Concept note:

Solid Biofuel Residential Consumption

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Introduction

IEA

The IEA is an organisation that is at the heart of the dialogue and transitions to a cleaner energy future, focused on providing an unbiased analysis and data covering all fuels, in order to provide policy advice and technology solutions implementations support at a worldwide level.

Within the internal division, the Energy Data Centre (EDC) is a specialised branch that is responsible of the data production through the submission of the OECD and non-OECD countries in mandatory and voluntary basis, respectively. The EDC hence collects, normalises, processes, analyses, validates and disseminates datasets of the energy supply, transformation and demand and the energy balances of the countries, just as energy statistics reports (IEA, n.d.). Additionally, the organisation is doing a huge effort to train and build capacity among energy statisticians at a global level.

The organisation is not related with the on-field data collection, but instead with the collection from official, reliable sources. Thus, the adoption of harmonised definitions is also a key issue in the framed mission. As the organisation aims to guarantee high quality on the datasets, the cooperation with international, regional and national scale organisations is crucial. To accomplish such a mission, IEA has a tight collaboration with regional and local organisations. A relevant organisation in the African continent is The African Energy Commission (AFREC), a regional agency of the African Union (AU), which coordinates, harmonizes and updates the database of the energetic resources of the continent.

Solid biofuels

The present guidelines are focused in the production of reliable and accurate data of solid biofuels in a set of Sub-Saharan African countries. The African continent is responsible for consumption of around 50% of the solid biofuels demand worldwide, having 82% of its population relying in this kind of fuel. In the Sub-Saharan, more than 900 million people rely strongly on biomass (a roughly estimated 95% of the population) is the form of fuelwood, charcoal and residues. Hence, having an accurate set of data to define the energy mix in which biofuel is a central contributor is a key task to develop policies and assess the completion of sustainability goals. However, the panorama is far from an ideal one. There is a systematic lack of data in the continent, with harmonisation issues of the reported data and based on outdated surveys in the different countries. This has led organisations, such as IEA or the AFREC to estimate the energy balances. These estimations have been made using in a lot of cases, using normalisations with either GDP, either population growth.

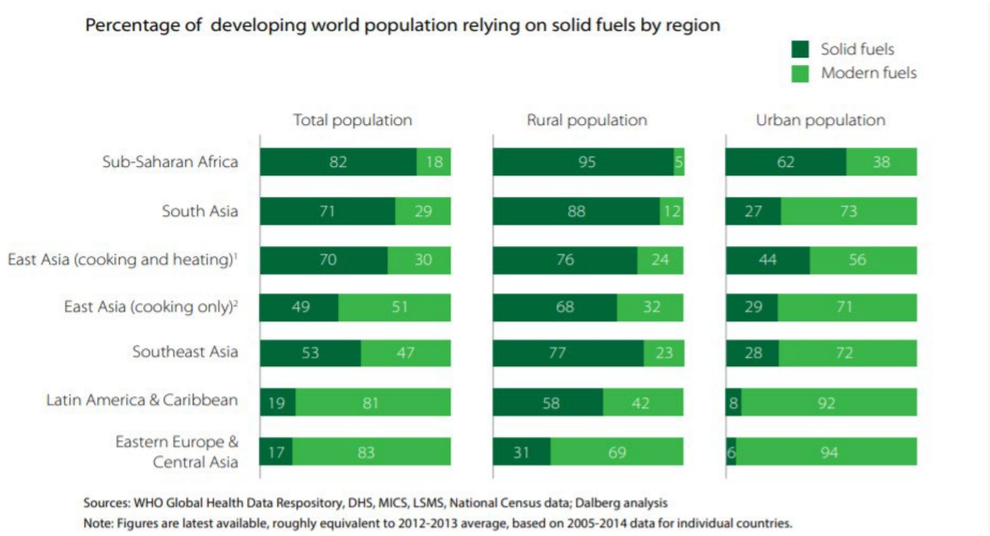


Figure 1. Percentage of developing world relying on solid biofuels (average 2012 – 2013) Source: The World Bank, 2014)

The International Energy Agency (IEA) is implementing a 4-year program co-funded by the European Commission titled "An Affordable and Sustainable Energy System for Sub-Saharan Africa". The programme aims to improve energy data management and long-term energy planning in 10 countries: Benin, Democratic Republic of Congo (DRC), Ethiopia, Ghana, Kenya, Nigeria, Rwanda, Senegal, Uganda and Zambia. The activities under the program include capacity development to reinforce in-country capabilities in energy information management, energy modelling, as well as measuring progress towards SDG-7, NDCs and other energy policy goals.

The programme activities also include a strong push for energy data improvement at the country level by cooperating directly with country administrations, identifying new data sources and particularly developing estimation tools for residential solid biofuels consumption.

Relevance

Solid biofuels are can be estimated to be up to 90% of the energy mix in some African countries. In Table 1, a rough panorama of the country is being outlined (IEA, 2021a). #

Table 1. Biomass share in the 10 selected African countries

Biomass and waste share in total energy supply (TES) share for selected sub-Saharan countries, 2018

Selected country	Biomass share of total primary energy supply
Benin	51.60%
DRC	94.70%
Ethiopia	91.60%
Ghana	39%
Kenya	64.70%
Nigeria	74.80%
Rwanda	74.40%
Senegal	45.10%
Uganda	91.20%
Zambia	70.30%

Additionally, most of the energy mix is used for residential purposes. This is a result of low-income developing countries, in which the industry accounts for a little portion of the total energy demand. Moreover, the aforementioned countries consumed up to 90% of the energy at a residential level, in which 80% of the energy expenditure is burnt to satisfy the cooking demand (Garba & Bellingham, 2021).

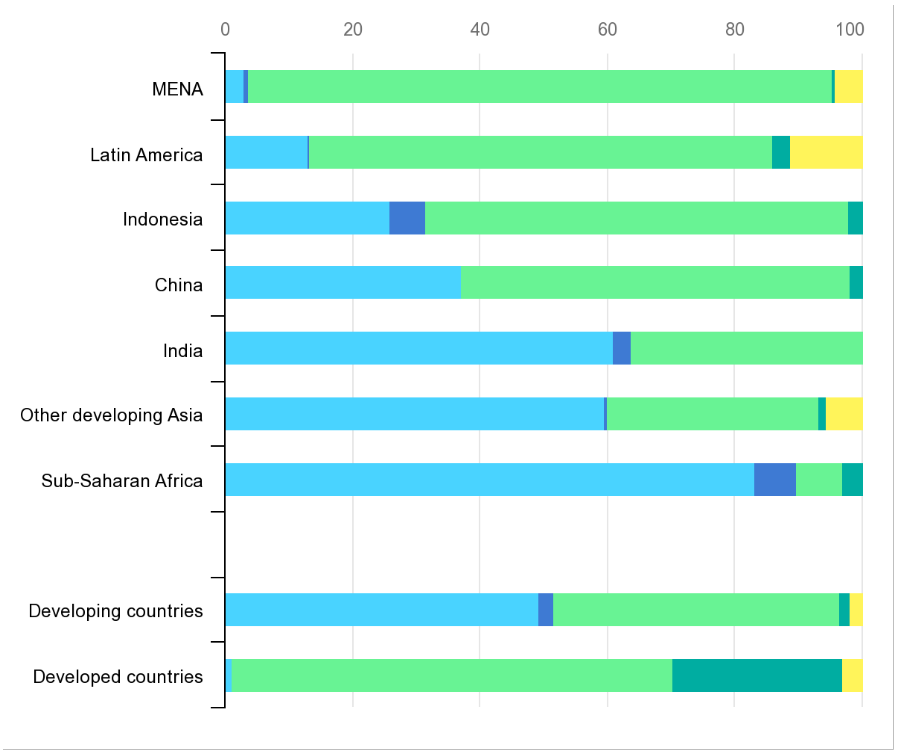


Figure 2. Share population relying on different fuels, 2015 Source: (IEA, 2015)

The extended use of biomass to satisfy the energy needs in such countries has triggered a set of concerns in terms of health and environmental issues:

1. **Indoor air pollution:** Household air pollution (HAP) is the second most common cause of disability and the third one in avoidable deaths. The EPA has determined that the standardised use of solid biomass in burning processes for cooking and heating purposes release large amounts of pollutants, like particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), sulphur dioxide (SO2), lead, mercury, and other 187 hazardous air pollutants (Partnership for Policy Integrity, 2011).

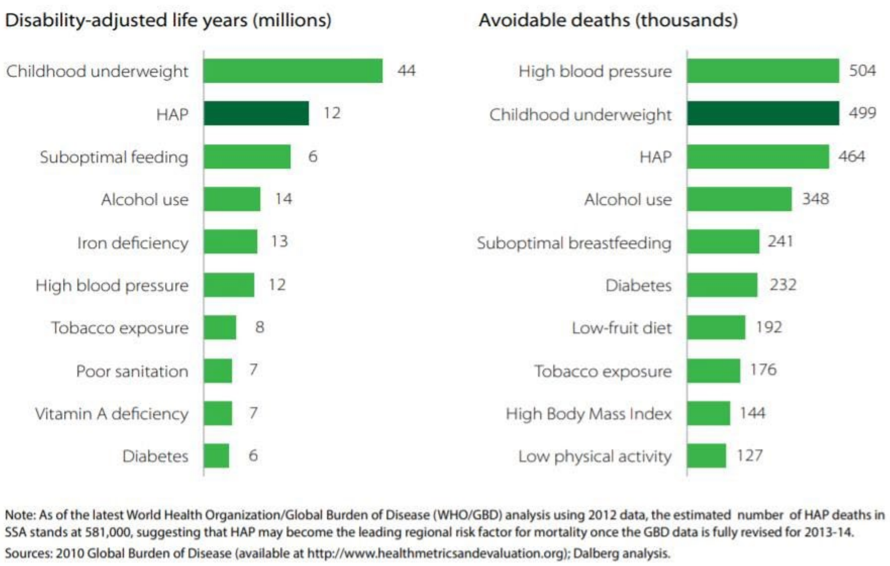


Figure 2. WHO's an estimation of top 10 causes DALY and avoidable deaths in Sub-Saharan Africa Source: (The World Bank, 2014)

2. **Environmental effects:** Deforestation and increase in GHG emission is also a strong consequence of traditional biomass use. Do the use of direct biomass for energy-matters in rural communities to be neutral following the IPCC guidelines, as it is assumed in a sustainable pathway. Nevertheless, Africa is one of the biggest producers of charcoal, accounting for 64% of its production worldwide (UNEP, 2019). Charcoal is the most common fuel shift from fuelwood. Therefore, as the urban population and income grow, so does the demand for charcoal. Additionally, most of the production of charcoal in Africa is carried out using traditional, inefficient technologies (Lambe et al., 2015).
3. **Gender issues:** in most of the Sub-Saharan African countries, biomass collection is a task that falls on women. On the one hand, the total extra time that encompasses collecting and cooking hours mean women have fewer available hours for education and other productive activities. On the other hand, there is a big issue related to physical safety in conflict zones and extreme geographical locations (Lambe et al., 2015).
4. **Economic:** Additionally, the use of biomass brings some economic losses linked to the man labour hours spent in biomass collection and extra time of cooking with traditional devices and fuels. According to a World Bank study (2014), more than 40 million worker years are wasted each year on fuelwood gathering and slow biomass cooking (UNEP, 2019).

Activity	Low (Full adoption of higher-performing biomass stoves)	Mid (Tier 3–4 gasifier biomass stoves at the top of the range)	High (Intermediate Tier 2–3 rocket stoves at the bottom of the range)
Mortality from household air pollution	0.3	3.5	6.8
Morbidity from HAP	0.2	0.7	1.1
Other health conditions (burns, eye problems)	0.1	0.8	1.5
Total health	0.6	5.0	9.4
Spending on solid fuels	0.4	3.8	7.3
Time wastage (fuel collection)	0.6	6.5	12.4
Time wastage (cooking)	3.3	10.2	17.2
Total economic	4.2	20.6	36.9
GHG emissions (fuel consumption)	0.2	2.1	3.9
GHG emissions (charcoal production)	0.2	0.7	1.2
Deforestation	0.2	3.5	6.7
Total environment	**0.6**	**6.3**	**11.9**
Total all categories	**5.4**	**31.8**	**58.2**

Figure 3. Economic losses and opportunity costs associated with solid biofuel dependence in Sub-Saharan Africa in 2010 Source: (Lambe et al., 2015).

The sustainable development goals (SDG):

Clean cooking is associated with a set of sustainable development goals, as it is entangled in a set of social, economic variables. The SDG7, related to the access to clean energies is the goal with a higher relation with this matter. In fact, in the sustainable development scenario, the goal for 2030 is to accomplish a 100% share in clean cooking fuel access[4].

Hence, different initiatives are promoting the adoption of modern fuels. The most common transitioning fuels are kerosene (an intermediate fuel) and LPG (a modern fuel). The standards could also be achieved using improved cookstoves (ICS), devices with higher efficiencies and lower-emitting rates (WHO et al., 2018).

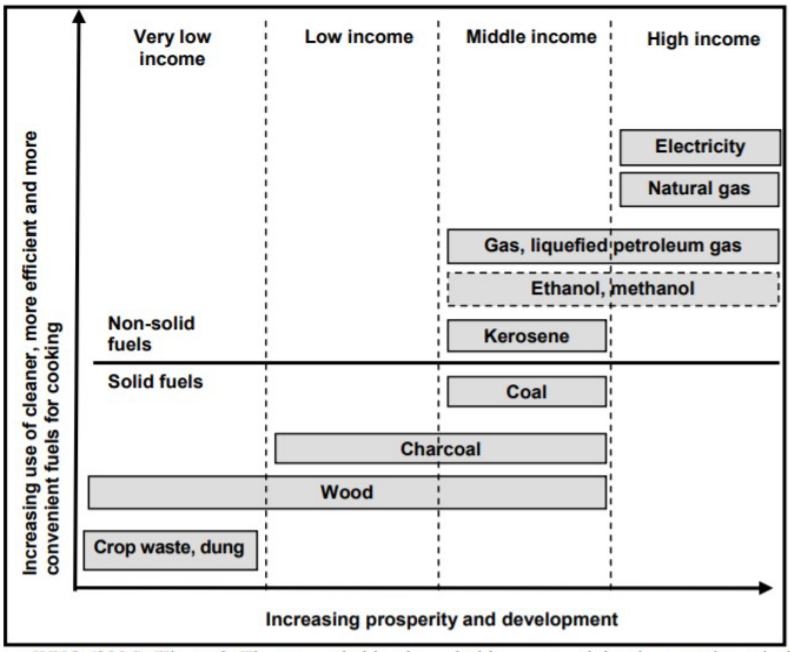
Drivers of biomass demand

- Population growth: in developing countries where the residential demand for energy is satisfied using solid biofuels, the increase of the population derives from a correlated growth of these fuels demand.
- Urbanisation: Predominant rural countries tend to have a higher share of solid biomass in the energy matrix. Conversely, in the Sub-Saharan African countries, the urbanisation phenomena have a positive effect on the charcoal demand, triggering an increase in the biofuels demand.
- Income growth: the spread and user adoption of technologies is highly dependable on the income of the demanding households. This concept is defined in the literature as the energy ladder. The energy ladder theory postulates that as income increases, households shift from traditional biomass and other solid fuels to more modern and efficient cooking fuels such as kerosene, LPG, and electricity. Therefore, the energy ladder has solid fuels, such as fuelwood

[4] It is worthy to mention that clean fuels are defined in terms of air quality guideline defined by the WHO. This means, the term is related to indoor pollution, and not in terms of GHG (WHO et al., 2018).

and charcoal at the bottom, nonliquid fuels such as gas and oil in the middle, and electricity at the top (Alinaitwe, 2021).

Figure 1.5. Transition from use of biomass fuels to use of modern fuels



From WHO (2006) (Figure 2: The energy ladder: household energy and development inextricably linked)
Note: Ethanol and methanol are rarely, if ever, used.
Dash: estimate

Figure 4. Energy ladder Source: (The International Agency for Research on Cancer, 2010)

- Education level: awareness of the harmful effect and alternative fuels are crucial to change fuels choices in developing countries. Additionally, a decrease in the time used in fuelwood collection means an increase in available hours, deriving in higher education enrolment rates, especially for women.

Harmonisation of variables and conversion of units

One of the main issues on the biofuels' reported data is the units and definition in which the data are published and reported.

- **Net Calorific Value (NCV):** the "net" energy content, which excludes the energy lost to produce water vapour during combustion (IEA, 2021b). This value is used then, for converting reported amounts from physical to energy units. To guarantee harmonisation, all the fuels must be in energy units, on a net basis instead of a gross one. It is highly dependable on a different set of parameters. The most important variable is humidity, which is inversely proportional to its calorific value. Additionally, the humidity on fuelwood is dependable on set different factors such as storage time, size of the collected matter and the different species. Finally, the NCV is correlated with seasonal variations of humidity in tropical countries, correlating with charcoal demand (Atteridge et al., 2013).

- **Improved Cooking Stoves (ICS) efficiencies:** the penetration of improved cooking stoves have an effect in reducing the demand input energy, as it has roughly twice the efficiency of a traditional device (The International Agency for Research on Cancer, 2010).

Table 2. Typical efficiencies of cooking fuels

Fuel source	Energy content (MJ/kg)	Typical conversion efficiency[a] (%)	Useful energy at final consumption stage of cooking (MJ/kg)	Approximate quantity of fuel necessary to provide 5 GJ of useful energy for cooking (kg)
Liquefied petroleum gas	45.5	60	27.3	180
Natural gas	38 [MJ/m^3]	60		219 [m^3]
Kerosene (pressure)	43.0	55	23.6	210
Kerosene (wick)	43.0	35	15.1	330
Biogas (60% methane)	22.8 [MJ/m^3]	60		365 [m^3]
Charcoal (efficient stoves)	30.0	30	9.0	550
Charcoal (traditional stoves)	30.0	20	6.0	830
Bituminous coal	22.5	25	5.6	880
Fuelwood (efficient stoves), 15% moisture	16.0	25	4.0	1250
Fuelwood (traditional stoves), 15% moisture	16.0	15	2.4	2000
Crop residue (straw, leaves, grass), 5% moisture	13.5	12	1.6	3000
Dung, 15% moisture	14.5	12	1.7	2900

From Sullivan & Barnes (2006)
[a] The typical conversion efficiency for charcoal, fuelwood and kerosene is based on their respective stove types.

Since the socio-cultural variables act like barriers in the fuel switching, it is quite relevant to get data about the real penetration of the stoves in the African countries. Some studies reveal most of the Sub-Saharan countries continue with a high prevalence of traditional cooking stoves.

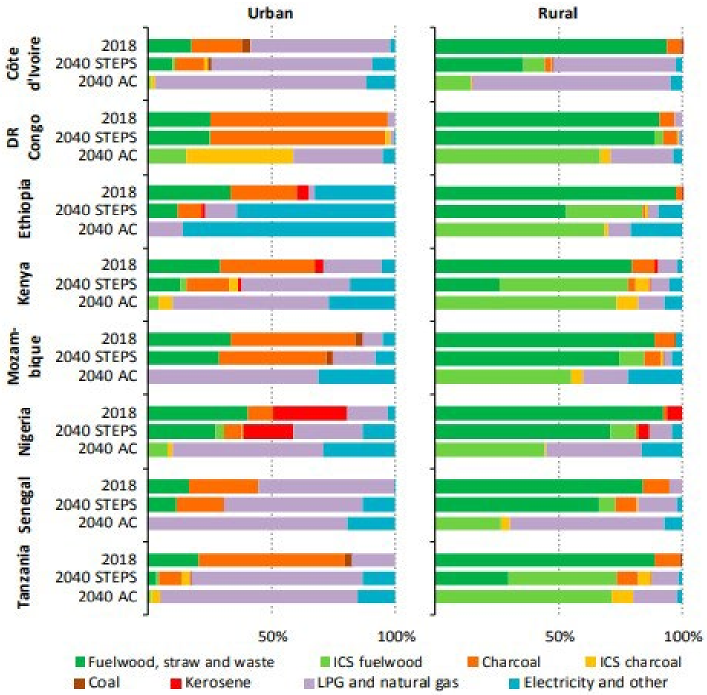


Figure 5. Primary fuels used for cooking in selected sub-Saharan countries in the Stated Policies Scenario and Africa Case, 2018 and 2040

Variables considered performing a comprehensive model:

Defining key variables that are crucial to determine the demand in developing countries.

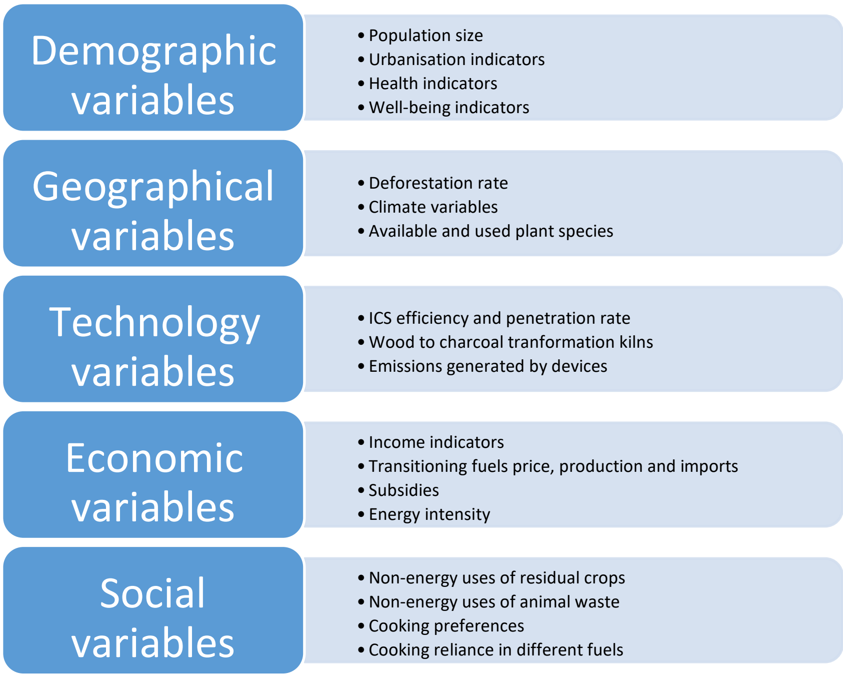


Figure 6. Key variables in the demand of biofuels

Data challenges

A comprehensive model will take into account the set of variables aforementioned. This however presents a great challenge in terms of the availability of the data. In order to create a strong framework suitable for the whole set of selected countries, some of the variables will be taken out as there are not enough reliable sources. Hence, the model is a good start to verify and get reliable data, but also propose a challenge to the national institutions amongst the countries to collect more on-field information and get better accuracy.

Model scope

A user-friendly model product will be delivered to both, national energy officials and statisticians and IEA data managers to estimate simply the solids biofuel production at a household in the 10 selected Sub-Saharan African countries.

- The product aims to **verify** and **estimate** the solid biofuel residential demand of each country to improve the data quality.
- The final interface must be **user-friendly** and developed in a very common environment. To avoid technical complications, the product has been developed on Microsoft Excel and programmed in Visual Basic.
- The model should enable users to assess the impact of policies, goals and international agreements, creating **scenarios.**

Methodology

The underlying estimation model adopted is based on hybrid approach combining top-down and bottom-up method to take advantage of available data and modelling limitations.

The primary determining factor in estimating solid biofuels residential energy consumption is demographic nature characteristics, in particular, the population and the number of households disaggregated in urban and rural areas (Farzaneh, 2019).

Therefore, on one hand, the top-down is used to select the predictors that drive specific consumption per fuel type and demography characteristic settling (Urban/rural). In that regard, various indicators are collected from diverse sources including but not limited to the IEA (International Energy Agency) database, the World Bank Sustainable Development Indicators[5], the World Urbanization Prospects 2018[6], World Health Organization indicators[7], the United Nations Global SDG Indicators Database and others official databases and literature. Specifically, the goal at the end of the top-down is to derive indicators that explain Urban/rural household consumption for firewood and charcoal in the region.

In prediction modelling, an interest is often to determine the most important predictors that should be included in a reduced, parsimonious model. This can be achieved by performing variable selection, in which optimal predictors are identified based on statistical characteristics such as importance or accuracy (Jaime Lynn Speisera, Michael E. Millerb, Janet Toozec, 2020).

More than hundreds (100) of variables have been gathered. To reduce dimensionality and find the most important variables that drive household-specific consumption per fuel type, three advanced features selection methods (BORUTA, Random Forest, xgboost method) are used. Boruta is a feature ranking and selection algorithm based on random forests algorithm. The algorithm is designed as a wrapper around a Random Forest classification algorithm. It iteratively removes the features which are proved by a statistical test to be less relevant than random probes (Kursa & Rudnicki, 2010). XGBoost provides the best score for every element, shows the significance of each element to prepare the model, and creates another tree with gradient direction (Satapathy et al., 2019; Wang, 2019). Random forests (RF) are a collection of classification and regression trees which are simple models using binary splits on predictor variables to determine outcome predictions (BREIMAN, 2001; Jaime Lynn Speisera, Michael E. Millerb, Janet Toozec, 2020). RF provides the best score for each feature, shows the importance of each feature to train the model, and generates a new tree by maximizing the label purity within these subsets. This statistical significance of identifiers can de directly used for feature selection (Satapathy et al., 2019).

A combination of the results of these methods is adopted to have a good confidence level. This step is critical in the modelling process to avoid redundant features in the situation of high dimensionality space and to build high performing model. A subset of the top 10 variables has been selected in each case.

While on the other hand, a multi-regression predictive model is designed using some countries as proxy based on the predictors derived above. Those countries are selected based on the progress they made in access to clean cooking fuel and that have reliable data including Angola, South Africa, Botswana, Senegal and Morocco. Angola is later selected as a reference country among others since

[5] https://databank.worldbank.org/source/world-development-indicators
[6] https://population.un.org/wup/
[7] https://www.who.int/data/gho/data/indicators

the average urban/rural household consumption computed (using IEA databases and demography data), stand within the average range of the specific consumption of the countries of the project. The comparison table is annexed to the concept note (Household specific **consumption per fuel type of references countries** Table 3).

One model is determined for household average charcoal/firewood consumption in urban/rural. A quality criterion is applied to choose the best out of many, using Adjusted R-Squared which effectively penalizes for additional predictors, and can decrease with added predictors. Model coefficients and accuracy are shown in the annexe (Model output).

This specific consumption derived from the top-down approach represents the unit mass needed per type of fuel per household, which is populated on the entire national population in a bottom-up approach. The consideration of technical values (efficiency of stoves and net calorific values) are taken into account to compute the energy consumption per end-uses and fuel type used. The conceptual framework below summarizes the modelling approach.

The modelling process overview of the Solid biofuels (SBE) -Model is illustrated as follows:

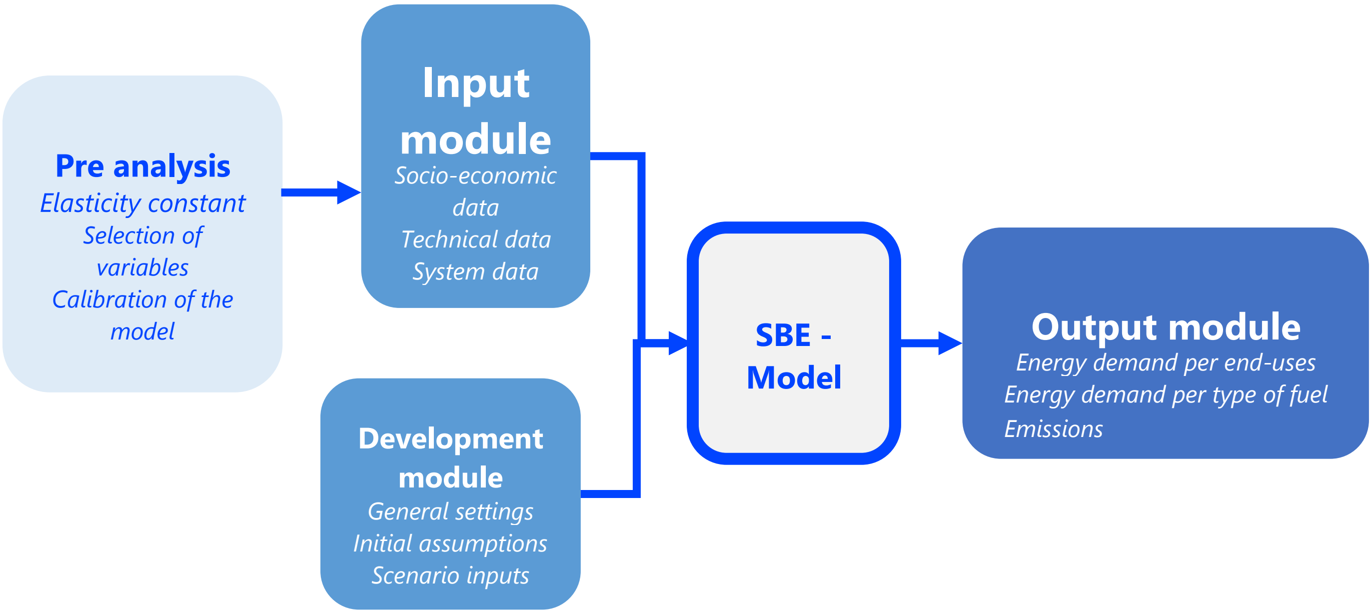


Figure 7: Model conceptual framework

Modules

The model has been conceptualised to be an easy Excel workbook, in which the user can add the relevant inputs information and navigate through, to generate historical estimation of solid biofuels as well as future projection. It is composed of several worksheets and contents explained in the table below.

Worksheet / Function	**Description**
Intro	Provides background information about the project and objective of this deliverable and contact information.

Notes	Provides some information on the different version of the model and new functionality added and changes that occurred.
References	Sources of all inputs parameters considered in the model.
Control board	A set of buttons in a form of control board to access the different features and modules in the model in an easy and efficient way. From the control board a button is also provided for the user to launch an external R script process to generate a new update model database.
Dashboard	It helps users to have a quick view of certain descriptive parameters and compare various countries trends.
Report worksheet	It provides the possibility to export graphs alongside defined parameters into printed format (pdf) for quick use.
Emissions and Health	It provides emissions-related calculations based on estimated consumption on the "Compute" worksheet.
Default Param	It contains significant assumptions as well as as units' conversion coefficient used. Limited access is given to the user in modifying some entries. • Net Calorific Value (NCV): a value for fuelwood of moisture of 20% (on a wet basis) is assumed, as the IRENA guideline proposes, low moisture charcoal with a value of approximately 33.33 GJ/tonne (IRENA, 2019). The residues are considered to be from herbaceous crops, Miscanthus spp. With moisture of 15% following the same guidelines. • Percentage of agricultural residues: The countries selected have a high reliance on fuelwood in rural zones and charcoal in urban ones. Thus, a small percentage of 5% of the total solid biomass is assumed for the agricultural residue. This number can be modified to have a more accurate estimation by the user. • Emissions factors: follow the IPCC guideline are in alignment with the IEA emissions. The sources of the different factors are also provided in the sheet • Unit consumption per fuel type equation slopes and intercepts are provided. It is hidden from the users.
EndUsesShare	Share of household energy expenditure end-uses: a percentage used for the main three activities is fixed using data found in different literature sources.
Demography World	UN World Urbanization Prospects[8] report figures of population growth in national and urban areas up to 2050.

[8] World Urbanization Prospects - Population Division - United Nations. (1950–2050). [Dataset]. https://population.un.org/wup/

Macroeconomic_forecast	It contains the IMF World Economic outlook Forecast (Latest version is of April 2022) for some macroeconomic variables. It includes Gross domestic product percent change, Gross domestic product per capita and population for all African countries
STEPS_Rate_Total **SDS_Rate_Total**	It contains projection of population with access (million) to clean cooking fuels based on the Stated Policies Scenario (STEPS) and Sustainable Development Scenario (SDS) from the IEA. It is been used in the "Compute" worksheet for the projection analysis.
Model_fit	It contains a subset of the entire database with major variables being used in the model estimation of solid biofuels consumption. A button allows the user to upload and refresh this database. The key variables are : *Access to clean fuels and technologies for cooking (% of population); Life expectancy at birth, total (years); Population growth (annual %); Rural Average Household size; GDP growth (annual %);Life expectancy at birth, female (years);Population In Largest City; Renewable energy consumption (% of total final energy consumption); National Average Household size; Urban Average Household size; Energy intensity level of primary energy (MJ/$2011 PPP GDP); Age dependency ratio (% of working-age population); Arable land (%land area) and GDP per capita growth (annual %).*
Future_dat	It contains projection up to 2050 of the key variables in the "Model_fit". The data in this worksheet change dynamically as per user's choice of scenario to perform for each variable in the "Compute" worksheet. Two tables are provided one for the simple projection and one for the comparative analysis.
Compute	It is the main sheet of the program where all the analysis and results are generated. A selection of a country is required to start computation for the historical consumption. The user is provided with the sensitivity table to adjust future trend of certain variable on which the model results will be based. This module provides to the consumption at the national level per fuel type and end-uses, the projection of the demand and the emission associated. $\boldsymbol{E_0} = \sum_i \sum_j (\boldsymbol{NH} * \%\, \boldsymbol{SH_i} * \boldsymbol{EFuel_{ij}})$ *and* **NH=**$\frac{\boldsymbol{Pop}}{\boldsymbol{\theta}}$**,** $\boldsymbol{E_0} = \sum_i \sum_j \sum_k \sum_l (\boldsymbol{NH} * \%\, \boldsymbol{SH_i} * \boldsymbol{Euse_{ijkl}})$ *and* **NH=**$\frac{\boldsymbol{Pop}}{\boldsymbol{\theta}}$**,** Where **$E_0$** is the total supply at a national level, **NH** is total number of households, **SH_i** is the share of household type (%), **EFuel** is the energy consumption for each type of fuel and per household type (TJ /Household). **θ** refers to the average household size (person/household), **i** refer to demographical nature (urban or rural area), **j** refers to the type of solid fuels: firewood, charcoal, agriculture residues. **Euse** refers to the energy consumption per end-uses where **k**

	refers to the type of end-uses (heating, cooking, lighting) and **l** refers to the type of stoves technology. The **Efuel** and **Euse** are calculated using the formulas below: $\boldsymbol{EFuel_{ij}} = \boldsymbol{NCV_j} * \boldsymbol{Q_{ij}}$, *where* ***Q*** *is the mass units need per fuel (Kg/year) per household and NCV in MJ/Kg* $\boldsymbol{Euse_{ijkl}} = \boldsymbol{NCV_j} * \boldsymbol{Q_{ijkl}}$, *where* ***Q*** *is the mass units need per fuel, end-uses and per technology (Kg/end-uses/technology/year).* Unit consumption per fuel type is computed based on the equations generated by the R script output. Slopes and intercept can be found in the annex of this document.

Model scripting structure

This model is a mix of a top-down and bottom-up approaches. The top-down is being written in R script which provides four multi-linear regression equations to estimate the household unit consumption per fuel type (firewood urban, firewood rural, charcoal urban, and charcoal rural) and associated variables. This constitutes a major input for the VBA code which performs the bottom-up approach to aggregate the unit consumption to the national values and provide forecast of demand. The R based program is composed of seven script files with distinct and interlinked role with set of instructions as summarised in the table below.

Scripts file name	Description
Africa_countries_code.R	Generates worldwide countries ISO_CODE and name and provides a subset over Africa. It provides inputs for other scripts files.
Construct_database.R	Generates a comprehensive one-table database by processing and combining different sources of datasets in different formatstructures. The "SBE_Model_database.xlsx" file is generated.
Database_pivot.R	Generate a comprehensive one-table database by processing and combining different sources of datasets in different format structures. It is a transformation of the output of the previous ''Construct_database.R'' in a ready to use for the Excel model.
Select_Model_key_variables.R	Select the best subset of variables that explain household unit consumption per fuel type in urban and rural areas (kg/household)
Model_fitting_per_fuel_type.R	This code helps to produce the best model with an optimal subset of variables that drive the dependent variable using AIC as criteria. it generates four equations per fuel type and per area (Firewood rural/Firewood urban/Charcoal rural/Charcoal Urban)
World_Development_Indicators.R	A set of instructions using WDI R package, which interacts with the World Development Indicators database to extract the most updated data information. It is crucial input to "Generate_Model_fit_database.R". The end year can be modified to download the most recent year possible from WDI.
Generate_Model_fit_database.R	Generate a comprehensive subset table database based on the key variables that can be directly called in the "model_fit" worksheet.

The VBA-based script is composed of seven main modules and a set of instructions in some worksheets to control users state of action. Modules can be assessed by using the shortcut "ALT+F11".

VBA Modules	Description
Action_onClick	Set of instructions to control users click on several buttons in the "Compute" and "Report" worksheets.
Comparative_analysis	Set of instructions to control the comparative analysis results in the "Compute" worksheet.

Compute_historical	Set of instructions to control model process to produce historical estimation in “Compute” worksheet.
Key_functions	Functions created to perform specific actions needed in other VBA modules
Projection	Set of instructions to control model process in producing projection results in the “Compute” worksheet.
Update_data	Set of instructions to control model inputs data based on different user preferences and scenario choices.
Users_button_control	Set of instructions to help navigating through the different worksheets

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Key definitions

A set of definitions have been developed using the IEA guidelines to keep the same framework used by the organisation.

- **Solid biofuels:** Solid biofuels, using the IEA conceptual frameworks, is defined as the sum of primary solid biofuels and charcoal. Overall, primary solid biofuels refer to any plant matter used directly as fuel or converted into other forms before combustion. (IEA, 2021)
- **Charcoal:** solid biofuels residual of a distillation and pyrolysis of wood and other vegetal material (IEA, 2021). This fuel is selected instead of fuelwood as it has a higher energy density than the former one. Charcoal in Africa is produced mostly by traditional kilns which efficiency is rated from 8-15%. (UNEP, 2019).
- **Total energy supply (TES):** the final energy flow a country can use for its demand and transformation processes.

$$TES = Total\ energy\ production - Export + Imports - International\ bunkers \pm Stock\ changes$$

- **Total final energy consumption (TFEC):** the quantity used in the different energy demand sectors, subtracting the final non-energy use in a country. For biofuels, the non-energy uses are excluded from the general balances, thus its final calculation requires exclusively the fuel demand for energy purposes at industrial, electricity and heat production, and the other uses among which it is expressed the residential flow.
- **Residential consumption:** refers to the quantity consumed at the household level, excluding transport fuels usage. The quantity also reflects the energy consumed by the home office and a different sets of productive activities made at a household level.

Annexe

Model output

Charcoal rural					
Residuals:					
Min 1Q Median 3Q Max					
-0.0139915 -0.0044373 0.0005825 0.0041291 0.0130937					
Coefficients :					
	Estimate	Std.	Error	t value	Pr(>|t|)
(Intercept)	0.037259	0.313054	0.119	0.907407	
Access to clean fuels and technologies for cooking (% of the population)	0.021699	0.006124	3.543	0.004608	**
Energy intensity level of primary energy (MJ/$2011 PPP GDP)	0.03392	0.005757	5.892	0.000104	***
Population growth (annual %)	0.260735	0.047286	5.514	0.000182	***
Rural Average Household	-0.079152	0.121683	-0.65	0.528736	
Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**					
Residual standard error: 0.007547 on 11 degrees of freedom					
Multiple R-squared: 0.9868,	Adjusted R-squared: 0.982				
F-statistic: 205.2 on 4 and 11 DF, p-value: 2.989e-10					

Charcoal Urban

Residuals:

Min	1Q	Median	3Q	Max
-0.0033386	-0.0020692	-0.0003354	0.0014815	0.0047662

Coefficients :

	Estimate	Std.	Error	t value	Pr(>|t|)
(Intercept)	0.464768	0.627726	0.74	0.480221	
Access to clean fuels and technologies for cooking (% of population)	-0.059542	0.002555	-23.305	1.22E-08	***
Age dependency ratio (% of working-age population)	0.02042	0.005254	3.887	0.004632	**
Arable land (%land area)	-0.047362	0.013796	-3.433	0.008914	**
Energy intensity level of primary energy (MJ/$2011 PPP GDP)	-0.011672	0.003413	-3.419	0.009095	**
Urban Average Household	0.401832	0.058334	6.888	0.000126	***
GDP growth (annual %)	-0.300612	0.041637	-7.22	9.07E-05	***
GDP per capita growth (annual %)	0.310514	0.043127	7.2	9.24E-05	***

Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.003467 on 8 degrees of freedom

Multiple R-squared: 0.9998, Adjusted R-squared: 0.9997

F-statistic: 7616 on 7 and 8 DF, p-value: 1.188e-14

Firewood Rural

Residuals:

Min 1Q Median 3Q Max

-0.0063204 -0.0015644 -0.0001158 0.0017436 0.0041330

Coefficients:

	Estimate	Std.	Error	t value	Pr(>|t|)
(Intercept)	0.144087	0.157018	0.918	0.3785	
Access to clean fuels and technologies for cooking (% of population)	0.0311	0.004119	7.55	1.13E-05	***
Life expectancy at birth, total (years)	-0.02344	0.003431	-6.831	2.84E-05	***
Population growth (annual %)	0.054189	0.01688	3.21	0.0083	**
Rural Average Household	0.867303	0.05316	16.315	4.69E-09	***

Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.003201 on 11 degrees of freedom

Multiple R-squared: 0.9997, Adjusted R-squared: 0.9996

F-statistic: 9025 on 4 and 11 DF, p-value: < 2.2e-16

Firewood urban

Residuals:

Min 1Q Median 3Q Max

-0.0082421 -0.0040443 -0.0009956 0.0027975 0.0174716

	Estimate	Std.	Error	t value	Pr(>|t|)
(Intercept)	1.86963	1.63947	1.14	0.291637	
Life.expectancy.at.birth..female..years.	-10.6311	0.47705	-22.285	9.26E-08	***
Life.expectancy.at.birth..total..years.	10.94896	0.49723	22.02	1.01E-07	***
Arable.land....of.land.area.	-0.10078	0.03733	-2.699	0.03067	*
Age.dependency.ratio....of.working.age.population.	0.04689	0.0161	2.913	0.022579	*
Urban_Average_Household	1.01622	0.16249	6.254	0.000423	***
Population.growth..annual...	1.51765	0.5142	2.951	0.021362	*
GDP.growth..annual...	-0.90543	0.44448	-2.037	0.081062	.
GDP.per.capita.growth..annual...	0.93547	0.46043	2.032	0.081703	.

Signif. codes: 0 '*' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1**

Residual standard error: 0.009733 on 7 degrees of freedom

Multiple R-squared: 0.9999, Adjusted R-squared: 0.9998

F-statistic: 1.105e+04 on 8 and 7 DF, p-value: 1.186e-13

Household specific consumption per fuel type of references countries

Table 3: Average household consumption per fuel type of references countries (kg/household/day)

Variables		Country	Computed using EDC data				Acceptable range found in the literature
			sd	mean	min	max	
Rural	Average household firewood consumption	Angola	0.15	5.43	5.12	5.57	[5.14 - 8.59]
		Botswana	1.81	24.46	23.58	28.92	[5.14 - 8.59]
		Morocco	0.87	3.13	2.34	4.85	[5.14 - 8.59]
		Senegal	2.31	9.22	6.66	12.70	[5.14 - 8.59]
		South Africa	1.92	7.91	5.85	12.89	[5.14 - 8.59]
Urban	Average household firewood consumption	Angola	0.88	4.41	3.09	6.08	[2.6 - 5.88]
		Botswana	5.16	16.90	10.68	26.19	[2.6 - 5.88]
		Morocco	0.59	2.08	1.51	3.26	[2.6 - 5.88]
		Senegal	2.19	10.63	8.49	15.36	[2.6 - 5.88]
		South Africa	1.65	4.13	2.33	8.23	[2.6 - 5.88]
Rural	Average household charcoal	Angola	0.05	1.58	1.43	1.62	[0.01 - 1.35]
		Botswana	0.17	1.35	1.09	1.59	[0.01 - 1.35]
		Morocco	0.00	0.02	0.02	0.02	[0.01 - 1.35]
		Senegal	0.62	1.85	0.68	2.68	[0.01 - 1.35]
		South Africa	0.11	0.57	0.43	0.75	[0.01 - 1.35]

Urban	Average household consumption of charcoal	Angola	0.25	1.28	0.90	1.70	[0.64 - 3.14]
		Botswana	0.11	0.89	0.72	1.02	[0.64 - 3.14]
		Morocco	0.00	0.01	0.01	0.01	[0.64 - 3.14]
		Senegal	0.86	2.23	0.65	3.24	[0.64 - 3.14]
		South Africa	0.10	0.29	0.17	0.48	[0.64 - 3.14]