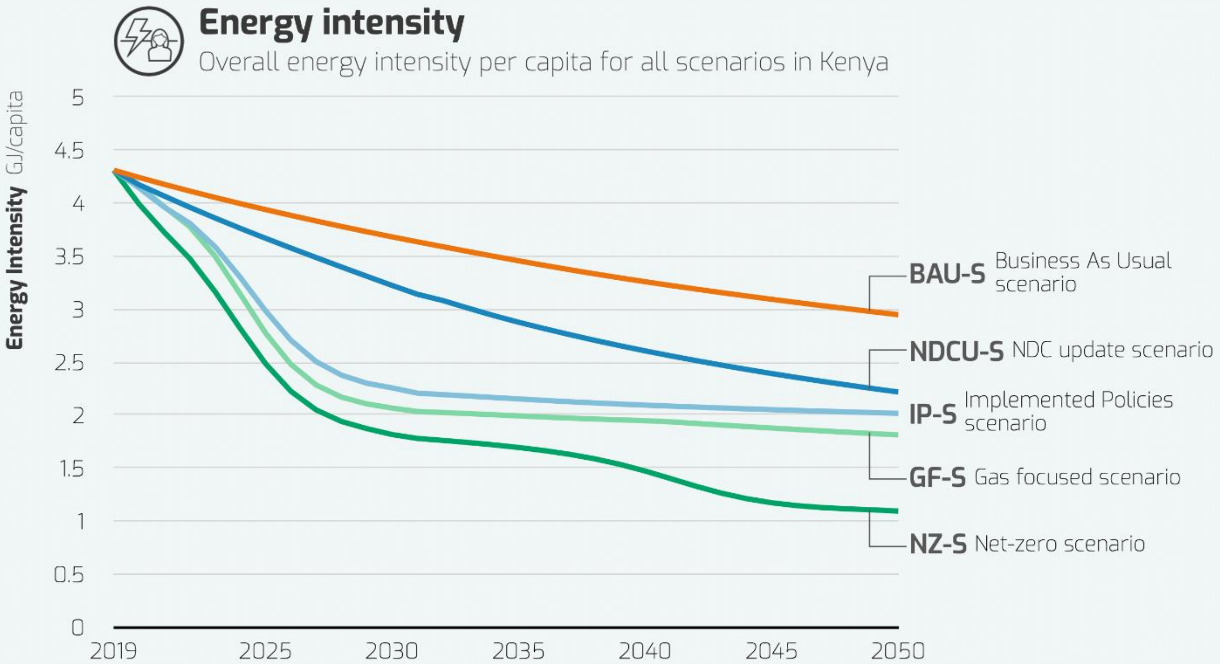

Figure 24. Overall energy intensity per capita (GJ/capita) for all scenarios.

The intensities refer to the average energy intensity based on the total energy demand and may in reality vary across households depending on the specific household fuel mix.

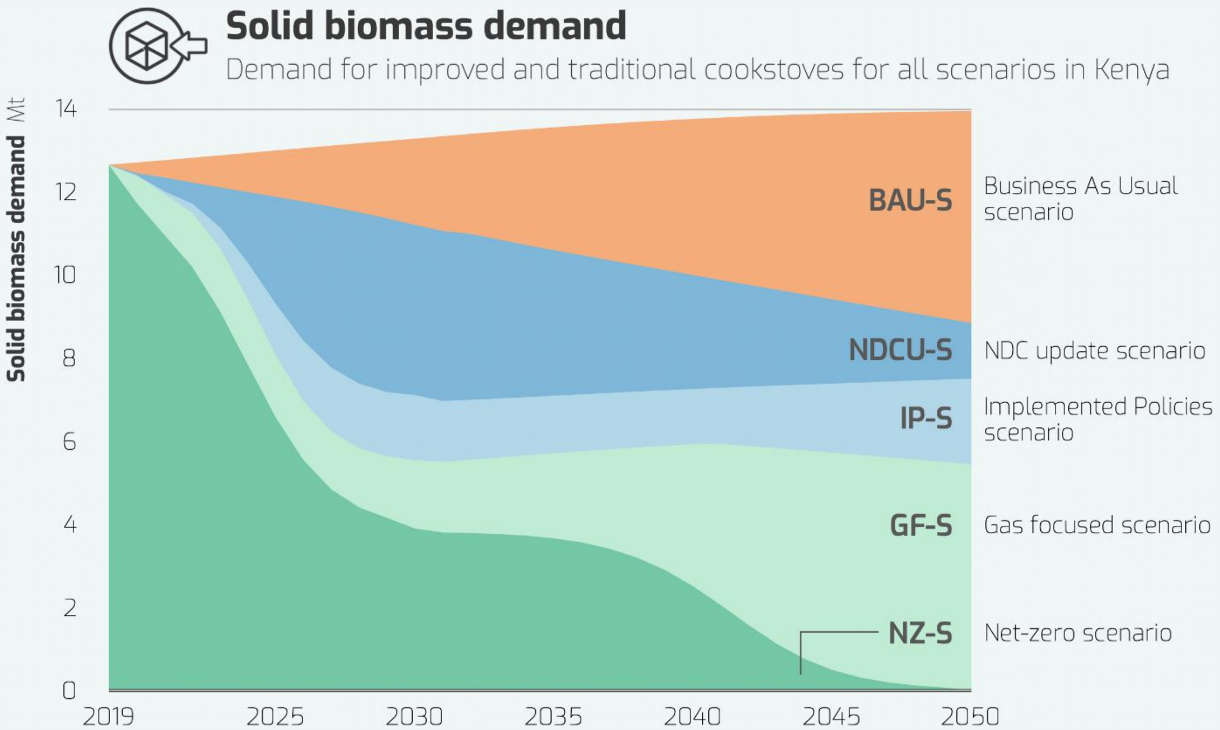

Figure 25. Solid biomass demand (Mt) from improved and traditional cookstoves for all scenarios.

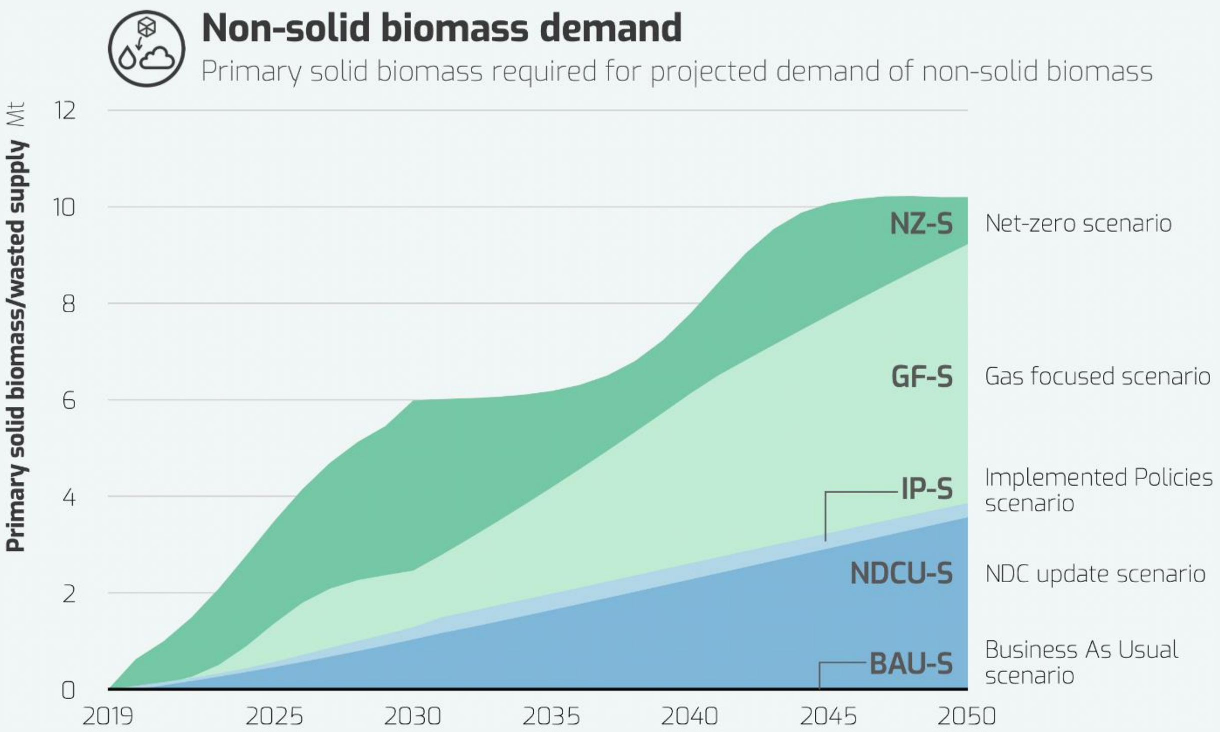

Figure 26. Primary solid biomass (Mt) required to produce the projected demand of non-solid (biogas and bioethanol) biomass for all scenarios.

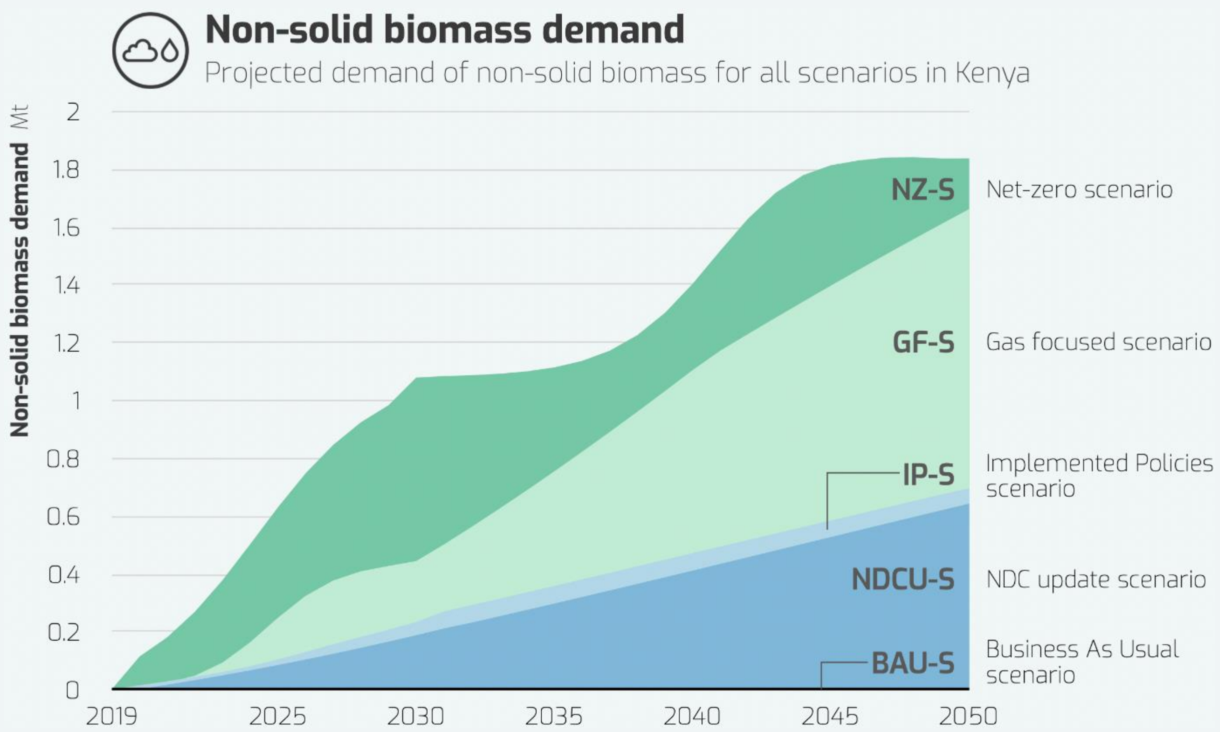

Figure 27. Projected non-solid (biogas and bioethanol) demand (Mt) for all scenarios.

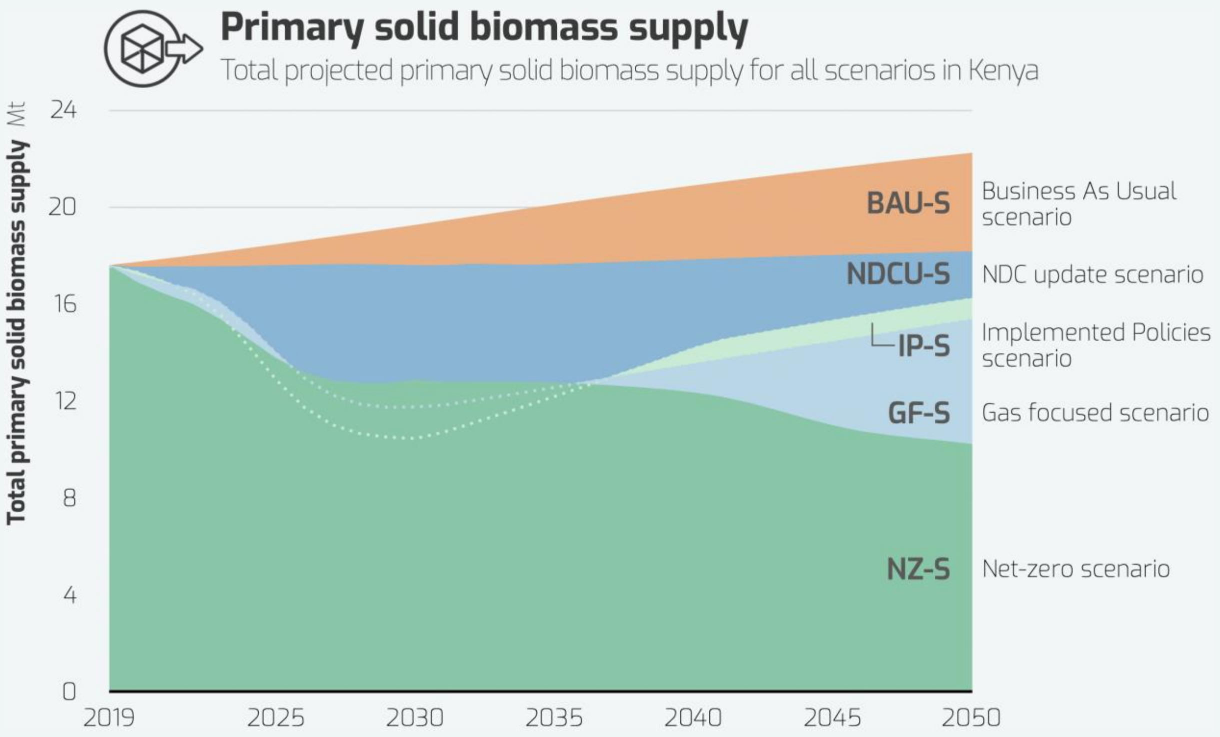

Figure 28. Total projected primary solid biomass supply (Mt) for all scenarios.

The estimates refer to biomass required to satisfy the demand for clean, improved and traditional biomass cookstoves.

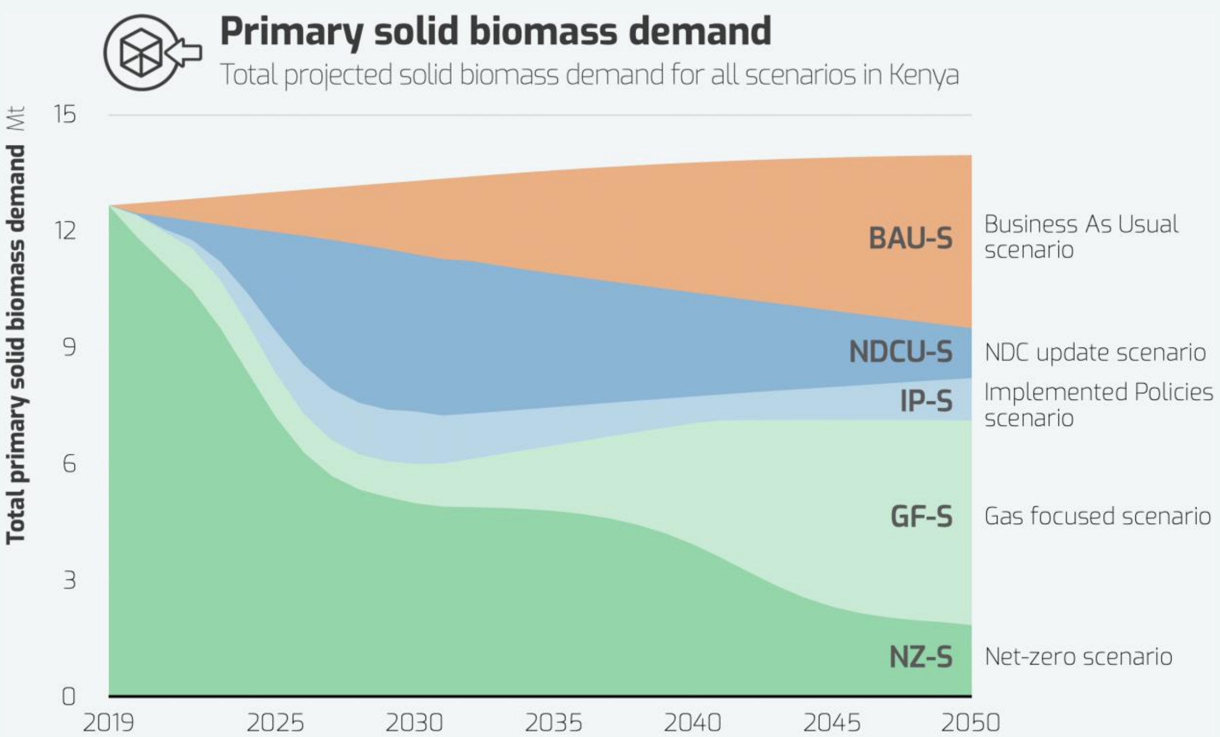

Figure 29. Total projected solid biomass demand (Mt) for all scenarios.

The estimates refer to the projected demand for solid biomass, arising from improved and traditional biomass cookstoves, requiring solid biomass (wood or charcoal) as input fuel.

SCOPE AND LIMITATIONS

Existing data gaps present limitations to the modelling exercise and results (Chapter 3). Thus, the following data issues must be carefully considered when interpreting the scenarios.

Uncertainty about population and urbanisation growth

The major driving factor of cooking demand is the expected population and urbanisation growth. Long term population projections are obtained from UN World Population Prospects (United Nations Department of Economic and Social Affairs, 2019). To those, urbanisation projections from the *Shared Socio-economic Pathway 2: Middle of the road* (SSP2) are applied to derive expected rural and urban population projections (IIASA, 2020). As the residential cooking sector looks rather different in rural and urban communities, the sensitivity to the urbanisation factor can be expected to be significant with regards to the final results. In the literature, there are various urbanization pathways which differ significantly in the long term. Depending on the pathway chosen, the model output results may vary.

Inconsistent data on fuel and technology use

As historic data on fuel and technology usage differs across data sources, a simplified approach is used to define target setting for specific technologies relative to the start year. The fuel and technology distribution in 2019 from the 2019 National Cooking Sector Study is used across all scenarios, to which input data is harmonised to match the base year data (Ministry of Energy, 2019). That is, in cases where the alternative data source has conflicting values, a similar growth rate has been applied to the base year data as obtained when using the alternative data source. That is, in cases where the alternative data source has conflicting values, a similar growth rate has been applied to the base year data as obtained when using the alternative data source. One parameter which is particularly challenging in this matter is the current share of improved charcoal and fuelwood stoves. Various data sources may use different definitions of what an improved cookstove is, and thus end up with disagreeing estimates on the current share of improved cookstoves. In this study, the shares are derived from the 2019 National Cooking Sector Study (Ministry of Energy, 2019), which leans toward more conservative values. Of total fuelwood cookstove owners, 3% are estimated to own an improved cookstove, while the corresponding share for charcoal stove owners is estimated to 76% (derived from the 2019 National Cooking Sector Study). In general, there is a higher uptake of improved charcoal cookstoves compared to improved fuelwood cookstoves as for the former, higher efficiencies bring down fuel expenditures for the owner. That is commonly not the case for fuelwood cookstoves since fuelwood in most regions is collected at no costs.

Lack of data on the fraction of non-renewable biomass

A third challenge linked to solid biomass is the current fraction of non-renewable (unsustainable) biomass (fNRB) of the total solid biomass supply. According to data compiled by the UNFCCC, the fNRB in Kenya between 2012 and 2017 was estimated to be at 92%, which is assumed to be the case throughout the time series in this study (UNFCCC, 2012). The 2018-2022 NCCAP highlights efforts related to the production of sustainable charcoal, however, this is not accounted for in the scenario analysis due to the lack of clearly defined quantitative targets.

Discrepancy of non-GHG emission factors in the literature

Finally, there is a lack of consensus in the existing literature on air pollution emission factors ($PM_{2.5}$, NO_X and SO_2). For this study, available data is collected and harmonised by using the weighted average emission factor in those cases where multiple data points are available (Karnani *et al.*, 2014; Zhang *et al.*, 2000; the World Bank Group, 2014; Paolini *et al.*, 2018; Mitchell *et al.*, 2019; Republic of Kenya Ministry of Energy, 2019; Adhikari, Mahapatra and Pokheral, 2020; Wagner *et al.*, 2020).

Implications for the Kenyan power sector

Although some of the scenarios developed in the study may have significant implications on the Kenyan power sector, this is outside of the scope of this study. The NZ-S in particular would contribute to the peak power demand and the system load curve of the power sector. Moreover, the power emission intensity pathway in this study is based on projections based on current and planned power capacities in Kenya, and is used as an input in all scenarios. As such, the effects and requirements an increased deployment of electrified cooking would put on the Kenyan power sector, as well as its implications on emissions from the residential cooking sector, is suggested as a future research topic.

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