Aligning science and practice in evaluations of cookstove carbon projects

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Carbon markets are thought to be central to global climate strategies,[1] but their scalability depends on the credibility of emissions reduction claims,[2] a point that has recently faced scientific and public doubt.[3,4] Carbon projects typically generate their own estimates of averted emissions to produce credits, a practice that introduces potential conflicts of interest and underscores the need for rigorous oversight. Focusing on cleaner cookstoves, we explore the difficulties in using academic studies as benchmarks for evaluations of carbon projects and highlight how methodological choices shape both evaluations and conclusions. Reexamining one influential study on cookstove carbon project overcrediting[5], we show that under alternative assumptions consistent with the state of the science estimated overcrediting falls by half. While the overall sector still exhibits worrisome overcrediting, one-fifth of projects analyzed show no clear evidence of it. Enhanced collaboration between researchers and project developers, we argue, is essential for improving the accuracy of carbon market assessments and ensuring that these initiatives deliver genuine social and environmental benefits.

Carbon credits, often regarded as central to global climate finance, channel investments into projects that promise measurable emissions reductions across diverse sectors—from forestry and renewable energy to waste management and improved household technologies. Yet skepticism persists over the verifiability of claimed emissions reductions, with project-level reporting of credits frequently at odds with independent assessments.[4,6–8]

The voluntary carbon market was valued at US$1.4 billion in 2024[9]; 190 million carbon credits were 'retired'—or removed permanently from circulation because they were used—and nearly 2.25 billion carbon credits were issued in 2024[10]. Fueled at least in part by quality concerns, carbon credit prices fell 20% from 2023, sitting at around US$5 per ton, and total credits retired has remained relatively steady since 2020.

Cookstove projects comprise around 7% of all credits issued, and intend to reduce greenhouse gas emissions by reducing biomass fuel consumption and making combustion more efficient. These projects are concentrated in sub-Saharan Africa, South Asia, and parts of Latin America, where reliance on biomass fuels is widespread[11]. Beyond carbon emissions reductions, these projects can reduce air pollution exposures[12] and alleviate the gendered burden of fuel collection[13].

Recent analyses,[3,5] however, argue that project-reported emissions reductions far exceed true impacts, estimating that cookstove carbon credit projects overestimate their offsets by more than nine times and only about 11% of credits are valid. By scrutinizing project reporting, these studies have sparked conversations about accountability and methodological rigor in the cookstove carbon market, directly shaping funding flows.

To estimate averted carbon, cookstove projects typically start by establishing a baseline—measuring the fuel consumption of traditional stoves through household surveys or historical fuel purchase data—and then converting that usage into CO_2 emissions using standard emission factors. Improved cookstove performance is then assessed, with project developers often relying on self-reported surveys, periodic field measurements, or even direct metering of stove use. Some projects use kitchen performance tests (KPTs), which observe stove operation under controlled conditions, while others employ continuous monitoring sensors that provide granular usage data. Each methodology has its strengths and weaknesses: surveys and KPTs are prone to biases like respondent over-reporting or altered behavior when under observation, whereas direct metering offers more objective data but can be costlier and technically challenging to implement across all households.[14,15]

To evaluate the estimated carbon offsets from cookstove projects, recent overcrediting analyses compare project-reported reductions against independent benchmarks derived from academic studies. These academic studies are primary research efforts—often based on field observations, experiments, or surveys—that provide parameter estimates for key factors such as cookstove adoption, fuel consumption, combustion efficiency, and emissions factors. In contrast, the overcrediting analyses use these academic benchmarks to assess whether the carbon projects' own estimates are realistic.

The overcrediting analyses observe that carbon projects tend to report higher adoption and usage rates for improved cookstoves than those documented in academic studies. Moreover, they note that projects often use more generous assumptions regarding stove efficiency, the non-renewability of biomass, rebound effects, and emissions factors. As a result, these analyses argue that the projects claim larger carbon savings than what is supported by independent research. Regulatory bodies and carbon crediting mechanisms are increasingly requiring project developers to anchor their estimates to academic benchmarks.

Drawing on academic studies as their reference points, the overcrediting analyses establish what is considered 'reasonable' for projects to report. They aim to align project estimates with academic benchmarks by focusing on two broad categories. The first category comprises factors central to the deployment and use of cookstoves—such as adoption rates, fuel stacking, fuel consumption, and rebound effects—which are largely within the control of project developers. The second category includes inherent characteristics of the stoves, like efficiency and rebound, as well as the stoves' capacity to reduce carbon emissions through the use of non-renewable biomass, factors that remain outside the direct control of the projects.

The remainder of this article examines the factors that might explain differences between cookstove carbon projects and academic studies, focusing in particular on those factors that are controllable by projects. We document pervasive misalignment with definitions used in overcrediting analyses and the definitions employed in academic studies. We then reassess conclusions based on updated academic parameter estimates, call for greater accountability and transparency in carbon credit accounting, and stress the need to phase out poorly managed projects. Throughout, we emphasize the importance of clearly framing research conclusions within the methodological choices inherent in both academic studies and overcrediting analyses.

Challenges in the alignment of carbon projects and academic studies

Carbon projects, such as improved cookstove interventions, seek to maximize emissions reductions in order to generate and sell as many carbon credits as possible. This financial imperative creates a clear conflict of interest: project developers are strongly incentivized to report parameter estimates that will yield the most credits, such as high adoption rates and sustained usage. Critics have argued that such incentives may lead developers to manipulate data or choose measurement methods with larger error margins. On the other hand, these same incentives drive project developers to design their projects in such a way that maximizes credits. For example, rather than deploying stoves at random in a region, they may actively target households that are most likely to use the new stoves frequently to maximize adoption and use or have high baseline biomass use to maximize potential fuel consumption reductions. They may also enhance sustained use through proactive monitoring and hands-on support. In comparison, academic evaluations are typically designed to generate assessments of cookstove use under natural, free-market conditions, with the goals of capturing real-world dynamics that might generalize widely. These distinctions mean that academic studies may not adequately represent populations, conditions, and dynamics at play in carbon projects.

Misalignment of key parameters in carbon projects and academic studies

Adoption, usage, and stacking

Central to critiques like those of Gill-Wiehl, Kammen, and Haya (2024)[5] (hereafter, GKH) is the interpretation of key parameters. They define adoption as the percentage of distributed stoves still in active use, rather than simple stove ownership. Usage is the percentage of meals cooked with the project stove, and stacking is the percentage of meals cooked using the baseline (traditional) stove in concert with the project stove.

While these terms are widely used in the academic literature, studies generate estimates of these parameters in multiple ways, posing challenges for using academic studies as benchmarks. Our review of 63 academic studies that report estimates of cleaner cookstove adoption, use, and stacking reveals the challenge of aligning academic evaluations with carbon project metrics (see Supplement): although studies often use similar terminology—adoption, usage, and stacking—the underlying measurement tools and definitions can vary significantly, with substantial consequences for parameter estimates. For example, a survey that asks whether households used the intervention stove at all in the past week may produce a high adoption rate, whereas a survey that inquires whether the stove is the primary cooking device may yield a lower adoption rate. Both studies, however, would plausibly generate an estimate of cookstove adoption. Moreover, evidence indicates that the apparent adoption of improved biomass stoves declines over time as stoves degrade and become less reliable. Yet, there is little standardization in the academic literature regarding when adoption should be measured. If a study assesses adoption only a few weeks after distribution, it may report very high usage rates; conversely, measuring adoption five years later—perhaps past the expected lifespan of a stove—can yield much lower rates.

Cookstove use can also be measured using various approaches: from surveys that ask a household the frequency with which they use a stove in subjective (e.g., “frequently”, “infrequently”) and objective terms (e.g., “multiple times daily”, “one time daily”, “multiple times per week”) to with stove use monitors that are capable of estimating use down to the minute. To match the definition put forward in GKH, a study would need to identify the precise proportion of cooking completed using a project stove—perhaps by summing up the total cooking either in minutes or events completed on every stove in the household.

GKH’s definition of stacking—measured as the percentage of specific meals where both improved and traditional stoves are used together—provides a precise metric for assessing the displacement of carbon-intensive cooking practices. However, the academic literature typically defines stacking more broadly, often by simply noting whether households own both stove types or use them over a given period.

These differences in how academic studies both define and measure adoption, usage, and stacking pose significant challenges for any attempt to consolidate these findings into a single meta-analyzed estimate.

For adoption, only five of the nine studies cited by GKH provide estimates aligned with their definition of adoption (see Supplement 1). In some cases, their figures appear to misinterpret the original work. For example, GKH cite a 50% adoption rate from Ruiz-Mercado et al. (2011)[16], though this study does not explicitly report this number. Instead, Ruiz-Mercado et al. report that after three months, 95% of households responded "yes" when asked if they were using the Plancha stove, and after 2.6 years, 90% of stoves were still in daily use. The 50% figure may instead stem from an observation that half of households continued using their traditional stoves—a different metric altogether.

GKH also selectively draw on data that ultimately skew toward lower adoption rates (what may be termed exercising ‘researcher degrees of freedom’). They favor the longest time to follow up, even when it is not the study’s primary outcome. In Burwen and Levine (2012)[17], a study on cookstove adoption in Ghana, adoption is defined as the share of stoves classified as “appears in use” out of all households surveyed. An alternative approach—excluding households with uncertain stove use from the denominator—would increase the estimated adoption rate from 49% to 65%. Similar “pessimistic” choices appear in four of the five valid studies they cite.

For cookstove usage, GKH primarily rely on Jeuland and Pattanayak (2012), which uses academic studies to generate estimates of the costs and benefits of improved cookstoves.[18] Only one of the nine studies GKH cite aligns with their stated definition of usage. Those that do not meet their definition of usage are either aligned with estimates of adoption—two of which are already included in their adoption estimates—or are unidentifiable.

Stacking estimates are also problematic. None of the twenty-four stacking estimates plausibly match GKH's definition. Most cited studies report the percentage of households that use both the improved and traditional stove to some extent, but they do not specify the percentage of meals cooked using both, as necessitated by GKH's definition. Those that report stacking related to improved biomass cookstoves (n=2), as opposed to clean commercial fuels like gas, have stacking rates of 19%.

When inappropriately selected studies are removed, estimates of adoption and usage increase, while stacking rates decline (Fig 1). Adoption rates go from 55% (range 40%, 92%) from nine studies to four credible studies with adoption rates of 55%. When we draw on less pessimistic estimates, average estimated adoption rises to 80%. Usage rates go from 52% (16%, 85%) from nine studies to one credible study with usage rate of 70%. For stacking we go from 68% (19.3%, 100%) from 24 estimates to no valid estimates; in the absence of valid estimates, we might draw on fuel stacking rates from the two improved biomass cookstove projects (the most common stove type in the study sample), and generate an estimate and range of 19% (5%, 33%).

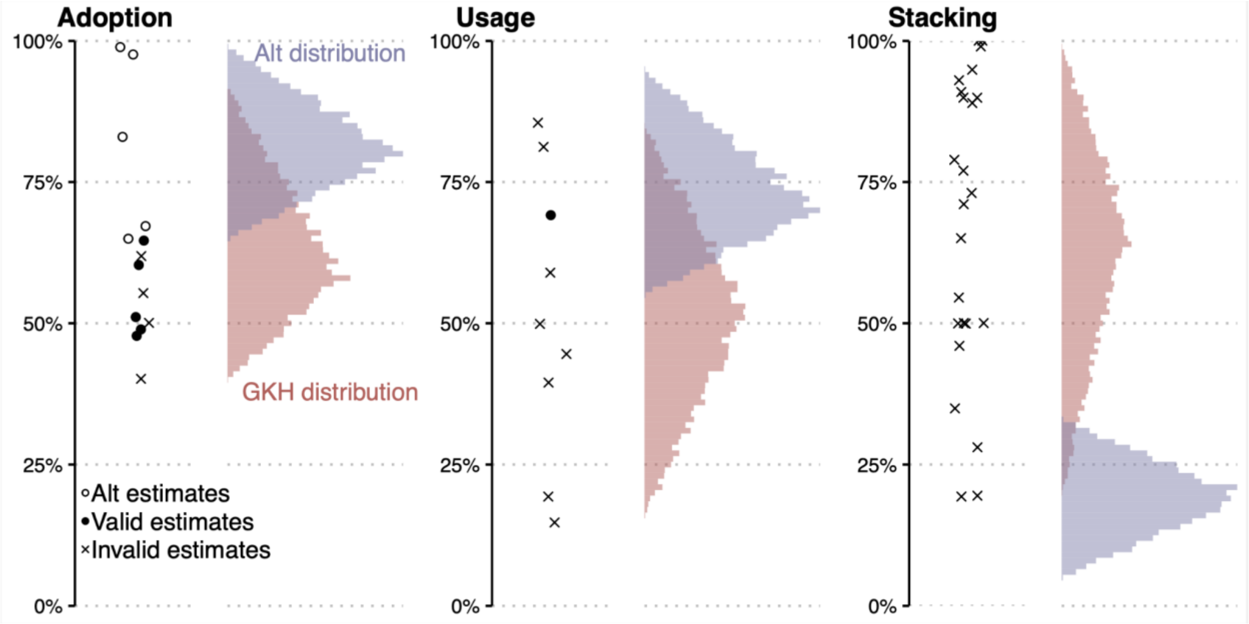

Figure 1. Parameters critical to understanding the uptake of cookstoves for carbon offset calculations were systematically downward biased and drawn from studies that do not provide appropriate estimates. Points indicate individual study estimates for adoption (n=9), usage (n=9), and stacking (n=24). For adoption, we additionally plot alternative estimates that could have been drawn from studies included in GKH but where they chose lower adoption stimates. Estimates were used to generate 10,000 bootstrapped estimates from a triangle distribution (where mode was taken as the average of the estimates). Because stacking had no appropriate estimates, we drew on the closest viable options which were two estimates from improved firewood cookstove studies.

Adjusting estimates of fuel consumption

Fuel consumption estimates form the backbone of carbon offset calculations, serving as the basis for quantifying emissions reductions. GKH assess fuel consumption in cookstove projects by comparing project-reported values to estimates from literature and their own adjustments. They identify three primary methodologies: efficiency-based estimates that use baseline fuel consumption and differences in stove efficiency, often relying on default values and lab tests; direct measurement through kitchen performance tests (KPTs) or metered monitoring; and back-calculation, where baseline fuel use is inferred from measured project fuel consumption, assuming households previously used an equivalent amount of energy.

GKH adjust project-specific fuel consumption estimates for two main reasons. First, they constrain the estimates to a reasonable range—specifically, 2–4 MJ per capita per day of delivered energy—to ‘correct’ for values that are either excessively high or low relative to empirical expectations. Given these limits, the baseline fuel consumption, which is expected to exceed the post-adoption figure, is generally lowered, while project fuel consumption is typically raised. Second, GKH updates efficiency values using the latest Clean Development Mechanism (CDM) Methodology Panel recommendations, adjusting baseline and project consumption independently.

Of the 51 projects, only five were exempt from adjustments. In 34 projects, baseline fuel consumption was modified—reduced in 28 instances—and project fuel consumption was adjusted in 22 projects, with increases occurring in 19 cases (see Supplement 2). These revisions reduced the average estimated fuel consumption reduction from 57% to 30% (excluding projects that switched fuels). In some instances, a fuel adjustment led to further recalibration when the revised baseline fell below the project's consumption, or vice versa, ultimately narrowing the implied fuel savings.

It is not self-evident that it is appropriate to adjust only the baseline estimates while accepting the project fuel consumption estimates as given, for example, since both are likely derived from the same data-generating processes and may be subject to similar errors in direction and magnitude. An alternative approach might retain the same percentage change between baseline and project fuel consumption but adjust the absolute values to bring them within a reasonable range, under the assumption that estimation errors affect both measures equally. It is worth noting explicitly that identification of a reasonable range of values for household fuel consumption for global applications is itself a fraught endeavor, but beyond the scope of this work.

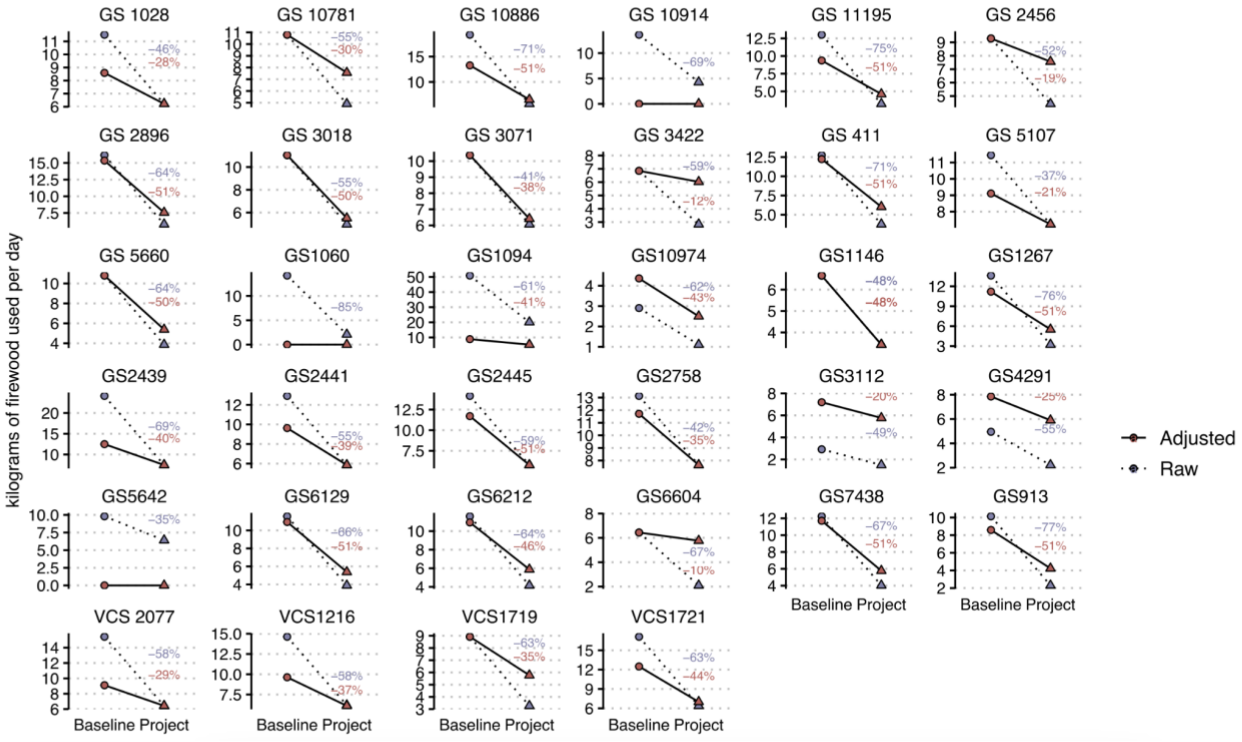

Figure 2. Fuel consumption estimates were systematically changed to fit within a reasonable range of energy use at the expense of estimated reductions in fuel consumption. Baseline and project fuel consumption estimates in kilograms of firewood used per day are shown from improved firewood cookstove projects, noting the changes following adjustment to fit within a ‘reasonable’ range of energy consumption of 2-4 MJ/capita/day. In large part, baseline fuel consumption was lowered and project fuel consumption, when changed, was increased. Consequently, implied fuel consumption reductions were reduced. Purple annotations are raw (unadjusted) estimates of declines in fuel consumption due to project stoves and red are the adjusted estimates.

Rebound

Rebound is defined as an increase in total cooking energy consumption following the adoption of an improved stove, attributing it to behavioral shifts such as longer cooking times or greater fuel use. For projects that do not measure fuel consumption through kitchen performance tests, GKH adjust for the rebound effect by reducing estimated carbon offsets by 22%, an estimate drawn from Beltramo et al. (2023)[19]. Quantifying the rebound effect has not been a central focus of research to date.

Implications of the changing state of science for cookstove carbon projects

Advances in our understanding of biomass energy and emissions necessitate periodic revisions of the models and estimates that underpin cookstove carbon projects. As scientific knowledge evolves, so too must our methodologies. However, this raises a crucial question: to what extent should present-day insights be used to reassess decisions made under the best available science at the time? A project that, in good faith, operated with the most current data may be unfairly penalized if newer research reveals that some of its underlying assumptions were later found to be flawed.

fNRB

A central parameter in these discussions is the fraction of non-renewable biomass (fNRB), which determines the share of emissions reductions that can be attributed to the depletion of non-renewable resources. Unlike factors such as adoption rates, usage intensity, or fuel stacking—which project developers can directly influence—fNRB is largely dictated by external environmental conditions and historical land-use practices. Its estimation has proved particularly volatile in recent years, complicating the attribution of carbon credits.

Sophisticated modeling has demonstrated that previous methodologies—including outdated CDM default values—systematically overstated the extent of forest degradation due to household biomass burning[20]. This, in turn, resulted in inflated fNRB values and an overissuance of carbon credits. To correct for this, GKH replace project-reported fNRB values with estimates derived from the Bailis et al. (2015)[21] using a Monte Carlo approach to generate more conservative, literature-based distributions. Project-reported fNRB values are, on average, three times higher than Bailis et al.'s estimates. For the most recent estimates, the gap may be even larger.

Recent assessments, particularly in regions such as India, suggest that fNRB values may be as low as 5%, implying that up to 95% of the carbon savings previously claimed could be effectively nullified if biomass use does not substantially deplete non-renewable resources. From a climate policy perspective, this recalibration is both scientifically and ethically compelling. However, it is important to recognize that the uncertainties surrounding fNRB are of a fundamentally different nature than those related to behavioral or technological factors like adoption or usage, where project managers have direct leverage.

Firewood-charcoal conversion

Improved charcoal cookstove projects use conversion factors to estimate the amount of charcoal produced from a given amount of firewood. For example, a 6:1 wood-to-charcoal ratio means that six units of wet firewood yield one unit of dry charcoal. This method is used because direct measurements of emissions are often difficult, and these factors provide a consistent approach based on established scientific guidance and local practices.

The choice of conversion factor greatly affects the estimated carbon savings. If the conversion factor overestimates charcoal production, it inflates the carbon credits earned by the project. Recent scientific advances suggest that earlier conversion factors may have been too generous. When new, more conservative factors are applied, the estimated carbon savings drop, revealing that previous calculations may have significantly overcredited the projects.

GKH sidestep the traditional firewood-to-charcoal conversion process by using upstream emissions factors. Instead of applying a conversion factor—which can vary with local production practices and introduce significant uncertainty—they estimate emissions based on data from the charcoal production process itself. Nevertheless, GKH estimate that firewood-charcoal conversion factors are one of the single largest contributing factors to overcrediting.

Findings from replication of overcrediting of cookstove carbon projects

We successfully replicate GKH’s procedure: they generate 10,000 simulated scenarios to see whether the project’s credits are over- or under-estimated. For each project period, they compute a ratio comparing carbon offset estimates from project data with those derived from academic parameters (covering factors like adoption, usage, and stacking), then average these ratios and weight them by the total number of “stove days” (households times days monitored). Finally, they apply this weighted ratio to each project’s total verified credits (even those outside the main study period) to get an overall overcrediting factor (see Supplement 3)—originally estimated at 9.24 times.

Table 1 summarizes the results from our replication and reanalysis. In our replication, we found that project GS3112—which generated over 312,000 verified credits across 112 million stove-days—was mistakenly labeled with only 696 total credits. This error likely came from copying the credit figure from a much smaller project (GS11195), which did have 696 credits after deploying 225 stoves in Kenya. Since GKH estimated GS3112's overcrediting to be above the sector-wide average of 9.24 times, this mistake biased the overall estimate downward. Additionally, because GKH's code deduplicates the dataset separately for total verified credits (the numerator) and their own estimate of credits analysis (the denominator) before estimating the ratio, the 696 credits were dropped from the sum of the numerator, further downward biasing their estimate. Correcting these errors increases estimated overcrediting to 9.30 times.

Additional analytical choices further affect the overcrediting estimates. First, the rebound effect is measured in terms of post stove intervention cooking practices – either time spent cooking or fuel consumption – but GKH instead apply it as a discount to averted emissions. Additionally, in their application of rebound to estimates, GKH multiply averted emissions per stove-day by 0.78; however, because 1 / 0.78 = 1.28, a 22% increase in consumption would correspond to a factor closer to 0.82. Applying rebound as a 22% increase on fuel consumption yields total overcrediting of 9.47 times. A 10% rebound adjustment, per updated methodological guidelines, results in estimated overcrediting of 9.05 times. Second, while GKH fully discount carbon savings when project stoves are used in tandem with baseline stoves, applying a 50% discount is arguably more appropriate. Doing so yields an estimate of total overcrediting of 8.76 times.

Independent of other changes, our new adoption, usage, and stacking ranges (described above) produce an estimate of overcrediting of 7.18 times. When combined with other changes, overcrediting is estimated at 6.48 times and nine of 51 projects have lower bounds that do not indicate overcrediting. Holding fNRB constant (i.e., not adjusting for fNRB) yields an estimate of overcrediting of 4.89 times. If we additionally use an alternative approach for adjusting project and baseline fuel consumption for improved firewood stove projects, overcrediting falls to 2.32 times.

Table 1. Summary of alternative overcrediting estimates

No	Model	Justification	Total Overcrediting
1	None	Replication	9.24
2	Project credit fix	Correcting error for total credits for GS3112	9.3
3	Alternative rebound calculation	GKH appear to misapply rebound to their calculations - we correct this	9.47
4	10% Rebound	Lower value of 10% may also be appropriate	9.05
5	Alternative stacking calculation	GKH completely discount potential carbon related savings when cooking on the project stove is completed in tandem with the baseline stove - we apply a 50% discount instead	8.76
6	Alternative adoption, usage, and stacking ranges	We document systematic issues with the supporting literature that support GKH's adoption, usage, and stacking ranges - we develop new ranges	7.18
7	Alternative fuel adjustments[a]	We document that GKH's approaches to fuel adjustments are very penalizing. For improved firewood stove projects, we develop some alternative approaches that retain observed fuel savings (in percentage terms), where feasible	8.24[b] or 9.93
8	No fNRB	The choice of appropriate fNRB values remains unresolved in the literature - as such, it may be useful to present differences absent fNRB choice	6.74
9	All	Model Numbers 2 + 3 + 4 + 5 + 6	6.48
10	All	Model Numbers 2 + 3 + 4 + 5 + 6 + 8	4.89
11	All	Model Numbers 2 + 3 + 4 + 5 + 6 + 7 + 8	2.32

[a] We design two approaches to estimating alternative fuel consumption.

[b] Total overcrediting for improved firewood cookstove projects is 11.74 times

Conclusion

Critics of carbon projects raise serious concerns about the accuracy and integrity of emissions reduction estimates because they have strong financial incentives to overstate their offset claims. We share these concerns. The potential for distortion was vividly illustrated by the case of C-Quest Capital (CQC). In October 2024, former CQC CEO Kenneth Newcombe was charged with fraud for allegedly falsifying emissions data from cookstove projects in Africa and Asia[22]. Investigations revealed that CQC had exaggerated stove efficiency and manipulated baseline emission estimates, leading to the overissuance of millions of carbon credits that were sold to corporations seeking to offset their carbon footprints. Such manipulation has no place in the future of carbon markets.

Cookstove carbon projects may be especially susceptible to these distortions due to the complex nature of energy efficiency uptake, the challenges of displacing longstanding traditional cooking practices, and an evolving scientific understanding of the relationship between biomass use, deforestation, and CO_2 emissions. These projects are sustained by a delicate balance of investor capital, subsidies, and external funding—a financial ecosystem where overstating benefits can secure critical funds, even when underlying methodologies remain opaque or flawed. As carbon credit prices continue to fall, the pressure to cut costs may further erode measurement standards and independent verification processes, increasing the risk of overcrediting and market instability.

In this article, we detail our efforts to better align academic studies with the proposed definitions for estimating carbon offsets from cookstove projects, with the goal of enhancing the accuracy of overcrediting analyses. Yet, to our knowledge, only three academic studies have rigorously evaluated cookstove carbon projects. In a randomized evaluation of 187 homes in rural India, Aung et al. (2016)[23] did not find reduced fuel consumption relative to the control; households exclusively using the new stove did have lower $PM_{2.5}$ concentrations but potentially higher black carbon emissions, casting doubt on expected carbon reductions. In Uganda, Beltramo et al. (2023)[19] leveraged a randomized staggered delivery of an improved woodburning stove as part of an Impact Carbon project, finding modest reductions in fuel consumption and ambient air pollution that were largely offset by observation biases (i.e., the Hawthorne Effect). Berkouwer and Dean (2024)[24] reported a 39 percent reduction in charcoal fuel consumption in a randomized evaluation of 1,000 households in Kenya under the BURN project—an outcome aligning with engineering estimates and implying about 7 tCO2e averted over two years. Beltramo et al. (2023) was the sole benchmark incorporated in GKH’s analysis, with its findings treated as equivalent to those of all other academic studies.

Despite our efforts to reconcile estimates from academic studies and cookstove carbon projects, significant uncertainty remains regarding the appropriateness of using academic evaluations, designed for non-carbon projects, as benchmarks for carbon projects. The fundamental differences in goals and operational contexts raise serious questions about their direct comparability; in effect, apples-to-apples comparisons are nearly impossible. We propose that collaborations between researchers and project developers to conduct high-quality randomized evaluations of cookstove carbon projects is crucial for restoring integrity in this field. Such partnerships would help shift the market away from low-integrity, low-cost credits to projects that deliver genuine, measurable benefits.

The future of carbon markets depends on our ability to enforce transparency and rigorous verification across all projects. Only high-quality projects—those built on rigorous measurement, independent verification, and transparent reporting[25]—should be allowed to continue. Equally, academics must approach evaluations with rigor and contextual sensitivity to provide reliable evidence that informs both policy and practice. Such measures are essential not only for restoring confidence in the market but also for ensuring that cleaner cooking technologies deliver genuine, measurable benefits.

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Competing interests

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SUPPLEMENT

Supplement 1. Review of GKH’s included studies and their appropriateness for providing estimates of adoption, usage, and stacking

Adoption

Appendix Table 1 reproduces GKH’s included studies for defining their stacking range, along with identifiers for reference. Here we review each study.

[A1 Duflo] is a randomized controlled trial conducted over several years in India. GKH identify an adoption rate of 40% after two years. This parameter extracted is inappropriate for defining adoption because of a mismatched study design. The basic design of the study centers not around the effects of an improved cookstove on socioeconomic and health outcomes, but around the effect of a *lottery to have the opportunity to purchase an improved cookstove at a reduced rate*. The authors identify the impacts of this lottery on outcomes, with randomization being used as an instrumental variable for the effectiveness of the improved cookstove. As such, only just over 70 percent of households that won one of the lotteries built a project stove during the first six months of the program.The data provided seek to answer the following research question: Among households in a village offered the opportunity to purchase an improved cookstove at a subsidized rate, how many had such a stove 36 months later as compared to the fraction of households in similar villages that were not offered a stove at the subsidized rate? Here, mismatched study design stems from the fact that not all households that were offered to purchase a stove did so. The 40% adoption parameter is drawn from a regression based proportion of households that were offered the opportunity to build a stove with an improved stove 25 to 30 months after offer.

[A2 Burwen] reports results after 8 months of a randomized controlled trial in Ghana. Adoption is inferred from field observations of households that did initially acquire an improved cookstove. Burwen report results in three categories: broken (not in use), appear in use, and unclear in use. GKH define adoption as the proportion of households that fall into the category “appear in use” out of all sampled households. This is an appropriate study and an appropriate parameter for adoption, though it is perhaps *pessimistic* because an alternative option would be to remove “unclear in use” from the denominator. Doing so would change adoption from 49% to 65%.

[A3 Islam] is a randomized controlled trial conducted over several years in India. GKH identify an adoption rate of 61.9% after two years. We are unable to identify where GKH find this parameter in the referenced article and thus are unable to determine its appropriateness.

[A4 Beltramo] is a randomized controlled trial conducted over several years in Uganda. This is an appropriate study and an appropriate parameter for adoption. Beltramo et al. report the impacts of an improved cookstove on fuel use and pollution. Study enumerators then made unannounced visits three and a half years later, finding that 65% of households had a project stove with obvious signs of use. Beltramo et al. also measure project stove use within the first year of stove acquisition, which are expected to be higher than 65% adoption, though they do not provide clear adoption-related measures as they for their long-term follow up. We believe that GKH make a small math error. The calculation should yield an estimate of 67% adoption. An alternative option would have been 73% self-reported to still use the Envirofit after 3.5 years.

[A5 Rosa] is a randomized controlled trial conducted among 566 households in Rwanda conducted over five months assessing the combined impacts of a water filter and an improved biomass cookstove on children's respiratory health. This article reports on the impacts on drinking water quality and household air pollution. GKH report an adoption rate of 47.5% over six months. Rosa et al. report data on cookstove use in several different ways. They report data from 'Evaluator's surveys' – these are surveys collected by the researchers – as well as data from 'Implementer's surveys' - surveys collected by the project implementers. GKH report data from the Evaluator's surveys, which is a fair choice under the assumption that researchers might be more likely to produce least biased estimates (though both surveys yield similar results). Rosa et al. report data separately among households that were actively cooking while the survey visit occurred from those that were not cooking. GKH report data from those that were not actively cooking, which is a fair choice. Next, Rosa et al. report whether the household reported to have used only the intervention stove (78%), both the intervention and traditional stove (19.3%), or only the traditional stove for their last stove use (2%). They also report whether the intervention stove was reported to have been used in all three of the last follow-up visits (47.5%). It is clear that GKH opt for this last parameter as their measure of adoption. Plausibly, GKH could have also identified adoption as 98%, where adoption is identified from reporting to have used the intervention stove during their last meal. The implementer's survey is more extensive, and reports that 89.1% of households identified the intervention stove as their primary stove and 93.3% report using it 7 or more times per week. Taken together, we deem GKH's parameter extraction as appropriate and the study design is also appropriate, but the parameter extraction is also *pessimistic*.

[A6 Ruiz-Mercado] is a long term monitoring study of plancha stoves in Mexico. We are unable to identify where GKH identify an adoption rate of 50% after 10 months. The parameter extracted does not appear appropriate and the study design is appropriate. The authors report that, after 2.6 years, 90% of stoves are still used on a daily basis (section 4.1.1, Figure 3). After three months, 95% of households responded yes to “Are you using the Plancha for cooking?” (Figure 4A). We identify two plausible data points that led GKH to extract 50% adoption rates. First, the authors report data from an initial sample of 50 households during the initial adoption stage. Second, the authors identify that half of households continued using their traditional stoves in the long term.

[A7 Garcia-Frapolli] reports results on adoption from a different study (Pine et al. 2010). Here, we discuss Pine et al., who report results from a quantitative longitudinal study of households in Mexico. GKH identify an adoption rate of 60% after two to seven years. In their Figure 2, Pine et al. report that 60% of households used their stove, defined as any reported use of the Patsari, at month five, with Figure 3 reporting similar levels of any Patsari use at month 10. Plausibly these data points match GKH’s definition of adoption. With that said, Pine et al. also write “Of the 259 households in the sample, 10% or 26 of the 259 did not adopt the Patsari stove at all” and “... some (17%) of the households ultimately rejected the technology by the end of the 10 month follow-up period.” We are unable to identify where GKH derive their 2-7 year time frame. There is some lack of clarity as to what Pine et al. refer to when they indicate that 10-17% of households rejected the technology, but that reported usage was closer to 60% of households. GKH report the 60% figure for adoption, though one could imagine also reporting 83% adoption based on this study. Ultimately, we deem that the parameter extracted is appropriate and the study design is appropriate, though the extraction of these parameters over others is perhaps *pessimistic*.

[A8 Adrianzen] is a cross-sectional observational study in the northern Peruvian Andes. GKH identify an adoption rate of 55% after 10 months. The parameter extracted is not appropriate for defining adoption and the study design is not appropriate. First, this cross-sectional study purposefully identified a sample ‘where relatively low usage rates were expected.’ As such, it is inherently a downward biased estimate. Second, in their Table 1, Adrianzen report data on the proportion of visited beneficiaries in a village that received their improved stove but were not making use of it. The average was 55%. We believe that this is where GKH defined their adoption, erroneously interpreting the table. Were the study design to have been appropriate, GKH should have extracted an adoption rate of 45%. Adrianzen further clarify in text: ‘Table 1 also indicates that approximately 45% of the visited beneficiaries per village reported using the new stove as their main cooking device.’

[A9 Bensch] is a randomized controlled trial conducted in rural Senegal. GKH identify an adoption rate of 51% after 3.5 years. The study design is appropriate and the parameter extracted is appropriate for defining adoption, although it may be *overly pessimistic*. The authors report that the expected lifetime of the stoves was one to three years. As such, adoption beyond that expected lifetime is anticipated to be low. The authors write: “Considering an expected life span of one to three years, the proportion of 49% of treatment households still using the randomized ICS can, nevertheless, be considered surprisingly high.” Note a small error from GKH in reporting adoption of 51% instead of 49% after 3.5 years. Bensch’s Figure 4 reports the proportion of households still using the project stove by month. At their initial follow-up, Bensch reports that there are only 2 households out of 253 that do not use the project stove. Plausibly, adoption could have been identified as 99%.

Supplemental Table 1. Reproduction of GKH's adoption rates table, with an identifier

Identifier	Study Title	Country	Time period (years)	Adoption Rate
[A1 Duflo]	Up in smoke: The influence of household behavior on the long-run impact of improved cooking stoves.	India	2	0.4
[A2 Burwen]	A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana	Ghana	0.67	0.49
[A3 Islam]	Assessing the Effects of Stove Use Patterns and Kitchen Chimneys on Indoor Air Quality during a Multiyear Cookstove Randomized Control Trial in Rural India	India	3.5	0.619
[A4 Beltramo]	The Effects of Fuel-Efficient Cookstoves on Fuel Use, Particulate Matter, and Cooking Practices: Results from a Randomized Trial in Rural Uganda	Uganda	3.5	0.65
[A5 Rosa]	Assessing the Impact of Water Filters and Improved Cook Stoves on Drinking Water Quality and Household Air Pollution: A Randomised Controlled Trial in Rwanda	Rwanda	0.5	0.475
[A6 Ruiz-Mercado]	Quantitative metrics of stove adoption using Stove Use Monitors (SUMs)	Guatemala	0.83	0.5
[A7 García-Frapolli]	Beyond fuelwood savings: Valuing the economic benefits of introducing improved biomass cookstoves in the Purépecha region of Mexico	Mexico	2 to 7	0.6
[A8 Adrianzén]	Social Capital and Improved Stoves Usage Decisions in the Northern Peruvian Andes	Peru	0.83	0.55
[A9 Bensch]	The intensive margin of technology adoption - Experimental evidence on improved cooking stoves in rural Senegal	Senegal	3.5	0.51

Usage

GKH largely draw on a previous review - Jeuland et al. - for their identification of usage rates. They additionally include one other study. While not explicitly referenced in the appendix, based on context clues, we believe this study is Ruiz-Mercado (2012). Each of these are described in Appendix Table 2, and reviewed one by one below.

[U1 Rosa] is a randomized controlled trial conducted over several years in Rwanda. It is the same as [A5 Rosa]. This parameter extracted is inappropriate for defining usage because it more closely matches GKH's definition for adoption.

[U2 Ruiz-Mercado] The study by Ruiz-Mercado et al. (2012) uses Stove Use Monitors (SUMs) to measure stove usage in 80 rural Guatemalan households over 32 months. The study defines usage metrics based on daily stove use, counting the percentage of days in use, the number of meals cooked per day, and the total stove-hours recorded. The reported usage rate of 50% refers to the percentage of monitored stoves actively in use during the study period. While the study tracks sustained stove use, it does not directly quantify how often traditional stoves are used for meal preparation versus the improved stove, which is critical for GKH's definition. Therefore, this measurement method does not fully align with GKH's definition of usage rate.

[U3 Hanna] is the same as [A1 Hanna].

[U4 Traction] is an unknown study.

[U5 Garcia-Frapolli] is an economic analysis study that focuses on the costs and benefits of the Patsari Cookstove among Purépecha regions. Conducted by García-Frapolli et al. from 2003 to 2008, the study disseminated 1,672 Patsari stoves to randomly selected households. The study found a usage rate of 60%, indicating that "60% or 1,003 stoves were being used on a sustained long-term basis". This study design is appropriate for measuring the usage rate.

[U6 Adrianzen] This study examines the role of social capital in the adoption and usage of improved cookstoves in the Northern Peruvian Andes. The reported usage rate of 45% was determined through household surveys conducted 8–12 months after stove distribution, where beneficiaries self-reported whether they used the improved stove as their primary cooking device. Since the study does not specify whether traditional stoves were still used for some meals, the reported usage rate does not fully capture the metric defined by GKH.

[U7 Bensch] is a randomized controlled trial conducted from 2009 to 2013. The study employs various measurement methods, including household surveys, firewood measurement, and health indicators, to evaluate the effectiveness of a low-cost, maintenance-free portable clay-metal stove (ICS) and its impact on health. The study reports a utilization rate of 69.1% among the treatment group using the ICS at follow-up. The parameters and study design are appropriate for accurately measuring the usage rate.

[U8 Traction] is an unknown study.

[U9 Ruiz-Mercado] It is unclear how the 85% usage rate was determined. The study primarily focuses on measuring the sustained use of improved cookstoves using Stove Use Monitors (SUMs). The key metric presented is the "percent stove-days in use," which quantifies the number of days the improved stove was used relative to the monitoring period. However, GKH's definition of usage rate would require clear data on the proportion of total cooking done on the improved stove versus the traditional stove. Since this study does not explicitly quantify the continued use of traditional stoves or the proportion of meals cooked on them, it does not align with GKH's definition of usage.

Supplemental Table 2. Development of a table that describes GKH's usage rates table[a]

Identifier	Study Title	Country	Time period (years)	Usage Rate
[U1 Rosa]	Assessing the Impact of Water Filters and Improved Cook Stoves on Drinking Water Quality and Household Air Pollution: A Randomised Controlled Trial in Rwanda	Rwanda	0.5	0.8
[U2 Ruiz-Mercado]		Mexico	0.83	0.5
[U3 Hanna]	Up in smoke: The influence of household behavior on the long-run impact of improved cooking stoves.	India	2	0.4
[U4 Traction]	Unknown	India	Unknown	0.2
[U5 García-Frapolli]	Beyond fuelwood savings: Valuing the economic benefits of introducing improved biomass cookstoves in the Purépecha region of Mexico	Mexico	2 to 7	0.6
[U6 Adrianzén]	Social Capital and Improved Stoves Usage Decisions in the Northern Peruvian Andes	Peru	0.83	0.45
[U7 Bensch]	The intensive margin of technology adoption - Experimental evidence on improved cooking stoves in rural Senegal	Senegal	3.5	0.69
[U8 Traction]	Unknown	India	Unknown	0.16
[U9 Ruiz-Mercado]	The Stove Adoption Process: Quantification Using Stove Use Monitors (SUMs) in Households Cooking with Fuelwood	Guatemala	2.67	0.85

[a] Studies U1-U8 are from Jeuland et al. whereas study U9 is added by GKH.

Stacking

Recall that GKH define stacking as the percentage of meals where the traditional stove and the project stove are used in tandem. We review specific studies cited by GKH for their ranges of stacking and whether they meet this definition.

[S1 Asante] report data that are now published under the title ‘Experiences with the Mass Distribution of LPG Stoves in Rural Communities of Ghana.’ This study is a cross-sectional that reports that, after 9 months, less than 5% of households used LPG for cooking their main meals the previous day based on self-reported survey data. GKH cite a stacking rate of 100%. Given the data reported in Carrion et al., this is not appropriate because their reported data do not match GKH’s definition of stacking.

[S2 Pollard] This study evaluates Peru’s Fondo de Inclusión Social Energético (FISE) program, which promoted the adoption of liquefied petroleum gas (LPG) through a voucher system subsidizing half the cost of one LPG cylinder per month for eligible households. The study reports a stacking rate of 95%, which was determined through household surveys conducted in rural Puno, where participants self-reported their stove use patterns. This study's approach captures whether households used multiple stoves within a given period but does not track whether both stoves were actively used together for the same meal; therefore, the reported stacking rate is inconsistent with GKH’s definition.

[S3 Gould] This study is a cross-sectional observational study that reports a stacking rate of 79%, with households in a very rural area of Ecuador using woodfuel weekly or more frequently despite having LPG stoves. The stacking rate of 79% comes from the survey data indicating that woodfuel is frequently used as a secondary fuel, with 86% of households using woodfuel alongside LPG. GKH cite this stacking rate based on the survey data that measures woodfuel use. However, this is not appropriate because the measure used—reporting woodfuel use weekly or more frequently—does not align with GKH’s definition of stacking, which focuses on the concurrent use of traditional and project stoves for cooking meals.

[S4 Thoday] The study by Thoday, which reports a stacking rate of 73% in various provinces of Indonesia, calculates this rate using survey questions like "Which stoves have you used in the last three days?" and "List all stoves you have in the household." The 73% stacking rate indicates that a majority of households are using multiple stoves, including both LPG and traditional stoves. However, this measurement doesn't fully align with GKH's definition of stacking, which focuses specifically on the percentage of meals where both traditional and project stoves are used simultaneously.

[S5-S6 Bruce] This study evaluates the government-led initiative for LPG scale-up in Cameroon. The reported stacking rates of 90% and 99% were derived from household surveys conducted in peri-urban and rural areas, as part of the LPG Adoption in Cameroon Evaluation (LACE) studies. The survey questions focused on whether households used multiple fuels and how often LPG was refilled. Since the reported stacking rates were found through self-reported fuel use surveys and refill frequency data, which indicate continued use of traditional stoves but do not capture concurrent stove usage during meal preparation, this measure does not align with GKH's definition of stacking.

[S7 Ozier] This study evaluates a commercial pilot program promoting ethanol-methanol CleanCook stoves in Lagos, Nigeria. The reported stacking rate of 65% was determined through a combination of household surveys, stove use monitors, and fuel canister sales data collected from 30 experimental households over five months. The surveys asked households whether they continued using traditional stoves, while stove use monitors (SUMs) tracked temperature changes as a proxy for use. This study's approach to measure stacking captures overall stove usage patterns over time rather than whether both stoves were actively used together for the same meal; therefore, it does not match GKH's definition of stacking. However, this measure does not align with GKH's definition of stacking, which focuses on the percentage of meals where both the traditional and project stoves are used in tandem.

[S8 Benka-Coker] This study is a randomized controlled trial and pilot study that reports a stacking rate of 65% in Lagos, Nigeria, where CleanCook ethanol-methanol stoves were introduced. GKH cite this stacking rate based on a combination of surveys and stove use monitors, which show households using both CleanCook stoves and traditional stoves. However, this measure is uncertain in terms of fully aligning with GKH's definition of stacking, as it is based on indirect indicators like fuel canister usage rather than directly measuring the percentage of meals cooked using both stove types in tandem.

[S9 Carter] In the study by Carter et al., the reported stacking rate of 77% in southwestern China is based on a before-and-after intervention that introduced semi-gasifier stoves and biomass pellets. This rate was calculated by observing the continued use of traditional wood chimney stoves alongside the new stoves. However, this measure reflects general stove usage over time rather than concurrent use during meal preparation, which is how GKH defines stacking.

[S10-S12 Clemens] This study is a cross-sectional one-time survey that reports a stacking rate of 46% in Kenya, where households with biodigesters use both biogas and traditional fuels for cooking. GKH cite this stacking rate based on data showing that while 54% of households use biogas exclusively, 46% stack biogas with other fuels. However, this is not appropriate because the measure used—percentages of households exclusively or partially using biogas—does not align with GKH's definition of stacking, which focuses on the concurrent use of traditional and project stoves for cooking meals.

[S13-S14 Hyman] This study evaluates a national biodigester program in Cambodia and reports two stacking rates: 28% and 50%. The stacking rate was determined through household surveys and stove use monitors, which tracked household fuel use and cooking patterns. Surveys asked respondents about their primary and secondary stove use, while stove use monitors recorded temperature fluctuations on traditional and biodigester stoves as a proxy for stove usage. Additionally, observational data collected from a subset of households indicated that while biogas was used for primary cooking, many households continued to rely on traditional stoves, particularly for cooking tasks requiring high heat or large pots. Therefore, since the reported stacking rate in this study was found through a combination of survey self-reports and indirect monitoring methods that did not specifically capture simultaneous stove use during meal preparation, it does not meet GKH's definition.

[S15 Rosa] This is a parallel household RCT conducted over a year in three rural villages in Rwanda. The study reports a stacking rate of 19.3% among 585 participating households. This rate does not align with GKH's definition because it reflects the percentage of households using traditional and improved cooking stoves together during the study, rather than the percentage of meals prepared with both stoves. Additionally, the 19.3% stacking rate is different from the researchers' observations, where only 4.3% of households used both stoves simultaneously during their visit.

[S16-S17 Ruiz-Mercado] This study uses sensor-based monitors to observe the adoption process and impacts of the improved cookstove program implemented in Purepecha and Mestizo villages in Mexico. The study reports a stacking rate of 90% among Purepecha participants, indicating that "90% now stack the TSF with Patsaris, LPG stoves, and microwaves (MW)." It also reveals a stacking rate of 50% among Mestizos, who "continue using the three-stone fire (TSF) with gas (LPG) stoves and even microwaves (MW)." These stacking rates generally meet GKH's definition because they focus on the concurrent use of the TSF and project stoves for cooking meals, based on sensor monitors. We note that GKH report these race/ethnic group stratification statistics in reverse.

[S18 Hanna] This study evaluates the long-term effects of an improved cookstove intervention in India, examining behavioral patterns and sustained use of traditional stoves. The reported stacking rate of 93% was derived from household surveys and direct observations conducted over a two-year period. Surveys captured self-reported stove usage, while field observations tracked cooking behaviors in randomly selected households. Since the reported rate primarily reflects stove ownership and continued use rather than the percentage of meals cooked using both traditional and project stoves in tandem, it does not match GKH's definition of stacking.

[S19 Bensch] This is a randomized controlled trial conducted in rural Senegal from 2009 to 2013. The study evaluates the usage of improved cookstoves and their potential impacts on participants' health. Based on surveys of 253 randomly selected households, the study reports that 19.5% of the treatment group continue to use open fires (three-stone stoves or open fires) for cooking. This data suggests that the treatment group "stacks" project stoves with open-fire stoves. However, this data does not exactly reflect concurrent stove usage during meal preparation, but it rather provides a general overview of stove usage patterns among households. Therefore, it does not meet GKH's definition of stacking.

[S20 Pattanayak] This is a multiphase randomized controlled study assessing the implementation and adoption of improved biomass stoves and LPG stoves. It involves about 1,000 households from the Indian Himalayas. The study does not explicitly discuss the stacking rate, but it does report that the treatment group had an average daily use of 231.6 minutes for traditional cooking stoves (TCS) three months after the intervention. Additionally, the supplementary information indicates that 26.6% of the control group and 54.5% of the treatment group used improved stoves in the past week. However, this measure is not an appropriate parameter for stacking. It does not meet GKH's definition, which focuses on the concurrent use of project stoves and traditional stoves.

[S21 Pine] This study evaluates the adoption and sustained use of Patsari improved biomass cookstoves in rural Mexico. The reported stacking rate of 35% was determined through a combination of structured household surveys, follow-up interviews, and observational data. Households were classified into different stove usage groups based on self-reported cooking practices and physical evidence of stove use gathered during home visits. The study captures broader patterns of stove use over time without explicitly tracking concurrent use for the same meal; therefore, it does not match GKH's definition which requires measuring the percentage of meals where both stoves are used simultaneously.

[S22 Burwen] This is a randomized controlled study conducted in rural Ghana that examines the impacts of improved cookstoves. The study uses stove usage monitors, field observations, and self-reported surveys. The results show that the treatment group uses the improved cookstoves more frequently than traditional cookstoves but continues to use the traditional ones during their cooking events. The stove usage monitors indicate that "50% of improved cookstoves remained in use" within the treatment group. However, this measure is not an appropriate parameter for stacking and does not meet GKH's definition of stacking.

[S23 Beltramo] This study is a randomized controlled trial conducted in Uganda that assesses the impact of fuel-efficient cookstoves on fuel use, particulate matter exposure, and cooking behaviors. The study reports a stacking rate of 90.9%, which was determined through a combination of self-reported surveys and temperature-based stove use monitoring. Households were given improved cookstoves, and researchers tracked their cooking behaviors using Stove Use Monitors (SUMs), which recorded temperature fluctuations to infer stove usage. However, this measure does not align with GKH's definition of stacking, which focuses on the percentage of meals where both the traditional and project stoves are used in tandem.

[S24 Ruiz-Mercado] The study by Ruiz-Mercado et al. evaluates the sustained adoption and usage patterns of improved cookstoves in rural Guatemala. The reported stacking rate of 50% is derived from Stove Use Monitors (SUMs), which recorded temperature fluctuations in 80 households over 32 months. The SUMs tracked daily cooking events, defining "fueling events" based on temperature spikes, which were clustered into cooking events or "meals." The study found that while 90% of stove-days involved the use of the improved chimney stove, 50% of households continued to use open cookfires alongside it. The reported stacking rate in this study was found through general household-level stove usage patterns, meaning it captures whether a household continued using both stoves but does not specify if both were used for the same meal; therefore, this measure does not align with GKH's definition of stacking.

Appendix Table 3. GKH’s table of stacking rates

Identifier	Study Title	Stacking Rate
[S1 Asante]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Ghana	100.00%
[S2 Pollard]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Peru	95.00%
[S3 Gould]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Ecuador	79.00%
[S4 Thoday]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Indonesia	73.00%
[S5 Bruce]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Cameroon (2 values reported)	90.00%
[S6 Bruce]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Cameroon (2 values reported)	99.00%
[S7 Ozier]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Nigeria	65.00%
[S8 Benka-Coker]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Ethiopia	100.00%
[S9 Carter]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - China	77.00%
[S10 Clemens]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Kenya	46.00%

[S11 Clemens]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Tanzania	71.00%
[S12 Clemens]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Uganda	89.00%
[S13 Hyman]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Cambodia (two values reported)	28.00%
[S14 Hyman]	Everybody Stacks: Lessons from household energy case studies to inform design principles for clean energy transitions: Case Study - Cambodia (two values reported)	50.00%
[S15 Rosa]	Assessing the Impact of Water Filters and Improved Cook Stoves on Drinking Water Quality and Household Air Pollution: A Randomised Controlled Trial in Rwanda	19.30%
[S16 Ruiz-Mercado]	Adoption and sustained use of improved cookstoves: Purepecha	50.00%
[S17 Ruiz-Mercado]	Adoption and sustained use of improved cookstoves: Mestizo	90.00%
[S18 Hanna]	Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves	93.00%
[S19 Bensch]	The intensive margin of technology adoption — Experimental evidence on improved cooking stoves in rural Senegal	19.50%
[S20 Pattanayak]	Experimental evidence on promotion of electric and improved biomass cookstoves	54.50%
[S21 Pine]	Adoption and use of improved biomass stoves in Rural Mexico	35.00%
[S22 Burwen]	A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana	50.00%
[S23 Beltramo]	The Effects of Fuel-Efficient Cookstoves on Fuel Use, Particulate Matter, and Cooking Practices: Results from a Randomized Trial in Rural Uganda	90.90%
[S24 Ruiz-Mercado]	Quantitative metrics of stove adoption using Stove Use Monitors (SUMs)	50.00%

Supplement 2. Approach to understanding fuel consumption adjustments

There is no replicable procedure for understanding the fuel consumption adjustments made by GKH. Changes can be inferred, with some irregularity, by comparing two excel files in the replication archive:

- ‘Raw’ fuel consumption was obtained from “9_27_23_python_inputs_project_recreation_gillwiehl_et_al.xlsx”.
- ‘Adjusted’ fuel consumption was obtained from “9_27_23_python_inputs_charc_firewood_baseline_adjusted_gillwiehl_et_al.xlsx”

In an excel file in the replication archive, we found the following table.

Supplemental Table 4. Fuel adjustments made by GKH

Protocol ID	**Adjustment Explanation**
GS10974	This project has a low baseline; therefore, we adjusted the baseline up and then we utilized the stove's efficiency to find the project consumption from subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
VCS1216	This project has a high baseline; therefore, we adjusted the baseline down and then we utilized the stove's efficiency to find the project consumption from subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
GS2094	This project has a high baseline; Therefore, we adjusted the baseline down and then we utilized the stove's efficiency to find the project consumption from subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
VCS1719	This project has a low project consumption; therefore, we adjusted the project consumption up to be within the range.
VCS1721	This project has a high baseline; therefore, we adjusted the baseline down and then we utilized the stove's efficiency to find the project consumption from

	subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
GS7312	In the 2020 crediting period, the project has both a high baseline and a low project consumption. Therefore, we both adjust the baseline down and the project consumption up to be within the 2-4MJ/capita/day range. In the 2021 crediting period, the project has a low project consumption. When we adjust it up to 2MJ/capita/day, it is larger than the reported baseline. Therefore, we adjust the project consumption up, and then add the original differential that the project reported to that adjusted project consumption to obtain the baseline consumption.
GS500	This project has a low baseline; therefore, we adjust the baseline up to within the range.
GS10884	This project has a low project consumption; therefore, we adjust the project consumption up to within the range.
GS447	This project frames it as biomass savings and combined domestic and commercial values to obtain that biomass saved. We do not adjust commercial consumption and we refered back to their excel "GS 447 Round II Submission" to ensure that their kg/capita/day was within the range of ~2-4MJ/capita/day. Therefore, no adjustment was made.
GS2564	Not adjusted; the project's baseline and project includes multiple fuels and in total does not exceed 4MJ/capita/day.
GS7438	This project has a high baseline and a low project consumption value; therefore, we adjust the baseline down and the project consumption value up to stay in the range. For charcoal, the project has a low project consumption. When we adjust it up to 2MJ/capita/day, it is larger than the reported baseline. Therefore, we adjust the project consumption up, and then add the original differential that the project reported to that adjusted project consumption to obtain the baseline consumption.

GS913	This project has a high baseline and a low project consumption value; therefore, we adjust the baseline up and the project consumption value up to stay in the range.
GS6212	This project has a high baseline; therefore, we adjusted the baseline down and then we utilized the stove's efficiency to find the project consumption from subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
GS2758	This project has a high baseline; therefore, we adjusted the baseline down.
GS3112	The project has a low project consumption. When we adjust it up to 2MJ/capita/day, it is larger than the reported baseline. Therefore, we adjust the project consumption up, and then add the original differential that the project reported to that adjusted project consumption to obtain the baseline consumption.
GS5642	For the first crediting period, the project has a low project consumption value; therefore, we adjust this value up. For the second crediting period, we adjust the fireword down to keep the 2-4 MJ/capita/day total in the project scenario.
GS1060	The project has a low project consumption. When we adjust it up to 2MJ/capita/day, it is larger than the reported baseline. Therefore, we adjust the project consumption up, and then add the original differential that the project reported to that adjusted project consumption to obtain the baseline consumption.
GS2744	Not adjusted
GS1094	This project has a high baseline; therefore, we adjusted the baseline down and then we utilized the stove's efficiency to find the project consumption from subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
GS4291	This project has a high baseline; therefore, we adjusted the baseline down and then we utilized the stove's efficiency to find the project consumption from

	subtracting baseline savings (from the water boil test efficiency).This is the same approach that the protocol implements.
GS6604	The project has a low project consumption. So we adjust the project consumption up to be within the range.
GS1267	This project has a high baseline and a low project consumption value; therefore, we adjust the baseline up and the project consumption value up to stay in the range.
GS2439	This project has a high baseline; therefore, we adjusted the baseline down.
GS2445	This project has a high baseline; therefore, we adjusted the baseline down.
GS7578	Not adjusted
GS2513	Not adjusted
GS4677	This project has a high baseline; therefore, we adjusted the baseline down.
GS2441	This project has a high baseline; therefore, we adjusted the baseline down.
GS5003	Scaled back project charcoal as total baseline and project consumption was over 4MJ/capita/day across firewood and charcoal. Therefore, we took a combination of firewood and charcoal based on the KPT ratio that would have the combination stay under the range, then subtracted the charcoal savings from that new baseline value for the project scenario.
GS6129	This project has a high baseline and a low project consumption value; therefore, we adjust the baseline up and the project consumption value up to stay in the range.
GS407	The project has a low project consumption. We thus adjust it up to 2MJ/capita/day. We do not adjust the commercial stoves.

GS11509	This project has a low project consumption; therefore, we adjust the project consumption up to within the range.
GS11352	This project has a low project consumption; therefore, we adjust the project consumption up to within the range.
GS11507	This project has a low project consumption; therefore, we adjust the project consumption up to within the range.
GS1146	In the exclusive LPG scenario, the project has a low project consumption value, so we adjust it up to stay within the range. The other scenarios are already within the range. We do not adjust the commercial scenario.
GS 11330	This project has a low project consumption; therefore, we adjust the project consumption up to within the range.
GS 3071	This project has a high baseline; therefore, we adjusted the baseline down.
GS 10777	This project has a high baseline; therefore, we adjusted the baseline down.
GS 10886	This project has a high baseline; therefore, we adjusted the baseline down.
GS 5107	This project has a high baseline; therefore, we adjusted the baseline down.
GS 11195	This project has a high baseline; therefore, we adjusted the baseline down.
GS 2077	This project has a high baseline; therefore, we adjusted the baseline down.
GS 411	This project has a high baseline; therefore, we adjusted the baseline down.
GS 10914	This project has a high baseline; therefore, we adjusted the baseline down.
GS 10781	This project has a high baseline; therefore, we adjusted the baseline down.

GS 5660	This project has a high baseline; therefore, we adjusted the baseline down.

We have three notes on this table.

First, some projects that were noted as not having been changed, appear to have different fuel consumption values between what we interpreted as the ‘raw’ fuel consumption and the ‘adjusted’ fuel consumption.

Second, some projects not noted in this list apparently had adjusted fuel consumption, i.e., fuel consumption was different between what we interpreted as the ‘raw’ fuel consumption and the ‘adjusted’ fuel consumption. ‘Raw’ fuel consumption was obtained from “9_27_23_python_inputs_project_recreation_gillwiehl_et_al_1.xlsx”. These projects include: GS3018, GS2456, GS2896, GS3422, and GS1028.

Third, in another case (GS 1060), a charcoal project, charcoal fuel consumption values in the ‘raw’ file are not available. So, it is not possible to recover baseline fuel reductions to recalculate alternatively-adjusted fuel consumption.

In other cases (like GS 10914), there are firewood consumption (baseline and project) values in the raw file, but in the adjusted file only charcoal consumption values are available. In these cases, we keep the charcoal consumption values unchanged.

Supplement 3. Approach to summarizing and comparing carbon credit overcrediting

GKH summarize over/under crediting across the 10,000 estimate in the following a set of equations (our interpretation based off of python code):

$$R_i^a = VERs_i^{academic} / VERs^{project\text{-}period}$$

$$R_{avg}^a = \sum R_i^a / \text{length}(i)$$

$$R_{pp}^{overcredit} = R_{avg}^a * \text{Project-Stove-Days}_{pp}$$

$$R_p^{weighted\_overcredit} = \sum R_p^{overcredit} / \sum \text{Project-Stove-Days}_p$$

$$\text{Credits}_p^{estimated} = \text{Credits}_p^{reported} / R_p^{weighted\_overcredit}$$

$$R_{total} = \sum \text{Credits}_p^{estimated} / \sum \text{Credits}_p^{reported}$$

where R_i^a is the ratio of verified estimated reductions (VERs) for protocol *a* for bootstrapped run *i* using academic studies ($VERs_i^{academic}$) to VERs from the project ($VERs^{project\text{-}period}$).

R_{avg}^a represents the average ratio for all bootstrapped runs for protocol *a*.

R_{avg}^a is multiplied by the total number of project stove days (the product of households receiving a stove and the number of days in the monitoring period) to yield $R_{pp}^{overcredit}$ – a way of weighting the project period contribution to overcrediting.

Some cookstove carbon projects have multiple protocols (project periods). These are summarized using a weighted average of contributed project stove days, yielding $R_p^{weighted\_overcredit}$.

For each project (n=51 in GKH's analysis), GKH identify the total number of credits that have ever been verified, including some that are not directly evaluated in the project period protocols ($\text{Credits}_p^{reported}$). These are divided by $R_p^{weighted\_overcredit}$ to generate a new estimate of total credits ($\text{Credits}_p^{estimated}$).

R_{total} (the total times over/under credited) is estimated as ratio of the sum of $\text{Credits}_p^{estimated}$ to the sum of $\text{Credits}_p^{reported}$.