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Drivers of land use efficiency and trade embodied biomass use of Finland 2000–2010

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ABSTRACT

Globally human pressure on the biosphere is increasing, in spite of increases in land use efficiency. The pressure consists of land use and potential degradation. Human appropriation of net primary production (HANPP) is emerging as an indicator, which combines the dual aspects of biomass use and land degradation. Recently HANPP has been used to map the increasing dependence of European countries on biomass imports and the conflicting processes of increased yields and increased consumption. However large overview studies could be complemented with indepth analysis into the causes of changes in individual countries and economic sectors. This allows the analysis of the macroeconomic drivers of change and the responses in sectors to these drivers. In this study we decomposed the HANPP of Finland including imports for the years 2000–2010 using IPAT and applied input-output analysis to look at sectoral land use efficiency in that time period. Finland is a country with intensive biomass trade, and with a very high per capita HANPP. During the study period the sum of domestic and embodied in imports HANPP of the Finnish economy decreased from 76 Mt C/a to 62 Mt C/a (−1% annually on average), while the HANPP related to imports increased from 12 Mt C/a to 14 Mt C/a. The overall trend was that of declining exports and increasing domestic consumption. Of the economic sectors wood harvesting and processing dominated HANPP results, followed by residential construction, animal production and energy supply. In terms of HANPP, most of these decreased, but housing and energy production increased considerably from 2002 to 2010. At the macroeconomic level domestic biomass use per unit of value added decreased (−2.2%/a) as did the amount of HANPP per unit of biomass (−1.1%/a) reflecting increased economic efficiency in land use. In contrast, GDP/capita (+1.3%/a), population (+0.4%) and the share of outsourced HANPP (+0.6%) resulted in increased consumption-based HANPP (from 21 Mt C in 2002 to 27 Mt C in 2010). Our results underline the importance of including international trade and consumption in interpreting overall change in regional HANPP.

1. Introduction

Human pressure on the biosphere is increasing: the global human appropriation of net primary production (HANPP) grew from 6.9 Gt C in 1910–14.8 Gt C by 2005, (0.8% annually on average) (Krausmann et al., 2013). Net primary production (NPP) is a key process for life on Earth and through examining its appropriation the possible impact of land use on the health of the ecosystem can be estimated. HANPP has emerged as a key indicator for quantifying the dual aspects of land use: biomass harvest and potential land degradation. HANPP integrates the appropriation of biomass harvest or burning (harvested HANPP, HANPPharv) and the productivity changes resulting from conversion of natural ecosystems to managed lands (HANPP related to land use change, HANPPluc). Globally approximately half of the human appropriation of ecosystem productivity is contributed by harvests and the other half by land use-induced productivity changes and human-induced fires (Haberl et al., 2007).

Globally, HANPP results are dominated by agriculture (Krausmann et al., 2013), but considerable variation exists among regions. In general, population density, the stage of industrialization and international trade have all been identified as key determinants for HANPP (Krausmann et al., 2012; Krausmann et al., 2013; Teixidó-Figueras et al., 2016). The HANPP of a given region depends on a combination of factors: while a low population density results in low biomass consumption, it may also include harvesting for export purposes. And while higher levels of indus-

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trialization generally increase land use efficiency (yield) they also increase trade and possibly consumption (Krausmann et al., 2012). In Europe the general trend is a high level of HANPP, stagnated by the conflicting processes of cropland intensification, reducing agricultural and grazing land and increasing settlement and forest areas, but with considerable differences among countries (Gingrich et al., 2015).

Traditionally HANPP has been used to analyze the extent of human impact compared to a natural reference state in a region. A recent development has been the inclusion of embodied HANPP (eHANPP) of imported products (Erb et al., 2009). This allows the analysis of the impacts of international trade between regions, the potential externalization of biomass production and the linkages between production and consumption. Recent eHANPP studies have highlighted the increasing dependence of Europe from outsourced biomass production from other regions (Kastner et al., 2015). Therefore the consumption-based approach, accounting for the total global impacts occurring from economic consumption within a country, is becoming increasingly important also for land use, as it has become for evaluating climate change (Peters and Hertwich, 2008). In an area-specific approach, HANPP serves as an indicator of land-use impacts on a defined area, and the consumption-based embodied HANPP approach allows assessment of impacts related to individual products or the aggregate consumption of countries (Haberl et al., 2014). With increased international trade, embodied HANPP should be a key component in identifying the drivers of increasing HANPP at the country or regional level.

Finland represents a sparsely populated industrialized country with a forest dominated landscape (Luke, 2014). Finland both exports and imports considerable amounts of biomass (Sandström et al., 2014). Expressed in land area the biomass imports corresponded to 55% of the domestic land area, amounting to 134,000 km^2 in 2010 (Mattila and Saikku, submitted). Domestic HANPP is high, approximately 50% of the potential net primary production (NPP) but has decreased 75 Mt C to 62 Mt C in 1990–2010 (Saikku et al., 2015). In a comparison of 28 EU member states, Finland ranked the highest in production-based per capita HANPP and sixth in respective consumption-based accounting (Kastner et al., 2015). The overview studies have not provided insight on why the Finnish HANPP is so high and have so far not estimated the amount of HANPP embodied in imports. The aim of this study was to apply IPAT-decomposition to the Finnish HANPP dataset for the years 2000–2010, to quantify the changes over time in eHANPP and to identify the key drivers behind the overall change. This study examines the reasons behind the high Finnish HANPP and tests the applicability of IPAT-decomposition analysis and input-output analysis in identifying these drivers.

The paper is structured as follows. First we describe the methodologies and their application, especially the estimation of embodied HANPP for imported commodities, the application of IPAT-decomposition and disaggregating the results to sector level. Then we present the results on the embodied HANPP, the decomposition to IPAT factors and the disaggregation to economic sectors. Finally we discuss the implications of this analysis to the development of resource efficiency in Finland, the usefulness of the analysis methods, and the use of HANPP as a resource efficiency indicator.

2. Materials and methods

2.1. Estimating HANPP embodied in imports

The methods for calculating HANPP and eHANPP are well established, but in this study we used two modifications to those. The first change was the consideration of reduced NPP in forestry as $HANPP_{luc}$, according to Saikku et al. (2015). The previously calculated dataset with the forestry induced HANPP was used as such, and the details of the methodology and its changes compared to the standard method are described in Saikku et al. (2015). The changes in quantifying the import embodied HANPP are described in this chapter. The main terminology used in this paper is described in Table 1.

Table 1
The terminology used in this paper.

Term	Abbreviation	Explanation/consists of
Human Appropriation of net primary production	HANPP	harvested HANPP (used + unused extraction) + HANPP related to land use change
HANPP embodied in imports		HANPP related to the imported goods in the producing country
HANPP embodied in exports		HANPP related to exported goods including both the HANPP from Finland and from countries from which goods were imported prior to processing and re-export
Consumption-based HANPP		HANPP embodied in imports + domestic HANPP – HANPP embodied in exports
Production-based HANPP/domestic HANPP		HANPP from Finnish industries primary production
Impact	I	domestic HANPP + HANPP embodied in imports
Affluence	A	GDP/capita
Population	P	
Consumption	C	used biomass/GDP (=used extraction/GDP)
Technology	T	domestic HANPP/used biomass
Outsourcing	O	(domestic HANPP + HANPP embodied in imports)/domestic HANPP.

The commonly used approach in HANPP studies is to estimate the embodied HANPP through bilateral trade and biophysical data (Kastner et al., 2015). A problem with this approach is that highly processed goods and services are not included (Hubacek and Feng, 2016). The second change to the standard methodology was to use life cycle assessment to convert material flows into primary biomass flows for the imports of processed goods.

The first stage was to link the import commodity flows to available life cycle inventories (see Supplementary information SI for the raw material equivalents of traded biomass and HANPPluc). Ecoinvent 2.2. and 3.0 databases (Ecoinvent, 2015) were used to find 240 life cycle inventory datasets, which corresponded to the imported commodities. The dataset was complemented through individual LCA studies on animal products (Williams et al., 2006), fish (Ytrestøyl et al., 2011; Nielsen et al., 2003) and beverages (Coltro et al., 2006; Ntiamoah and Afrane, 2008; Amienyo et al., 2013; Brewers of Europe, 2002; Gazulla et al., 2010). The original data on Finnish imports was in the combined nomenclature (CN) classification. For analysis it was then aggregated to the Classification of Product by Activity (CPA) level and then to a customized 180 product aggregated resolution (ETTL) used in previous studies (Koskela et al., 2011). A correspondence table was used to link the LCI inventories to the products of the import statistics. Used and unused flow of imports was compiled based on this data.

For the harvested HANPP, used and unused extraction was calculated. The above mentioned life cycle inventories included the resources extracted during the life cycle of the product. For the purposes of this study, only biotic raw materials were included. This covered wood, crops and fibres, which were aggregated into a total biomass used extraction figure. Unused extraction was added to