Why current assessment methods may lead to significant underestimation of GHG reductions of improved stoves

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The inclusion of improved stove programmes in carbon trading schemes requires valid methods for estimating their impact on greenhouse gas emissions. Current approaches often make use of IPCC default emission factors or those from controlled water boiling tests (WBT), yet little is known about whether these emission factors are representative of normal daily stove use. This article compares the use of IPCC and WBT-derived emission factors with those measured in homes during normal daily stove use and found that both the IPCC and WBT-derived emission factors resulted in substantially underestimating the carbon savings achieved from the installation of a Patsari improved stove in rural Mexico. It also evaluates using community-level fuel renewability estimates in the calculation of carbon savings and looks at the carbon savings that can be made using this factor

Introduction

There is a growing interest in the potential to trade carbon offsets from improved stove programs on carbon markets for voluntary reductions, or as part of international accords. To include improved stoves in these trading schemes, methods meeting minimum accountability standards for quantifying their impact on GHG emissions are needed. Such methods are especially important given that 2 billion people in the developing world still rely on biomass for cooking and, depending on fuel renewability, up to the equivalent of 10 tonnes of carbon dioxide may be saved per household per year with an improved stove (Johnson et al., 2007).

Calculating carbon emissions from stoves incorporates at least five key parameters: stove adoption rates, stove maintenance, fuel consumption, emission factors, and fuel renewability where biomass is the main energy source. This article focuses on methods for deriving emission factors and renewability since they are not well established. Experience in rural Mexico indicates that using IPCC emission factors or emission factors from controlled laboratory tests instead of emission factors measured during normal daily stove use, are likely to lead to significant errors in estimation of carbon savings. In addition we find that community specific estimates of biomass renewability have the potential to dramatically improve carbon savings estimates.

The Patsari Project

Over 6,000 Patsari improved stoves have been disseminated in Mexico by the non-profit Grupo Interdisciplinario de Tecnología Rural Apropiada (GIRA - www.gira.org.mx), of which 2,500 are in Purépecha communities in the central Mexican highlands. The Patsari Project, which received a 2006 Ashden sustainability award for Health and Welfare (www.ashdenawards.com), incorporates community-based monitoring and evaluation of the overall impacts of the Patsari improved stove. This includes studies on health, indoor air pollution, stove adoption, social perception, fuelwood renewability, energy performance, and greenhouse gas (GHG) emissions. The primary goal of the GHG study was to demonstrate and validate approaches for the quantification of GHG emissions from traditional and Patsari stoves in rural Purépecha communities, which could be applied on a wider scale. The results provided the quantitative basis for subsequent trading of carbon offsets from the project in carbon markets.

Estimation of GHG emissions from cooking in rural communities

The majority of cookstove emission factors have been derived using controlled testing procedures in simulated kitchens (e.g Smith et al., 2000; Zhang et al. 2001), due to the complexity of applying standard measurement techniques in homes. The most commonly used controlled testing procedure has been the Water Boiling Test (WBT). Since the bulk of current stove emissions knowledge comes from research using the WBT, current IPCC stove emission factors and those often cited in emissions inventories for climate modelling are ultimately derived from the WBT. However, little formal testing has been conducted to evaluate if the WBT produces emissions representative of those from cookstoves in homes during normal daily activities. In Mexico the relationship between using emission factors from the IPCC, WBTs, and normal daily stove use in homes were evaluated for both traditional open fire stoves and improved Patsari stoves (see Figure 1).

Nominal combustion efficiency (NCE), or the amount of fuel carbon converted to CO_2, during WBTs in the simulated kitchen was found to substantially over predict the efficiency of open fires (Figure 2). NCEs produced during WBTs in a simulated kitchen also indicated the mud-cement Patsari was 7% less efficient than traditional open fires, while the converse was true in homes during normal stove use by local residents, where the mud-cement and brick Patsaris were 2.6 and 7.9% more efficient, respectively. Thus using the WBT for cookstove GHG estimates in these communities would result in erroneous emissions levels.

This result is not entirely surprising given that the Patsari was designed primarily for tortilla cooking, which ac-

Figure 1. Traditional open fire (A), mud-cement Patsari (B), and brick Patsari (C) (Photo: M. Johnson)

counts for half of fuel consumption in rural Mexico, rather than boiling water. An energy performance study by Berrueta et al. (2007) found the Patsari used approximately twice as much fuelwood as open fires during the high power boiling phase of the WBT, yet required 44-57% less fuelwood per tortilla in controlled cooking tests. In agreement with the combustion efficiency results, Berrueta et al. (2007) also found the Patsari reduced household fuelwood consumption by 48-66% during kitchen performance tests, further confirming that local stove use practices diverge significantly from WBT burn cycles.

Similar results are obtained when comparing global warming contributions, where the CO_2-equivalent carbon savings from an improved cookstove can be underestimated by up to 64% (Figure 3). Emission factors of gaseous species[1] were converted to CO_2-equivalent using IPCC 100-year global warming potentials, then combined with fuel use estimates from Berrueta et al (2007) assuming that 80% of the fuelwood was harvested renewably (see below). For both gases included in Kyoto protocols (CO_2 and CH_4) and a more expanded set (CO_2, CH_4, CO, and TNMHC[2]), carbon savings of the Patsari were significantly underestimated by both WBT and IPCC default emission factors, although the latter do not differentiate by stoves and are therefore solely a function of reduced fuel consumption.

In addition to the erroneous carbon estimates, Figure 3 also shows the significant fraction of mitigated carbon emissions from the use of household improved cookstoves that is not included when only Kyoto Protocol sanctioned gases are considered, due to the large fraction of carbon that is diverted into other GHGs. For residential cook stoves, therefore, all GHGs should be included, especially as non-inclusion of some of the gases can lead to wrong conclusions about the relative benefits of different stove types (Edwards et al., 2004).

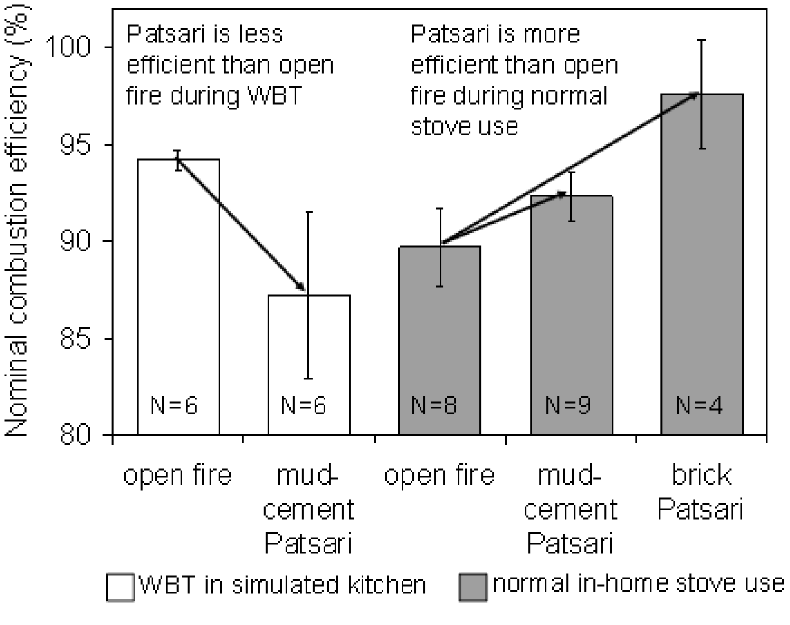

Figure 2: Nominal combustion efficiency of stoves during WBTs and in-home stove use. Arrows highlight that WBT resulted in open fires producing higher NCEs than Patsaris, when the converse was found to be true under normal daily stove use.

WISDOM and renewability

For biomass combustion, fuel renewability is a critical component in calculating carbon emissions since the CO_2 that is reintegrated into the next cycle of vegetative growth must be subtracted from the original emissions. The difference in emissions assuming renewable compared to non-renewable biomass use far outweighs the differences between stove types, and so accurate estimation is critical in assessing carbon savings (Edwards et al, 2004). Wood fuel renewability in the Purépecha region was estimated using WISDOM (Woodfuel Integrated Supply/Demand Overview Mapping model) (Masera et al., 2006; Ghilardi et al., 2007), a GIS-based model that spatially integrates fuel wood supply and consumption, and has been applied in several countries. The supply of fuel wood is estimated on a village basis by defining accessible areas through cost-distance maps and other GIS techniques, and combined with data on land cover classes, land cover change and fuel wood productivity. Fuel wood demand comes from local surveys, case studies and geo-referenced population censuses, and includes indica-

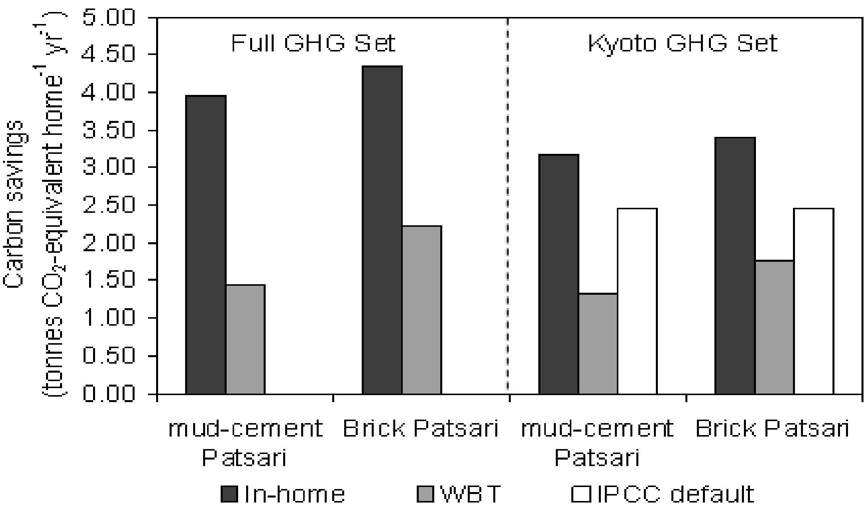

Figure 3: Carbon savings per home using in-home, WBT, and IPCC emissions factors. Savings were calculated assuming 80% fuel renewability for the Purépecha region (Ghilardi et al., 2007) and fuel consumption data from Berrueta et al. (2007). Notes: a. WBT emission factors for brick Patsaris were derived from WBTs conducted within homes rather than in the simulated kitchen. b. The 2006 IPCC Guidelines for National Greenhouse Gas Inventories only report wood emission factors for CO_2 and CH_4 for stationary residential combustion. No CO_2 emission factor is provided for wood stoves and a broad range (258-2190 kg TJ^{-1}) is presented for CH_4. The default value for stationary residential wood combustion was used for CH_4 (300 kg TJ^{-1} [4.8 g kg^{-1} assuming a calorific density of 16,000 kj kg^{-1}]).

tors such as population density, percentage of households using fuel wood and fuel wood consumption by main species. The use of detailed local data allows WISDOM to make consistent renewability estimates at the community level.

Such fine discrimination makes calculating emission reductions on a community basis possible, rather than applying mean regional renewability estimates based on top down surveys. The importance of the renewability component is demonstrated in Figure 4, which presents the carbon savings achieved from replacing an open fire with a mud-cement Patsari under different renewability scenarios. Potential CO_2-equivalent savings under non-renewable harvesting are a factor of 3.7 larger than those assuming renewable harvesting of biomass. The potential for underestimating marketable carbon savings is made evident by the village of Puacuaro, for which WISDOM estimates 15% of fuelwood is harvested renewably, in contrast to the region's mean 80% renewability (see Figure 5). Use of the mean regional renewability in this case would indicate the Patsari saves less than half of that which is achieved using Puacuaro's renewability estimate. Such large error for a single village also demonstrates the importance of community-level renewability data for projects focused in a small number of communities. Additionally, the relatively large carbon savings per household in Puacuaro illustrate WISDOM's potential to maximize GHG reductions by focusing cookstove dissemination efforts in areas with less renewable harvesting of biomass.

Conclusions

Methods have been developed to assess rural residential cookstove GHG emissions that rely on: locally derived GHG emission factors during daily cooking activities, in home assessments of fuel wood savings, and a spatially explicit determination of fuelwood renewability at village level. Results demonstrate the significant potential for carbon savings as a result of installation of the Patsari improved cookstove.

Methodologically, if these results hold true for other stoves and other communities, controlled WBT based emission factors from simulated kitchens should not be used in the estimation of carbon savings from improved cook stoves. Instead, continued efforts should be made to assess emissions from stoves during daily activities in local communities

Finally, differences in carbon savings between non renewable and renewable harvesting are of such magnitude that community based assessments of renewability are critical in assessment of carbon savings, and provide an opportunity for maximizing GHG reductions by focusing cookstove dissemination efforts in areas with less renewable harvesting of biomass.

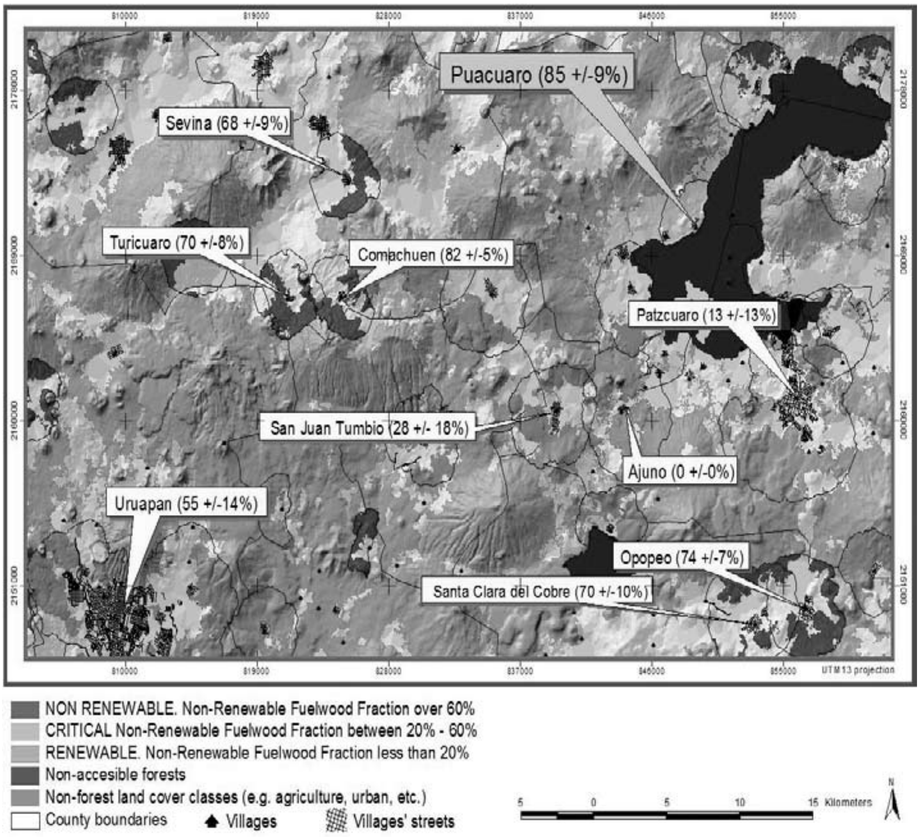

Figure 4. The use of detailed local data allows WISDOM to make consistent renewability estimates at the community level [figures are % non-renewable].

Acknowledgements

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Notes and References

1. Although particulate emissions were made they are not reported here, see Johnson et al., (2007)

2. Total non methane hydrocarbons

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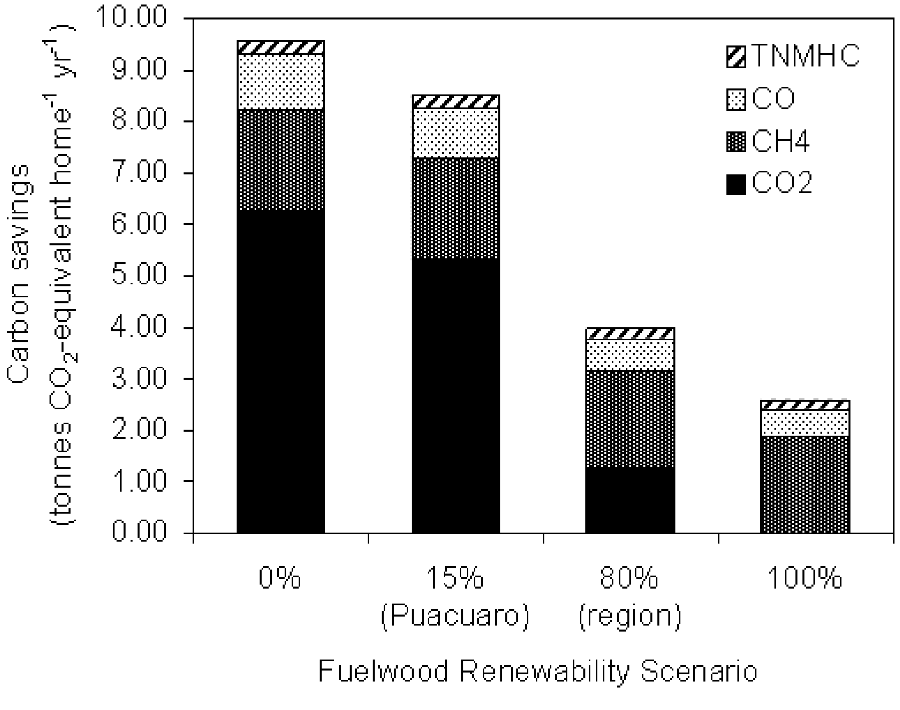

Figure 5. Carbon savings from switching from an open fire to mud-cement Pastari for four renewability scenarios.

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