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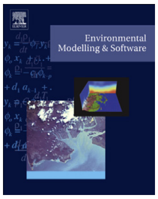

Spatiotemporal modeling of fuelwood environmental impacts: Towards improved accounting for non-renewable biomass

Adrián Ghilardi [a], [*], Robert Bailis [b], [1], Jean-François Mas [a], Margaret Skutsch [a], José Alexander Elvir [c], Alexander Quevedo [a], Omar Masera [d], Puneet Dwivedi [e], Rudi Drigo [f], Ernesto Vega [d]

[a] Centro de Investigaciones en Geografía Ambiental (CIGA) & Laboratorio Nacional de Análisis y Síntesis Ecológica (LANASE), Escuela Nacional de Estudios Superiores, Universidad Nacional Autónoma de México, antigua carretera a Pátzcuaro 8701, Morelia, Michoacán 58190, Mexico
[b] School of Forestry & Environmental Studies, Yale University, 195 Prospect Street, New Haven, CT 06511, USA
[c] Departamento de Investigación Forestal, Escuela Nacional de Ciencias Forestales, Apartado Postal N°2, Siguatepeque, Honduras
[d] Instituto de Investigaciones en Ecosistemas y Sustentabilidad (IIES), Universidad Nacional Autónoma de México, antigua carretera a Pátzcuaro 8701, Morelia, Michoacán 58190, Mexico
[e] Warnell School of Forestry and Natural Resources, University of Georgia, 180 E Green Street, Athens, GA 30602-2152, USA
[f] Loc. Collina 5, 53036 Poggibonsi (SI), Italy

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ABSTRACT

The extraction and burning of woody biomass at rates exceeding re-growth (i.e. non-renewable extraction) results in net emissions of CO_2. Quantification of the amount of non-renewable woody biomass through a robust and widely applicable method is urgently needed for a wide variety of applications including cookstove carbon-offset projects, national GHG inventories, and sustainable forest management strategies under REDD+. Within this context, we developed “Mofuss” (Modeling fuelwood savings scenarios), a dynamic model that simulates the spatiotemporal effect of fuelwood harvesting on the landscape vegetation and that accounts for savings in non-renewable woody biomass from reduced consumption. The model was tested in western Honduras where collected and marketed fuelwood is used by the residential sector in both urban and rural settlements. We argue that geospatial modeling, aimed at representing real situations more closely while integrating uncertainty, should be used in calculations of carbon savings from cookstove projects or fuel switching interventions.

Software and data availability

Mofuss integrates a set of scripts that requires some freeware to be installed first. The first step consists in downloading Mofuss user manual: www.mofuss.unam.mx. This document contains detailed but concise instructions for downloading, installing and using Mofuss and any other needed freeware.

Mofuss (version 1.0) was designed and coded by Adrian Ghilardi between September 2011 and April 2015 with contributions from four co-authors of the present work: Jean-François Mas, Robert Bailis, Rudi Drigo and Omar Masera. A fifth co-author, Ernesto Vega, helped with R code issues during debugging. Developer contact details are available in affiliations of authors.

Dinamica EGO (one of the required freeware) is only available for Windows operating system. Mofuss has been tested successfully in various configurations of Windows 7, 8 and 10 versions, and in Intel-based Macs using Boot Camp. There is no recommended hardware as overall processing time will depend on the size of the selected area of interest. For replicating the present study area (4 departments in western Honduras), a desktop with an Intel i7 CPU at 3.40 GHz with 16 GB of RAM should take about 24–36 h for completing each of the three more time demanding processes: IDW submodule and both simulations (BaU and ICS) using 100 MC realizations. A much smaller area with few MC realizations will take a couple of minutes using the same equipment. The user manual also provides a link to already processed IDW indexes for the same study area as shown in this work, in order to gain some time if trying to replicate this particular study example. Both 64-bit and 32-bit systems will work (although under 32-bit some figures will

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[*] Corresponding author.
E-mail addresses: aghilardi@ciga.unam.mx (A. Ghilardi), Rob.Bailis@sei-us.org (R. Bailis), jfmas@ciga.unam.mx (J.-F. Mas), mskutsch@ciga.unam.mx (M. Skutsch), alexit98@yahoo.com (J.A. Elvir), alequech@gmail.com (A. Quevedo), omasera@cieco.unam.mx (O. Masera), puneetd@warnell.uga.edu (P. Dwivedi), rudi.drigo@tin.it (R. Drigo), evega@cieco.unam.mx (E. Vega).

[1] Stockholm Environment Institute – US Center.

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Abbreviations and definitions

AGB	(aboveground biomass)
CDM	(Clean Development Mechanism)
fNRB	(fraction of non-renewable biomass): When NRB (defined below) is referred to as a fraction of total fuelwood use, the acronym fNRB is used instead, standing for the “fraction of non-renewable biomass”, a number which describes the degree to which of the harvesting of wood is unsustainable
Forest	We define forest or “forest cover” broadly, to include sparse and mosaic woodlands and rangelands not necessarily classified as “forest” under more conventional definitions which use thresholds for canopy cover or tree height
Fuelwood, also known as firewood	Woody biomass used as an energy source without any thermochemical transformation and with little or no mechanical processing
ICSs	(improved cookstoves): Efficient end-use cooking devices using less fuel and emitting fewer pollutants in comparison to traditional (i.e. less-efficient) models. It is used interchangeably with efficient or fuel-saving cookstoves
IDW	(Inverse Distance Weighted)
K	(carrying capacity): Maximum achievable AGB stock given a certain class of Land Use and Land Cover, plus any other biophysical constraints. K is assumed to remain constant in time within Mofuss
LULCC	(Land Use and Land Cover Change): Direct or indirect human modification of the earth's terrestrial surface. Land cover refers to the physical and biological cover over the surface of land, including water, vegetation, bare soil, and/or artificial structures. Land use is defined in terms of human activities such as agriculture, forestry and building construction that alter land surface processes including biogeochemistry, hydrology and biodiversity
MAI	(Mean Annual Increment): Equivalent to Maximum Sustainable Yield (MSY)
MC	(MonteCarlo simulation)
NRB	(non-renewable biomass): Extraction of woody biomass at rates exceeding the rate of natural re-growth within a given time period, most commonly one year
tDM	(tons of dry matter)
TOF	(trees outside forests): Trees on farmland, household compounds, and roadside commons, where wood is accessed by pruning live trees and/or collecting dead/downed branches. This category also includes shade trees in coffee plantations, which are pruned regularly and constitute a major source of wood in coffee-growing parts of the study region
Simulation	Corresponds to the progression of fuelwood harvest - regrowth spatial patterns over a given time period in discrete time steps or iterations. In the particular example of our case study each simulation lasted 30 years, by annual time steps. Iterations cannot be shorter than a week or longer than 10 years, while simulation periods have no upper bounds
Realization	Each of many homologous simulations (i.e. set under same parameters and assumptions) that are run to account for uncertainty and sensitivity. Realizations should be understood as the process of how simulations “come out” after each Monte Carlo run

be purposely rendered at lower resolution).

Mofuss and any other needed software are freely available to download and use, and all Mofuss scripts can be opened, edited and saved using any free code editor such as Notepad++ or Sublime Text. Mofuss scripts were coded in Dinamica EGO (.egoml), R (.R), LaTeX (.tex) and Windows batch scripting (.bat). Mofuss scripts and associated files (e.g. ffmpeg.exe, zip.exe, pdf messages) is roughly 45 MB, and the Honduras dataset (spatial raster data in geotiff, spatial vector data, and tables) is roughly 550 MB and is downloadable as a separate file, as explained in the user manual.

1. Introduction

Despite the fact that traditional wood energy (fuelwood and charcoal) is still in widespread use in many developing countries (IEA, 2012a, b), the impact of woodfuel harvesting on forests and woodlands is still a point of contention. Identified as the “other energy crisis” in the 1970s (Eckholm, 1975), fuelwood extraction and charcoal production by poor rural and peri-urban populations were seen then as major drivers of environmental degradation (de Montalembert and Clement, 1983). Some analyses still report a direct connection between woodfuels and “severe deforestation” (e.g. Pang et al., 2013; Singh et al., 2010) or “forest degradation” (e.g. Ahrends et al., 2010; Cantarello et al., 2014; Moroni and Musk, 2014; Orozumbekov et al., 2015; Ryan et al., 2012; Specht et al., 2015). However, others think woodfuel demand has limited impact on forest cover (e.g. Hansfort and Mertz, 2011; Shrestha et al., 2013) because it is overshadowed by other socioeconomic and ecological processes (de Waroux and Lambin, 2012; Dewees and Arnold, 1997; Foley, 1985; Hosier, 1993).

Broad generalizations are inherently misleading, as spatiotemporal patterns of woodfuel supply and demand are site specific and impacts on vegetation vary greatly from place to place (Ghilardi et al., 2007; Wangchuk et al., 2014) and as a result of specific patterns of resource use, e.g. subsistence fuelwood or commercial charcoal (Naughton-Treves et al., 2007). In addition, vegetation responds to disturbance in ways that may impact harvesting practices, changing species preference, extraction sites, and volumes extracted (He et al., 2009; Jagger and Shively, 2014; Ruger et al., 2008).

Within the policy arena, more nuanced and accurate assessments accounting for spatiotemporal effects are needed to better predict the impact of interventions such as improved cookstove (ICS) programs and improved charcoal kilns. In the past, positive impacts have been assumed as a matter of faith in the technology rather than as demonstrated through scientific analysis. Thus, there is a pressing need for models which will robustly assess impacts of interventions, such as carbon fluxes, since program financing is often predicated on the generation of carbon credits.

Geospatial modeling techniques are a promising option to render the spatiotemporal variability explicit (Costanza and Voinov, 2004; Deaton and Winebrake, 2000; Murayama and Thapa, 2011; Paegelow and Camacho-Olmedo, 2008). The core questions that need to be addressed are:

1) How much woodfuel is harvested at a given location within a specific time frame?