Comprehensive Lowered Emission Assessment and Reporting (CLEAR) Methodology for Cooking Energy Transitions

Summary, Context, and Justification for CLEAR Methodology Approaches

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Abstract

This document provides the rationale for the key approaches to quantifying emission reductions (ERs) from clean and improved cooking activities laid out in the CLEAR methodology developed by the Clean Cooking and Climate Consortium (4C).

While the specific requirements and guidelines are presented in the methodology, this document serves as a supplementary resource to provide justification, supporting arguments, and evidence behind key requirements of the methodology, demonstrating why the credits resulting from adhering to these approaches should be considered high integrity.

About 4C

Founded in 2021 and led by the Clean Cooking Alliance (CCA), 4C is a group of partners supporting efforts to achieve climate goals through clean cooking action. In addition to CCA, 4C members include the United States Environmental Protection Agency (U.S. EPA), Berkeley Air Monitoring Group, the Climate & Clean Air Coalition (CCAC), Stockholm Environment Institute (SEI), and the United Nations Framework Convention on Climate Change (UNFCCC) secretariat.

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1. Acronyms

4C	Clean Cooking and Climate Consortium
CCA	Clean Cooking Alliance
CLEAR	Comprehensive Lowered Emission Assessment and Reporting Methodology for Cooking Energy Transitions
CTEC	Continuously Tracked Energy Consumption
ER	Emission Reduction
fNRB	Fraction of Non-Renewable Biomass
GHG	Greenhouse Gas
ICVCM	Integrity Council for the Voluntary Carbon Market
ISO	International Organization for Standardization
KPT	Kitchen Performance Test
LMIC	Low- and Middle-Income Country
LPG	Liquified Petroleum Gas
MC	Monte Carlo
MoFuSS	Modeling Fuelwood Savings Scenarios
PTDs	Project Technology Days
SEI	Stockholm Environment Institute
SUM	Stove Use Monitor
UNAM	National Autonomous University of Mexico
UNFCCC	United Nations Framework Convention on Climate Change

2. Introduction

CLEAR is a comprehensive carbon project methodology for estimating ERs from more efficient cooking stoves and/or cooking fuel switch projects.

Background: The CLEAR methodology originated in response to stakeholder feedback at a side event at the 2022 Clean Cooking Forum focused on field monitoring. It addresses a stated need for a new rigorous clean cooking carbon methodology with a harmonized approach, that would increase quality, transparency, and consistency across cooking carbon projects.

This new methodology has been developed by the clean cooking sector, for the clean cooking sector, through a process facilitated by 4C. Its development involved collaboration with more than 250 stakeholders, including the UNFCCC secretariat, voluntary carbon standards bodies, project proponents, researchers, carbon buyers, and others.

Relevance: The credibility of ERs claimed by clean and improved cooking initiatives has come under increased scrutiny. Journalists, carbon rating agencies, and academic publications have raised concerns about the methods used to estimate these ERs, which can differ significantly depending on the cookstove technologies and methodologies involved. Many of these methodologies have relied on outdated scientific approaches or data.

Moreover, the multiple methodologies currently in use, and the disparities in how they assess the ERs from cooking energy transitions, have generated the risk of project proponents choosing the methodology that will maximize credit issuance rather than one that will provide the most robust and reliable results. Such practices not only undermine the credibility of clean cooking carbon projects but also compromise the potential climate, health, and livelihood benefits that these projects deliver.

The CLEAR methodology helps to address these concerns by incorporating the latest science on key parameters and increasing the requirements for substantiating the input parameters that make the most difference in estimating ERs from clean and improved cooking projects. Moreover, this new methodology covers all common cooking transition scenarios, and it has been developed as a public good available for use by any standards body or bilateral/multilateral agreement. As such, the CLEAR methodology is intended to become the standard methodology for cookstove projects under Articles 6.2 and 6.4 of the Paris Agreement, and across the voluntary carbon market, increasing consistency across the clean cooking carbon landscape.

3. Methodology Approaches

This document presents justification, supporting arguments, and evidence behind key requirements of the CLEAR methodology, with the aim of ensuring clarity and transparency. Topics are organized in alphabetical order. For each topic, a summary of key requirements is provided, followed by a rationale explaining the reasoning behind them. Where applicable, additional background information and responses to specific stakeholder questions are also included.

Additionality – Common Practice

Summarized CLEAR Approach

Project activities using the CLEAR methodology shall demonstrate that the project technology has a market penetration of no greater than 30%, excluding carbon financed activities.

Rationale/Justification of CLEAR Approach

There is very little evidence on which to base the establishment of a common practice threshold for clean cooking technologies and/or fuels. However, a key indicator of common practice is the emergence of a self-sustaining market. A general rule of thumb suggests that a 20% market penetration can represent the tipping point for innovations to become self-sustaining. However, for cookstoves in low- and middle-income countries (LMICs) the needed penetration is likely to be significantly higher. This is due to several compounding factors, including the lack of distribution and knowledge networks connecting urban and rural areas, the relatively small middle-class consumer segment with disposable income, higher degrees of inequality in countries with a clean cooking gap[1] [1] and the fact that people who live in poverty have higher aversion to risk than people who don't, and as such are less likely to adopt new behaviors or technologies [2].

Given these constraints, a 30% market penetration threshold is a conservative context-appropriate estimate for when clean cooking technologies might begin to approach common practice in LMIC settings.

Additionality – Financial Analysis

Summarized CLEAR Approach

Project activities using the CLEAR methodology shall demonstrate that the project activity would not have occurred without carbon credit revenues and that such revenues enable project implementation by improving financial viability.

As part of this demonstration, project proponents must:

- Identify and describe relevant barriers faced by the proposed activity, and provide supporting evidence such as independent studies, publicly available surveys, or interviews with relevant stakeholders.
- List and describe parallel sources of funding for cooking energy transitions available within the project boundary and explain why they do not apply to the project activity. If they do apply, they must be considered in demonstrating the project's dependence on carbon credit revenues.

Rationale/Justification of CLEAR Approach

The CLEAR methodology requires that project proponents include financial viability information and a barrier analysis to align with UNFCCC Article 6.4 guidance on additionality [3].

CLEAR does not require an investment analysis (i.e., simple cost analysis, benchmark analysis, or investment comparison analysis) because such approaches are not feasible or appropriate for the majority of cookstove project activities the CLEAR methodology is designed to credit for the following reasons:

- As defined by UNFCCC [3], a simple cost analysis requires demonstrating that the implementation of the carbon project is associated with costs and does not generate any cost savings or revenues other than from carbon credits. This is not suitable for cookstove projects, as many generate modest revenues, such as partial cost recovery from cookstove or fuel sales. While these revenues are generally insufficient to make the project financially viable, they would disqualify the project under a simple cost analysis, even though the project still depends on carbon finance to exist or scale.

[1] LMICs have lower Gini coefficients than the high-income countries where the 20% threshold is observed.

- Benchmark analysis involves comparing a project's financial performance against a financial benchmark, such as the internal rate of return. However, cookstove projects often lack clear, centralized cash flows and are not implemented with the goal of achieving a financial return. Many are implemented by non-profit entities or social enterprises, which focus on public health and environmental outcomes rather than profit maximization.
- Investment comparison analysis requires comparing the project's financial attractiveness against alternative investment options. Similar to the benchmark analysis, this is not relevant in the clean cooking sector, where most projects are not structured as commercial investments and do not compete with alternative profit-generating options. Many projects are public-good interventions designed to address energy access, health, and climate challenges, not maximize financial return.

Applicability

Summarized CLEAR Approach

The CLEAR methodology can be applied to nearly all cooking energy transitions that result in greenhouse gas (GHG) ERs. To qualify to use this methodology, projects must meet certain criteria , including that all biomass-burning project cookstove models must be tested for thermal efficiency using the International Organization for Standardization (ISO) Standard 19867-1:2018 [4]. The test must be done three times for artisanal stoves, and once per stove type for all other stoves. For wood-burning project technologies that use a griddle surface (e.g., plancha cookstoves for making tortillas), the thermal efficiency requirement is 20% or higher. Project cookstoves burning charcoal must achieve 30% or higher. All other biomass-burning project cookstoves must achieve 25% or higher.

CLEAR is applicable to both Continuously Tracked Energy Consumption (CTEC) projects and non-CTEC projects; each category has its own approaches and requirements as detailed in the relevant sections of the methodology and this document.

Of note, as of June 2025, CLEAR provides guidance for household projects only. It is also intended for use for institutional cookstove projects, and some CTEC commercial cookstove projects; guidance for how to apply CLEAR to these scenarios is underway as of June 2025.

Rationale/Justification of CLEAR Approach

The CLEAR methodology includes a minimum thermal efficiency requirement for biomass project stoves to ensure a minimum level of performance and exclude low-quality project technologies, which is necessary to meet the directive for continually raising ambition under the Paris Agreement.

This requirement applies only to biomass stoves because stoves using fuels like liquified petroleum gas (LPG), bioethanol, and electricity can reasonably be expected to have thermal efficiencies of at least 40%. This is due to the properties of the fuels they combust and because they are mature technologies produced using advanced manufacturing processes, and generally uniform in design. Wood and charcoal stoves, by contrast, have enormous ranges of thermal efficiency performance, which is why the testing requirement applies to just this category. Requiring that LPG, bioethanol, and electric stoves be tested to ensure thermal efficiencies of 25/30% would introduce burdens to project proponents with no added benefit.

ISO testing for thermal efficiency is accessible through stove testing labs around the world (list available here). Unlike emissions testing, thermal efficiency testing is a straightforward process and does not require specialized or expensive equipment. While ISO thermal efficiency testing may present a (small) burden for some project proponents, similar quality assurance measures are standard practice in other sectors, and it is a necessary requirement to ensure that households don't receive inferior products as part of carbon project activities.

Baselines – Default Energy Consumption

Summarized CLEAR Approach

The CLEAR methodology provides two options to determine baseline fuel consumption for non-CTEC projects. The first option is to use a global default value, and the second option is to conduct a baseline Kitchen Performance Test (KPT). Determining baseline fuel consumption based on surveys alone is not allowed.

The global default for baseline fuelwood consumption is 0.5 tonnes/(person*year), and the default for charcoal is 0.1 tonnes/(person*year).

Rationale/Justification of CLEAR Approach

Both the global default for baseline fuelwood consumption (0.5 tonnes/(person*year)), and the global default for charcoal (0.1 tonnes/(person*year)) are based on published independent KPT studies [sources 5-16].

Based on the latest available evidence, 4C considers the 0.5 tonnes air dried wood per person*year baseline default value for fuelwood consumption to be conservative while still accounting for suppressed demand[2] [17]. In the context of cookstove carbon projects, accounting for suppressed demand means using a default baseline fuel consumption value that represents the amount of cooking fuel necessary to provide for basic human needs rather than the actual amount of fuel used for cooking, which may be lower than the default. The 0.5 tonnes/(person*year) baseline default value is set at the minimum per-capita energy consumption required for cooking to meet basic human needs.

The 0.5 tonnes/(person*year) value is equivalent to 0.0078 TJ/(person*year) assuming 0.0156 TJ/tonne of wood (see Appendix 5 of CLEAR methodology), and 0.00117 TJ of

[2] Suppressed demand is a situation where services provided to a population are insufficient to meet the basic human needs due to barriers, such as low income or lack of infrastructure, and where the growth of emissions resulting from meeting such needs requires special consideration in the assessment of baseline scenarios.

useful energy delivered per person*year assuming a thermal efficiency of 15% for baseline wood cookstoves.

The baseline default values are different for wood and charcoal because, as shown in Figure 1 below, in urban settings, where charcoal is more commonly used, the estimated charcoal consumption per person (0.0041–0.0055 TJ/(person*year) corresponds to an energy delivered value of approximately 0.0010–0.0014 TJ/(person*year) (assuming a thermal efficiency of 25% for baseline charcoal stoves). This is similar to the default assumption for basic cooking needs, which is 0.0012 TJ/(person*year). The slightly lower energy delivered values in urban areas, compared to rural wood users (who average 0.0016 TJ/(person*year)), are attributed to urban households relying on a diverse set of food sources. These may include meals from vendors or restaurants, school feeding programs, and other prepared food options, which reduce the amount of energy required for cooking at home.

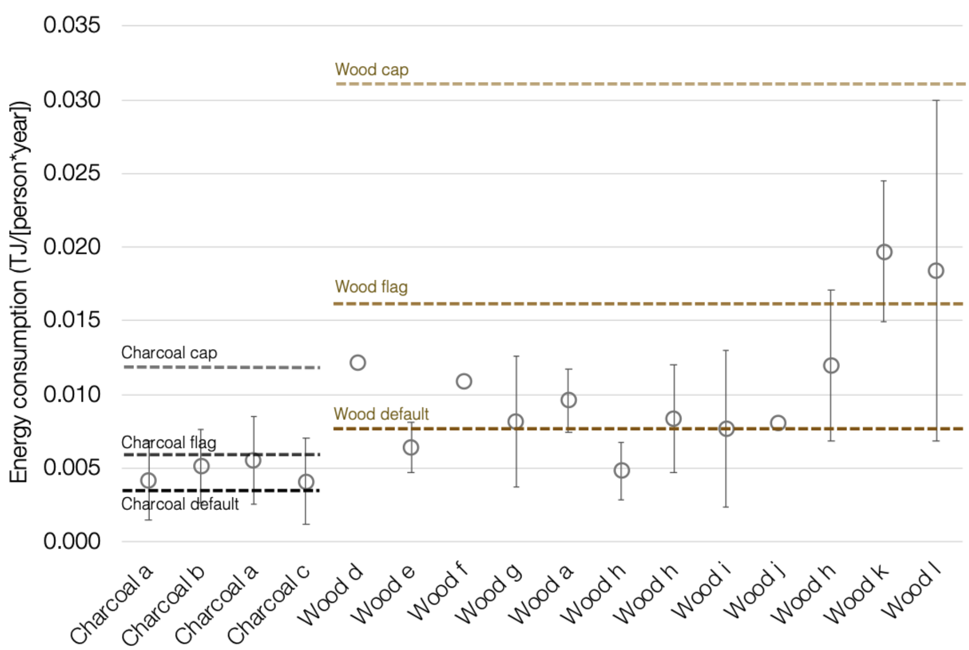

Figure 1. Differences in wood and charcoal consumption per person.

Baselines – Energy Consumption Caps and Flags

Summarized CLEAR Approach

For primary fuelwood users, baseline energy consumption values (estimated with the KPT or back-calculated) are capped at 0.031 TJ useful energy delivered/(person*year), equivalent to 2.0 tonnes/(person*year) of air-dried wood or a combination of wood and any other additional baseline fuels. Values above 0.016 TJ useful energy delivered/(person*year), equivalent to 1.0 tonnes/(person*year) of air-dried wood and additional baseline fuels are flagged for additional justification.

For baselines with charcoal as the primary fuel use, the cap is set at 0.012 TJ useful energy delivered/(person*year), equivalent to 0.40 tonnes/(person*year) of charcoal, and values above 0.0059 TJ useful energy delivered/(person*year) (0.20 tonnes/(person*year)) are flagged for further justification.

Rationale/Justification of CLEAR Approach
The CLEAR methodology bases its baseline cap and flag values on published independent KPT studies [sources 5-16 listed in references section], and they are supported by Figure 1 above which also demonstrates their relationship to the default values of energy consumption.

Baselines – Evolving

Summarized CLEAR Approach
CLEAR does not require comparison of project and non-project households to identify changes external to the project that could impact the project baseline over the course of the crediting period.

For projects with KPT baselines, the CLEAR methodology addresses potential over-crediting resulting from a mismatch between the fuel types, fuel mix proportions, and household sizes documented during the baseline scenario survey and those reported by actual project households during the first project usage survey, relying on retrospective questions of project households during the first usage survey in any given household.

Where a material discrepancy is revealed, project proponents must either not claim ERs for households that do not conform to the baseline scenario profile or follow requirements on adjusting the baseline (toward lower baseline emissions). If no mismatch is identified, the baseline shall be recalculated at the start of each crediting period (every 5 years at a maximum).

Rationale/Justification of CLEAR Approach
The five-year crediting period is short enough that CLEAR does not consider there to be a material risk that changes external to the project will impact the project baseline over the course of the crediting period, given the pervasive nature of lack of access to clean cooking solutions. This assumption is supported by current evidence, including World Health Organization (WHO) published estimates of past, current, and projected future household energy choices in LMICs. Their data indicate that throughout sub-Saharan Africa, for example, primary household fuel choices are evolving such that per capita emissions have increased in the recent past and will continue to increase through 2030.

A more immediate concern is that a project may end up with project households that do not conform to the baseline scenario profile, especially where households are not recruited, but rather self-select through technology purchases. As such, CLEAR provides guidance for identifying and addressing such mismatches.

Baseline Scenario Survey

<u>Summarized CLEAR Approach</u>

Under the CLEAR methodology, all CTEC and non-CTEC project proponents that use the KPT to measure baseline fuel consumption must apply a baseline scenario survey to the target population at the project design stage to:

- Establish household size,
- Identify cooking fuels and technologies used (by asking "How many times did you cook using [cooking device] yesterday?",
- Document the percentage of cooking events carried out on each fuel/technology combination,
- Capture seasonal or other variation in fuel mix (see Seasonality section below),
- Understand the impact (if any) of space heating on fuel consumption (see Seasonality section below), and
- Support common practice analysis.

Projects with KPT baselines must use this data to identify any mismatch between values documented during the baseline scenario survey and those reported by actual project households during the first project usage survey for primary fuel type and household size (see "Baselines – Evolving" section above).

<u>Rationale/Justification of CLEAR Approach</u>

The use of a baseline scenario survey allows project proponents to design the project around the needs of target project households, and as noted above, to identify mismatches between the target project households and actual project households.

To identify the cooking fuel and devices in use at the household, there are tradeoffs between asking about "yesterday" (which may not be a representative cooking day but is easiest to remember accurately) and "last week" (which may be more representative but is influenced by recall bias). The bias of "yesterday" not being a representative cooking day in some households can be offset through sampling, whereas recall bias cannot. The methodology uses "yesterday" for this reason.

Emissions – Leakage

<u>Summarized CLEAR Approach</u>

The CLEAR methodology requires that projects apply either a default adjustment factor of 2% to the ERs to approximate leakage emissions or evaluate the relevant potential sources of leakage and provide an evidence-based description and estimated quantification of each potential source and its relevance for the project.

<u>Rationale/Justification of CLEAR Approach</u>

The Table below presents the potential sources of leakage for cooking energy projects identified in the CLEAR methodology, as well as their evidence base and the rationale for the required action to address each source.

Source	Scenario description	Impact on ERs	Evidence base	Notes	Required action
Baseline equipment transfer	When a household primarily reliant on fuelwood or charcoal at baseline receives a more efficient biomass cookstove, they may sell or gift their baseline cookstove to a household outside the project boundary.	None	Sector expertise	In the LMIC context, projects promoting more efficient biomass cookstoves are almost always replacing three stone fires or very rudimentary traditional cookstoves. As these types of cookstoves are ubiquitous, there is no incentive to move them to a household outside the project boundary.	No leakage adjust-ment needed
Baseline equipment transfer	When a household using an efficient biomass cookstove at baseline benefits from a fuel-switch program, they may sell or gift their existing biomass cookstove to a household outside the project boundary.	Likely positiv e	Sector expertise	A household with a higher quality improved biomass cookstove that they no longer need might sell or gift it to a household outside the project boundary. Experience suggests the receiving household would only adopt such a cookstove if their baseline cookstove was a three stone fire or low performing biomass cookstove. This would create a positive impact on ERs.	No leakage adjust-ment needed
Baseline equipment transfer	When a household using biogas, ethanol, electricity, or LPG at baseline benefits from a program promoting a different one of these clean fuels, they may sell or gift their existing clean	Likely positiv e	Sector expertise	In the LMIC context where biomass cooking remains such a significant source of climate pollution relative to other cooking fuels, it would be extremely unlikely for a project proponent to propose this activity. It is further very likely that this case would result in a positive ER impact, as the relocated cookstove	No leakage adjust-ment needed

	cooking system to a household outside the project boundary.			would likely reduce emissions in its new location given the prevalence of biomass across the LMIC context.	
Competition for resources	When woodfuel use is reduced due to project activity, it may result in a decrease in wood harvesting outside the project boundary. The woody biomass left intact due to the project activity may be harvested by households outside the project boundary to increase their use of biomass for cooking beyond subsistence levels. It may also be harvested by fuel producers or other industrial actors.	Negative	Gill-Wiehl et al., in preparation, 2025 [18]	The existing evidence (which only covers the rural context) suggests that leakage from an increase in household cooking outside the project boundary is less than 1%. Commonly in the LMIC context, the household cooking volume is limited by the availability of food and water as well as access to refrigeration in addition to the availability of fuel. In many cases, it is unnecessarily burdensome to require a project proponent to determine the magnitude of this leakage. It may be measurable if the baseline fuel source is a well-defined area. However, in the urban context, chain of custody data is almost never available for charcoal, which is frequently produced illegally and commonly transported further than fuelwood.	Projects reducing biomass use or replacing biomass used in the baseline shall measure leakage from affected biomass sources or apply a 2% discount.
Competition for resources	A project produces pellets or briquettes for cooking fuel from agricultural waste, which reduces the natural fertilizer on agricultural land and results in an	Likely negative	Sector expertise	We have not found any evidence of this situation. For it to occur, the profit gained from selling agricultural waste as fuel feedstock would have to exceed the cost of synthetic fertilizer, which is highly unlikely in the LMIC context.	No leakage adjust-ment needed

	increase in synthetic fertilizer.				
Competition for resources	If a project facilitates the electrification of multiple large institutional kitchens in the same community, it could cause the affected utility to adopt load-shedding measures among residential customers cooking with electricity, causing them to substitute more polluting fuels, such as biomass, for cooking.	Likely negative	Sector expertise	For material leakage to occur, a significant portion of households would need to already be cooking with electricity. This is not common in the current LMIC context.	No leakage adjust-ment needed.

While project proponents may choose to evaluate and quantify leakage based on project-specific evidence, this can be complex and resource-intensive. A conservative default leakage value of 2% is provided as a pragmatic and conservative approach.

Previously, methodologies relied on a default leakage deduction of 5% due to a lack of published data to guide a more precise requirement. However, a recent analysis of leakage from rural cookstove projects [18] studied the primary leakage risk for cookstoves, which is the risk that non-project households will use more fuelwood made available by neighboring project households using less. This research estimated leakage from multiple rural cookstove projects at around 0.53%. The 2% default offers a conservative margin to cover all leakage risks across both urban and rural contexts, while allowing flexibility for projects that can provide more precise quantification.

Emissions – Lock-in

The CLEAR methodology assumes that improved cooking technologies have a technical or operational lifetime of no more than 10 years, and as such no lock-in risks are assumed, per guidance from UNFCCC [3].

Emissions – Upstream

Summarized CLEAR Approach

Upstream emissions from the production, processing, transportation, and distribution of cooking fuels are included in the emissions accounting for all cooking fuels used in the baseline and project scenarios. Conservative default values are used in the CLEAR methodology.

Rationale/Justification of CLEAR Approach

The profiles of upstream emissions of various cooking fuels vary widely in the field, depending on characteristics like moisture content, fuel type, sourcing of feedstock, characteristics of production, etc. Some methodologies have made upstream emissions accounting optional, contributing to the risk of over-crediting from cookstove carbon projects.

In the CLEAR methodology, to ensure accurate and credible ERs, upstream emissions must be accounted for consistently in both baseline and project scenarios. Omitting these emissions in either case introduces asymmetry in the calculation, which can lead to overestimation of climate benefits. While the impact of upstream emissions can vary depending on factors such as fuel type and sourcing, applying a consistent and conservative approach helps mitigate the risk of distortion across diverse project contexts.

Fraction of non-renewable biomass (fNRB)

Background

Over time, UNFCCC and voluntary carbon-crediting programs have modified their methodologies to improve the approaches for determining fNRB. As of 2024, project proponents had two options: (a) use a default value of 30%; or (b) calculate project-specific fNRB values using UNFCCC's "TOOL30 Calculation of the Fraction of Non-Renewable Biomass," which was first released in 2017 and has been refined several times since.

Over time, it has become apparent that the global default fNRB value of 30% has seldom been applied in cookstove carbon projects. Instead, most projects have opted for using TOOL30, which yields significantly higher fNRB values. Projects have used values as high as ~90%, which implies that wood is being harvested at 5-10 times the rate at which forests and woodlands regenerate nationwide [19]. High fNRB values have been identified as one of the main sources of over-crediting in cooking carbon projects.

Stakeholders have also suggested that fNRB would be more accurately expressed as a marginal quantity rather than an average. Historically, fNRB has been calculated as a national average (or at sub-national administrative units), assessing the balance between how much wood is harvested and how much it regrows under standard conditions, over several years. A marginal approach to fNRB would focus on the change in woodfuel renewability due to the specific change a project makes in wood harvesting. Additional research and modeling are required to determine whether the marginal approach is consistently reliable and relevant.

Summarized CLEAR Approach

The CLEAR methodology requires the use of fNRB values derived from the Modeling Fuelwood Savings Scenarios (MoFuSS) model and disallows the use of TOOL30.

Project proponents have three options to determine fNRB under the CLEAR methodology, all using the MoFuSS model:

- Latest national or sub-national default values from the MoFuSS model published by UNFCCC;
- Customized project area (not aligned with national or subnational boundaries) using the online MoFuSS Default Scenarios (MoFuSS-DS) interface; or
- Where applicable, project proponents may run their own MoFuSS model using their own rigorously validated inputs.

MoFuSS developers are currently exploring the implications of using a marginal approach to estimating fNRB. If UNFCCC determines that a marginal approach to calculating fNRB is allowable, MoFuSS may be used to calculate marginal fNRB for a given project under the CLEAR methodology.

Rationale/Justification of CLEAR Approach

Developed by SEI and National Autonomous University of Mexico (UNAM), MoFuSS is a peer-reviewed, bottom-up spatial model that can be aggregated to any level, allowing for fNRB estimates to be made for any administrative unit (districts, counties, states, provinces, etc.) as well as project-specific areas that cut across administrative boundaries. In addition, the model relies on harmonized global datasets that are regularly updated, which make it easy to periodically update the fNRB defaults [20].

MoFuSS runs multi-year simulations, which allow users to compare intervention and non-intervention scenarios that incorporate dynamic variables like population growth, urbanization, and land cover change. In addition, though it requires some expertise to run, MoFuSS is built with freely available software using open-source code, making it transparent and accessible. An online user-friendly version of MoFuSS is under development and expected to be publicly available in the second half of 2025.

At the Clean Development Mechanism (CDM) Executive Board (EB)'s 125th meeting in June 2025, it made a decision to withdraw TOOL30, effective as of January 1, 2026. This is consistent with the recommendations from the Integrity Council for the Voluntary Carbon Market (ICVCM) [21].

The EB also approved default regional and national values of fNRB derived from the peer-reviewed MoFuSS model, now included in "TOOL33: Default values for common parameters" and opened a pathway for further approval of approaches to determining sub-national and project-level fNRB values, such as through MoFuSS.

CLEAR does not allow the use of the 30% global default for fNRB because available regional and national default values are more accurate and encourage the development of projects in locations where they can have the most impact.

Hawthorne Effect

Summarized CLEAR Approach

To adjust for any potential Hawthorne effect (i.e. a household may increase their use of the project stove when the KPT is being performed due to social desirability bias), the CLEAR methodology requires that non-CTEC projects either cap their ERs at 75% of what the project KPT-based estimate would be, or measure any effects directly with stove use monitors (SUMs), comparing stove use during the KPT to the month before or after. If a potential Hawthorne Effect is measured using SUMs (meaning SUMs don't show sustained project stove use), ERs will be adjusted proportionally downward. Project proponents cannot increase ERs based on SUMs data.

Rationale/Justification of CLEAR Approach

CLEAR's 75% cap on ERs when the Hawthorne effect is not directly measured is conservative based on a review of published and gray literature. This review included recently released findings from a 2012-13 study by Berkeley Air Monitoring Group, that did not find evidence of a strong Hawthorne Effect [22], as well as others that did find evidence of the Hawthorne Effect [23].

Non-Permanence

Summarized CLEAR Approach

CLEAR does not require adjustments to ER calculations based on a potential risk of non-permanence.

Rationale/Justification of CLEAR Approach

While non-permanence is a well-established concern in nature-based carbon projects (e.g., deforestation reversals), its relevance to cookstove projects is less clear, given that these projects do not involve the direct removal or long-term sequestration of carbon into biomass or soils. Instead, they reduce emissions at the point of fuel use by avoiding the inefficient combustion of non-renewable biomass fuels such as firewood and charcoal, through the adoption of cleaner fuels and/or more efficient cooking technologies.

While cookstove projects are not removal activities, 4C understands that they may be viewed as ER activities with potential reversal (or non-permanence) risks, on the basis that biomass not harvested for cooking could later be harvested for other uses (e.g., heating or industrial/commercial applications). However, for the reasons outlined below, the CLEAR methodology does not require application of the monitoring and reporting provisions contained in the first version of the standard "Requirements for activities involving removals under the Article 6.4 mechanism" [24]:

1. **No defined carbon pool or storage to reverse**: ERs from cookstove projects occur at the moment non-renewable biomass use is avoided or reduced through the adoption of cleaner fuels or more efficient technologies. Unlike afforestation or carbon capture projects, cookstove projects do not create or maintain a physical carbon stock (e.g., in trees or soils) that could later be lost due to a fire, pests, or other disturbances. Therefore, the risk categories listed in section 4.6.1 of the "Requirements for activities involving removals under the Article 6.4 mechanism" standard (ranging from asset ownership and regulatory uncertainty to natural disasters) may affect project continuity or cookstove adoption rates, but they do not create the possibility of a reversal of ERs already achieved. If cookstove use declines in the future, it simply reduces or halts future ERs; it does not undo the climate benefit already achieved.
2. **Indirect and diffuse impacts**: The impact of clean cooking projects on biomass stocks is often diffuse and spread across wide, indeterminate geographic areas. This situation is especially common for projects that displace charcoal in urban or peri-urban areas, where biomass is sourced from multiple production areas serving multiple markets. This complex and opaque supply chain makes it infeasible to delineate specific zones where potential reversals could be measured or monitored.
3. **No practical pathway for reversal risk monitoring**: Effective reversal risk monitoring would require establishing a causal relationship between cookstove adoption and observed changes in biomass stocks across wide and variably defined sourcing areas. Even if such areas could be precisely identified and bounded, attributing changes in biomass stock to a specific project remains highly uncertain, as biomass cover is affected by numerous concurrent human and natural factors.
4. **Focus on degradation, not deforestation**: Scientific literature indicates that nonrenewable biomass use for cooking primarily contributes to forest degradation rather than deforestation. Degradation is significantly more difficult to detect and monitor (even without considering the diffuse boundaries and attribution challenges described above). Demonstrating measurable impact on degradation would require the use of sophisticated remote sensing techniques with extensive ground truthing and/or the creation of semipermanent plots in both project and non-project areas. Both of these options require specialized knowledge and investment that are prohibitively resource-intensive for most project proponents.
5. **CLEAR methodology already integrates permanence considerations**: The CLEAR methodology requires the application of a scientifically derived and periodically updated fNRB value to ER estimates. The fNRB value reflects the balance between tree offtake and regeneration, meaning that ERs are only credited for the portion of biomass that would not have regrown without the project activity, implicitly addressing non-permanence/potential reversal risks.

> This approach ensures that credits represent real, non-temporary climate benefits and negates the need for impractical use of a buffer pool or additional reversal safeguards.

As of June 2025, the Article 6.4 Supervisory Body is considering exempting cookstove projects from removals monitoring and reporting requirements, as suggested by the Article 6.4 Methodologies Expert Panel [25].

Project – Direct Measurement Requirements

Background
Cookstove carbon methodologies have allowed the use of surveys and self-reported usage as a basis for ER calculations, raising concerns that the displacement of baseline technologies may be overestimated.

Summarized CLEAR Approach
Under the CLEAR methodology, project energy consumption must be measured directly through KPTs (a field-based assessment used to estimate household fuel consumption under real-world conditions), or continuously tracked, as detailed below. Survey-only approaches for measuring fuel consumption are not allowed. Annual usage surveys are applied to monitor any changes in household size or fuel mix, and to confirm ongoing use of the stove.

CTEC projects: CTEC projects continuously measure fuel or energy consumption directly on all project technologies and in all project households (no sampling allowed) using built-in or external data loggers (also known as metering), or through fuel sales records.

Non-CTEC projects: Non-CTEC projects are those that do not use metering or fuel sales to directly measure project energy consumption in all project households. To determine project fuel consumption, non-CTEC project proponents must conduct a project KPT, which may be done on only a subset of sites. The use of surveys only to determine project fuel consumption is not allowed.

Rationale/Justification of CLEAR Approach
Surveys and self-reported usage are often unreliable methods for estimating the displacement of baseline cooking technologies due to several factors that can bias participants' responses. When asked about their use of a new cookstove provided by a carbon project, participants may over-report its usage due to social desirability bias, where they want to please the surveyors or align with the perceived objectives of the project. Project participants may also believe that reporting higher usage could influence future benefits, such as additional support or upgrades from project sponsors. Furthermore, self-reported data can suffer from recall bias, as participants may not accurately remember or may overestimate the frequency and duration of their use of the new cooking technology. These biases lead to an inflated perception of displacement of traditional cookstoves, obscuring the actual adoption and impact of the intervention cookstoves. Thus, relying solely on survey data and self-reports

can result in a misleading assessment of the success and environmental impact of such interventions.

For these reasons CLEAR disallows the use of self-reporting for fuel usage and requires direct measurements in all cases, whether through metering, fuel sales data or KPTs with Hawthorne Effect adjustments.

Project Technology Days (PTDs)

Summarized CLEAR Approach

The CLEAR methodology includes requirements for what constitutes a user:

- A user is defined as a project participant with a functioning cookstove that is in use once or more per week during a given monitoring period, confirmed through both self-reporting (annual usage surveys) and visual inspection. This determination indicates whether the household can be included as part of the project, and is not used to calculate fuel consumption for that household.
- PTDs indicate the number of days for which project technologies are available (at the participant's household, within the project boundary, and functioning) and in regular use (once or more per week) during a given monitoring period. This parameter is used for non-CTEC projects only.

The CLEAR methodology includes caps on the number of PTDs based on whether the project provides certain customer support actions described in the methodology. For a non-CTEC project to be eligible to claim up to 90% of maximum PTDs, the project proponent must take the customer support actions described in the methodology and provide details of how each condition has or will be met on the Project Information Cover Sheet during the design phase of the project. Project proponents who do not undertake all the customer support actions may claim up to 75% of maximum PTDs.

For non-CTEC projects, fuel consumption calculations are a function of household size, KPT-derived energy consumption, and PTDs. For CTEC projects, fuel consumption is measured continuously in all project households, so the PTD parameter does not apply.

Rationale/Justification of CLEAR Approach

While CLEAR's minimum threshold of cookstoves being in use once per week is not highly frequent, it is considered sufficient to indicate regular ongoing use and provides a consistent definition for all projects. This threshold provides a practical criterion for determining whether a household is included in ER calculations. Importantly, this "user" designation does not affect how much fuel consumption is attributed to the household. To calculate ERs, non-CTEC projects still also need to measure the actual fuel consumption of included households via KPTs.

The two caps on the total number of PTDs non-CTEC projects can claim when calculating their baseline and project emissions reflect higher expectations of sustained use in cases where customer support actions are undertaken.

The PTD caps of 90% (for projects with customer support) and 75% (for those without) are justified by the fact that KPTs directly measure household fuel consumption under real-world usage conditions. Because KPTs reflect actual cookstove use, including the effects of partial adoption and stacking with other technologies, any underutilization of project cookstoves is already accounted for in the fuel consumption estimates. The cap limits the number of days over which these savings can be applied, providing a conservative constraint that aligns the number of cookstove-days claimed with what is realistically observed through direct fuel use measurements. These caps are also in alignment with similar Gold Standard guidance from "Requirements and Guidelines: Usage rate Monitoring" (v2.0), which states that usage rates are capped at 75% when using only mandatory monitoring practices, and 90% when using best practices [26].

Rebound Effect

To date, there is very little evidence in the published literature of rebound effects in cookstove projects. Most cookstove carbon projects operate in LMICs where food insecurity and poverty are often also present, suggesting that fuel cost and/or availability is not necessarily the primary driver for cooking quantities.

The CLEAR methodology addresses potential rebound effects by requiring direct fuel consumption measurements either through KPTs or continuously tracked project energy consumption. KPTs further account for stacking by measuring all fuels and stoves in the household.

Sampling

Summarized CLEAR Approach
The CLEAR methodology requires that all monitored parameters meet a 95/10 precision guideline, meaning that the 95 percent confidence interval must be no greater than 10 percent of the estimated mean or proportion. This precision requirement strengthens the statistical rigor of monitoring compared to earlier methodologies, which often used a 90/10 guideline (wider confidence intervals). By increasing the confidence level to 95 percent, the CLEAR approach reduces uncertainty in key parameters used for emissions calculations. If a monitored parameter does not meet the 95/10 precision guideline, project proponents must either conduct additional sampling or apply the conservative lower bound of the confidence interval when calculating ERs.

The CLEAR Sampling Appendix provides practical and statistical guidance to meet this requirement. It outlines appropriate sampling strategies, including both simple random sampling and cluster sampling, depending on the characteristics of the study population and logistical constraints. The appendix also details methods for determining required sample sizes for proportional parameters, such as the percentage of cooking events using a primary fuel or stove, and for continuous parameters, such as household energy consumption. For continuous variables, the methodology incorporates statistical approaches that account for skewed data distributions, which are common in household energy use patterns. To further promote consistency and safeguard against underpowered studies, the methodology sets conservative minimum sample sizes even when the 95/10 guideline is achieved with smaller samples.

Rationale/Justification of CLEAR Approach

Proportional Variables: For parameters that represent proportions, such as the percentage of households using a primary fuel or the fraction of homes using the project stove at least once per week, the number of samples required to meet the 95/10 precision guideline could be considered modest. These modest sample sizes occur because the statistical variability of proportion estimates is mathematically constrained. Variance in proportion estimates is highest when the proportion is around 50 percent and decreases as the proportion approaches either 0 percent or 100 percent. As a result, fewer samples are needed to achieve high precision when the proportion is extreme.

The CLEAR methodology includes lookup tables based on simple random sampling that illustrate the relationship between expected prevalence and required sample size. These tables show that even for proportions near 50 percent, a sample size of around 100 to 120 households is typically sufficient to achieve 95 percent confidence within 10 percent relative precision. For proportions near the extremes, the required sample size may be even smaller.

Despite the statistical sufficiency of these smaller samples, the CLEAR methodology sets a minimum sample size of 200 households for all proportional parameters. This minimum helps ensure that results are resilient to unanticipated variation, facilitates subgroup analysis, and promotes consistent standards across projects.

Continuous Variables: For parameters that are continuous, such as baseline energy consumption per person, average daily stove use, or specific energy consumption per kilogram of food, required sample sizes depend on the variability of the data and the desired level of precision. In household energy studies, these continuous variables often have positively skewed distributions, meaning that some households may exhibit much higher values than others.

To accurately reflect this variability, the CLEAR methodology uses skew-normal distribution theory when determining sample size requirements. This approach accounts for the asymmetry in real-world data and avoids underestimating sample size, which can occur if normality is incorrectly assumed.

The methodology provides lookup tables and algorithms for determining sample sizes based on the coefficient of variation, precision target, and assumed skewness. In addition, a minimum of 50 households is required for continuous parameters such as KPTs and stove use monitoring. This minimum accounts for potential data loss, measurement error, or within-group similarity that might otherwise reduce the effective sample size.

Mathematical background theory on the above approaches is provided in [Appendix 1.]

Seasonality

Summarized CLEAR Approach

The CLEAR methodology incentivizes transparency and accounts for potential seasonal variation in fuel use by requiring that prior to project validation, non-CTEC and CTEC projects using the KPT to measure the baseline must also use the baseline scenario survey to collect data on the relative fuel use at different times of the year.

The following question (or an appropriate variation) must be asked, "Relative to the amount of fuel you used this week, are there other times of the year when you use more fuel? If so, when? And/or less fuel? If so, when?"

Project proponents are required to incorporate the resulting information into their monitoring plan design and to justify on the Project Information Cover Sheet how the approach they are taking will result in accurate baseline and project fuel use measurements. If space heating is common in the project area, the justification must include an explanation of how space heating has been addressed in the project design. If an accurate approach cannot be taken, then the project proponent must instead select and justify a conservative approach.

Rationale/Justification of CLEAR Approach

Fuel consumption patterns can vary by season (including due to weather, holidays, migration patterns), and seasons themselves vary by location. Even within a single location, fuel consumption can cycle through multiple seasonality-related patterns in a given year, making monitoring in every season logistically impractical. It is also not possible to select a season for monitoring that is uniformly conservative in all cases.

Given very different project contexts, no methodological monitoring plan can prescribe guidelines that cover all seasonality-related fuel consumption variability in all locations, so CLEAR takes the approach of requiring data collection and transparency on potential seasonality-related variations in fuel consumption patterns.

Uncertainty

Summarized CLEAR Approach

The CLEAR methodology addresses uncertainty through a combination of conservative defaults and in-situ measurements and by requiring transparency and justification for all parameter inputs, assumptions, and decisions. This is done by requiring all project parameters utilized to be listed on a Project Information Cover Sheet at the time of project design and updated at the time of each issuance.

CLEAR also includes extensive sampling guidelines for all monitored parameters (included as Appendix 10 in the CLEAR methodology), which clearly explain the type of variable (proportional or continuous variables), required precision, minimum sample size, and data collection methods (e.g., surveys, direct field measurements, or passive data-logging instruments). In addition, to support project proponents, CLEAR is linked to a web-based app that calculates sample sizes for surveys and field-based measurements.

CLEAR also describes all the parameters that must be monitored throughout the crediting period (included in section 13 of the CLEAR methodology document). This includes detailed descriptions of each parameter, the methods and frequency with which they must be monitored, and the purpose that the parameter serves. Where applicable, this section of the methodology includes specific QA/QC procedures, thresholds above or below which parameter values must be justified, and caps that parameters cannot exceed. All parameters are then listed in the Project Information Cover Sheet to facilitate external review.

Rationale/Justification of CLEAR Approach

The CLEAR methodology provides mechanisms to address over-crediting risks associated with uncertainty while balancing rigor and accuracy with the realities of the clean cooking sector.

Estimating every single cause of uncertainty in cookstove carbon projects is unfeasible for the following reasons:

1. **Complexity and number of parameters in cookstove carbon projects**. Estimating ERs from cooking energy transitions involves many different parameters, including fuel consumption, fNRB, stove use, emission factors, stove thermal efficiency, among others. These parameters draw from diverse data sources and are subject to significant variability across different contexts.
2. **Unrealistic burden on project proponents**. Requiring project proponents to estimate the uncertainty of each of these parameters is impractical, as it would require specialized expertise and considerable financial and technical resources that many proponents, particularly in low-income countries, cannot realistically access. This creates a significant barrier to participation in carbon markets. Further, the uncertainty indicators for some parameters would be provided by outside entities (e.g., for emissions factors and fNRB) and thus beyond the control of project proponents.
3. **Rigid uncertainty requirements can hamper market viability**. Several key parameters in cookstove projects are dynamic and influenced by changing user behavior. Requiring uncertainty estimations for all parameters and corresponding adjustments to ERs introduces a high degree of unpredictability. For instance, basing annual downward adjustments on uncertainty estimations would introduce unpredictability into the ex-ante estimation of ERs without ensuring greater accuracy. This unpredictability would undermine projects' ability to attract the upfront financing necessary for implementation.

Wood to Charcoal Conversion

Summarized CLEAR Approach
The CLEAR methodology uses a 6:1 conversion factor, which is incorporated into upstream emission factor values and fNRB. Nonetheless, the methodology also includes emission factors based on a 4:1 conversion factor, to enable ICVCM Core Carbon Principles eligibility.

Rationale/Justification of CLEAR Approach
While a charcoal conversion factor 4:1 is appropriate for a more industrialized context, 4C research supports a 6:1 charcoal conversion factor in the LMIC context.

In 2024, CCA and 4C partner SEI conducted a charcoal conversion factor literature review and analysis, which supports the conclusion that a 6:1 ratio is more realistic than the current 4:1 UNFCCC default. Figure 2 presents preliminary results from this analysis, which considers recent studies of charcoal conversion and loss in Sub-Saharan Africa [sources 27-33 listed in references section]. In this chart, circle size corresponds to the sample size of each study, with countries listed along the X axis. The Y axis represents conversion efficiency, with 17% corresponding to a 6:1 oven-dry wood to charcoal conversion factor. Both the mean and the median values of the individual kilns measured in the studies generally agree with the 6:1 ratio.

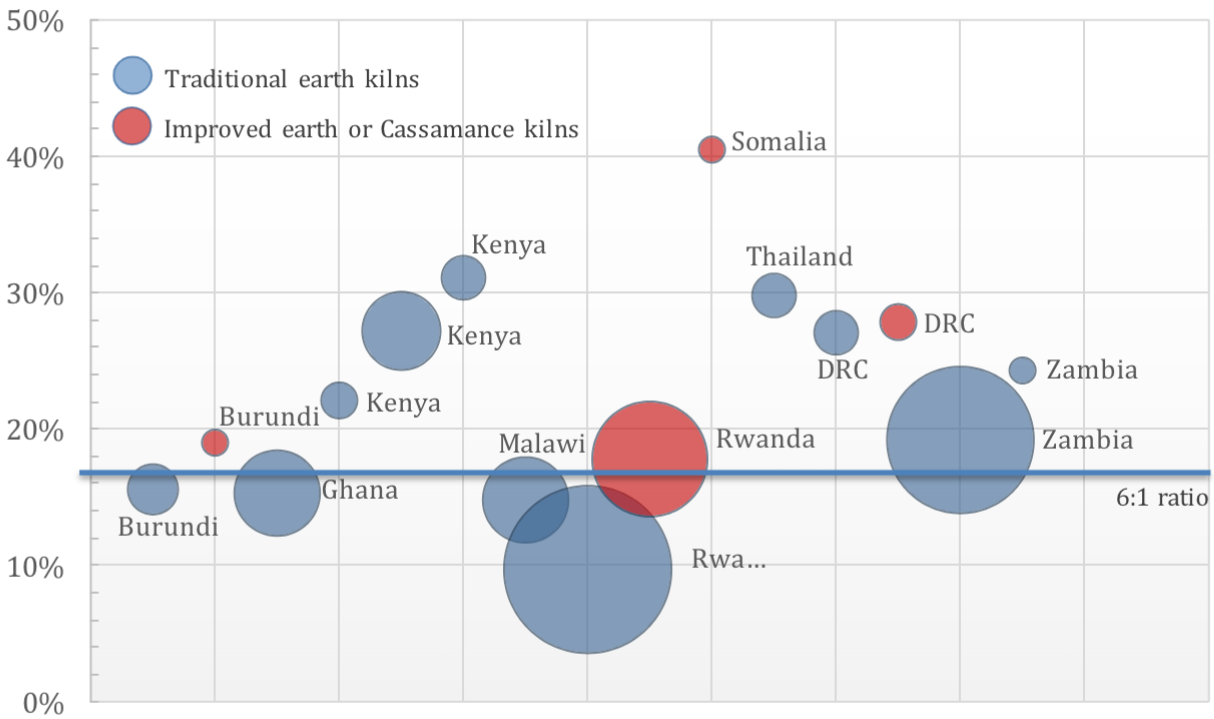

Figure 2: Preliminary analysis of traditional and improved kiln conversion factor studies.

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5. Appendix 1: Theory and background on sample sizes and precision for CLEAR

Prepared by Santu Gosh[3]
for the Clean Cooking and Climate Consortium

Background Theory

1. Sample size for estimating mean for continuous parameters.

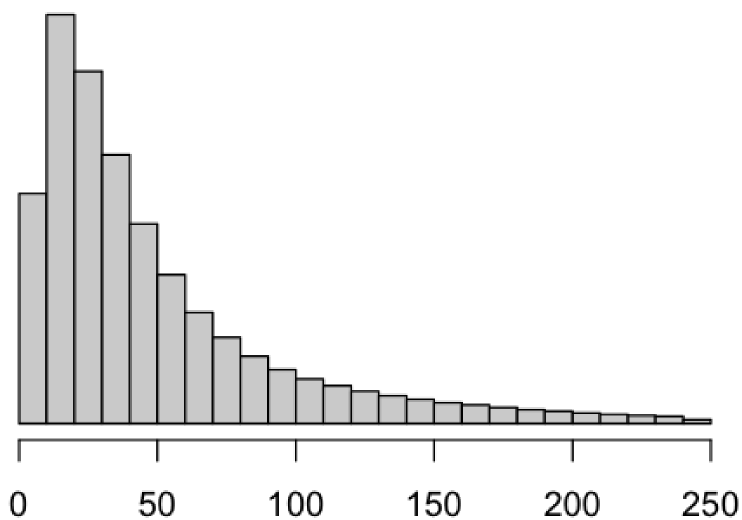

Figure 1: Distribution of duration per cooking
(similar distributions for events per day, fuel consumption, etc… could also be plotted).

Considering a positively skewed distribution of stove events per day, fuel consumption, and household size, the skew-normal probability distribution is adopted for subsequent steps.

1.1. Skew Normal Distribution

A skew normal distribution is defined by a location parameter ξ, scale parameter ω and shape parameter λ(skewness). That is if $X \sim SN(\xi, \omega^2, \lambda)$, then the pdf is

$$f(x) = \frac{2}{\omega}\phi\left(\frac{x-\xi}{\omega}\right)\Phi\left(\lambda\frac{x-\xi}{\omega}\right)$$

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The mean and variance are

$$E(X) = \xi + \sqrt{\frac{2}{\pi}}\delta \text{ and } V(X) = \omega^2\left(1 - \frac{2}{\pi}\delta^2\right)$$

where $\delta = \frac{\lambda}{\sqrt{1+\lambda^2}}$

If $Z = \frac{X-\xi}{\omega}$, then Z will follow a standard skew normal distribution $SN(\lambda)$ with pdf

$$f(z) = 2\phi(z)\Phi(\lambda z)$$

where $\phi(.)$ and $\Phi(.)$ are the standard normal pdf and cumulative distribution function respectively.

1.2. Sample size for mean

Minimum required sample size for estimating a mean is determined by

$$n = \left(\frac{Z_{1-\frac{\alpha}{2}}}{f}\right)^2, f = \frac{d\bar{x}}{s} = \frac{d}{CV}$$

where d is relative precision of the estimate and CV is the coefficient of variation.
Let assume f_1 and f_2 such that $\{|f_1|, f_2\} \leq f$ and

$$L(n) = \sqrt{n}\left(f_1\sqrt{1 - \frac{2}{\pi}\delta_*^2} + \sqrt{\frac{2}{\pi}}\delta_*\right)$$

$$U(n) = \sqrt{n}\left(f_2\sqrt{1 - \frac{2}{\pi}\delta_*^2} + \sqrt{\frac{2}{\pi}}\delta_*\right)$$

where $\delta_* = \frac{\lambda}{\sqrt{1+n\lambda^2}}$.

Then sample size n and f_1, f_2 for given f can be solved from the equation below

$$P\{L(n) \leq Z \leq U(n)\} = 1 - \alpha$$

Algorithm:
Sample size can be determined for a given confidence level, precision, CV and a guess about amount of skewness. The sample skewness can be estimated from small pilot data. In absence of a pilot data, one can approximate by $\gamma = (2 \times CV)$ which is the skewness of a gamma probability distribution considering positively skewed distribution of the cooking duration.

Step 1: Get a guess of skewness parameter λ with sample skewness (γ) as follows

$$\hat{\delta} = \sqrt{\frac{\pi}{2}\frac{\gamma^{\frac{2}{3}}}{\gamma^{\frac{2}{3}} + \left(\frac{4-\pi}{2}\right)^{\frac{2}{3}}}} \ \& \ \hat{\lambda} = \frac{\hat{\delta}}{\sqrt{1-\hat{\delta}^2}}$$

It is important to note that sample skewness can often be more than equal to 1. In such case the denominator $\hat{\lambda}$ will be undefined. To overcome this problem, the maximum theoretical skewness is obtained by setting $\delta = 1$ in the skewness equation, giving $\gamma = 0.9952717$. When using the method of moments in an automatic fashion, for example to give starting values for maximum likelihood iteration, one should therefore let $\gamma = \min\{0.99, \hat{\gamma}\}$.

Step 2: Get a guess of CV and set desired precision (d), then calculate

$$f = \frac{d}{CV}$$

Choose several pairs of $f_{ij} = (f_{1i}, f_{2j})$ such that $-f \leq f_{1i} < 0\,; 0 < f_{2j} \leq f$.

Step 3: For a given n, identify if any of the f_{ij} can satisfy

$$P\{L(n) \leq Z \leq U(n)\} \geq 1 - \alpha. \qquad (A)$$

Step 4: If no pair (f_{ij}) satisfy the above equation for given n, choose another value of n of n repeat Step 3

Step 5: continue step 4 till a combination of f_{ij} and n is found that satisfy equation(A).

Step 6: The choice of lowest n that can make at least one pair of f_{ij} satisfy equation (A) should be the required sample size.

1.3. Adjustment for cluster sampling

To adjust the required sample size for cluster random sampling over simple random sampling a design effects should be estimated by following formula

$$DesignEffect(DE) = 1 + (m - 1) \times ICC$$

where m is cluster size and ICC is the intraclass correlation. Suppose m =10 and ICC=0.05, then $DE = 1 + 9 \times 0.05 = 1.45$.

The adjusted sample size will be

$$n_{clus} = n_{srs} \times DE$$

Reference:

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R Code:

```
nsampleSN<-
function(cv=0.45,prec=0.05,conf=0.95,nmin=25,nmax=1000,nby=5,nf=15){
 f<-prec/cv
 g<-min(c(0.99,2*cv))  #Gamma
 #sk<-cv*(cv^2+3) #log normal
 d1<-0.5*pi*g^(2/3)
 d2<-g^(2/3) + (0.5*(4-pi))^(2/3)
 delta<-sqrt(d1/d2)
 lambda<-delta/sqrt(1-delta^2)
 f_hat<-NULL;N<-nmax
 nset<-seq(nmin,nmax,by=nby)
 for (n in nset){
  delta_star<-lambda/sqrt(1+n*lambda^2)
  ff<-expand.grid(-seq(0,f,length.out=nf),seq(0,f,length.out=nf))[-1,]
  for(i in 1:nrow(ff)){
   L<-sqrt(n)*(ff[i,1]*sqrt(1-2*delta_star^2/pi)+delta_star*sqrt(2/pi))
   U<-sqrt(n)*(ff[i,2]*sqrt(1-2*delta_star^2/pi)+delta_star*sqrt(2/pi))
   library(sn)
   if(psn(U)-psn(L)>=conf){
    f_hat<-ff[i,]
    break
   }
  }
  if(!is.null(f_hat)){
   N=n
   break
  }
 }
 return(N)
}
```

Precision of the estimate of Mean under skew Normal Distribution
This section explains how to calculate the precision of the mean when the underlying distribution is skew-normal rather than normal, which is assumed to be the case for the continuous parameters monitored for the CLEAR methodology. The assumption of a skew-normal distribution provides a more accurate representation of variability.

1. Skew-Normal Distribution Parameters

A skew-normal distribution is defined by three parameters:
- ξ (xi): location (analogous to the mean in a normal distribution)
- ω (omega): scale (analogous to the standard deviation)
- α (alpha): shape (controls skewness)

If X follows a skew-normal distribution, X ~ SN(ξ, ω, α), then:
- Mean: $\mu = \xi + \omega\delta\sqrt{2/\pi}$
- Variance: $\sigma^2 = \omega^2 \times \left(1 - \frac{2\sigma^2}{\pi}\right)$
- Where $\delta = \frac{\alpha}{\sqrt{(1+\alpha^2)}}$

2. Standard Error (SE) of the Mean

Given a sample size n, the standard error of the mean is:

$$SE(\bar{X}) = \frac{\left[\omega \times \sqrt{1 - \left(\frac{2\delta^2}{\pi}\right)}\right]}{\sqrt{n}}$$

3. Precision

The precision, which is the confidence width of mean, can be written as

$$p \times \bar{X} = Z_{\frac{\alpha}{2}} \times SE(\bar{X})$$

That means $p = Z_{\frac{\alpha}{2}} \times \left(\frac{SE(\bar{X})}{\bar{X}}\right)$

Algorithm:

1. Get mean ($\bar{x}$) and SD (s) from the data collected
2. Derive $CV = \frac{s}{\bar{x}}$ and get sample skewness $\hat{\gamma} = 2 \times CV$; $\gamma = \min\{0.99, \hat{\gamma}\}$
3. Derive $\hat{\delta} = \sqrt{\frac{\pi}{2}\frac{\gamma^{\frac{2}{3}}}{\gamma^{\frac{2}{3}}+\left(\frac{4-\pi}{2}\right)^{\frac{2}{3}}}}$

4. Calculate $\widehat{\omega} = \frac{s}{\sqrt{1-\frac{2s^2}{\pi}}}$

5. Calculate $SE(\bar{X}) = \frac{\left[\omega \times \sqrt{1-\left(\frac{2\delta^2}{\pi}\right)}\right]}{\sqrt{n}}$

6. Precision can be estimated by $p = Z_{\frac{\alpha}{2}} \times \left(\frac{SE(\bar{X})}{\bar{X}}\right)$ assuming degree of confidence (95% or 90%)

Why Use Skew-Normal Distribution for Sample Size Calculation Instead of Assuming Normality?

Sample size calculations typically assume a normal distribution for simplicity. However, when the underlying data are **skewed**, this assumption can lead to **inaccurate estimates**—either overestimating or underestimating the required sample size. The **skew-normal distribution** accounts for asymmetry in the data by incorporating a shape parameter for skewness.

Using the skew-normal distribution in sample size calculation helps:

- **Improve precision**: It provides a more realistic model of the population, leading to better estimates of variability and central tendency.
- **Avoid bias**: Skewed data can distort confidence intervals and hypothesis testing if normality is falsely assumed.
- **Enhance power calculations**: The power of a statistical test can be misestimated under the wrong distributional assumptions, potentially affecting study outcomes.

In short, using the skew-normal distribution ensures that sample size calculations reflect the **true shape of the data**, which is especially important in fields like health science, economics, or environmental studies where skewed data are common.