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THE FOREST DEGRADATION BY FUELWOOD TOOL: UNDERLYING DATA AND METHODS

Winrock International

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1. SCOPE

This document describes the underlying data sources and calculation methods employed in the Forest Degradation by Fuelwood (FDF) Tool of the AFOLU Carbon Calculator (http://afolucarbon.org/). The FDF tool is designed for project activities that aim at reducing greenhouse gas (GHG) emissions from consumption of fuelwood and charcoal in home cooking applications.

2. APPLICABILITY

The FDF tool is applicable to activities that disseminate and encourage the use of improved cookstoves in regions where biomass collection drives long-term forest degradation. Because of the focus on forest degradation, the tool only considers activities related to wood and charcoal burning stoves. The FDF tool considers the renewability of local biomass, as well as the non-renewable emissions related to biomass collection, charcoal kilns, and direct combustion in the household.

3. APPROACH TO THE FOREST DEGRADATION BY FUELWOOD TOOL

The FDF tool uses the IPCC approach of combining activity data with emission factors, as well as approaches adapted from CDM (Clean Development Mechanism) and ACR (American Carbon Registry) cookstove methodologies. In the context of this tool, an “improved” cookstove is one that requires less fuel to accomplish the same amount of cooking as non-improved, or baseline stoves. There are other important ways an improved stove could provide benefits, including switching to non-biomass fuels, reducing indoor air pollutants, and lowering costs for users. **This tool, however, is restricted to quantifying the GHG reductions that occur from emissions in the household, as well as the indirect emissions from charcoal kilns and biomass damaged during collection.**

The general approach for this tool is to compare the total emissions from a target population from both a baseline and a project scenario. The baseline scenario assumes that households will continue to use existing cookstove technology, while the project scenario assumes that some fraction of cooking activities will be displaced by the improved, or project stoves. The calculation of savings requires three general forms of information:

1) Magnitude of project, expressed as the total number of households where improved stoves are adopted.

2) Emissions savings per household. Savings are related to the baseline annual rate of biomass consumption per household, the relative efficiency of baseline versus project stoves, and the types of fuel used (wood or charcoal) used in each stove type.

3) Non-renewable composition of local biomass supplies. In areas with high forest productivity, ample plantation-sourced biomass, and low demand, it is conceivable that less than 10% of biomass used in cooking is considered non-renewable, while the non-renewable component can approach 100% in highly exploited forest. Biomass that comes from timber plantations, as well from offcuts from ongoing land-use conversions, also is not considered non-renewable because it is either expected to be replanted (as in the case of plantations), or represent emissions that would happen regardless of cookstove activity.

In the FDF tool, an "activity" implies the substitution of users' existing stoves with an improved stove for some number of targeted households. A central determinate of non-renewable (NR) emission savings is the relative performance of baseline and improved stoves. Stove performance is measured in several ways, the most pertinent of which include thermal efficiency and fuel consumption rate. In cases where existing practices involve a mix of stove types, it is acceptable to use a weighted average to derive baseline stove performance values. The Global Alliance for Clean Cookstoves (GACC) maintains a database with performance indicators for many types of stoves.[1] Depending on the data available to a tool user, the FDF tool allows computation based on either thermal efficiency or fuel consumption rate.

A major assumption of this tool is that an increase in stove efficiency is directly translated into a reduction in the need for fuel. This reduction in biomass is converted into emissions savings in three ways:

1) **Direct emissions that occur in the household**. Biomass saved in the household is converted to emissions using default IPPC values for net caloric value (NCV), expressed as terajoules per tonne of fuel (TJ/t), and emission factor (tCO_2e / TJ). Different factors are applied based on the whether wood or charcoal fuels are used. Charcoal and wood have similar emission factors that differ by only 3%. However, they differ significantly in NCV as charcoal contains almost twice the energy per fuel mass as compared to wood according to IPCC default factors.

2) **Indirect Emission that occur during the charcoal kiln process**. Kiln emissions are only applicable to charcoal stoves. The process of converting wood to charcoal releases energy and emissions. Because charcoal is fired at low temperatures in a low oxygen environment, a different composition of gases is released than high-temperature combustion (e.g. low oxygen environment releases more methane, a more potent GHG than $CO_{2)}$). Default kiln emission factors are taken from literature.[2]

3) **Biomass damaged and left in the field to decompose**. When living tree biomass is harvested, roots and small debris are usually left in the field to decompose, resulting in emissions. The FDF tool assumes that for every unit of biomass collected from the forest, an

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[1] Performance statistics for many stove types available at http://catalog.cleancookstoves.org/#/stoves
[2] Smith et al. (1999)

additional 32%[3] is damaged and remains in the field. For fuelwood, the amount collected in the field is assumed to be the same as the amount used in the household. However, charcoal use measured in the household must be converted to pre-kiln wood mass in order to estimate biomass collected in the field. The FDF tool uses a 30.6% kiln yield rate, meaning each tonne of charcoal used in the home is assumed to correspond to 3.27t wood collected in the field.

The **FDF tool only reports emissions savings that come from the non-renewable fraction of biomass collection, or fNRB**. An fNRB factor is used in all major cookstove crediting standards, including Gold Standard, CDM, VCS and ACR. The fNRB can vary significantly based on the population and the regional fuel sources involved in a cookstove project. For areas with high forest productivity, ample plantation-sourced biomass, and low demand, it is conceivable that less than 10% of biomass used in cooking is considered non-renewable, while fNRB can approach 100% in highly exploited forest. A tool user can provide their own value for fNRB based on knowledge of the targeted region, landscape modeling, or field surveys. In the absence of local data, the FDF tool provides a default value for fNRB for most tropical and subtropical countries at the subnational jurisdictional level, produced though a global WISDOM[4] analysis.

The general structure of the calculations underlying the tool is presented in **Figure 1**. Total (gross) emissions from each of the baseline and project scenarios are converted into non-renewable (net) emissions by applying an fNRB factor. Total net savings are related to the difference in baseline and project net emissions GHG emissions.

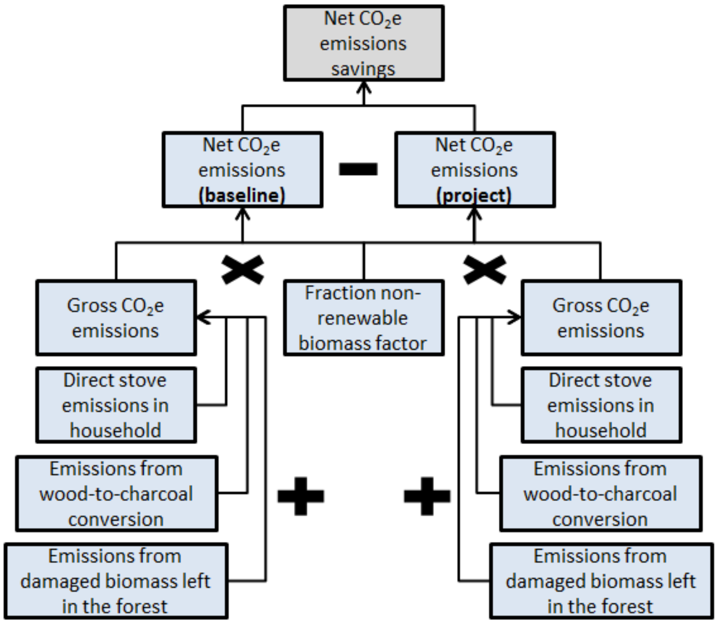

Figure 1: General structure of calculation of non-renewable emissions savings

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[3] Derived from American Carbon Registry cookstove methodology (2013)

[4] Woodfuel Integrated Supply/Demand Overview Mapping developed by Rudi Drigo and colleagues. More information at http://www.wisdomprojects.net/global/

4. DATA SOURCES AND DEFAULT VALUES

4.1. STOVE EMISSION FACTORS

Emission factors (EF) for wood and charcoal use in home cooking are derived from Volume 2 of 2006 IPCC guidelines, Vol. 2 Energy. These EFs only apply to the combustion that happens in the household. Other emissions occurring at-kiln or in the forest are not computed using these values. According to IPCC guidelines, EFs for fuel combustion are conveyed as emissions per unit of energy produced. These guidelines provide upper, lower and default EFs for CO_2, CH_4 and N_2O for charcoal and wood.[5,6] For the FDF tool, default EFs are used for all fuel types. CH_4 and N_2O emissions are converted into CO2-equivalent based on IPCC AR4 100-year time horizon. To estimate emissions based on the mass of fuel consumed, it is necessary to incorporate the net caloric value (NCV) of wood or charcoal. IPCC 2006 provides the FDF tool with defaults for NCV. By multiplying together an energy-based EF and the associated NCV of the fuel type, an EF based on fuel mass is produced. (**Table 1**)

Table 1. Emission Factors and Net Caloric Value (NCV) for charcoal and wood burned in household stoves. Assumes a CO_2-equivalent global warming potential of 25 for CH4 and 298 for N2O based on IPCC AR4 100-year time horizon (KJ = Kilojoule).

Fuel Type	Emission Factors ($tCO_2e\ KJ^{-1}$)				Net Caloric Value ($KJ\ t_{fuel}^{-1}$)	Emission Factors ($tCO_2e\ t_{fuel}^{-1}$)
	CO_2	CH_4	N_2O	All Gases		
Charcoal	112.0	5.0	0.3	**117.3**	**0.0295**	**3.460**
Wood	112.0	7.5	1.2	**120.7**	**0.0156**	**1.882**

The effective mass-based EF for charcoal and wood are, respectively, 3.460 and 1.882 $tCO_2e\ t^{-1}$. The higher EF for charcoal is largely a reflection of its high energy density compared to wood.

4.2. KILN EMISSION FACTOR AND KILN YIELD

Charcoal is produced by the heating of wood in a low-oxygen environment to remove undesirable resins, volatile organic compounds, and water. The process of conversion produces a combination of CO_2, CH_4, and N_2O that is different from open combustion, and therefore requires a different emission factor. The FDF tool relies on emission factors calculated based on a 1999 EPA study comparing the emissions profile of various kiln types (Smith et al. 1999). A FDF tool user is not expected to know what kin type is used in regional charcoal production, and therefore expected kiln emissions are averaged across all kiln types. This averaging of kiln types results in an emission factor of **2.055** tCO_2e per tonne of charcoal produced (**Table 2**). These kiln emissions are *additional* to emissions that occur when charcoal is finally combusted in the household, as well as resulting from damaged biomass in the forest.

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[5] 2006 IPCC Guidelines for National GHG Inventories, Vol. 2 Energy, Chapter 1, Table 1.2
[6] 2006 IPCC Guidelines for National GHG Inventories, Vol. 2 Energy, Chapter 2, Table 2.5

Table 2: Emission factor for charcoal kilns, based on Smith et al. (1999). Assumes a CO_2-equivalent global warming potential of 25 for CH4 and 298 for N2O based on IPCC AR4 100-year time horizon. [7]

Kiln Class	Emissions per tonne charcoal produced (tCO_2e)				Kiln Yield (mass charcoal produced per mass kiln wood input)
	CO_2	CH_4	N_2O	All Gases (CO_2 + CH_4 + N_2O)	
Brick Beehive	0.966	0.795	0.005	1.766	33.3%
Mud Beehive	1.235	0.5425	0.006	1.784	30.8%
Singe Drum	1.517	1.4425	0.008	2.967	29.4%
Earth Mound	1.140	0.6925	0.014	1.846	29.8%
Rice Husk Mound	1.570	0.3175	0.025	1.913	29.6%
Average				**2.055**	**30.6%**

Kiln yield refers to the amount of charcoal that is produced per oven-dry wood. Yield is important because it allows conversion of charcoal measured in the home into the amount of biomass removed from the field. The FDF tool also relies on Smith et al. (1999) to estimate yield. The average yield across five kiln types is 30.6% based on the dry mass of wood used in the kiln process. This means that for every tonne of charcoal used in the home, the FDF tool assumes 3.27t of wood are used to produce that charcoal.

4.3. FOREST BIOMASS DAMAGE FRACTION

Forest biomass is collected using numerous methods, from gathering of small deadwood debris, to wholesale felling and processing of live standing trees. Collection activities that damage living biomass reduce the renewability of the resource and can ultimately lead to permanent forest degradation and loss. In all forms of biomass collection, some form of wood is damaged and left to decompose in the forest. In situations where tree mortality is induced, root biomass is also left to decompose.

The FDF tool uses a 1.32 expansion factor to convert biomass measured at the home (for fuelwood) or as input into a charcoal kiln, to the total biomass emitted from harvesting activities. This factor is taken

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[7] IPCC Working Group I (2007) table 2.14. Available at http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html

from ACR's *Energy efficiency measures in thermal applications of non-renewable biomass* methodology. This factor of 1.32 is based on the assumption that for every unit of biomass extracted from the forest, an additional 10% is left in the field from uncollected aboveground biomass. A further 20% is conservatively estimated to remain from root biomass. These factors, multiplied together, produce a 1.32 expansion factor.

4.4. FRACTION NON-RENEWABLE BIOMASS

Fraction non-renewable biomass represents the portion of fuelwood and charcoal consumption that leads to long-term degradation of the forest resource. The fNRB for a given project is difficult to measure directly, because it entails tracing all fuel consumed by users to its original source. Fuelwood, and especially charcoal, is often transported over long distances and across jurisdictional boundaries, obscuring the original source of the fuel. Users are also likely to use a combination of fuel collected locally and purchased from long-distance commercial networks. For cookstove activities with modest scope, it is not cost-effective to directly measure fNRB.

The FDF tool provides default values for fNRB for 1,626 subnational administrative units from 86 tropical and subtropical countries. The fNRB values were produced based on a pantropical implementation of the WISDOM model performed by Rudi Drigo and the Yale-UNAM project (Bailis et al. 2015). The WISDOM implementation used here is unique to the FDF calculator, but is closely related to the national-scale model currently awaiting publication by Drigo et al (2014). The model used in the FDF combines local fuelwood/charcoal demand, biomass availability, generation of regional commercial "woodsheds," and cost distance for modeling of local collection.

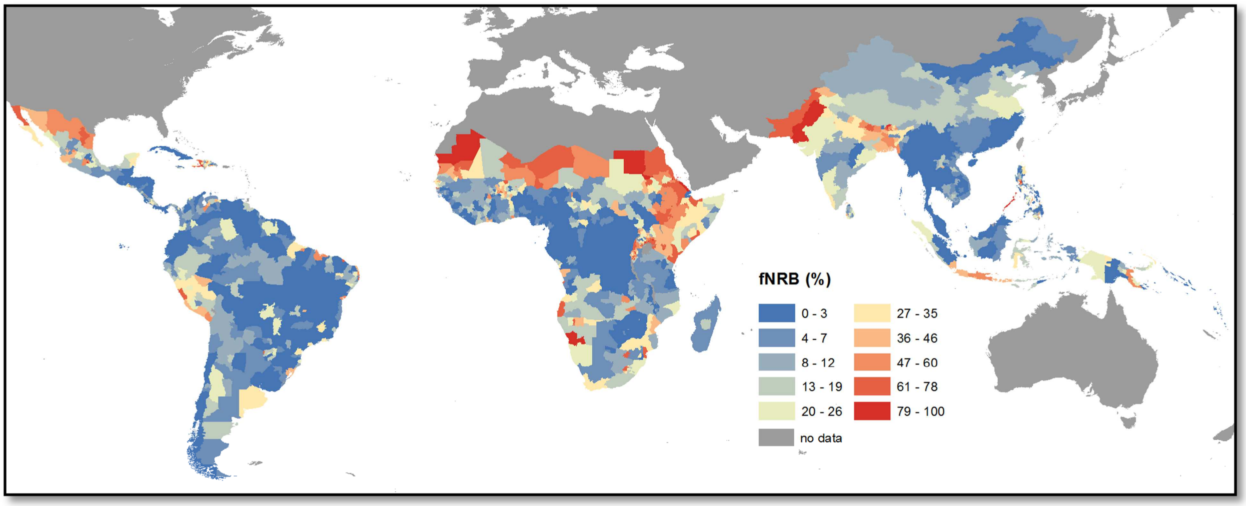

Figure 2. fNRB value from Drigo et al., weighted average of urban and rural fNRB based on local consumption per market type

The FDF tool provides fNRB values for both urban and rural areas within each province, with these terms coinciding with national census designations. This differentiation acknowledges the different pathways that fuel reaches users in the urban and rural context, and the resulting differing effects on renewability. Rural areas are more likely to meet some fuel demand with non-commercial/local sources, while urban centers may be almost entirely dependent on commercial markers. However, some densely populated rural areas also have unmet local demand and are served by the commercial market, and as such exhibit “urban” characteristics of consumption. Non-commercial/local demand here identifies largely informal collection that is limited to a few kilometers from users. In the commercial model, unmet local demand can be satisfied by fuel sources from a larger area, or ”woodshed,” that takes into account transportation networks. In this WISDOM implementation, woodsheds are constrained within national boundaries.

Several assumptions were made in deriving fNRB. The first concerns the management practices, assuming: (i) "optimal" management levels, which is unrealistic but useful in determining the "physiologic" limit of forest management and, (ii), "current" management levels, inferred using national forest management statistics produced by FAO. Assuming "optimal" management results in Minimum fNRB values, while assuming "current" management results in Expected fNRB. The FDF consider only the “expected” fNRB values.

The second assumption regards the treatment of fuel made available through ongoing land-cover transitions unrelated to fuelwood use. In regions with ongoing conversion of forests to agriculture or other land use, it is assumed in the FDF tool that the forest biomass damaged through conversion is used as fuelwood before any new supplies are collected from standing forests. Even though conversion of forests to non-forests represents a “non-renewable” process for forests, emissions from conversion are already committed to the atmosphere (through decomposition or on-site burning), and using these materials as fuelwood or charcoal does not incur additional forest degradation. In countries with high rates of forest loss, much of the demand for fuelwood can be met from ongoing forest clearing, resulting in low values for fNRB.

In regions with developed commercial fuelwood markets, timber plantations specifically grown for energy are a common source of fuelwood. In the WISDOM model, two growth increments are used: a low productivity and high productivity variant. The FDF uses the high productivity variant, based on default plantation growth data indicated in IPCC guidelines, as this variant results in slightly lower fNRB values and is thus more conservative.

5. CALCULATION METHODS

Parameters in blue must be specified by the user under Required Inputs. Parameters in red have default values under Advanced Inputs, but can be changed by the user. Parameters in black are fixed within the calculations.

Adjusted Fraction non-Renewable Biomass

The values of fNRB are available for both urban and rural households. By specifying whether a cookstove improvement project primarily targets urban or rural users, the resulting fNRB value applied to the activity will vary.

Equation 1. Adjusted fNRB

$$fNRB_{adj} = fNRB_{r} \times R + fNRB_{u} \times (1-R)$$

R = Percent Rural Users: The percent of fuelwood/charcoal consumed by target users residing in "rural" census-designated areas. A Default value for R is provided based on per-jurisdiction estimates of relative fuel demand. However, it is advised that users override this value based on knowledge of target users. (%)

$fNRB_{u}$ = Fraction of fuelwood/charcoal consumption in urban areas that is derived from non-renewable sources. (%)

$fNRB_{r}$ = Fraction of fuelwood/charcoal consumption in urban areas that is derived from non-renewable sources. (%)

$fNRB_{adj}$ = Adjusted Fraction non-renewable biomass: The percent of biomass consumed in the project region that is derived from non-renewable sources, and reflecting the proportional targeting of urban and rural areas. (%)

Non-renewable cookstove emissions from one household, baseline scenario

Non-renewable (NR) emissions are the sum of NR emissions from direct burning, kiln, and damaged forest biomass. Equations below provide the annual NR emissions for a single household using only baseline, non-improved stoves.

Equation 2. Baseline NR emissions

$$e_{\text{direct.base}} = B_{\text{base}} \times NCV_{\text{base}} \times EF_{\text{direct.base}} \times fNRB_{adj}$$

$$e_{\text{kiln.base}} = B_{\text{base}} \times EF_{\text{kiln.base}} \times fNRB_{adj}$$

$$e_{\text{damage.base}} = (B_{\text{base}} / Y_{\text{base}}) \times 0.32 \times 0.47 \times (44/12) \times fNRB_{adj}$$

$$e_{\text{total.base}} = e_{\text{direct.base}} + e_{\text{kiln.base}} + e_{\text{damage.base}}$$

$e_{\text{direct.base}}$ = annual non-renewable CO_2e emissions from direct burning in the household (t)
$e_{\text{kiln.base}}$ = annual non-renewable CO_2e emissions from kiln (t)
$e_{\text{damage.base}}$ = annual non-renewable CO_2e emissions from damaged forest biomass (t)
$e_{\text{total.base}}$ = annual non-renewable CO_2e emissions from all sources (t)
B_{base} = Annual consumption of biomass per household for cooking under the baseline scenario ($t\ yr^{-1}$)
NCV_{base} = Net caloric value of baseline fuel ($TJ\ t^{-1}$)
$EF_{\text{direct.base}}$ = Emission Factor of baseline fuel ($t\ CO_2e\ TJ^{-1}$)

$EF_{kiln.base}$ = Kiln Emission Factor of baseline fuel (t CO_2e t_{fuel}^{-1}). EF_{kiln} = 2.055 for charcoal, and 0 for wood
Y_{base} = Kiln yield fraction of baseline fuel (%) Y = 0.306 for charcoal, and 1 for wood.

Non-renewable cookstove emissions <u>savings</u> in project versus baseline scenario, for one household

Emission calculations for project scenario are identical to the baseline scenario (**Equation 2**). However, biomass consumption for households using improved cookstoves (B_{impr}) is not estimated directly, but rather derived from the difference in performance between baseline and project stoves. The FDF tool allows calculation of B_{impr} based on either thermal efficiency or fuel consumption rate metrics (**Equation 3**).

Equation 3. Alternate methods for calculating biomass consumption in the project (improved) scenario

Thermal Efficiency Method	$B_{impr} = B_{base} \times (\eta_{base} / \eta_{impr}) \times (NCV_{base}/NCV_{impr})$
Fuel Consumption Rate Method	$B_{impr} = B_{base} \times (FC_{impr} / FC_{base})$

B_{impr} = Annual consumption of biomass per household for cooking under the project scenario, assuming 100% cooking displacement by improved cookstove (t yr^{-1})
η_{base} = Thermal efficiency of baseline stove (%)
η_{impr} = Thermal efficiency of improved stove (%)
NCV_{impr} = Net Caloric Value of fuel type used in improved cookstove (TJ t^{-1})
FC_{base} = Fuel Consumption Rate of baseline stove (units vary, mass of fuel consumed per standardized task)
FC_{impr} = Fuel Consumption Rate of improved stove (units vary, mass of fuel consumed per standardized task)

Equation 4. Annual NR emissions savings per household

$$e_{save} = (e_{total.base} - e_{total.impr}) \times Disp$$

e_{save} = Annual savings in non-renewable CO_2e emissions from a single household
$e_{total.impr}$ = Annual non-renewable CO_2e emissions from direct burning in the household (t) *note: $e_{total.impr}$ is calculated as is $e_{total.base}$ (**Equation 2**), with the modification that NCV_{base}, $EF_{direct.base}$, $EF_{kiln.base}$, Y_{base} are substituted with the appropriate values for the fuel type used in the improved stove.*
Disp = Estimate of the percent of household cooking that is displaced by improved stoves (%)

Total and annual activity-wide non-renewable cookstove emissions savings

Emissions per household are scaled to an entire project by multiplying e_{save} by the total households targeted for stove improvement. Benefits continue for as long as the expected operational lifespan of improved stoves. Benefits for the final year of a stove's anticipated operation are proportional to the fraction of the year remaining functional (e.g., a stove with a 2.5-year lifespan will produce 50% reduced benefits in the 3rd year).

Equation 5. Annual NR emissions savings per activity

$$E_{save} = e_{save} \times H$$

E_{save} = Annual activity-wide savings in non-renewable CO_2e emissions (t)
H = number of households targeted with improve cookstoves

Equation 6. Total NR emissions savings per activity, cumulative across all years

$$E_{save.cuml} = E_{save} \times L$$

$E_{.save.cuml}$ = Cumulative activity-wide non-renewable CO_2e emissions from all years (t)
L = Expected operation lifespan of improved stoves (years)

6. EXAMPLE CALCULATION

An activity is designed to distribute improved wood-burning stoves to Amhara Region, Ethiopia. The project targets users primarily residing in rural areas, and who currently use three-stone fireplace stoves. The project must measure or estimate the following values:

- Stove performance for baseline and improved stoves. (Either η_{base} and η_{impr} OR FC_{base} and FC_{impr})
- Percent of household cooking on three-stone stoves that is displaced by improved stoves (DISP)
- The average operational lifespan of improved stoves (L)
- The number of households targeted (H)
- Average annual consumption of tonnes fuelwood or charcoal per targeted household using three-stove stoves scenario before introduction of improved stoves (B_{base})
- Percent of target households that reside within rural census-designated areas (R)

Based on project design, stove performance data, and knowledge of the region, a user estimates the following values:

Value	User estimate
η_{base}	10%
η_{impr}	35%
FC_{base}	n/a (user has opted to use thermal efficiency)
FC_{impr}	n/a (user has opted to use thermal efficiency)

DISP	30%
L	3.5 years
H	5,000
B_{base}	1.5 t y^{-1}
R	90%

An adjusted fNRB ($fNRB_{adj}$) is calculated based on the percent of targeted households in rural versus urban areas. A value of 58.93% is derived from weighting of the rural (54.37%) and urban (100%) default values for Amhara. (**Equation 1**)

$$fNRB_{adj} = fNRB_r \times R + fNRB_u \times (1-R) = 0.5437 \times 0.9 + 1 \times (1 - 0.9) = \mathbf{58.93\%}$$

Non-renewable emissions for one household in the baseline scenario are calculated as the sum direct, kiln and damage emissions. Because the fuel type is wood, the kiln emission factor is 0 and kiln yield is 1, effectively removing any effect of kiln processing on final emissions. (**Equation 2**)

$$e_{direct.base} = B_{base} \times NCV_{base} \times EF_{direct.base} \times fNRB_{adj} = 1.5\ ty^{-1} \times 0.0156\ TJ\ t^{-1} \times 120.7\ tCO_2e\ TJ^{-1} \times 0.5893 = \mathbf{1.66\ tCO_2ey^{-1}}$$

$$e_{kiln.base} = B_{base} \times EF_{kiln.base} \times fNRB_{adj} = 1.5\ ty^{-1} \times 0\ tCO_2et^{-1} \times 0.5893 = \mathbf{0\ tCO_2ey^{-1}}$$

$$e_{damage.base} = (B_{base} / Y_{base}) \times 0.32 \times 0.47 \times (44/12) \times fNRB_{adj} = (1.5\ ty^{-1} / 1) \times 0.32 \times 0.47 \times (44/12) = \mathbf{0.49\ \ tCO_2ey^{-1}}$$

$$e_{total.base} = e_{direct.base} + e_{kiln.base} + e_{damage.base} = 1.66\ tCO_2ey^{-1} + 0\ tCO_2ey^{-1} + 0.49\ tCO_2ey^{-1} = \mathbf{2.15\ tCO_2ey^{-1}}$$

Annual fuel consumption in tonnes of wood for a single household using only improved stoves is estimated using the difference in thermal efficiency of baseline and improved stoves. (**Equation 3**)

$$B_{impr} = B_{base} \times (\eta_{base}/\eta_{impr}) \times (NCV_{base}/NCV_{impr}) = 1.5\ tCO_2ey^{-1} \times (0.1/0.35) \times (0.0156/0.0156) = \mathbf{0.43\ ty^{-1}}$$

Non-renewable emissions for one household in the improved scenario are calculated in the same manner as for the baseline. (**Equation 2**)

$$e_{direct.impr} = B_{impr} \times NCV_{impr} \times EF_{direct.impr} \times fNRB_{adj} = 0.43\ ty^{-1} \times 0.0156\ TJ\ t^{-1} \times 120.7\ tCO_2e\ TJ^{-1} \times 0.5893 = \mathbf{0.47\ tCO_2ey^{-1}}$$

$$e_{kiln.impr} = B_{impr} \times EF_{kiln.impr} \times fNRB_{adj} = 1.5\ ty^{-1} \times 0\ tCO_2et^{-1} \times 0.5893 = \mathbf{0\ tCO_2ey^{-1}}$$

$$e_{damage.impr} = (B_{impr} / Y_{impr}) \times 0.32 \times 0.47 \times (44/12) \times fNRB_{adj} = (1.5\ ty^{-1} / 1) \times 0.32 \times 0.47 \times (44/12) = \mathbf{0.14\ \ tCO_2ey^{-1}}$$

$$e_{total.impr} = e_{direct.impr} + e_{kiln.impr} + e_{damage.impr} = 1.66\ tCO_2ey^{-1} + 0\ tCO_2ey^{-1} + 0.49\ tCO_2ey^{-1} = \mathbf{0.61\ tCO_2ey^{-1}}$$

Displacement of non-improved stoves is typically less than 100%. For this project, the 30% estimate displacement results in the following non-renewable emissions reduction (savings) per household. (**Equation 4**)

$$e_{save} = (e_{total.base} - e_{total.impr}) \times Disp = (2.15\ tCO_2ey^{-1} - 0.61\ tCO_2ey^{-1}) \times 0.3 = \mathbf{0.46\ tCO_2ey^{-1}}$$

Per-household NR emissions savings are scaled up to the activity by multiplying by the number of targeted households, 5,000 in this case. (**Equation 5**)

$$E_{save} = e_{save} \times H = 0.46\ tCO_2ey^{-1} \times 5000 = \mathbf{2{,}306\ tCO_2ey^{-1}}$$

Finally, the total cumulative project benefit is calculated based on the expected operational lifespan of the improved stove. (Equation 6)

$$E_{save.cuml} = E_{save} \times L = 2{,}306\ tCO_2ey^{-1} \times 3.5y = \mathbf{8070\ tCO_2e}$$

The project in Amhara is estimated by the FDF to produce 8,070**t of reduction in non-renewable CO_2e emissions over the life of the activity. If these emissions were translated into forest carbon, based on estimated carbon density of Amhara's forests of 112tha^{-1} (Saatchi, in prep.), the result would be the avoided deforestation of 20 hectares of forest. In reality, impact from fuel collection is dispersed and not likely to cause full deforestation. However, this is a useful value to intuit the ultimate effect of a cookstove improvement project on forest cover.**

7. OVERRIDING DEFAULT DATA

Under Advanced Inputs, the user is given an option to change default parameters by entering project-specific data. The only value available to override is the adjusted fraction non-renewable biomass ($fNRB_{adj}$). If a user has local measurements of fNRB for the target population, that value should be used. Without local data, the defaults provided by the FDF tool should be used.

8. REFERENCES

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