Digitally native methodology to quantify greenhouse gas emission reductions from improved wood-fuelled cookstoves

Simulation of a 1000-household project

Nova Institute

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1 CO_2 emission reduction due to project activity (t/yr)

Definition

The total mass of CO_2 avoided per annum due to the project activity.

Rationale

CO_2 emissions are linked to climate change.

Source(s) of data

- stove tests (WBT)
- baseline and project field tests (KT)
- non-renewable biomass (NRB) assessment
- (ongoing) stove usage monitoring
- stove use logbooks
- usage survey

Credibility

Avoidance of specification error
Give preference to tests that represent the actual situation of the end-user.
Give preference to objective methods for ongoing sampling.
Use a randomly selected sample.

Avoidance of coverage or frame error
Keep a complete record of all participating households.

Avoidance of non-response error
Consider a moderate compensation to households for participating in tests that are invasive (like the KPT).

Avoidance of measurement error
Give preference to objective measurements.
Use triangulation.

Avoidance of processing errors
Report calculations transparently so that all processing steps, including intermediate steps, are visible.

Calculation

1.1 Notation

$fr_{(B)ijk}$: fire frequency for household j in subpopulation i on day k in the baseline scenario of the KT phase.

$fr_{(P)ijk}$: fire frequency for household j in subpopulation i on day k in the project scenario of the KT phase.

$fr_{(BS)ijk}$: Brick Star frequency for household j in subpopulation i on day k in the project scenario of the KT phase.

$fr^*_{(BS)ijk}$: fire frequency for Brick Star for household j in subpopulation i on day k in the post KT phase.

$x_{(B)ijk}$: daily fuel use (in kg) for household j in subpopulation i on day k in the baseline scenario of the KT phase.

$x_{(P)ijk}$: daily fuel use (in kg) for household j in subpopulation i on day k in the project scenario of the KT phase.

$x_{(BS)ijk}$: daily Brick Star fuel use (in kg) for household j in subpopulation i on day k in the project scenario of the KT phase.

$n_{(B)ij}$: total number of days that household j in subpopulation i was observed in the baseline scenario of the KT phase.

$n_{(P)ij}$: total number of days that household j in subpopulation i was observed in the project scenario of the KT phase.

n^*_{ij}: total number of days that household j in subpopulation i was observed in the post KT phase.

n_i: total number of subpopulations in the project.

1.2 Calculation of ER_y

1.2.0.1 Calculation

$$ER_y = BE_y - PE_y - LE_y$$

Where:

ER_y = The total mass of CO_2 avoided in year y across all project participants due to the project activity (tonnes)

BE_y = The total baseline CO_2 emissions for year y across all project participants (tonnes)

PE_y = The total project CO_2 emissions for year y across all project participants (tonnes)

LE_y = The total leakage CO_2 emissions for year y across all project participants (tonnes)

Table 1: Calculation of ER from simulation study

place	year	fuel	BE	PE	LE	ER
Lwandlamuni	2023	wood	579.1968 [t]	375.5824 [t]	8.425329 [t]	195.1891 [t]

1.3 Calculation of project CO_2 emissions

1.3.1 Calculation of PE_y

1.3.1.1 Calculation

PE_y is calculated as:

$$PE_y = \sum_f C_{(P)y,f} \times EF_{(CO_2)f} \times f_{(NRB)y}$$

Where:

$C_{(P)y,f}$ = The total project consumption of fuel f for year y across all project participants (tonnes)

$EF_{(CO_2)f}$ = CO_2 emission factor for fuel f

$f_{(NRB)y}$ = The fraction of non-renewable biomass in the fuel-sourcing environment for year y

For simplicity in notation we will from this point forth use the notation $C_{(P)}$ for $C_{(P)y,f}$ with the understanding that $C_{(P)}$ is the total fuel consumption across all subpopulations and households for year y and fuel type f.

Table 2: Calculation of PE from simulated results

place	year	fuel	PE	CP	COEF	fNRB
Lwandlamuni	2023	wood	375.5824 [t]	802.5265 [t]	1560 [g/kg]	0.3

1.3.2 Calculation of $C_{(P)}$

1.3.2.1 Calculation

$C_{(P)}$ is calculated as:

$$C_{(P)} = \sum_i^{n_i} C_{(P)i}$$

and $C_{(P)i}$ is the total fuel consumption in the project scenario for subpopulation i.

1.3.3 Calculation of $C_{(P)i}$

1.3.3.1 Calculation

$C_{(P)i}$ is calculated as

$$C_{(P)i} = (\overline{d}_{(P)i} \times N_{(P)i}) \times (\overline{fr^*}_{(BS)i} \times \overline{x}_{(BS)i})$$

- $\overline{d}_{(P)i}$ is the average days of project operation in subpopulation i.
- $N_{(P)i}$ is the project population size in subpopulation i.
- $\overline{fr^*}_{(BS)i}$ is the average Brick Star frequency per day in subpopulation i in the post KT phase .
- $\overline{x}_{(BS)i}$ is the average Brick Star fuel use (in kg) for subpopulation i in the project scenario of the KT phase.

Table 3: Calculation of project emissions

place	year	fuel	start	end	mean_days	CPi	frMi	N	CP
Lwandlamuni	2023	wood	2023-01-29	2023-05-31	122 days	5.55	1.18	1000	802.5265 [t]

Table 4: Sample of data from project kitchen test results summarised by household

place	year	fuel	assignment	household_qr_code	XMij	frMij	frBPij	XBPijk
Lwandlamuni	2023	wood	projectKT	0060	2.68	0.81	0.19	1.20
Lwandlamuni	2023	wood	projectKT	0136	5.82	1.21	0.14	0.73
Lwandlamuni	2023	wood	projectKT	0166	2.70	0.86	0.06	0.50
Lwandlamuni	2023	wood	projectKT	0197	2.32	1.11	0.25	0.34
Lwandlamuni	2023	wood	projectKT	0356	1.91	1.22	0.06	0.25
Lwandlamuni	2023	wood	projectKT	0357	2.75	0.99	0.15	0.69

1.3.4 Calculation of d_{ij}

1.3.4.1 Calculation The average days of project operation is calculated as

$$\bar{d}_i = \frac{1}{n_i} \sum d_{ij}$$

and d_{ij} is the total days of project operation for household j in subpopulation i. The total days of operation for each household can be determined as the number of days since the project technology has been implemented for each household and will be available in the project register.

Table 5: Sample of continuous monitoring data summarised by household

place	year	fuel	qr_code	ndays	total_frMij	date_start	date_end	frMij	XMi	CPi
Lwandlamuni	2023	wood	0036	123	133	2023-01-29	2023-05-31	1.1	4.5	4.9
Lwandlamuni	2023	wood	0086	123	139	2023-01-29	2023-05-31	1.1	4.5	5.1
Lwandlamuni	2023	wood	0182	123	153	2023-01-29	2023-05-31	1.2	4.5	5.6
Lwandlamuni	2023	wood	0219	123	155	2023-01-29	2023-05-31	1.3	4.5	5.7
Lwandlamuni	2023	wood	0249	123	139	2023-01-29	2023-05-31	1.1	4.5	5.1
Lwandlamuni	2023	wood	0255	123	143	2023-01-29	2023-05-31	1.2	4.5	5.3

1.3.5 Calculation of $\overline{fr^*}_{(BS)i}$

1.3.5.1 Calculation The average Brick Star frequency per day $\overline{fr^*}_{(BS)i}$ for subpopulation i is determined from a sample in the continuous monitoring phase and is calculated as

$$\overline{fr^*}_{(BS)i} = \frac{1}{n_i^*} \sum_i^{n_i^*} \frac{fr^*_{(BS)ij.}}{n_{ij}^*}$$

- $fr^*_{(BS)ij.}$ is the total frequency Brick Star fires for household j in subpopulation i for the post KT phase.
- n_{ij}^* is the total number of days that household j in subpopulation i was observed in the post KT phase.
- n_i^* is the number of households that were observed in the post KT phase.

Table 6: Sample of daily monitoring data

place	year	fuel	qr_code	ndays	total_frMij	date_start	date_end	frMij
Lwandlamuni	2023	wood	0036	123	133	2023-01-29	2023-05-31	1.1
Lwandlamuni	2023	wood	0086	123	139	2023-01-29	2023-05-31	1.1
Lwandlamuni	2023	wood	0182	123	153	2023-01-29	2023-05-31	1.2
Lwandlamuni	2023	wood	0219	123	155	2023-01-29	2023-05-31	1.3
Lwandlamuni	2023	wood	0249	123	139	2023-01-29	2023-05-31	1.1
Lwandlamuni	2023	wood	0255	123	143	2023-01-29	2023-05-31	1.2

1.3.6 Calculation of $\overline{x}_{(BS)i}$

1.3.6.1 Calculation The average Brick Star fuel use (in kg) in the project scenario for subpopulation i is calculated as the average of the household average fuel use per Brick Star fire observed in the kitchen test.

$$\overline{x}_{(BS)i} = \frac{1}{n_{(P)i}} \sum_{j}^{n_i} \frac{x_{(BS)ij.}}{fr_{(BS)ij.}}$$

1.3.7 Calculation of $x_{(BS)ij.}$

1.3.7.1 Calculation The total Brick Star fuel use for household j in subpopulation i is the total fuel use in the project scenario minus the fuel use by non-Brick Star fires in the project scenario.

$$x_{(BS)ij.} = x_{(P)ij.} - (\overline{x}_{(B)i} \times (fr_{(P)ij.} - fr_{(BS)ij.}))$$

Table 7: Sample of kitchen test monitoring data summarised by household

place	year	fuel	assignment	qr_code	XMij	frMij	frBPij	XBPijk
Lwandlamuni	2023	wood	projectKT	0060	2.7	0.8	0.2	1.2
Lwandlamuni	2023	wood	projectKT	0136	5.8	1.2	0.1	0.7
Lwandlamuni	2023	wood	projectKT	0166	2.7	0.9	0.1	0.5
Lwandlamuni	2023	wood	projectKT	0197	2.3	1.1	0.2	0.3
Lwandlamuni	2023	wood	projectKT	0356	1.9	1.2	0.1	0.3
Lwandlamuni	2023	wood	projectKT	0357	2.7	1.0	0.2	0.7

1.4 Calculation of baseline CO_2 emissions

1.4.1 Calculation of BE_y

1.4.1.1 Calculation

BE_y is calculated as:

$$BE_y = \sum_f C_{(B)y,f} \times EF_{(CO_2)f} \times f_{(NRB)y}$$

Where:

$C_{(B)y,f}$ = The total baseline consumption of fuel f for year y across all project participants (tonnes)
$EF_{(CO_2)f}$ = CO_2 emission factor for fuel f
$f_{(NRB)y}$ = The fraction of non-renewable biomass in the fuel-sourcing environment for year y

For simplicity in notation we will from this point forth use the notation $C_{(B)}$ for $C_{(B)y,f}$ with the understanding that $C_{(B)}$ is the total fuel consumption across all subpopulations and households for year y and fuel type f.

Table 8: Calculation of BE from simulated results

place	year	fuel	BE	CB	COEF	fNRB
Lwandlamuni	2023	wood	579.1968 [t]	1237.6 [t]	1560 [g/kg]	0.3

1.4.2 Calculation of $C_{(B)}$

1.4.2.1 Calculation

$C_{(B)}$ is calculated as:

$$C_{(B)} = \sum_i^{n_i} eef_i \times C_{(P)i}$$

$C_{(P)i}$ is the total fuel consumption for subpopulations i (see calculation in previous paragraph).

eef_i is the energy efficiency factor for subpopulation i.

Table 9: Calculation of CBy from simulated results

place	year	fuel	start	end	mean_days	CPbar	mean_eef	CBbar	N	CB
Lwandlamuni	2023	wood	2023-01-29	2023-05-31	122 days	5.55	1.83	10.14	1000	1237.6 [t]

1.4.3 Calculation of eef_i

1.4.3.1 Calculation

eef_i is calculated as

$$eef_i = \frac{\overline{x}_{(B)i} \times \overline{rr}_i}{\overline{x}_{(BS)i}}$$

Where: $\overline{x}_{(B)i}$ the average fuel use (in kg) in the baseline scenario for subpopulation i.

$\overline{rr}_i$ the average replacement ratio at which non-Brick Star fires are replaced by Brick Star fires for subpopulation i.

$\overline{x}_{(BS)i}$ the average Brick Star fuel use (in kg) in the baseline scenario for subpopulation i.

Table 10: Calculation of eef from simulated data

place	year	fuel	base_kg	project_kg	eef
Lwandlamuni	2023	wood	251.6561 [kg]	137.7268 [kg]	1.827212 [1]

1.4.4 Calculation of $\overline{x}_{(B)i}$

1.4.4.1 Calculation The average fuel use (in kg) in the baseline scenario for subpopulation i is calculated as the average fuel use (in kg) for the j households in subpopulation i.

$$\overline{x}_{(B)i} = \frac{1}{n_{ij}} \sum_{j} \overline{x}_{(B)ij}$$

and $\overline{x}_{(B)ij}$ is the average fuel use (in kg) in the baseline scenario for household j subpopulation i.

$$\overline{x}_{(B)ij} = \frac{1}{n_{ijk}} \sum_{k}^{n_{ijk}} x_{(B)ijk}$$

Table 11: Sample of baseline kitchen test monitoring data summarised by household

place	year	fuel	assignment	qr_code	XBij	frBij
Lwandlamuni	2023	wood	baselineKT	0060	7.2	1.5
Lwandlamuni	2023	wood	baselineKT	0136	10.9	1.7
Lwandlamuni	2023	wood	baselineKT	0166	9.9	1.5
Lwandlamuni	2023	wood	baselineKT	0197	12.2	1.4
Lwandlamuni	2023	wood	baselineKT	0356	5.3	1.1

1.4.5 Calculation of $\overline{rr}_i$

1.4.5.1 Calculation The average replacement ratio is the average ratio for subpopulation i of the replaced non-Brick Star fires replaced by Brick Star fires and is calculated as

$$\overline{rr}_i = \frac{1}{n_{ij}} \sum_{j} rr_{ij}$$

and rr_{ij} is the replacement ratio for household j in subpopulation i.

1.4.6 Calculation rr_{ij}

1.4.6.1 Calculation

$$rr_{ij} = \frac{\overline{fr}_{(B)ij} - (\overline{fr}_{(P)ij} - \overline{fr}_{(BS)ij})}{\overline{fr}_{(BS)ij}}$$

$\overline{fr}_{(B)ij}$ is the average number of fires per day in the baseline scenario for household j in subpopulation i and is calculated as the total fires in the baseline scenario for household j in subpopulation i divided by the total days for household j in subpopulation i in the baseline scenario.

1.4.7 Calculation of $\overline{fr}_{(B)ij}$

1.4.7.1 Calculation

$$\overline{fr}_{(B)ij} = \frac{fr_{(B)ij.}}{n_{(B)ij}}$$

Similarly $\overline{fr}_{(P)}ij$ is the average number of fires per day in the project scenario for household j in subpopulation i

$$\overline{fr}_{(P)ij} = \frac{fr_{(P)ij.}}{n_{(P)ij}}$$

and $\overline{fr}_{(BS)ij}$ is the average number of Brick Star fires per day in the project scenario for household j in subpopulation i

$$\overline{fr}_{(BS)ij} = \frac{fr_{(BS)ij.}}{n_{(BS)ij}}$$

1.5 Calculation of leakage CO_2 emissions

1.5.1 Calculation of LE_y

1.5.1.1 Calculation Leakage will be due to continued use of baseline technology. LE_y is calculated as:

$$LE_y = \sum_f L_{(P)y,f} \times EF_{(CO_2)f} \times f_{(NRB)y}$$

Where:

$L_{(P)y,f}$ = The total leakage consumption of fuel f for year y across all project participants. This is fuel consumption by the baseline technologies in the project scenario (tonnes)
$EF_{(CO_2)f}$ = CO_2 emission factor for fuel f
$f_{(NRB)y}$ = The fraction of non-renewable biomass in the fuel-sourcing environment for year y

For simplicity in notation we will from this point forth use the notation $L_{(P)}$ for $L_{(P)y,f}$ with the understanding that L is the total fuel consumption across all subpopulations and households for year y and fuel type *f*.

Table 12: Calculation of LE from simulated results

place	year	fuel	LE	LP	COEF	fNRB
Lwandlamuni	2023	wood	8.425329 [t]	18.00284 [t]	1560 [g/kg]	0.3

1.5.2 Calculation or $L_{(P)}$ and $L_{(P)i}$

1.5.2.1 Calculation $L_{(P)}$ is calculated as:

$$L_{(P)} = \sum_i^{n_i} L_{(P)i}$$

and $L_{(P)i}$ is the total leakage in the project scenario for subpopulation i.

$L_{(P)i}$ is calculated as

$$L_{(P)i} = (\overline{d}_{(P)i} \times N_{(P)i}) \times (\overline{frr}_i \times \overline{fr^*}_{(BS)i} \times \overline{x}_{(B)i})$$

- $\overline{d}_{(P)i}$ is the average days of project operation in subpopulation i.
- $N_{(P)i}$ is the project population size in subpopulation i.
- $\overline{frr}_i$ is the average frequency ratio of non Brick Star fires to the Brick Star fires in subpopulation i in the project scenario of the KT phase.
- $\overline{fr^*}_{(BS)i}$ is the average Brick Star frequency per day in subpopulation i in the post KT phase .
- $\overline{x}_{(B)i}$ is the average fuel use (in kg) for subpopulation i in the baseline scenario of the KT phase. This is derived from the baseline kitchen performance test.

1.5.3 Calculation of $\overline{frr}_i$

The average frequency ratio of non-Brick Star fires to the Brick Star fires in the project scenario for household j in subpopulation i is calculated as

$$\overline{frr}_i = \frac{1}{n_{(P)i}} \sum_j \frac{fr_{(P)ij.} - fr_{(BS)ij.}}{fr_{(BS)ij.}}$$

These values are derived from the project kitchen test.

Table 13: Sample of kitchen test records showing calculation of frr_{ij}

place	year	fuel	assignment	household_qr_code	frBPij	frMij	frr
Lwandlamuni	2023	wood	projectKT	0060	0.2	0.8	0.2
Lwandlamuni	2023	wood	projectKT	0136	0.1	1.2	0.1
Lwandlamuni	2023	wood	projectKT	0166	0.1	0.9	0.1
Lwandlamuni	2023	wood	projectKT	0197	0.2	1.1	0.2
Lwandlamuni	2023	wood	projectKT	0356	0.1	1.2	0.1

Table 14: Value of $\overline{frr}$ from simulagted data

place	year	fuel	frrbar
Lwandlamuni	2023	wood	0.1