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Analysis

Global patterns and trends of wood harvest and use between 1990 and 2010

Anna Liza S. Bais *, Christian Lauk, Thomas Kastner, Karlheinz Erb

Institute of Social Ecology, Alpen-Adria University, Schottenfeldgasse 29, 1070 Vienna, Austria

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ABSTRACT

Wood biomass forms the basis for a variety of products and it represents an important source of technical energy. Woodfuels and forests play an important role for climate change mitigation, by their ability to replace fossil fuel and sequester atmospheric carbon. At the same time, wood extraction is an important driver for deforestation. However, large uncertainties relate to the amount and spatio-temporal pattern of wood use. We here present a comprehensive assessment of wood biomass flows in 11 world regions from 1990 to 2010. We found that global total biomass appropriation (TBA) amounts to 1.81 GtC/year in 1990 and 1.94 GtC/year in 2010 (+7%). In 2010, TBA represents 4% of the global forest net primary production. Only 54% of TBA enters socioeconomic systems while 46% remain in forests or represent waste flows. About 56% of economically used wood biomass enters the energy sector. There are considerable regional variations in wood biomass flows among world regions, owing to differences in population, affluence, and area. Global demand for wood is expected to increase in the near future, putting additional pressure to forest ecosystems. We discuss the potential of cascading use of wood as a means to reduce impacts related to resource use.

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1. Introduction

Wood biomass is among the most important natural resources for society. Already in the early civilizations, biomass, mainly in the form of traditional fuel such as firewood and charcoal, was the single most important source of energy for cooking, heating, and other domestic use (Tillman, 1978), and was one of the most important resources for construction materials. During the industrial revolution, wood has been largely replaced by fossil fuels (e.g. oil, coal and natural gas) for transportation, industries, and heating in most industrialized regions while it remained an important source of energy in many developing countries, especially in rural areas (FAO, 2008). The significant growth of fossil fuel used in the past led to increased atmospheric CO_2 concentration contributing about 78% of the total GHG emission increase from 1970 to 2010 (IPCC, 2014). We are now facing the situation of increasing human-induced climate change, mainly caused by the combustion of fossil fuels. Due to this concern, in recent years wood energy has regained importance. Wood biomass is increasingly promoted by industrialized countries as a carbon-neutral source of energy, based on the idea that for biomass, only the amount of carbon previously absorbed in the course of plant growth will be released to the atmosphere. While this assertion may only be correct under rare circumstances (Haberl et al., 2013; Schulze et al., 2012; Searchinger et al., 2009), the promotion of woodfuels as a climate change mitigation option is continued, adding another driver to the global consumption of wood biomass.

In consequence, the modern use of wood biomass for energy provision gained a significant share in the global energy market during the last years, especially in developed regions such as the European Union and North America (Roos and Brackley, 2012; Cocchi et al., 2011; Heinimö and Junginger, 2009). For example, the production of global wood pellets grew by 12% in 2013, reaching 22 million metric tons (FAO, 2014b). At the same time, traditional biomass remains the dominant source of energy for heating and cooking in the rural areas of most developing countries. However, wood extraction for fuel has been identified as one of the principal drivers of forest degradation and depletion of forest carbon storage, trends initiatives like the 'Reducing Emissions from Deforestation and Degradation of forests (REDD) programmes' aim to halt or at least slow down (Schure et al., 2014; Rudel, 2013). This shows that there is a potential trade-off between the sustainability goals of poverty reduction, climate change mitigation and energy security and the preservation of ecosystem services provided by forests.

An accurate assessment of these trade-offs requires an improved understanding of global patterns and trends of wood harvest and use. An enhanced knowledge of how biomass is flowing through different socioeconomic compartments represents the prerequisite to assess issues of carbon neutrality or trade-offs of wood biomass use. However, the current understanding is limited due to the lack of a consistent and robust account on global wood biomass flows. This is mainly due to the large uncertainties that prevail on existing widely used databases. For instance, woodfuel removals are known to be under-reported in FAO

* Corresponding author.
E-mail address: annaliza.bais@aau.at (A.L.S. Bais).

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statistics and illegal logging or unrecorded industrial wood removals are not captured in the national statistics provided to FAO (Nellemann, 2012; Meyfroidt and Lambin, 2009). To our knowledge, only Sims et al. (2006, 2007) have so far quantified global wood flows, but only focusing on energy use and disregarding other uses of wood. Other wood flow studies focused on Europe at regional (Mantau, 2012) and national levels (Kalt, 2015; Jungmeier and Subotić, 2011; METLA, 2011).

This study aims at assessing flows of wood biomass in a comprehensive manner, following its pathway from primary production in forest ecosystems, along the different stages of economic processing to final consumption, in order to draw a comprehensive picture of global wood C flows. It explicitly includes direct (i.e. primary wood removals) and indirect wood flows (i.e. logging residues and belowground biomass losses, appropriated but not subject to further socio-economic use). By combining data from different sources and following a sound accounting framework, it detects discrepancies in official statistical data regarding industrial wood removals and provides alternative estimates (minimum and maximum) on woodfuel removals. It covers all wood biomass uses such as paper and paperboards, semi-finished wood products (e.g. sawnwood, veneer and wood panels), other wood products (e.g. poles, piles, etc.), energy use, wood wastes and losses. It allows to estimate the apparent consumption of traditional (e.g. fuelwood and wood charcoal) and modern (e.g. wood pellets and wood for heat and power) woodfuels and their respective consumers (e.g. residential, wood industries and other industries). Wood biomass flows were calculated for the years 1990, 2000, and 2010 on the country level and aggregated to 11 world regions. This database allows to analyse and discuss trends and patterns of wood biomass flows, its share in the total primary energy consumption, and its relation to population, forest area and forest productivity. In the last section we discuss factors influencing regional patterns of wood biomass use and strategies to meet the future demand for wood resources.

Table 1
The definition of the indicators referred to in text and in Fig. 1.

Used extraction (UE)	The amount of extracted wood biomass entering the socioeconomic system for further processing or consumption (Fischer-Kowalski et al., 2011), including woodfuels and industrial roundwood. It is equivalent to "wood removals" and to indicator "domestic extraction (DE)" as it is used in Material Flow Accounts (Haberl, 2001).
Unused extraction (UnE)	The amount of wood biomass that are killed through harvest but not economically used thereafter, includes logging residues and below ground biomass losses.
Total biomass appropriation (TBA)	The sum of used extraction (UE) and unused extraction (UnE). It is equivalent to Human Appropriated Net Primary Production ($HANPP_{harv}$), the amount of carbon in wood biomass harvested or killed during harvest within a year (Krausmann et al., 2013; Erb et al., 2009).
Net trade (imports—exports)	Imports minus exports of all roundwood and wood biomass products.
Apparent consumption	Used extraction plus net trade, equivalent to "domestic biomass consumption (DBC)" in MFA.
Waste flows	These flows include unutilized industrial residues and wood losses produced in wood processing industry which were commonly disposed of in landfills and incinerators. Post-consumer wastes are not included in this study.
Recycling flows	These flows include recovered paper that have been collected and re-used for the manufacture of paper and paperboard.
Wood biomass supply	The sum total of all types of used extraction plus net imports.
Wood biomass use	The sum total of all types of wood biomass use plus net exports.
Forest harvest intensity	Used extraction per unit area of forest (tC/ha/year) or per unit of actual NPP (%).

2. Data and Methods

In order to ensure consistency, we applied the standard of material- and energy flow accounting (MEFA; Fischer-Kowalski et al., 2011; EUROSTAT, 2001) throughout this study. Fig. 1 shows the schematic representation of global wood biomass flows based on MEFA and Table 1 provides an overview on the used terminology. We accounted wood biomass from ecosystems, along the different stages of economic processing to final consumption. We compiled and calculated data on wood flows for 188 countries in a decadal time series from 1990 to 2010. In 1990, only 166 countries were included, as the 15 countries forming the USSR (Union of Soviet Socialist Republics) then represented a single statistical entity and due to some data gaps related to a few other countries (see Table S1). Only countries with complete availability of international statistics on forestry production (FAO, 2014a) were included in the assessment. We aggregated countries into 11 world regions, with macro-geographical (continental) regions and geographical sub-regions according to UNSD (2006; Table S1). Wood flows are consistently accounted in ton Carbon (tC). As all primary data from FAO were given in solid cubic metre (m^3), all data were converted into tons of dry matter (0% water content) by applying region-specific wood density coefficients (Table S2) for coniferous (C) and non-

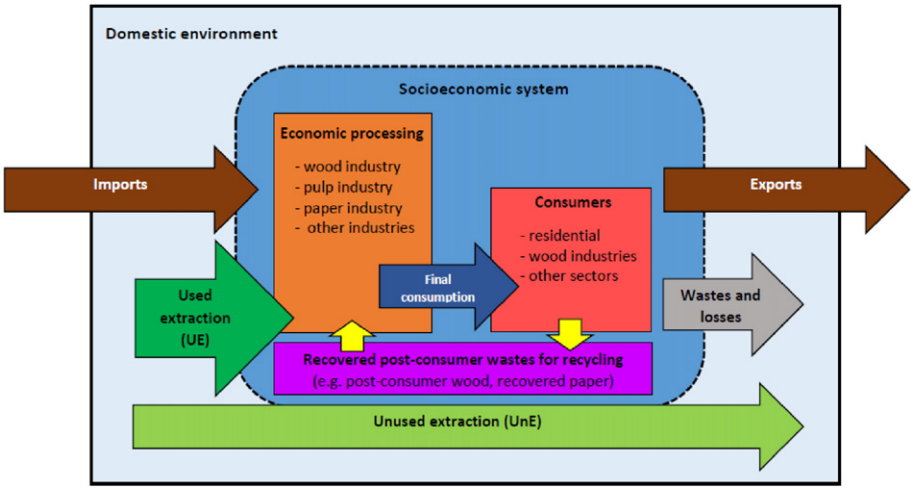

Fig. 1. A schematic representation of wood biomass flows in and between countries.

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