Effects of switching from biomass stoves to electric stoves and subsequent reduction in resultant emissions in the Kenyan energy sector

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Research Article

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Abstract

Being a major source of fuel for cooking in Kenya, biomass presents various challenges that are both environment and health related in terms of greenhouse gas emissions and indoor air pollution complications respectively. In this regard, it is imperative to encourage a switch to cleaner and safer technologies for cooking. The present paper tries to address the challenge of GHG emissions linked to using biomass fuel in the cooking sector through modelling analysis. The OseMOSYS modelling platform has been used to create three scenarios that have been used to evaluate the effects of switching from biomass stoves to electric stoves within the electricity sector in the country. Results showed that a stepwise switch to electric stoves will lead to a decrease in total emissions and specifically from biomass which contributes the largest emissions in the Kenyan energy sector at 84% for the whole modelling period. There was however an increase in emissions from coal to meet an increased demand in electricity. A scenario to limit the emissions from fossil fuels led to introduction of nuclear power plants in the electricity generation mix that brought about very high investment and operating costs in the power sector. It was recommended that an analysis should be carried out of linkages between different sectors to know effects of fuel switching on demand-side technologies and allow informed decisions by policy makers on policies. The model does not calculate and present emissions from every sub sector. This limited in depth analysis of how emissions from each sector were affected in each scenario. It was therefore recommended that this improvement on emissions presentation be done as part of future work to allow easier tracking and proposed specific actions.

1. Introduction

Biomass is the largest source of energy in Kenya accounting for 68% of the total final energy demand in the country and providing for about 90% of the energy needs of rural households [1]. In a population of about 55 million people, 72% being rural dwellers, about 86% of those living in the rural areas rely on biomass mainly for cooking, as shown in Fig. 1 [2] [3]. The amount of biomass being used for cooking in the country is three times the total amount of petroleum being consumed and 4 times the total amount of electricity consumption [3].

This has led to implications on health with the ministry of environment estimating about 14,000 people dying annually from indoor air pollution [4]. The World Health Organization (WHO) states that 25% of all diseases are respiratory related with 3.8 million lives lost to smoke from cooking fuels in 2019. An estimated 70–90% of all energy used in low income households goes into cooking with women and children taking the lead role and being most adversely affected [3] [5]. It then follows that women who take this lead role have an influence on the choice of fuel for cooking.

The study attempts to address these challenges faced in the cooking sector by proposing a shift to other cleaner alternative fuels for cooking. Biomass fuel is generally considered as carbon neutral considering that emissions released from burning the fuel should be absorbed by the forests themselves. This has however been disrupted by the unsustainable practices of burning biomass coupled with forest degradation without replenishing the resource, to meet growing demand for fuelwood. It means that only some of the carbon emitted from burning biomass is recovered by what is planted in terms of forests [6] [7].

The main purpose of the study was to reduce the utilization of biomass for cooking and resultant emissions from alternative technologies deployed where necessary. In the study, it was assumed that the emissions coming from biomass used in cooking can be equated to have similar global warming potential as that of carbon dioxide from fossil fuels. The Open Source Energy Modelling System (OseMOSYS), a modelling platform for long-run integrated assessment and energy planning was used to model defined scenarios to address the research question of the study. Several interfaces exist for this platform but the clicSAND (Simple and Nearly Done) interface was used for this study. Three scenarios were then modelled as follows:

- Least cost scenario: this was to reflect what is currently existing in the country in terms of the cooking sector;
- Adoption of Electric cooking: it was assumed that there would be a reduction of the use of biomass as the main source of fuel for cooking and adoption of electric cooking gradually to 100% by 2050. The scenario was modelled by increasing in steps the demand for electric cooking to 100% in 2050 of total residential cooking demand, and;
- Reduction of annual emissions: the scenario assumed a reduction of total annual emissions by applying an annual emissions limit in the model. The Nationally Determined Contribution (NDC) target of 32% by 2030 and net zero by 2060 was applied.

2. Methodology

The OseMOSYS modelling platform was used to model defined scenarios that would seek to reduce use of biomass for cooking by switching to cooking using electricity. clicSAND a Graphical User Interface (GUI) for OSeMOSYS was selected for this study. Input data was entered via an excel spreadsheet then open-source solvers (GLPK and CBC) were used to run the model. The interface had various parameters that were adjusted for the scenarios on applicable sets (defined technologies, commodities and emissions). Results were then pushed into an Access database, and an Excel template to visualize them in a sharable format [8]. The model used the Kenyan data starter kit for energy from the climate compatible growth (CCG) forum that had input data for the Kenyan cooking sector availed from public and accessible sources, including the websites and databases of international organizations, journal articles, and existing modelling studies and predefined in the model [9]. The model also had predefined scenarios made available online that sought to partially meet the U4RIA goals. These are goals that seek to improve energy modelling that provides policy support (EMoPS) and is short for Ubuntu (meaning community focused), together with retrievability, reusability, repeatability, reconstructability interoperability and auditability [10]. This study was directed towards the rural community of Kenya which has the largest population in the country using biomass for cooking. It also looked at how policy can cut across and affect the various subsectors within the energy sector. The study can therefore be used to support policies by Government that focus on improving the livelihoods of the rural community in Kenya. In this regard it tallies with the U4RIA goals. A least cost scenario was selected from those already modelled and availed by CCG to form the base scenario (scenario 1) and modified to create two other scenarios. Scenario 2 applied the stepwise switch from biomass to electric stoves while scenario 3 had a constraint to limit the total annual emission on carbondioxide (CO2) in the energy sector using NDCs target.

Scenario Development

The least cost scenario applied a conservative assumption for investments on demand-side-fuel-switching and energy efficiiency. A limit of 5% of each total demand technology capacity in 2050 in a run without demand side investement constraints could be invested annually. There was also no new investment allowed in nuclear power plants [9].

In scenario 2 with focus on demand for residential cooking, a switch from biomass and oil stoves was made to adopt electric stoves to 100% of the total residential cooking demand by 2050 from 2028 in a stepwise manner. The TotalTechnologyAnnualActivityLowerLimit parameter, which is the minimum rate of activity a technology must produce each year and has a deafult of zero was used for this purpose [11]. It was applied to the DEMRESCKNELC (residential electric stove) technology to make the model select electric stoves to meet residential cooking demand from 2028. This specific year is in alignment to Kenya's Government target of shifting to clean cooking technologies by 2028 [3]. An application of a percentage of between 20% to 100% of the total annual cooking demand was calculated and entered as the electric cooking annual lower limit. This cooking demand was obtained from the AccumulatedAnnualDemand parameter applied on the RESCKN (residential cooking demand) commodity.

In scenario 3 the total annual emissions in the cooking sector from the base scenario were calculated and retrived from the results. A limit was calculated using the updated NDC target of reducing greenhouse gas (GHG) emissions by 32% by 2032 relative to the business as usual scenario [12]. The data affected the AnnualEmissionLimit parameter that limits the sum of all emissons from the energy system being modelled [11]. It was applied on EMICO2 (emission factor for carbondioxde) set from the default value of 99999. The calculated annual emissions was reduced by between 32% and zero between 2030 and 2060. The Kenya's Ministry of Environment Long Term Strategy (LTS) of towards a net zero scenario by 2050[1] was selected and adjusted to reflect zero emissions by 2060. The cap on new investments on nuclear power was removed from 2040 onwards.

[1] Ministry of Environment engaged various stakeholders and developed scenarios for Kenya's long-term GHG emission and climate resilience development strategy for 2050 under the Paris agreement. Various workshops were held between July and October 2021 in preparation for the then COP26.

3. Results And Discussions

The results for the following parameters were retrived after running clicSAND and compared across the three scenarios

Annual CO2 emissions by Technology

In scenario 1, results showed that there were three major emitting technologies, biomass (MINBIO, IMPBIO), coal (MINCOA) and light fuel oil (IMPLFO). These emissions were employed at the point of extraction in the model and were therefore seen on the imported technologies (IMP) or locally available technologies (MIN). It was seen that biomass, both imported and locally available, was the largest emmitter contributing about 84% of the total annual emissions. From analysis it was also seen that residential cooking and heating took up the biggest proportion of demand for biomass (60% and 24% respectively). This showed that residential cooking using biomass as the fuel contributes the highest to the total emissions in the Kenyan energy sector. From the results the other two technology sources of emissions that included MINCOA and IMPLFO were being used to meet demand in industry (mainly for heating), power generation and transport sectors. The emissions from these technologies were low in comparison to the emissions from the use of biomass as shown in Fig. 2.

In scenario 2, results show that with the gradual switch to electric cooking, there was a subsequent decrease in emissions from both imported and locally produced biomass. Emissions from IMPBIO were completely phased out due to decreased demand in cooking using biomass stoves. This was counteracted by an increase in emissions from MINCOA and IMPCOA as illustrated in Fig. 3.

It can be translated that the increase in demand for electricity from cooking requires new generation for power and in this case MINCOA was the technology used to provide the coal fuel for coal power plants. The results also showed that the highest demand for biomass is in cooking as emissions begin to decrease relative to the switch from biomass stoves.

Scenario 3 results showed a decrease in total emissions with the annual limit applied. All technologies incurred the decrease however LFO emissions were completely phased from 2050 onwards as shown in Fig. 4. This was because other cleaner technologies for electricity production were now being preferred.

Annual Electricity Production

In the least cost scenario, the power generation mix was made up of renewable sources as seen in Fig. 5. Geothermal contributed the highest energy in the generation mix accountng for about 45% of the total electricity produced in the entire modelling period. This is beacuse of its nature to provide baseload capacity.

An annual limit was placed on Solar PV (PWRSOL) and wind (PWRWND) power plant technologies applied on the TotalTechnologyAnnualActivityUpperLimit parameter for the variable renewable technologies. This constraint was to allow the system to be flexible enough to operate with a considerabe share of varibale renewable energy (VRE) [9].

In scenario 2, with the new demand for electricity, a new power plant, PWRCOA (coal power plant) was selected as shown in Fig. 6. It was seen that generation from PWRBIO (biomass power plant) increased towards the end of the plan, from 2050.

There was also a notable increase in generation from the hydropower plants (PWRHYD) with other additional categories (large and small hydropower plants) of the technology being selected to cater for the increase in demand for electricity. These categories have been defined in the SETS sheet within the clicSAND excel based interface.

Contribution from PWRSOL and PWRWND also increased with some of them being selected earlier on in the plan as compared to the least cost senario. However the annual technology limits for these VREs were maintanined as provided in the model.

The introduction of PWRCOA technology in the generation mix explained why the emissions from MINCOA increased. The emissions from MINBIO on the other hand did not increase with its subsequent increase in the power generation mix as the contribution of demand for biomass for electricity production is quite small in comparison to demand for cooking.

Scenario 3 showed that there was a bigger increase in demand for power compared to scenarios 1 and 2. This was because there was a fuel switch in the demand-side technologies to cleaner technologies from the heating and transport sectors as seen from the results. This included switching from the conventional coal, biomass and oil used for industrial and residential heating to using electricity and switching from gasoline to electric vehicles so as to constrain the emissions to meet the new targets set. This leap in demand led to the introduction PWRNUC (nuclear power plant) technology in the generation mix as shown in Fig. 7

The results showed that PWRCOA was removed from the generation mix while PWRBIO generation was no longer increasing towards the end of the plan. The generation from PWRBIO reverted back to what it was in the least cost scenario. Both effects were because of the the cap on annual emissions.

Generation from PWRNUC technology had the highest contribution to the generation mix of about 30% of the total electricity produced. This is also because of the ability of this technology to provide baseload capacity allowing it to compete with PWRGEO (geothermal power plant) technology.

Investment and operating costs

The results on capital, fixed and variable operating costs for electricity production were analyzed for the three scenarios as follows:

Fixed operating costs

In all the scenarios, the fixed costs were increasing over the plan period however scenario 3 incurred the highest fixed operating costs as seen in Fig. 8. This is due to the PWRNUC technology that had the most expensive fixed costs in comparison to all the other power generating technologies.

The scenario also had other technologies with considerable high fixed costs in the generation mix that included large, dammed, hydropower plants and offshore wind power plants. This was also part of the reason why scenario 2 had higher fixed costs compared to scenario 1. The installed capacity of these plants was however lower compared to scenario 3 in this case.

The other reason why scenario 2’s fixed costs were higher compared to scenario 1 was the addition of PWRCOA and inclusion of PWRBIO in the generation mix towards the end of the plan. The two technologies also have relatively high fixed costs.

Variable operating costs

The variable costs also increased over the plan period as the total annual generation increases. The costs for scenario 2 were much higher compared to scenario 1 due to higher demand for electricity as well addition of PWRCOA that had fuel costs attached to the technology. PWRBIO had fuel costs as well but relatively small compared to the PWRCOA technology. Scenario 3 had the highest variable costs amongst the scenarios due to the effect of the inflated demand from the other sectors with fuel switching in the demand-side technologies. PWRNUC technology had the least in terms of fuel cost but contributed the highest power in the generation mix causing the variable costs to still increase in this scenario. Scenario 3 and scenario 2 weren’t far apart in terms of variable costs. This was because scenario 3 had only renewable energy sources in the generation mix while scenario 2 had a share of fossil fuels in the mix. Figure 9 shows a comparison of the variable costs across the three scenarios.

Capital costs

The capital costs were different for the different years in the plan following the investments in new power plants as seen in Fig. 10.

Scenario 3 had a sharp rise in investment cost in 2045 and 2060. This was because of huge invetsments in nuclear power plants to meet the rise in demand coming from industrial heating using electricity in the scenario. The contribution from nuclear plants was 97% and 78% of the total capital costs for the two years respectively.

Scenario 2 similarly had a leap in capital cost in 2050 due to a large investment in biomass power plants. This was when demand in biomass stoves was completely phased out thereby availing the biomass commodity for use in the electricity sector. Scenario 1 also had the same leap in 2050 due to investment in geothermal and offshore wind power plants. This was to meet the new demand in electric cars that came online in 2050 from the results.

Scenario 3 had the highest capital costs out of the three scenarios as nuclear power plants were the most expensive in terms of investment costs out of all the power generating technologies.

4. Conclusions And Policy Insights

The Kenyan government has set a target to transition to clean cooking fuels and technologies by 2028. The aim of the study was to assess the impact of switching from biomass stoves to electric stoves for cooking, on the Kenyan energy system, with the consideration that electricity is a cleaner source of fuel. Three scenarios were modelled using OseMOSYS modelling platform to see the effect of phasing out biomass stoves to switch to electric stoves by 2050 and reducing any resultant emissions drawn from the power sector with increase in electricity demand.

The results showed that by switching to electic stoves total emissions reduced as biomass was the biggest contributor to GHG emissions in the country. The increase in demand due to the fuel switch resulted in an increase in emissions from coal as coal power plants were used to increase generation for power. Biomass power plants were also dispatched towards the end of the plan to meet the grwoth in demand for electricity

An annual emissions limit resulted in a further increase in demand for electricity as other sectors that included heating and transport had a fuel switch to electricity on the demand-side technologies. The result of this demand leap was committment of nuclear power plants that caused an increase in both investment and operating costs. The scenario ended up incurring large costs as nuclear was the most expensive technology in regard to power generation.

It was recommended that

- The Government focus efforts on clean cooking alternatives to biomass that are affordable, convenient and sustainable.
- An analysis made of linkages between different sectors to know effects of adoption of different technologies to allow infomed decisions.
- Demand-side technologies in the heating and transport sectors be based on different sources of clean fuels that are cheaper and sustainable incuding biodiesel.

Future work on OseMOSYS

The following suggestions were made for improving modelling of the Kenyan case using OseMOSYS;

- Consideration should be given for other alternative technologies for cooking that offer similar advantages on the Kenyan Starter Data Kit e.g. Improved cookstoves, LPG stoves
- Emissions calculations should be done per sector rather than as a sumtotal of all emissions modelled in the energy system as this allows an understanding of where most emissions come from and specific actions can be applied.

Declarations

5. Acknowledgement

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Figures

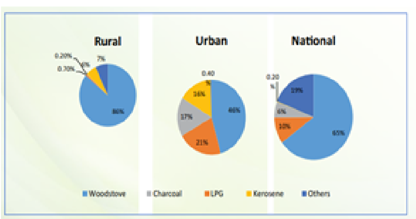

Figure 1

Primary Fuels used by households in Kenya at Urban, Rural and National Levels

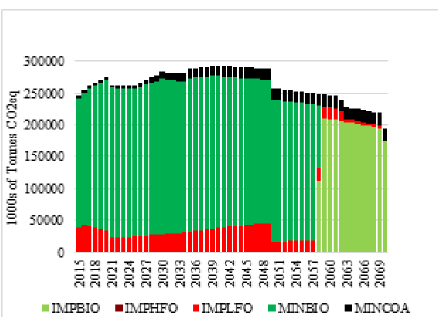

Figure 2

Annual CO2 Emissions by Technology (Least cost scenario – Scenario 1)

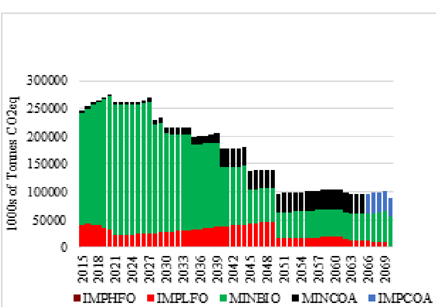

Figure 3

Annual CO2 Emissions by Technology - Electric cooking (Scenario 2)

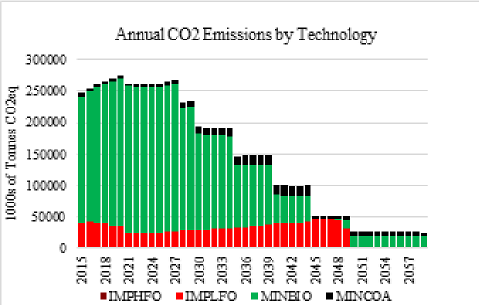

Figure 4

Annual CO2 Emissions by Technology - Emissions Limit (Scenario 3)

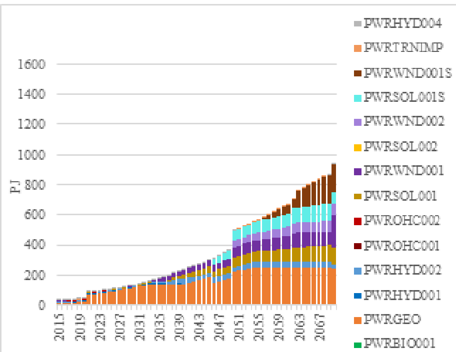

Figure 5

Annual Electricity Production - Least cost scenario (scenario 1)

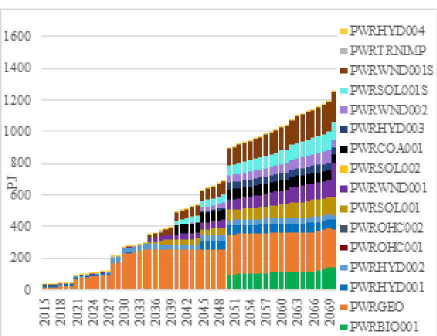

Figure 6

Annual Electricity Production - Electric cooking (Scenario 2)

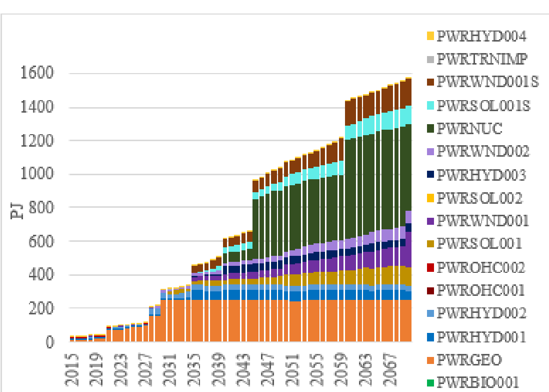

Figure 7

Annual electricity production - Annual emissions limit (scenario 3)

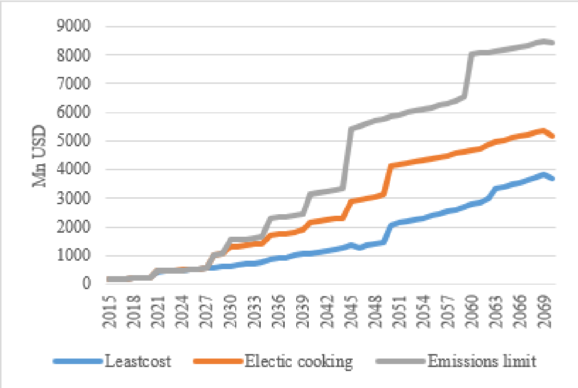

Figure 8

Fixed operating costs

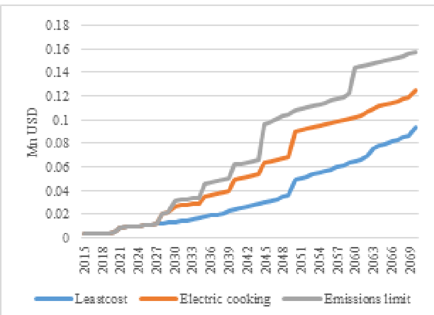

Figure 9

Variable operating costs

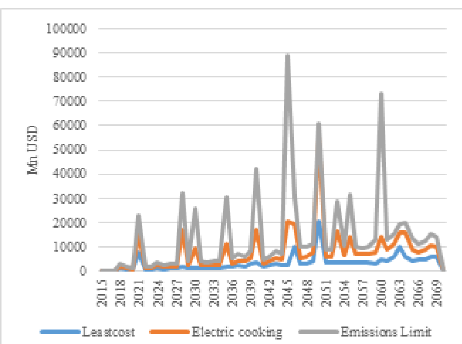

Figure 10

Capital costs

Supplementary Files

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