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The effect of industrialization and globalization on domestic land-use: A global resource footprint perspective

Highlights

- Nations are increasingly disconnected from their domestic biological productivity.
- Pressure on domestic ecosystems is reduced through external inputs and imports.
- Environmental burdens are shifted to spatially distant lands and future generations.
- Superficially efficient land-use systems have the highest resource footprints.
- Global resource appropriation patterns hamper global sustainable land-use.

Abstract

Land-use activities are increasingly globalized and industrialized. While this contributes to a reduction of pressure on domestic ecosystems in some regions, spillover effects from these processes represent potential obstacles for global sustainable land-use. This contribution scrutinizes the complex global resource nexus of national land-use intensity, international trade of biomass goods, and resource footprints in land-use systems. Via a systematic account of the global human appropriation of net primary production (HANPP) and input-output modelling, we demonstrate that with growing income countries reduce their reliance on local renewable resources, while simultaneously consuming more biomass goods produced in other countries requiring higher energy and material inputs. The characteristic 'outsourcing' country appropriates 43% of its domestic net primary production, but net-imports a similar amount (64 gigajoules per capita and year) from other countries and requires energy (11 GJ/cap/yr) and material (~400 kg/cap/yr) inputs four to five times higher as the majority of the global population to sustain domestic land-use intensification. This growing societal disconnect from domestic ecological productivity enables a domestic conservation of ecosystems while satisfying growing demand. However, it does not imply a global decoupling of biomass consumption from resource and land requirements.

Keywords: embodied HANPP, environmentally-extended multi-regional input-output analysis, land-use, international trade, resource nexus, teleconnections

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1. Introduction

While human societies are connected to the biosphere through flows of materials and energy, we observe an increasing disconnection of national socio-economic activities from the limits of domestic ecological productivity – here defined as the net primary production (NPP) of terrestrial ecosystems (Dorninger et al., 2017; Erb et al., 2009; Haberl et al., 2007). There are two main ways for countries to overcome the limits imposed by domestic ecological productivity. Firstly, the intensification of land-use via increased inputs of material and energy extracted from the lithosphere (primarily via the use of fossil fuels based technologies) allows local ecological constraints to be transcended through enhancing NPP per unit area or through increased conversion efficiencies of NPP to final biomass goods (Gingrich et al., 2015; Krausmann et al., 2013). Secondly, biomass production can be outsourced to other countries, leading to land-use change or intensification elsewhere (Bergmann and Holmberg, 2016; Pendrill et al., 2019). A disregard for the resource footprints associated with outsourced land-use and domestic intensification processes – i.e., the direct and indirect appropriated NPP flows and the direct and indirect material, energy, and labor inputs required to sustain appropriated flows of biomass – represents a major obstacle for global sustainable land-use management.

In this paper, we explore how domestic land-use intensity is increasingly shaped by external resource inputs and global resource flows. In doing so we highlight global resource use footprints related to biomass production and consumption. We empirically assess global patterns of two opaque resource flows that mask the land and resource requirements of domestic biomass production and consumption. These two resource flows relate to: (1) flows of non-renewable lithospheric resource inputs (fossil fuels, metals, and non-metallic minerals) into the land-use system (Cooke et al., 2016; Dorninger et al., 2017; Pendrill et al., 2019); and (2) globally traded flows of embodied biomass (and therefore land-use) in domestic biomass production and consumption. The systematic combination of domestic land-use intensity with both these flows represents a significant advancement over previous studies and allows to study the complexity and sustainability of domestic land-use intensity from a comprehensive resource footprint perspective.

Both types of resource flows can be operationalized via the concept of the human appropriation of net primary production (HANPP) (Haberl et al., 2007). For a given area, HANPP quantifies the human appropriation of the products of photosynthesis (NPP), via two processes: (1) the alteration of NPP due to land-use, and (2) the withdrawal of biomass from ecosystems through harvest. HANPP can either be measured in absolute numbers (e.g., in Joules/yr) or as percentage of the potentially available net primary production (NPP_{pot}), that is, the NPP of the natural vegetation hypothetically prevailing in a given area in the absence of land-use (Haberl et al., 2007). HANPP is an indicator of land-use intensity and can be interpreted as a proxy for human pressure on biodiversity, or human domination of ecosystems (Haberl et al., 2014).

Lithospheric resource flows are tightly related to the industrialization of agriculture and forestry (Balmford et al., 2018; Erb et al., 2013; Pretty et al., 2018). Industrial land-use intensification allows harvesting more biomass from the same amount of land by enhancing NPP per unit area. Consequently, increases in harvest are compensated for by increases in NPP and thus do not result in proportional changes of HANPP. In fact, there may even occur reductions in HANPP because the NPP increases not only affect harvested biomass, but also the biomass that remains in ecosystems (Gingrich et al., 2015; Niedertscheider et al., 2016). This can be interpreted as a reduction of land-use pressure, at least in terms of availability of trophic energy. However, boosting conversion efficiencies (that is, the ratio of converting harvested biomass into final goods for consumption) and intensifying land-use typically requires increased inputs of external energy (Coomes et al., 2019; Pimentel et al., 2008) and non-renewable materials (Cumming et al., 2014; Erb et al., 2012).

Global trade of biomass products leading to land-use based teleconnections – i.e. socio-ecological connections over distances (Friis and Nielsen, 2019; Liu et al., 2013) – has increased over the last decades (Bergmann and Holmberg, 2016; Kastner et al., 2014; Pendrill et al., 2019) creating a growing 'spatial disconnect' between domestic land-use and the embodied land-use required for domestic consumption. The HANPP embodied in traded biomass goods, i.e. the HANPP associated with their production, is denoted as eHANPP; it can be used to measure the socio-ecological teleconnections between distant places (Erb et al., 2009; Haberl et al., 2009; Kastner et al., 2015). The outsourcing of biomass production plays an increasingly important role in how countries are able to meet their demand for biomass products and at the same time spare domestic land for biodiversity conservation (Haberl, 2015; Yu et al., 2013). It involves a shift of socio-environmental burdens related to land-use expansion and intensification, e.g. land-use change, deforestation, or biodiversity loss, to the exporting region (Dorninger and Hornborg, 2015; Prell et al., 2017; Wiedmann and Lenzen, 2018). In that regard, a recent study based on embodied HANPP flows found that international trade does globally not lead to a more efficient distribution of land-use in terms of NPP appropriation (Roux et al., 2020).

The opaqueness of these two aspects of biomass consumption reinforces the notion, particularly popular within widespread ecological modernization and green growth paradigms, that human activities can be decoupled from the expansion of land-use and environmental impact on terrestrial ecosystems (Wanner, 2015). In particular, there is a dominant discourse that industrial agricultural intensification generates 'efficiencies' that reduce pressure on the environment (Loos et al., 2014). Unlike other definitions of 'decoupling' which refer to simultaneous GDP growth with declining or slower growth in resource use (absolute or relative resource decoupling), we here focus on the decoupling of resource use from environmental impact (impact decoupling) (Fischer-Kowalski et al., 2011), specifically the decoupling of biomass use from the human appropriation of net primary production (HANPP) from both a production- and consumption-based perspective. A sole focus on local or national land-use optimization will not guarantee a global optimum nor even a globally satisfactory solution. Instead, a re-focus and systematic analysis of global resource-based interconnections, which highlight the problem of localized partial equilibrium solutions (Norgaard, 2010), is needed. We argue that the resource nexus (Bleischwitz and Miedzinski, 2018) of external inputs in land-use systems, teleconnections, and the domestic human domination of ecosystems must be analyzed in unison as these processes are part of a system of interconnected elements, feedbacks, and spillover effects determining an emergent system behavior that is crucial for sustainability outcomes (Robinson et al., 2018): To produce and harvest biomass from ecosystems (i.e., the process of human NPP appropriation) labor needs to be invested. In the course of industrialization of land-use, labor is increasingly substituted with energy and materials (fossils, metals, and other minerals) in the form of machinery, agrochemicals, or infrastructure. These non-renewable resource inputs are external to the biosphere and can also be used to intensify land-use and boost biological productivity (NPP). Technically speaking this is a spatiotemporally limited increase of NPP in a given area which can lead to a reduction of HANPP in relation to extracted biomass, i.e., improve HANPP efficiency of biomass production (Krausmann et al., 2012).

Here we present an integrated and comprehensive empirical assessment of global land-use systems that not only considers domestic land-use intensity (Pretty, 2018), but also the system’s spillover effects occurring from industrialization of land-use and from international trade of biomass products (Dorninger et al., 2017). We use the most recent input-output tables of EXIOBASE 3 (Stadler et al., 2018; Tukker et al., 2018, 2013; Wood et al., 2015), updated and improved HANPP extensions to model global embodied HANPP flows up until 2015. The innovative significance of our study goes beyond a number of methodological improvements; much more we try to answer questions around the resource nexus behind domestic land-use (intensity). We do this by quantifying and analyzing resource and labor inputs in land-use system sectors, which are needed to appropriate the NPP and which can be used to decouple biomass harvest from HANPP, in conjunction with domestic and global embodied HANPP flows. Thus, our approach allows us to assess this critical resource nexus in a global, comprehensive, and systematic manner.

This is the first study to analyze embodied HANPP flows systematically in conjunction with the global energy, material, and labor flows (measured as resource footprints, i.e., direct and indirect resource inputs required to sustain such appropriated flows of biomass products). This represents a significant advancement over previous assessments of embodied HANPP which did not systematically capture these resources and labor inputs embodied in traded biomass goods which, crucially, affect the scale of domestic HANPP and of HANPP embodied in traded goods. The exploration of this land-use resource nexus aids in meaningful comparison of the sustainability of agricultural intensification with regards to how non-renewables are required to appropriate NPP, sustain NPP in ecosystems, substitute land requirements, and potentially bolster biomass production.

The goal of this contribution is to reveal and better understand the complex nexus of domestic land-use intensity, international trade with biomass products, labor and resource inputs in land-use sectors. For this, we empirically quantify and relate these different resource flows from both a production- and consumption-based perspective and categorize countries in relation to their domestic and embodied resource footprints. Our analysis presents a novel, holistic perspective on how nation states appropriate material, energy and labor resources related to land-use and biomass consumption. In particular, we highlight patterns of resource dependencies between different regions and how external resource inputs and teleconnections enable disconnections from domestic ecological productivity.

2. Datasets and methods

Methodologically, we combine HANPP accounts with an environmentally-extended multi-regional input-output approach (EEMRIO) (Stadler et al., 2018; Tukker et al., 2013; Wiedmann and Lenzen, 2018) to provide a comprehensive analysis of global trade-related land-use teleconnections (embodied HANPP or 'eHANPP'). To model global direct and indirect requirements (resource footprints) of labor, energy, and materials inputs of land-use sectors and global eHANPP flows we use an input-output (IO) approach based on EXIOBASE 3 (Stadler et al., 2018). We study two periods of time (1995 and 2015) among 44 countries and 5 rest-of-the-world regions as provided by EXIOBASE 3.

2.1. Calculating global HANPP data

The human appropriation of net primary production (HANPP) is a socio-ecological indicator for land-use intensity. It measures the extent to which human activities affect flows of trophic energy (biomass) in ecosystems, namely net primary production (NPP), a key process in the Earth's biosphere (Haberl et al., 2014). HANPP is defined as the difference between the NPP of the natural vegetation assumed to exist in the absence of land-use (i.e., the NPP of potential natural vegetation, NPP_{pot}) and the fraction of NPP remaining in the ecosystem after harvest under current conditions (NPP_{eco}). HANPP comprises harvested NPP ($HANPP_{harv}$) and changes in NPP related to land conversion ($HANPP_{luc}$). $HANPP_{harv}$ not only includes used extraction of biomass but also unused extraction (like leaves, roots, and by-products not further used) (Haberl et al., 2014). HANPP flows are typically measured in g C per year or Joules (gross calorific value) per year; here we use J/yr. 1,000 t C roughly equal 37 TJ.

HANPP data were sourced from the global HANPP database available at the Institute of Social Ecology (Krausmann et al., 2013). The database provides HANPP data at the national level for 176 countries for the years 1990, 2000 and 2005. We updated the database for the years 2010 and 2015 following the methodological guidelines and assumptions described in detail in the Supporting Information of Krausmann et al. (2013). More technical information can be found in the appendix.

2.2. Allocating HANPP to sectors of EXIOBASE

We utilized the recently released environmentally-extended multi-regional input-output (EEMRIO) tables of EXIOBASE 3 (Stadler et al., 2018) which feature 44 single countries and five world regions from 1995-2015, covering 99.2 % of the world population in 2015. A full list of included countries is provided in the appendix (Table A. 1). The database distinguishes eight different crop production sectors, seven livestock sectors, two manure treatment sectors, and one forestry sector. The high level of sectoral disaggregation represents a major advantage over input-output databases operating with only one single agricultural sector, as sectoral disaggregation is indispensable for a precise allocation of flows (Bruckner et al., 2015; Schaffartzik et al., 2015). Applying HANPP values [J/yr] to the respective appropriating sectors is the basis for the reallocation of HANPP embodied in traded goods to the country of final consumption (Weinzettel et al., 2019).

EXIOBASE provides four matrices for each year from 1995-2015: the matrix of technical coefficients (**A** matrix), the matrix of final demand (**Y** matrix), the matrix of direct resource requirements of industry sectors (**F** matrix) and the matrix of direct resource requirements of final demand sectors (**F_hh** matrix) – including the direct household consumption (e.g., subsistence activities).

We allocated the national HANPP values from the database to the NPP-appropriating sectors with the help of the land-use satellite accounts provided in the **F** and **F_hh** matrices. The **F** matrix of EXIOBASE contains 1,104 satellite accounts (environmental extensions) which are allocated to 7,987 sectors of 49 countries/regions, i.e., 163 different sectors per country. In sum, 20 of the 1,104 satellite accounts concern land-use, including 13 'cropland' types, three types of 'permanent pastures', 'forestry area', 'other land-use', 'infrastructure land', and 'forest area – marginal use'. The latter two are fully allocated to households and, thus, only appear in the **F_hh** matrix. Therefore, following the allocation logic of land-use in EXIOBASE, not all HANPP flows enter the market economy and are internationally redistributed by the input-output table: we attributed HANPP on settlement and infrastructure land and HANPP from certain types of subsistence land-use (e.g., private gardening, subsistence forestry) to domestic final consumption only and did not reallocate them via trade flows.

The remaining, much larger, share of biomass products and the associated HANPP was absorbed by the market and reallocated to consumers along downstream supply chains. We attributed HANPP flows to the EXIOBASE sectors proportionally to their land requirements, as documented in the land-use satellite accounts. For instance, we assigned HANPP from grassland according to the sectors' requirements of permanent pastures as shown in EXIOBASE. Analogously, HANPP from cropland was allocated to sectors according to their cropland use, and the HANPP from forestry according to the sectors' forest area requirements. For the land-use category 'other land-use' of EXIOBASE we applied the average HANPP intensity [J per ha] of each sector's specific land-use profile. For instance, for a sector with 80 ha forestland and 20 ha grassland-use, we assumed that 'other land-use' has a HANPP intensity of $HANPP_{forestland} * 0.8 + HANPP_{grassland} * 0.2$.

However, as HANPP is an indicator of land-use intensity, our sectoral HANPP allocation not only reflects the total land-use of sectors, but also differences in the land-use intensity of subsistence land-use (**F_hh** matrix) and commercially used land (**F** matrix). Using country level data for harvest on subsistence and commercially used grass- and forestland, respectively (FAOSTAT) (FAO, 2018), we calculated country specific coefficients – from 1995 to 2015 – reflecting the land-use intensity of subsistence land-use in comparison to commercial land-use. A coefficient below 1 indicates a lower land-use intensity of subsistence compared to commercial land-use. Consequently, per unit of land-use area, a proportionally lower amount of HANPP is allocated to the **F_hh** matrix and, thus, not internationally reallocated with trade. Advanced economies (compare the SI of EXIOBASE 3 (Theurl et al., 2018)) are assumed to have the same land-use intensity on commercial and subsistence land, i.e. a coefficient of 1. Note that these countries do have a very low percentage of land-use in the subsistence category (the coefficient data matrix is made available in the appendix). Applying this procedure, we received a matrix of vectors with the HANPP for each EXIOBASE sector by land-use category.

2.3. Re-allocating HANPP with EXIOBASE 3

In general terms, monetary IO tables capture sectoral interconnections by recording monetary transactions among industries (**Z** matrix of interindustry flows), final demand (**y**, the row sums of matrix **Y**) and the total output of sectors (**x**). Using the technology matrix of direct input coefficients **A** of EXIOBASE (163 sectors times 49 regions result in a dimension of 7,987x7,987) and an identity matrix (**I**) with ones on the main diagonal and zeros in all other cells, we calculate the Leontief inverse (**L**) whose elements l_{ij} quantify total upstream inputs (direct *and* indirect) of sector *i* which are required to produce a unit of industry output *j* for final demand (Leontief, 1936; Miller and Blair, 2009). This procedure represents the mathematical centerpiece for the re-allocation process of every input-output based footprint analysis (see the formula below).

To re-allocate HANPP along downstream supply chains with the monetary IO tables of EXIOBASE, we summed up the HANPP vectors described before into one vector giving the total HANPP value for each sector and treated this as an environmental satellite account which extends the MRIO table. For this, we start with the technical coefficient matrix (**A**) of EXIOBASE 3, which represents the direct input coefficients (i.e. the amount of input a sector requires from other sectors to create one Euro of output) (Kitzes, 2013). We calculated the Leontief inverse (**L**):

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$$

where **I** is an identity matrix with ones on the main diagonal and zeros in all other cells.

The total output of sectors (**x**) was calculated as:

$$\mathbf{x} = \mathbf{L}^{*}\mathbf{y}$$

where **y** equals the row sums of **Y**.

Finally, we calculated a vector of HANPP coefficients (**e**) by dividing the total HANPP by **x** (total output of each sector). By multiplying the diagonalized HANPP coefficient vector ($\hat{\mathbf{e}}$) with the Leontief inverse (**L**) and final demand per country/region (**Y**), i.e., $\hat{\mathbf{e}}\mathbf{LY}$, we got a matrix, which gives the HANPP footprint of each country by country and sector of origin.

2.4. Calculating supply chain requirements (footprints) of land-use sectors

In addition to the attribution of HANPP to final demand, we calculated the total, i.e., direct and indirect, input requirements of the agriculture and forestry sectors, including energy, material, and labor inputs, as well as CO_2 emissions from fossil fuel combustion. Country level input data for these flows are available from the EXIOBASE 3 database (Stadler et al., 2018). For this purpose, we applied the total flow concept (Szyrmer, 1986; Wood and Lenzen, 2009), which describes the total throughflow of a sector without double counting (for a discussion see Miller and Blair 2009: 283 ff. and 625). The total throughflow of an input **e** through each sector of an economy is derived by $\hat{\mathbf{e}}\mathbf{L}\hat{\mathbf{L}}^{-1}\mathbf{x}$, where $\hat{\mathbf{L}}$ is a square matrix with only the on-diagonal elements of **L** and zeroes on the off-diagonal, and **x** gives the gross production of each sector in Million Euros. This equation quantifies the inputs that are required from all other industries in order to produce the gross output of each sector. The division of each column in the Leontief inverse by the element on the main diagonal ensures that the multipliers refer to one unit of output as opposed to one unit of final demand in the Leontief inverse.

We used this method to calculate sector footprints for the agriculture and the forestry sectors. For this, we first aggregated the eight crop-producing sectors, seven livestock sectors, and two manure treatment sectors of EXIOBASE into a single agricultural sector in order to avoid double counting otherwise caused by the applied total flow concept, which would account multiple times for flows occurring between the agricultural sectors. We used the following extensions of EXIOBASE: total use of energy carriers; employment hours (aggregate of six different extensions capturing skill level and gender); CO_2 equivalents from combustion to air (CO_2, CH_4, and N_2O); and domestic used extraction of metal ores, non-metallic minerals, and fossil fuels (an aggregate of 21 different extensions).

The resulting sector footprints were then reallocated to the countries finally demanding the outputs of the agriculture and forestry sectors, following the same procedure as for the reallocation of HANPP, i.e., applying the final demand-driven Leontief model: $\hat{\mathbf{e}}\mathbf{L}\hat{\mathbf{L}}^{-1}\mathbf{x}\mathbf{L}\mathbf{Y}.$ The result gives the resource throughputs of agriculture and forestry sectors driven by final demand worldwide.

This procedure allowed us to calculate resource and labor footprints of each national agricultural and forestry sector – i.e., the total direct and indirect resource inputs required for the production of these sectors – and based on this, also the resources embodied in the exports of these sectors to the countries of final demand. In other words, we do not only track the embodied HANPP of traded biomass but also the resources that went into the production of these biomass goods (and the appropriation of NPP through agriculture and forestry). This is of particular relevance since those 'resource footprints' potentially affect the scale of embodied HANPP contents of biomass products, e.g., resources invested to intensify land-use can reduce HANPP per unit of biomass use.

2.5. Cluster analysis

Building on the results achieved through the steps described in the sections 2.1, 0, 0, and 0, to identify global patterns, we carry out a cluster analysis with the countries and regions of EXIOBASE 3. We conducted an agglomerative hierarchical cluster analysis (Ward's cluster) (Ward, 1963) to identify 'connection clusters'. We set the cluster analysis with values for 2015 where each country (or world region) is represented by one case (n=46). We excluded the extreme outliers Malta, Luxemburg, and Taiwan, which would not allow for proper group formation. Note that in EXIOBASE many poorer countries are lumped together in the five world regions (Rest of the World Latin America; Rest of the World Asia and Pacific; Rest of the World Africa; Rest of the World Europe; Rest of the World Middle East).

For the clustering, we used the following nine variables, which are relevant for identifying different groups of countries that exhibit similar characteristic patterns of (tele)connected land and related resource usage:

(1) eHANPP exports, (2) eHANPP imports, and (3) eHANPP net-imports (all per capita); the (4) HANPP self-supply; (5) total energy embodied in biomass consumption; (6) direct labor, (7) total energy, and (8) total material inputs per biomass used extraction, as well as (9) the CO_2 emissions from combustion of non-renewables per biomass used extraction.

We used Ward 's hierarchical cluster analysis with the 'hclust' function and the 'agnes' function (agglomerative nesting) in R (R Core Team, 2019) to identify groups in our dataset where the cluster criteria follow pairwise distance matrix observations. The cluster analysis follows minimum within-cluster variance and maximum between-cluster variance. It yields five clusters (agglomerative coefficient of 0.89). To identify which variables most strongly characterize the clusters we used the 'indval' function of the 'labdsv' package in R. The defining cluster coefficients are provided in Table 1 of section 0.

2.6. Limitations and uncertainty of results

Several methodological studies have discussed the uncertainty and sensitivity of MRIO models related to the application of environmental satellite accounts in EEMRIO analysis, to sector aggregation, or country resolution (Caggiani et al., 2014; Lenzen et al., 2010; Rodrigues et al., 2018; Wilting, 2012). These studies find that the largest differences of environmental footprint results are due to differences in the used environmental extensions (Owen et al., 2016, 2014; Tukker et al., 2018). After harmonizing environmental extensions across EEMRIO databases (as has been done for

EXIOBASE), remaining differences in footprint results are below 10 % for carbon footprints (Moran and Wood, 2014) and below 15 % for material footprints (Giljum et al., 2019). With regards to the new environmental extension applied to EXIOBASE 3 in this study – the HANPP data – uncertainties relate, for example, to the so-called CO_2 fertilization effect (more CO_2 in the atmosphere) which may increase the NPP_{pot}, or to uncertainties in the reported forest harvest and the estimates of grazed biomass underlying the calculation of $HANPP_{harv}$. A more detailed discussion of uncertainties related to the HANPP data used in this study can be found in Krausmann et al. (2013).

Previous assessments have shown that sector resolution in the applied EEMRIO model has an impact on the calculated environmental footprints, with a high level of sector aggregation introducing higher uncertainty (de Koning et al., 2015; Piñero et al., 2015). We have chosen to work with EXIOBASE because it provides the highest level of sector detail in the land-use related sectors of all available MRIO databases. The high sector disaggregation of EXIOBASE allows for a more precise allocation of HANPP to export flows and, thus, helps to reduce uncertainties.

A drawback of EXIOBASE is, however, the comparatively low country resolution, as it only distinguishes 44 individual countries and aggregates all other countries, mainly low-income countries in the Global South, into 5 rest-of-the-world regions. This might specifically affect the HANPP self-supply indicator as it obscures intraregional trade between these countries. Therefore, larger agglomerations may have a higher self-supply than the individual countries in the agglomeration. We consider this effect, however, to be of low significance for our findings, since intraregional trade with biomass products in the Global South is comparatively low. We further tested for the effect of large differences in the size (area) of countries/regions on HANPP self-supply by weighting the "HANPP self-sufficiency" regression (Fig. 4b) with "agricultural and forestry area per capita" of countries which yields in a lower R^2 (0.205; instead of 0.302 when unweighted). This indicates that countries with a higher agricultural and forestry area available per capita do not – as a general rule – have automatically a higher HANPP self-sufficiency. Moreover, if we employ “agricultural and forestry area per capita” as the explanatory variable for HANPP self-sufficiency of countries, the explained variance is just a bit below 1 % (R^2), indicating that income per capita (GNI) is a much better predictor of HANPP self-sufficiency (R^2: 0.302) (compare Fig. 4b). However, future studies might be able to shed more light on these relations, for example, by using the recent work of Bjelle et al.(2020) who introduced a method that allows achieving a higher country resolution in EXIOBASE for land-use satellite accounts.

Another cause of uncertainty relates to the assumptions which we used to allocate national HANPP flows to economic sectors (**F** matrix) or to direct household consumption (**F_hh** matrix); note that this concerns only HANPP on forest and grazing land, since cropland is exclusively used in the F matrix. Whereas we believe that our approach – which is based on harvest intensity of market versus subsistence land-use – represents a methodological improvement and the most adequate solution for this issue to date, there is certainly a residual uncertainty relating to the assumptions used to determine how much NPP is appropriated through subsistence land-use with lower land-use intensity. This affects how much of the national HANPP is then allocated to economic sectors, from which it is partly reallocated with exports to final consumption in other countries. We tested for the sensitivity of our model with respect to these assumptions by assuming the same HANPP intensity on subsistence land and commercially used land. The resulting international embodied HANPP flows in 2015 are by -20.2 % lower than when taking differences in HANPP intensity into account, i.e., 138 EJ instead of 166 EJ. In other words, by assuming lower land-use intensity for subsistence than for commercially used land, a higher proportion of HANPP is redistributed via global trade. Assuming a difference between the HANPP intensity of subsistence forestry and grazing has a considerable impact on the size of eHANPP flows and increases eHANPP exports from poorer countries, but it does not impact the clustering of countries and the overall conclusions we draw on the differences between countries/regions.

3. Results

3.1. External inputs affect land-use intensity

By using non-renewable lithospheric resources to realize production gains humans have pushed the limits of ecological productivity (Krausmann et al., 2013). However, this push is spatially and temporally limited, requires continuous resource inputs and causes emissions and pollution. Yet, in the absence of external energy applied to boost NPP (e.g., via agrochemicals or irrigation) and conversion efficiencies (e.g., via minimizing the loss of biomass during harvesting), more land would be required to maintain harvest – resulting in greater HANPP.

While global total (i.e., direct and indirect) labor inputs into the agricultural and forestry sectors virtually stagnated (+ 2 %; 1995: 2.10 trillion hours; 2015: 2.14 trillion hours), the total energy inputs increased between 1995 and 2015 by 29 % (1995: 23.4 EJ; 2015 30.2 EJ) and that of materials by 63 % (1995: 668 Mt; 2015: 1,090 Mt) (Fig. 1). Consequently, CO_2 emissions (equivalents) from combustion increased alike by 41 % (1995: 0.95 Gt; 2015: 1.24 Gt). This contributed to a relative decoupling of the growing biomass harvest from HANPP: While global biomass harvest grew from 214 EJ for 1995 to 290 EJ in 2015 (+ 35 %), global HANPP increased in the same period only by 20 % (Fig. 1).

Together these footprints – material, energy, and labor— represent the combined physical and energetic resources required for the human appropriation of net primary production within our global economic system. Raising the inputs of materials and energy (i.e., industrial intensification of land-use) largely replaces labor inputs and has the potential to decouple biomass harvest from HANPP in a spatiotemporal limited manner by boosting conversion efficiencies and natural productivity (e.g., via the application of agrochemicals or irrigation). While causing CO_2 emissions from combustion, industrial land-use also requires a continuous inflow of non-renewable resources.

However, during the observed period, trends among world regions diverged. Growing energy and material inputs contributed to a strong relative decoupling of harvest from HANPP in Latin America, the Asia and Pacific world region, Australia, and to a lesser extent also in China. The Middle East and India saw a strong increase in inputs, but with comparatively little improvement in the decoupling between harvest and HANPP. In Africa energy inputs increased by 58 % and material inputs more than doubled (+102 %) supporting an increase in biomass harvest (+54 %), but also HANPP increased by 62 % (no decoupling). Compared to 1995, Europe, the USA, and Canada managed to stabilize HANPP and harvest slightly more biomass while energy and material inputs decreased somewhat. No sustained decoupling occurred in Russia, Japan, and South Korea even though material inputs increased sharply. See Table A. 2 and Table A. 3 for details for all regional trends.

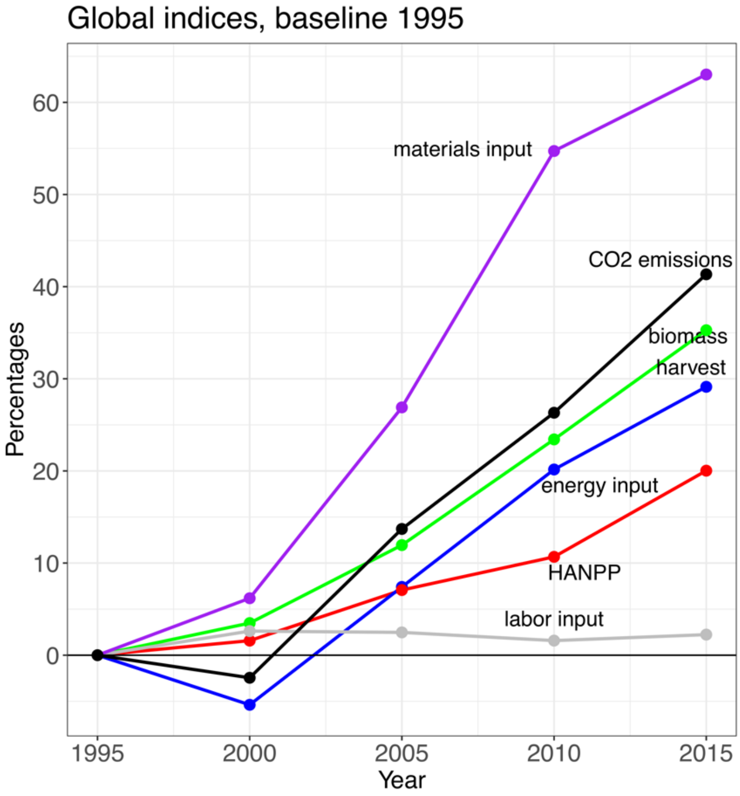


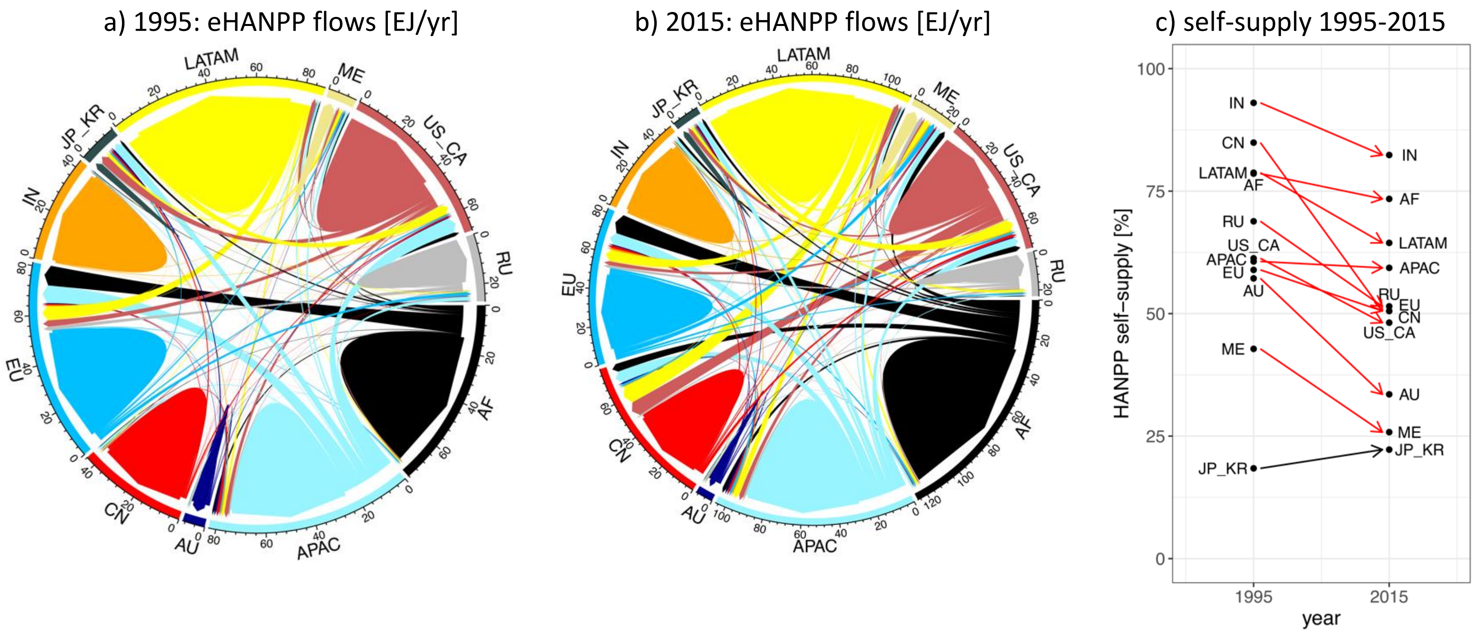
Fig. 1. Index development of biomass harvest, HANPP, emissions of CO_2 from combustion, and the inputs of energy, materials, and labor, from 1995-2015; base year 1995. Growing energy and materials inputs enabled a relative decoupling from biomass harvest and HANPP and caused an increase in CO_2 emissions from combustion, while labor inputs stagnated on a global level. Note that there is a data point only every 5 years. Years in between are interpolated.

3.2. Increasing trade causes spatial disconnections and reduced self-supply

Trade in biomass products and the associated eHANPP rapidly increased over the last decades, causing increased biophysical disconnectedness (Fig. 2a and b), as indicated by the declining 'HANPP self-supply'— the amount of NPP appropriated and consumed within a territorial boundary (Fig. 2c).

In 1995, global HANPP amounted to 464 exajoules (EJ/yr), of which 85 EJ were traded between the eleven world regions (eHANPP; Fig. 1a). By 2015, global HANPP had increased to around 556 EJ/yr (+ 20 %), with a disproportional increase of 145 EJ eHANPP traded (+ 59 %) (Fig. 2b). In consequence, the self-supply of HANPP decreased in most world regions (i.e., the self-links in the circular network plots). In Europe, it decreased from 48 EJ/yr in 1995 to 42 EJ/yr in 2015 (-14 %), while eHANPP imports increased from 28 EJ to 30 EJ and exports from 5 EJ to 10 EJ. In comparison, the HANPP self-supply in the USA and Canada decreased from 42 EJ/yr to 36 EJ/yr during the same time period (-17 %), while imports increased from 15 EJ to 19 EJ and exports from 12 EJ to 20 EJ. HANPP self-supply as a proportion of total HANPP availability (i.e., the sum of domestic HANPP plus eHANPP imports) in Europe decreased from 59 % in 1995 to 51 % in 2015. For the USA and Canada, the same proportion decreased from 61 % to 48 % and for China from 85 % to 51 % (Fig. 2c).

However, in 2015 HANPP self-supply, as a proportion of total HANPP was still high in some regions, e.g., 82 % in India, 73 % in Africa, and 64 % in Latin America. It was smallest in Japan and South Korea (22 %) and in the Middle East (26 %). See Fig. A. 1 and Fig. A. 2 for eHANPP flows between the regions. All regional HANPP, eHANPP, imports, exports, and HANPP self-supply data are provided in Table A. 4 and Table A. 5.



a) 1995: eHANPP flows [EJ/yr]

b) 2015: eHANPP flows [EJ/yr]

c) self-supply 1995-2015

Fig. 2. HANPP and embodied HANPP flows between world regions, including HANPP self-supply. a) and b): flows between regions in 1995 and 2015, respectively. Values in the circular network plot are given in exajoules [EJ/yr]. c): HANPP self-supply trends visualized as directed arrows. Red arrows indicate a decreasing HANPP self-supply from 1995 to 2015, black arrows an increase. Steady or decreasing domestic HANPP and growing embodied HANPP trade flows result in a decreasing HANPP self-supply. To reduce complexity, we here aggregated the 44 countries and 5 world regions of EXIOBASE into 11 world regions. LATAM = Latin America, ME = Middle East, US_CA = USA and Canada; RU = Russia, AF = Africa, APAC = Asia and Pacific, AU = Australia, CN = China, EU = Europe, IN = India, JP_KR = Japan and South Korea.

3.3. Global patterns of embodied HANPP and related resource footprints

In order to identify global patterns of embodied HANPP and related resource footprints we use cluster analysis which groups countries and regions into clusters of similar characteristics. Based on the EXIOBASE nations and world regions (n = 46, compare Fig. 3 and Table A. 1), Ward's hierarchical cluster method (Murtagh and Legendre, 2014; Ward, 1963) was used on a set of nine variables related to HANPP, resource use and labor for the year 2015 (see methods section 2.5 for details). The statistical clustering identified five groups of countries and world regions ('connection clusters') where within-group variance is low and between-group variance high (Fig. 3). The clusters were denoted as (1) 'exporters', (2) 'outsourcers', (3) 'intermediate', (4) 'self-sufficient', and (5) 'intensifiers' (Table 1).

The 'exporters' cluster consists of six countries, including Australia and Canada, characterized by a high level of eHANPP exports per capita. Other major exporters of biomass, like Brazil or Russia, exhibit significantly lower levels of eHANPP exports on a per capita basis, as compared to the ones classified here as 'exporters' (and were classified as 'intermediate' – see also below). The countries in the 'outsourcers' cluster show a high dependence on imported biomass, as indicated by high values for eHANPP imports and net eHANPP imports (eHANPP imports minus eHANPP exports). Among these 15 countries/regions are many European countries with high per capita income and high population density. The 'intermediate' cluster captures 15 countries/regions that are not characterized by distinct patterns of HANPP or eHANPP (per capita) in the dataset. This cluster comprises several important exporters of agricultural commodities (Brazil, Argentina, Russia, the USA). The 'self-sufficient' cluster covers six countries/regions mainly in Africa and Asia. However, they represent 69 % of the total world population in 2015. This cluster is characterized by high direct labor input and strong HANPP self-sufficiency. Finally, the 'intensifiers' cluster is characterized by high energy and materials inputs per unit biomass extracted.

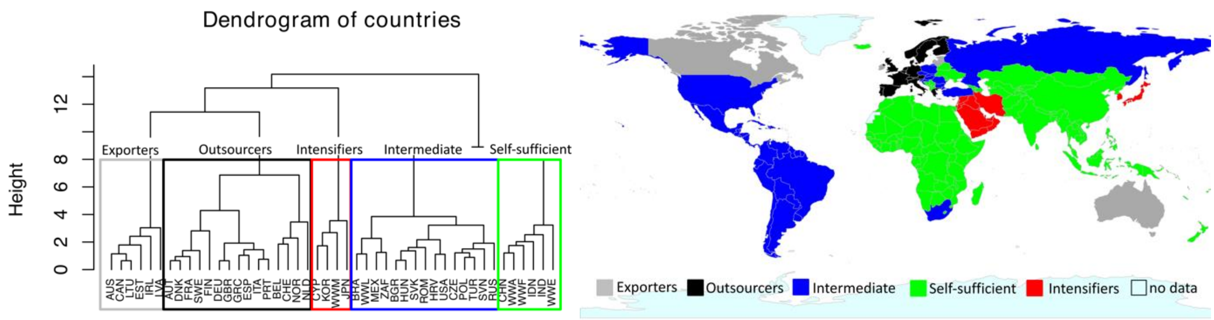


Fig. 3. World map and dendrogram of countries as the result of a hierarchical cluster analysis, year 2015. We identify five clusters of similar land-use, inputs, and trade characteristics: exporters, outsourcers, intensifiers, intermediate, and the self-sufficient cluster. Based on per capita values and in relation to the other clusters: the exporters are characterized by high values of eHANPP exports; the outsourcers by high imports and net-imports of eHANPP; the intermediate cluster does not show features that significantly differentiates them from the others; the self-sufficient cluster is characterized by a high HANPP-self supply and direct labor input; and the intensifiers by high energy and material inputs and CO_2 emissions per biomass unit extracted. The dendrogram visualizes the results of an agglomerative hierarchical cluster analysis (Ward's cluster) where proximity of countries (lowest within-group variance) is shown as neighboring countries forming one cluster. At each node a new cluster is formed following again lowest between-group variance until one single cluster remains (for more information see the methods section). The EXIOBASE world regions are: WWL = Rest of the World Latin America; WWA = Rest of the World Asia and Pacific; WWF = Rest of the World Africa; WWE = Rest of the World Europe; WWM = Rest of the World Middle East.

Table 1. Clusters of countries and world regions and the defining coefficients. The value in parenthesis indicates the strength of the coefficient in distinguishing the cluster from others (highest possible value: 1). All coefficients shown are significant at $p < 0.01$.

Connection clusters	Defining cluster coefficients
(1) Exporters (n = 6)	Embodied HANPP exports per capita (0.91)
(2) Outsourcers (n = 15)	Embodied HANPP imports per capita (0.56) Embodied HANPP net-imports per capita (0.53)
(3) Intermediate (n = 15)	-
(4) Self-sufficient (n = 6)	Direct labor input per biomass unit extracted (0.91) HANPP self-supply (0.64)
(5) Intensifiers (n = 4)	Energy inputs per biomass unit extracted (0.91) Materials inputs per biomass unit extracted (0.87) CO_2 emissions per biomass unit extracted (0.81)

To detect global patterns within the 'connection clusters' we built regressions with the economic development status of countries, reflected by their income (GNI/cap/yr), as predictor (Fig. 4). We chose five variables (direct labor input, HANPP self-supply, energy and materials embodied in biomass goods consumed, and net-imports of eHANPP) which reflect crucial differences in countries' and regions' biophysical disconnections. Wherever it was necessary to standardize variables, we either used data per unit of biomass extraction or per capita values where trade was involved.

Higher per capita income results in less direct labor inputs for land-use activities. With regions belonging to the 'self-sufficient' cluster having significantly higher direct labor inputs in land-use activities, i.e., up to 15 times higher than for regions in the 'outsourcers' cluster (Fig. 4a).

In countries/regions with higher per capita income merely around a quarter of their HANPP flows is appropriated and consumed domestically (Fig. 4b). Only for a smaller share of countries/regions in this dataset the NPP appropriated and consumed within the same territory is higher than total embodied HANPP imports and exports, i.e., where the HANPP self-supply is larger than 50%. It should be noted, however, that care is required in the interpretation of HANPP self-supply because the size of country’s resource endowments (agriculture and forestry area) relative to population, the total size of resource endowment, and population density are potentially cofounding factors in the explanation of HANPP self-supply.

More energy and materials are used (across the global supply chains) to produce the biomass goods that are finally consumed in regions with higher per capita income than compared to the final consumption requirements of lower-income regions (Fig. 4c and d). Income less clearly predicts net-imports of eHANPP. Only 20 % of the variance can be explained by income (the regression is still significant). However, the richer a country the more it tends to net-import (Fig. 4e).

In sum, with increasing income, countries and regions use less direct labor, rely less on domestic HANPP, and simultaneously tend to consume biomass goods with higher total energy and materials inputs and net-import more eHANPP. This trend is a clear indication that with growing income, countries become biophysically more disconnected from the ecological productivity of their domestic terrestrial environment.

Interestingly, income has a slightly positive (none significant) effect on the amount of energy and materials used to extract biomass (along the whole supply chains), and on how much CO_2 is emitted from fossil combustion during that process (see Fig. A. 3, Fig. A. 4, and Fig. A. 5 in the appendix). While one might have expected a negative relationship, i.e., the richer a country/region, the lower will be the input of resources per unit of biomass production (due to efficiency gains through technological investments), there is no decoupling between inputs and harvest with growing income observable.

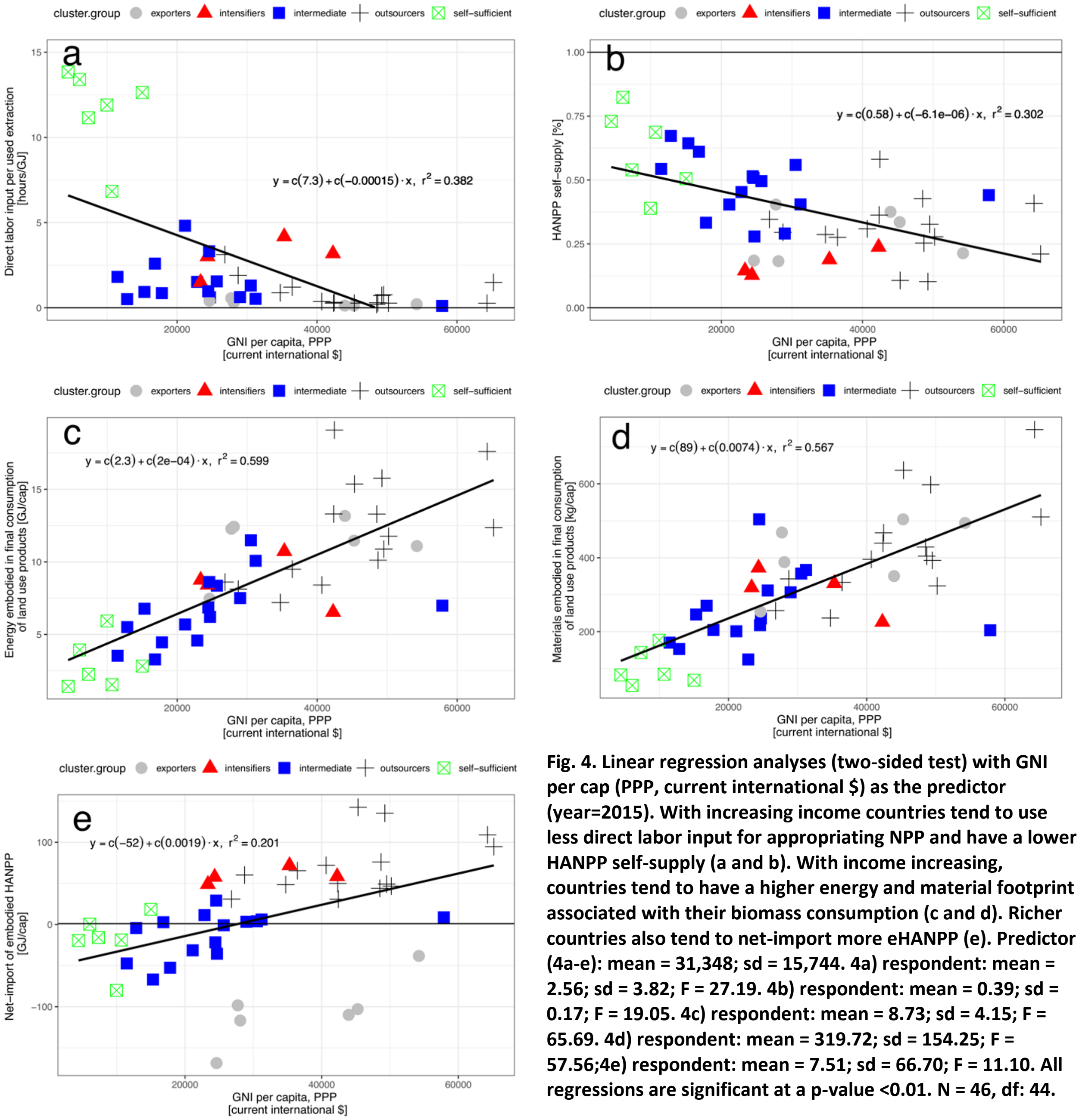


Fig. 4. Linear regression analyses (two-sided test) with GNI per cap (PPP, current international $) as the predictor (year=2015). With increasing income countries tend to use less direct labor input for appropriating NPP and have a lower HANPP self-supply (a and b). With income increasing, countries tend to have a higher energy and material footprint associated with their biomass consumption (c and d). Richer countries also tend to net-import more eHANPP (e). Predictor (4a-e): mean = 31,348; sd = 15,744. 4a) respondent: mean = 2.56; sd = 3.82; F = 27.19. 4b) respondent: mean = 0.39; sd = 0.17; F = 19.05. 4c) respondent: mean = 8.73; sd = 4.15; F = 65.69. 4d) respondent: mean = 319.72; sd = 154.25; F = 57.56;4e) respondent: mean = 7.51; sd = 66.70; F = 11.10. All regressions are significant at a p-value <0.01. N = 46, df: 44.

3.4. Characterizing the 'connection clusters'

To highlight further differences in resource usage between the clusters we depict key variables for the more distinctive clusters (leaving out the 'intermediate' cluster) on an average per capita basis. Data on all cluster, including the 'intermediate' cluster, are provided in table-format in the appendix, Table A. 6.Here, we present stacked bar plots to compare the different clusters with respect to their land-use intensity (HANPP), trade connections (eHANPP), as well as their labor, energy, and material inputs (Fig. 5). Barplots presenting the CO_2 emissions data can also be found in the appendix, Fig. A. 5.

In the 'outsourcers' cluster 43 % of NPP_{pot} (which is the sum of HANPP and NPP_{eco} in Fig. 5) is appropriated by humans (HANPP of 65 GJ/cap/yr), indicating that on average 57 % of the trophic energy in terrestrial ecosystems (NPP_{eco}) is available for non-human species. The high eHANPP net-imports (68 GJ/cap/yr) reveal that in the absence of trade, 'outsourcers' could not sustain their relatively low levels of domestic appropriation (HANPP/cap). In the 'outsourcers' cluster direct labor application (people working in agriculture and forestry) has nearly vanished, however, indirect labor and labor embodied in imported biomass is still required on a larger scale. In fact, while applying the lowest direct labor input (i.e., agricultural workforce), the 'outsourcers' exhibit the highest labor footprint of all clusters. Indirect labor refers to the labor invested in the production of machinery, agrochemicals or infrastructure etc., used by the land-use sectors. Embodied labor imports comprise both direct and indirect labor associated with biomass imports. Moreover, the countries in the 'outsourcers' cluster are characterized by a reliance on both domestic and imported embodied energy and material resources to appropriate their domestic NPP. This includes the energy and materials embodied in tractors, fertilizers, and on-farm infrastructure. Accounting for all the resources embodied in net-imports increases their energy and material footprints considerably (Fig. 5).

Compared to the other clusters, 'exporters' have a better average per capita endowment of NPP, indicated by a high NPP_{pot}/cap/yr, a high HANPP/cap/yr, and a relatively strong reliance on energy and materials inputs. However, the 'exporters' cluster is also a net importer of labor embodied in internationally traded biomass due to relatively low domestic labor input and the import of biomass products from countries with higher direct labor inputs.

The 'self-sufficient' cluster, home of almost 70% of the world’s population, has a considerable share of NPP_{eco} while remaining a minor net-exporter of eHANPP per capita. The cluster features a high amount of labor invested directly in agriculture and forestry and is the only net exporter of embodied labor. Conversely, energy and materials inputs are significantly lower than for other clusters.

The 'intensifiers' exhibit the lowest amount of NPP_{pot} per capita (due to either aridity or very high population density, or both), which is bolstered by eHANPP net-imports and boosted by energy and material inputs. Interestingly, with these external flows in place, they are still able to spare a relatively high share of their NPP_{pot} for biodiversity conservation (as indicated by a relatively high NPP_{eco}).

Fig. A. 7 in the appendix also provides stacked barplots for the CO_2 emissions occurring from the combustion of fossil fuels per capita which are directly or indirectly related to the appropriation of NPP, i.e., land-use system activities. The overall picture very much resembles the patterns of energy and materials invested and embodied in traded biomass goods as presented here in Fig. 5.

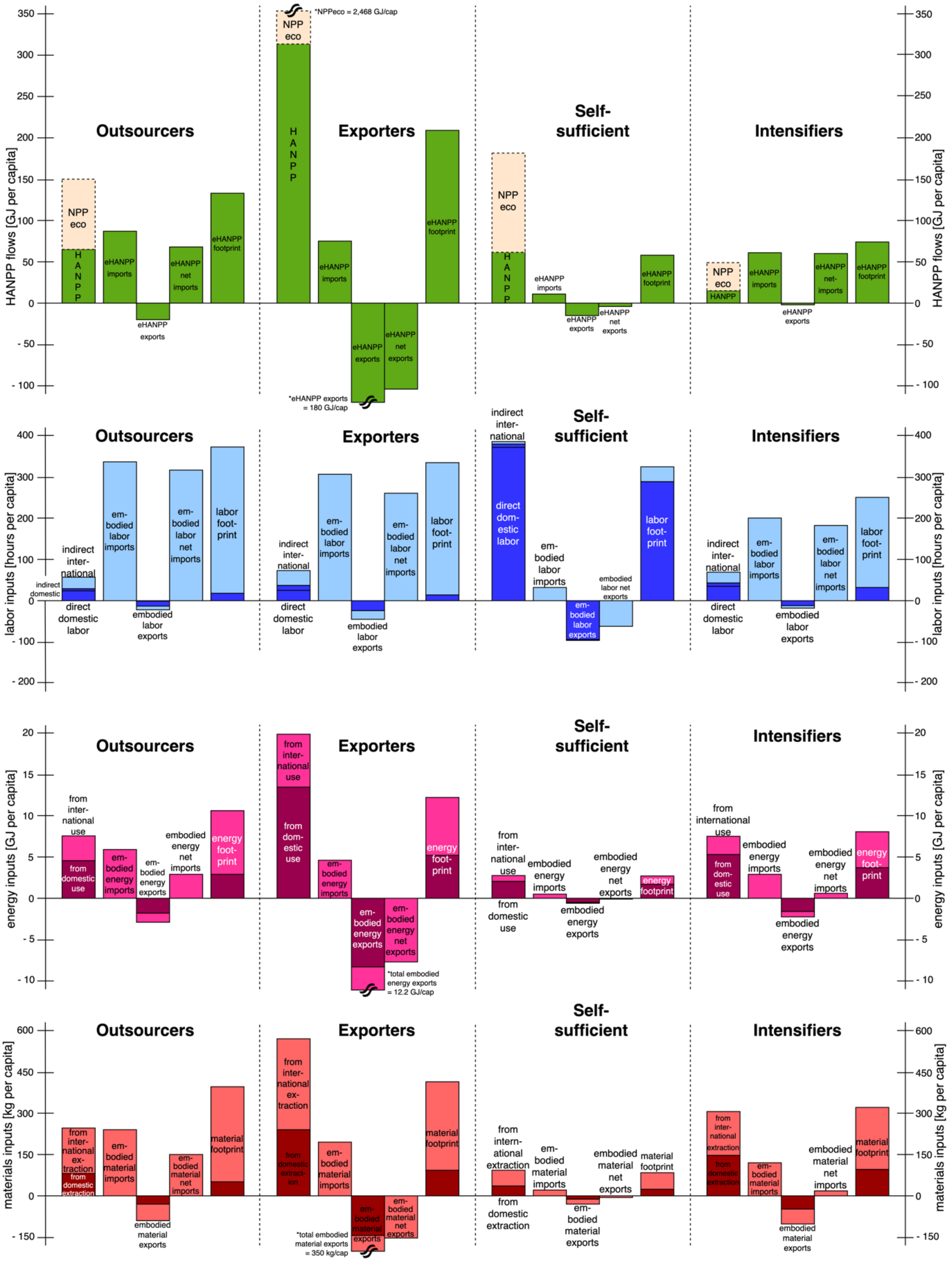


Fig. 5. Barplots indicating HANPP flows and inputs of labor, energy, and materials in the land-use system for the year 2015. Values for the CO_2 emissions and for the intermediate cluster are provided in the appendix. The first row describes the HANPP flows, including domestic HANPP and NPP_{eco} (their sum is NPP_{pot}), eHANPP trade flows, and the eHANPP footprint. The subsequent rows show the inputs of labor, energy, and materials required to appropriate domestic NPP and those embodied in traded biomass. Materials comprise all fossil materials, metals, and non-metallic minerals used directly or indirectly by the land-use sectors to produce their outputs. The first stacked bar of each group distinguishes the origin of the inputs used for domestic biomass production (domestic vs. international). The subsequent bars show the resources and labor embodied in biomass imports and exports. Their subtraction yields the net-trade and finally the footprint, which is the domestic appropriation plus net-trade. Note that each bar captures the same process, i.e., the first bar of each group presents the process of NPP appropriation and the resources required, the second row the eHANPP

imports and the resources embodied in those imports, etc. All values are given on per capita levels. The share of domestic labor, energy, and materials exported is calculated by assuming an equal distribution of domestic and international resources for domestic consumption and exports.

4. Discussion

Our analyses suggest the need to rethink notions of efficiency and sustainability in relation to land-use systems. Domestic patterns of land-use and their environmental consequences can only be fully understood via integrated global analyses. The structure of land-use in a country is a complex nexus of domestic ecological productivity, harvest, inputs of labor, energy, and materials, and of international trade relations. This implies that the five 'connection clusters' with their specific characteristics identified here can only exist due to their interconnectedness.

We demonstrated that domestic land-use intensity does not necessarily reflect the resource inputs required to satisfy national biomass consumption. Although wealthier countries (mostly 'outsourcers' or 'intensifiers') have reduced their dependence on the natural domestic NPP endowment of their land ecosystems, this does not represent a genuine decoupling of biomass production and use from environmental impacts (i.e., HANPP). With increasing eHANPP imports and use of lithospheric inputs, domestic HANPP can be stabilized (that is, a certain level of NPP_{eco} can be sustained) while total domestic biomass consumption continues to grow. As countries mature economically, they tend to have a lower degree of HANPP self-supply, a smaller direct labor input per unit of biomass extracted, but higher net-imports of eHANPP, and a larger amount of energy and materials embodied in biomass products for final consumption (and partly also for exports, e.g., the 'exporters' cluster).

In parallel to lower degrees of HANPP self-supply with increasing income, there is also a general trend towards less self-supply and more imports and exports of eHANPP observable over time (Fig. 2). Whereas the finding of increased land-use based teleconnections corroborates insights from previous studies (Bergmann and Holmberg, 2016; Kastner et al., 2014; Pendrill et al., 2019), here we investigated for the first time the effects of increasing globalization on the self-supply with biomass of countries. Except for Japan and South Korea (which had initially already very low levels of self-supply), all countries and regions decreased their self-supply from 1995-2015 due to increasing trade and stagnant or relatively slowly growing HANPP. But lower self-supply does not automatically imply less biomass available for consumption. However, it does imply a shifting of NPP appropriation and a loss of (potentially self-constraining) feedback between humans and their demand for biomass (Cumming et al., 2014; Dorninger et al., 2017; Seppelt and Cumming, 2016).

In this regard, meeting the growing demand for biomass products while being able to preserve the domestic environment (land ecosystems) via the twofold biophysical disconnectedness (outsourcing and industrial intensification) stimulates a misconception and misinterpretation of decoupling (Cumming and von Cramon-Taubadel, 2018; Fletcher and Rammelt, 2017; Ward et al., 2016). From a consumption-based perspective, a disconnect from domestic ecological productivity does not imply a decoupling from total resource use or land-use intensity (HANPP). On the contrary, countries that exhibit a high degree of biophysical disconnectedness tend to have larger total resource use footprints (of eHANPP, labor, CO_2, energy, and materials) than countries with tighter coupling to their domestic ecological resource systems.

For example, the domestic land-use patterns sustained by 'outsourcers' (mostly European countries in our dataset) seem extremely productive in terms of direct labor input but involve the highest labor inputs of all country-clusters when corrected for embodied labor transfers, i.e., labor footprints. With the application of non-renewable materials and energy, land-use is intensified and more NPP can be harvested while keeping HANPP (and therefore also its counterpart, NPP_{eco}) stable. However, even in these highly industrialized land-use systems, the preservation of NPP_{eco} would be much smaller (or maybe the other way round: the depletion of NPP_{eco} would be much larger) without net-imports of eHANPP, as indicated by the much larger total eHANPP footprints compared to domestic HANPP (Fig.

5, first row). These patterns of land-use have profound impacts on the global land-use system and largely determine its functions and outcomes.

Biophysical disconnectedness from domestic NPP, based on industrial intensification and unbalanced teleconnections, enables countries a seemingly unconstrained consumption of biomass goods while being able to spare land and preserve ecological productivity for conservation (NPP_{eco}). Ultimately, those land-use characteristics developed particularly by the 'intensifiers' and 'outsourcers' cannot be universalized because they are dependent on land- and labor-intensive land-use patterns in lower income, exporting countries. Moreover, it has been argued that such ecologically unbalanced exchange processes consolidate global inequalities and impede (sustainable) development in the Global South (Kosoy et al., 2012; Muradian and Martinez-Alier, 2001).

When it comes to reducing human pressure on domestic terrestrial ecosystems, attention must be paid on how market and political institutions are oriented towards industrial intensification and outsourcing of production. This requires appropriate monitoring instruments for trade flows including distant resource use embodied in domestic consumption. Poorer countries, in particular, are often adversely affected by the shifting of environmental burdens which comes with unbalanced land-use based teleconnections (Bergmann and Holmberg, 2016; Pendrill et al., 2019; Yu et al., 2013), often described as ecologically unequal exchange (Dorninger et al., 2021; Dorninger and Hornborg, 2015). Global trade agreements and policies need to address these issues, but are unlikely to do so as long as such outsourcing and embodied ecological and material flows are not included in national natural resource accounts (Bruckner et al., 2015; Peters et al., 2016).

Moreover, a growing reliance of the production of renewable biomass based on non-renewable inputs not only deprives future generations of sustaining similar land-use management (by depleting limited resources, causing emissions and pollution, and, thus, anthropogenic climate change leading to the destruction of life-supporting ecosystem functions (Weis, 2010)), it also increases the vulnerability of the current production system by making the efficient functioning of industrial land-use dependent on a continuous inflow of ultimately limited resources. Note that large parts of the global land-use system are not fully industrialized yet (see for example, the 'self-sufficient' cluster), implying that potentially more regions may follow this pathway and the required resources will become even scarcer.

5. Conclusions

We conclude that, applying a global systems perspective on domestic land-use reveals not only the tight interconnection of domestic land-use patterns, external inputs, and teleconnections, but also that the optimization of sub-systems does not necessarily lead to an improvement of the system as a whole, i.e., at the global scale. That is, in an effort of keeping a balance between HANPP and NPP_{eco} domestically (to preserve ecological productive land for conservation or recreational purposes), countries are increasingly (1) intensifying land-use to spare other land but requiring non-renewables and causing emissions and pollution, and (2) sourcing biomass from spatially distant regions, causing pressure on ecosystems and biodiversity elsewhere. See Norgaard (2010) for a more general discussion of the problems of such 'partial equilibrium frameworks' in relation to sustainable resource use.

Our results indicate that with income increasing, some countries manage to significantly reduce labor inputs needed in agriculture and forestry and to raise the levels of biomass consumption while sparing land ecosystems for conservation, sink, or recreational purposes. However, as we have shown, this was largely made possible by increasing inputs of non-renewables and by net-imports of biomass from other countries. Eventually, the countries with loosest coupling to domestic natural cycles, exhibit the highest resource footprints per capita (Fig. 5). As a consequence, the dominating general path of on-site focused development in the agricultural and forestry system needs to be questioned and alternative models and visions in the land-use management focusing on long-term global sustainability need to be developed and employed (Cooke et al., 2016; Cumming and von Cramon-Taubadel, 2018; Ives et al., 2018).This will be even more relevant as the global demand for biomass products will inevitably increase, driven by population growth, changes in diet (Erb et al., 2016; Yu et al., 2016) and further aggravated by bioeconomy strategies (Scarlat et al., 2015). Bioeconomy strategies will increase the biomass demand above all in the high-income countries, while food demand is bound to increase in the exporting lower income countries. To meet these needs and to still preserve domestic terrestrial ecosystems, and thus biodiversity, viable and necessary options include (1) a change in diets from animal to plant based products (Erb et al., 2016), i.e. a shift towards less HANPP intensive food products, (2) the reduction of food waste and losses (Foley et al., 2011), and (3) changes in the production system to close yield gaps (Kastner et al., 2014) based on sustainable intensification which requires low external inputs to increase harvest but not HANPP, e.g. by a more efficient cycling of biomass and nutrient flows in agro-ecosystems (Tello et al., 2016). However, optimizing efficiency ratios alone will most likely not suffice to change the trade dynamics highlighted in this article. Rather, decision-makers and stakeholders must broadly rethink the goals, power relations, and rules of the global land-use system to achieve the urgently needed sustainability transformation (Dorninger et al., 2020; Nielsen et al., 2019).

Data availability

The data that support the findings of this study are available in the SI and on the corresponding author's GitHub account at https://github.com/christiandorninger/biophysical-disconnect. We used the EXIOBASE3 IOTs in ixi format from 1995-2015 as they were released by the EXIOBASE consortium. The tables can now be downloaded from https://zenodo.org/record/3583071#.X_MjnhYxmUk.

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Appendices

Technical notes on '*2.1. Calculating global HANPP data'*

To estimate $HANPP_{harv}$ we used data from the FAOSTAT database of the Food and Agricultural Organization of the United Nations (FAO 2018). To estimate $HANPP_{luc}$, which accounted for 33 % of global HANPP in 2005, we had to make simplifying assumptions, because NPP_{pot} data for 2010 and 2015 were not available. We extrapolated $HANPP_{luc}$ on grassland by applying values of $HANPP_{luc}$ per unit of grazed biomass in 2005 derived from the HANPP database. $HANPP_{luc}$ on cropland was calculated by applying values of $HANPP_{luc}$ per m^2 of cropped area and per m^2 of cropland fallow in 2005 (derived from the database), taking into account that changes in $HANPP_{luc}$ on cropland are rather related to changes in the extent of cropland, since land-use intensification on cropland typically increases harvest per unit of land without impacting total HANPP per unit of cropland (Krausmann et al., 2013). Following Krausmann et al. (2013) we did assume $HANPP_{luc}$ to be zero on forests and wilderness areas. We extrapolated HANPP on built-up land (land used for infrastructure and settlement) by multiplying HANPP on built-up land per capita of urban population in 2005 with data on urban population (FAO, 2018) in 2010 and 2015, respectively. All national HANPP data are available in the appendix.

Table A. 1. Table of countries and world regions included in this study.

Country name	ISO3	Country code in EXIOBASE	Cluster
Afghanistan	AFG	WWA	self_sufficient
Albania	ALB	WWE	self_sufficient
Algeria	DZA	WWF	self_sufficient
Angola	AGO	WWF	self_sufficient
Argentina	ARG	WWL	intermediate
Armenia	ARM	WWA	self_sufficient
Australia	AUS	AUS	exporters
Austria	AUT	AUT	outsourcers
Azerbaijan	AZE	WWA	self_sufficient
Bahamas	BHS	WWL	intermediate
Bahrain	BHR	WWM	intensifiers
Bangladesh	BGD	WWA	self_sufficient
Belarus	BLR	WWE	self_sufficient
Belgium	BEL	BEL	outsourcers
Belize	BLZ	WWL	intermediate
Benin	BEN	WWF	self_sufficient
Bhutan	BTN	WWA	self_sufficient
Bolivia	BOL	WWL	intermediate
Bosnia and Herzegovina	BIH	WWE	self_sufficient
Botswana	BWA	WWF	self_sufficient
Brazil	BRA	BRA	intermediate
Brunei Darussalam	BRN	WWA	self_sufficient
Bulgaria	BGR	BGR	intermediate
Burkina Faso	BFA	WWF	self_sufficient
Burundi	BDI	WWF	self_sufficient
Cambodia	KHM	WWA	self_sufficient
Cameroon	CMR	WWF	self_sufficient
Canada	CAN	CAN	exporters
Cape Verde	CPV	WWF	self_sufficient
Central African Republic	CAF	WWF	self_sufficient
Chad	TCD	WWF	self_sufficient
Chile	CHL	WWL	intermediate
China	CHN	CHN	self_sufficient
Colombia	COL	WWL	intermediate
Comoros	COM	WWF	self_sufficient
Congo, Dem Republic of	COD	WWF	self_sufficient
Congo, Republic of	COG	WWF	self_sufficient
Costa Rica	CRI	WWL	intermediate
Côte d'Ivoire	CIV	WWF	self_sufficient
Croatia	HRV	HRV	intermediate
Cuba	CUB	WWL	intermediate
Cyprus	CYP	CYP	intensifiers
Czech Republic	CZE	CZE	intermediate
Denmark	DNK	DNK	outsourcers
Djibouti	DJI	WWF	self_sufficient
Dominican Republic	DOM	WWL	intermediate
Ecuador	ECU	WWL	intermediate
Egypt	EGY	WWF	self_sufficient
El Salvador	SLV	WWL	intermediate
Equatorial Guinea	GNQ	WWF	self_sufficient
Estonia	EST	EST	exporters
Ethiopia PDR	ETH	WWF	self_sufficient
Fiji Islands	EJI	WWA	self_sufficient
Finland	FIN	FIN	outsourcers
France	FRA	FRA	outsourcers
French Guiana	GUF	WWL	intermediate
French Polynesia	PYF	WWA	self_sufficient
Gabon	GAB	WWF	self_sufficient
Gambia	GMB	WWF	self_sufficient
Georgia	GEO	WWA	self_sufficient
Germany	DEU	DEU	outsourcers
Ghana	GHA	WWF	self_sufficient
Greece	GRC	GRC	outsourcers
Guadeloupe	GLP	WWL	intermediate
Guatemala	GTM	WWL	intermediate
Guinea	GIN	WWF	self_sufficient
Guinea-Bissau	GNB	WWF	self_sufficient
Guyana	GUY	WWL	intermediate
Haiti	HTI	WWL	intermediate
Honduras	HND	WWL	intermediate
Hungary	HUN	HUN	intermediate
Iceland	ISL	WWE	self_sufficient
India	IND	IND	self_sufficient
Indonesia	IDN	IDN	self_sufficient
Iran, Islamic Rep.	IRN	WWM	intensifiers
Iraq	IRQ	WWM	intensifiers
Ireland	IRL	IRL	exporters
Israel	ISR	WWM	intensifiers
Italy	ITA	ITA	outsourcers
Jamaica	JAM	WWL	intermediate
Japan	JPN	JPN	intensifiers
Jordan	JOR	WWM	intensifiers
Kazakhstan	KAZ	WWA	self_sufficient
Kenya	KEN	WWF	self_sufficient
Korea, Dem People's Rep	PRK	WWA	self_sufficient
Korea, Rep.	KOR	KOR	intensifiers
Kuwait	KWT	WWM	intensifiers
Kyrgyz Republic	KGZ	WWA	self_sufficient
Laos	LAO	WWA	self_sufficient
Latvia	LVA	LVA	exporters
Lebanon	LBN	WWM	intensifiers
Lesotho	LSO	WWF	self_sufficient
Liberia	LBR	WWF	self_sufficient
Libyan Arab Jamahiriya	LBY	WWF	self_sufficient
Lithuania	LTU	LTU	exporters
Luxembourg	LUX	LUX	not used in cluster
Macedonia, FYR	MKD	WWE	self_sufficient
Madagascar	MDG	WWF	self_sufficient
Malawi	MWI	WWF	self_sufficient
Malaysia	MYS	WWA	self_sufficient
Mali	MLI	WWF	self_sufficient
Malta	MLT	MLT	not used in cluster
Martinique	MTQ	WWL	intermediate
Mauritania	MRT	WWF	self_sufficient
Mauritius	MUS	WWA	self_sufficient
Mexico	MEX	MEX	intermediate
Moldova	MDA	WWE	self_sufficient
Mongolia	MNG	WWA	self_sufficient
Morocco	MAR	WWF	self_sufficient
Mozambique	MOZ	WWF	self_sufficient
Myanmar	MMR	WWA	self_sufficient
Namibia	NAM	WWF	self_sufficient
Nepal	NPL	WWA	self_sufficient
Netherlands	NLD	NLD	outsourcers
New Caledonia	NCL	WWA	self_sufficient
New Zealand	NZL	WWA	self_sufficient
Nicaragua	NIC	WWL	intermediate
Niger	NER	WWF	self_sufficient
Nigeria	NGA	WWF	self_sufficient
Norway	NOR	NOR	outsourcers
Oman	OMN	WWM	intensifiers
Pakistan	PAK	WWA	self_sufficient
Panama	PAN	WWL	intermediate
Papua New Guinea	PNG	WWA	self_sufficient
Paraguay	PRY	WWL	intermediate
Peru	PER	WWL	intermediate
Philippines	PHL	WWA	self_sufficient
Poland	POL	POL	intermediate
Portugal	PRT	PRT	outsourcers
Puerto Rico	PRI	WWL	intermediate
Qatar	QAT	WWM	intensifiers
Réunion	REU	WWA	self_sufficient
Romania	ROU	ROU	intermediate
Russian Federation	RUS	RUS	intermediate
Rwanda	RWA	WWF	self_sufficient
Samoa	WSM	WWA	self_sufficient
Saudi Arabia	SAU	WWM	intensifiers
Senegal	SEN	WWF	self_sufficient
Serbia and Montenegro	SRB	WWE	self_sufficient
Sierra Leone	SLE	WWF	self_sufficient
Slovakia	SVK	SVK	intermediate
Slovenia	SVN	SVN	intermediate
Solomon Islands	SLB	WWA	self_sufficient
Somalia	SOM	WWF	self_sufficient
South Africa	ZAF	ZAF	intermediate
Spain	ESP	ESP	outsourcers
Sri Lanka	LKA	WWA	self_sufficient
Sudan	SUD	WWF	self_sufficient
Suriname	SUR	WWL	intermediate
Swaziland	SWZ	WWF	self_sufficient
Sweden	SWE	SWE	outsourcers
Switzerland	CHE	CHE	outsourcers
Syrian Arab Republic	SYR	WWM	intensifiers
Taiwan	TWN	TWN	not used in cluster
Tajikistan	TJK	WWA	self_sufficient
Tanzania	TZA	WWF	self_sufficient
Thailand	THA	WWA	self_sufficient
Timor-Leste	TLS	WWA	self_sufficient
Togo	TGO	WWF	self_sufficient
Trinidad and Tobago	TTO	WWL	intermediate
Tunisia	TUN	WWF	self_sufficient
Turkey	TUR	TUR	intermediate
Turkmenistan	TKM	WWA	self_sufficient
Uganda	UGA	WWF	self_sufficient
Ukraine	UKR	WWE	self_sufficient
United Arab Emirates	ARE	WWM	intensifiers
United Kingdom	GBR	GBR	outsourcers
United States	USA	USA	intermediate
Uruguay	URY	WWL	intermediate
Uzbekistan	UZB	WWA	self_sufficient
Vanuatu	VUT	WWA	self_sufficient
Venezuela, RB	VEN	WWL	intermediate
Vietnam	VNM	WWA	self_sufficient
Yemen, Rep.	YEM	WWM	intensifiers
Zambia	ZMB	WWF	self_sufficient
Zimbabwe	ZWE	WWF	self_sufficient

Table A. 2. Development of indices in world regions, in percent (1/2). The numbers show the increase or decrease of regional biomass harvest, HANPP, as well as energy, materials, and labor inputs in percentages. The base year is 1995.

	Latin America (LATAM)				
year	Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
1995	-	-	-	-	-
2000	0.10	0.05	-0.04	7.37	7.49
2005	0.24	0.13	0.29	24.71	2.60
2010	0.49	0.18	0.49	40.74	1.60
2015	0.55	0.26	0.69	88.80	-1.34

Middle East (ME)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
0.00	-0.03	0.42	48.83	-2.57
0.13	-0.04	1.20	115.74	48.47
0.21	0.04	1.58	160.69	50.06
0.35	0.31	1.50	182.63	45.50

USA and Canada (US_CA)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
0.04	-0.01	-0.26	16.96	-30.14
0.09	0.04	-0.22	14.54	-1.59
0.09	0.06	-0.37	-22.86	-14.74
0.17	0.02	-0.35	-13.76	-14.34

	Russia (RU)				
year	Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
1995	-	-	-	-	-
2000	-0.29	-0.16	-0.31	-28.48	-4.16
2005	-0.17	-0.17	-0.39	356.58	-21.15
2010	-0.17	-0.37	-0.45	499.54	-31.20
2015	-0.02	-0.15	-0.47	554.54	-49.38

Africa (AF)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
0.10	0.08	-0.14	-14.66	9.62
0.20	0.24	0.07	1.86	20.11
0.39	0.40	0.51	65.58	39.64
0.54	0.62	0.58	102.14	57.98

Asia and Pacific (APAC)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
0.05	-0.00	0.17	10.12	18.58
0.12	0.01	0.35	2.09	16.95
0.34	0.06	0.75	60.99	11.42
0.47	0.22	0.91	105.27	42.28

Table A. 3. Development of indices in world regions, in percent (2/2).

	Australia (AU)				
year	Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
1995	-	-	-	-	-
2000	0.06	0.02	0.07	16.19	-27.52
2005	0.03	-0.04	0.65	66.06	0.30
2010	0.01	-0.09	0.48	76.05	1.30
2015	0.04	-0.09	0.40	137.61	1.65

China (CN)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
0.03	0.09	-0.23	9.07	-5.98
0.21	0.17	0.10	71.93	-7.50
0.21	0.07	0.37	156.20	-14.01
0.47	0.14	0.13	-26.83	-25.62

Europe (EU)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
-0.05	-0.02	0.03	1.13	-5.84
-0.00	-0.05	-0.12	-8.82	-17.13
-0.01	0.02	-0.14	-7.33	-19.21
0.12	-0.03	-0.20	-6.13	-30.23

	India (IN)				
year	Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
1995	-	-	-	-	-
2000	0.06	-0.01	0.11	15.74	4.57
2005	0.03	0.03	0.42	45.60	1.04
2010	0.23	0.04	0.81	5.28	-2.30
2015	0.25	0.10	2.52	54.74	-10.32

Japan and South Korea (JP_KR)				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
-0.06	-0.03	0.00	-35.34	-31.86
-0.13	-0.07	0.10	-12.35	-10.22
-0.02	0.03	0.34	21.15	-10.99
-0.00	0.11	0.06	19.85	-17.64

Global average				
Biomass index	HANPP index	Energy input index	Materials input index	Labor input index
-	-	-	-	-
0.03	0.02	-0.05	6.18	2.62
0.12	0.07	0.07	26.90	2.48
0.23	0.11	0.20	54.72	1.58
0.35	0.20	0.29	63.03	2.24

Table A. 4. 1995: HANPP data for world regions as used in Fig. 2.

World region	HANPP [EJ/yr]	eHANPP imports [EJ/yr]	eHANPP exports [EJ/yr]	eHANPP footprint [EJ/yr]	HANPP self-supply [EJ/yr]	HANPP self-supply [%]
Latin America (LATAM)	84.01	3.54	15.06	72.49	68.95	78.57
Middle East (ME)	5.60	6.00	0.63	10.97	4.97	42.80
USA & Canada (US_CA)	54.35	14.78	11.99	57.14	42.36	61.28
Russia (RU)	22.37	4.71	3.72	23.36	18.64	68.84
Africa (AF)	73.85	2.41	13.93	62.33	59.92	78.57
Asia and Pacific (APAC)	74.26	7.65	24.98	57.92	50.28	60.64
Australia (AU)	8.11	0.96	2.92	6.15	5.19	57.19
China (CN)	41.50	2.57	4.09	39.98	37.41	84.90
Europe (EU)	53.32	27.99	5.41	75.89	47.91	58.92
India (IN)	42.25	1.04	1.98	41.31	40.27	93.02
Japan & South Korea (JP_KR)	3.01	13.10	0.04	16.07	2.97	18.42

Table A. 5. 2015: HANPP data for world regions as used in Fig. 2.

World region	HANPP [EJ/yr]	eHANPP imports [EJ/yr]	eHANPP exports [EJ/yr]	eHANPP footprint [EJ/yr]	HANPP self-supply [EJ/yr]	HANPP self-supply [%]
Latin America (LATAM)	106.22	6.19	33.79	78.62	72.43	64.43
Middle East (ME)	7.33	17.01	1.05	23.29	6.28	25.81
USA & Canada (US_CA)	55.39	18.60	19.76	54.24	35.63	48.16
Russia (RU)	19.08	4.04	7.18	15.95	11.91	51.48
Africa (AF)	119.98	5.66	27.75	97.89	92.24	73.42
Asia and Pacific (APAC)	91.97	13.50	29.38	76.09	62.59	59.34
Australia (AU)	7.40	1.85	4.30	4.95	3.10	33.53
China (CN)	47.42	32.09	7.25	72.26	40.17	50.52
Europe (EU)	51.88	30.33	10.33	71.88	41.55	50.54
India (IN)	46.46	4.72	4.30	46.87	42.15	82.37
Japan & South Korea (JP_KR)	3.33	11.19	0.10	14.43	3.23	22.25

1995

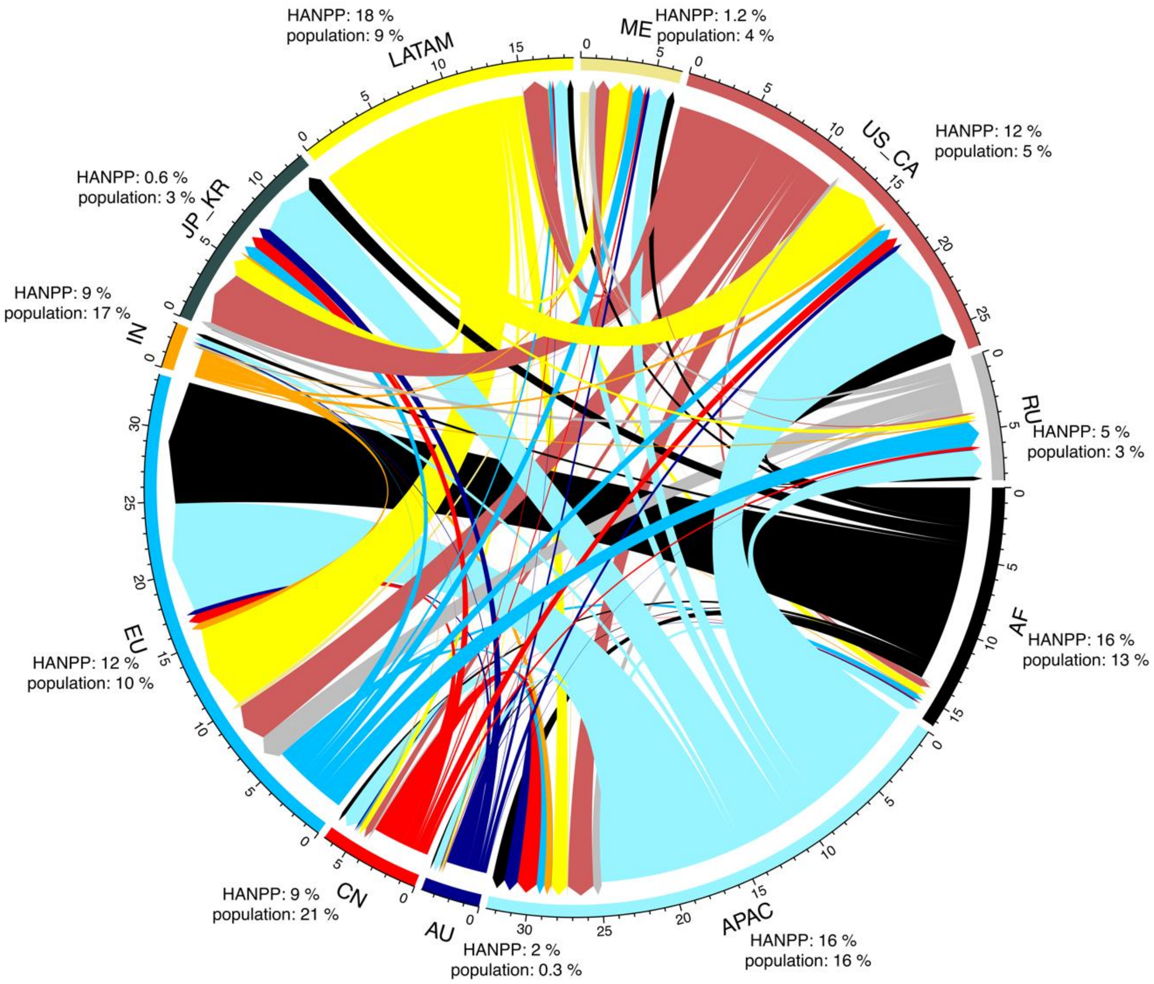

Fig. A. 1. Embodied HANPP flows between world regions as directed arrows in 1995. Values in the circular network plot are given in exajoules [EJ]. Annotated text gives shares of global HANPP and population respectively. LATAM = Latin America, ME = Middle East, US_CA = USA and Canada; RU = Russia, AF = Africa, APAC = Asia and Pacific, AU = Australia, CN = China, EU = Europe, IN = India, JP_KR = Japan and South Korea.

2015

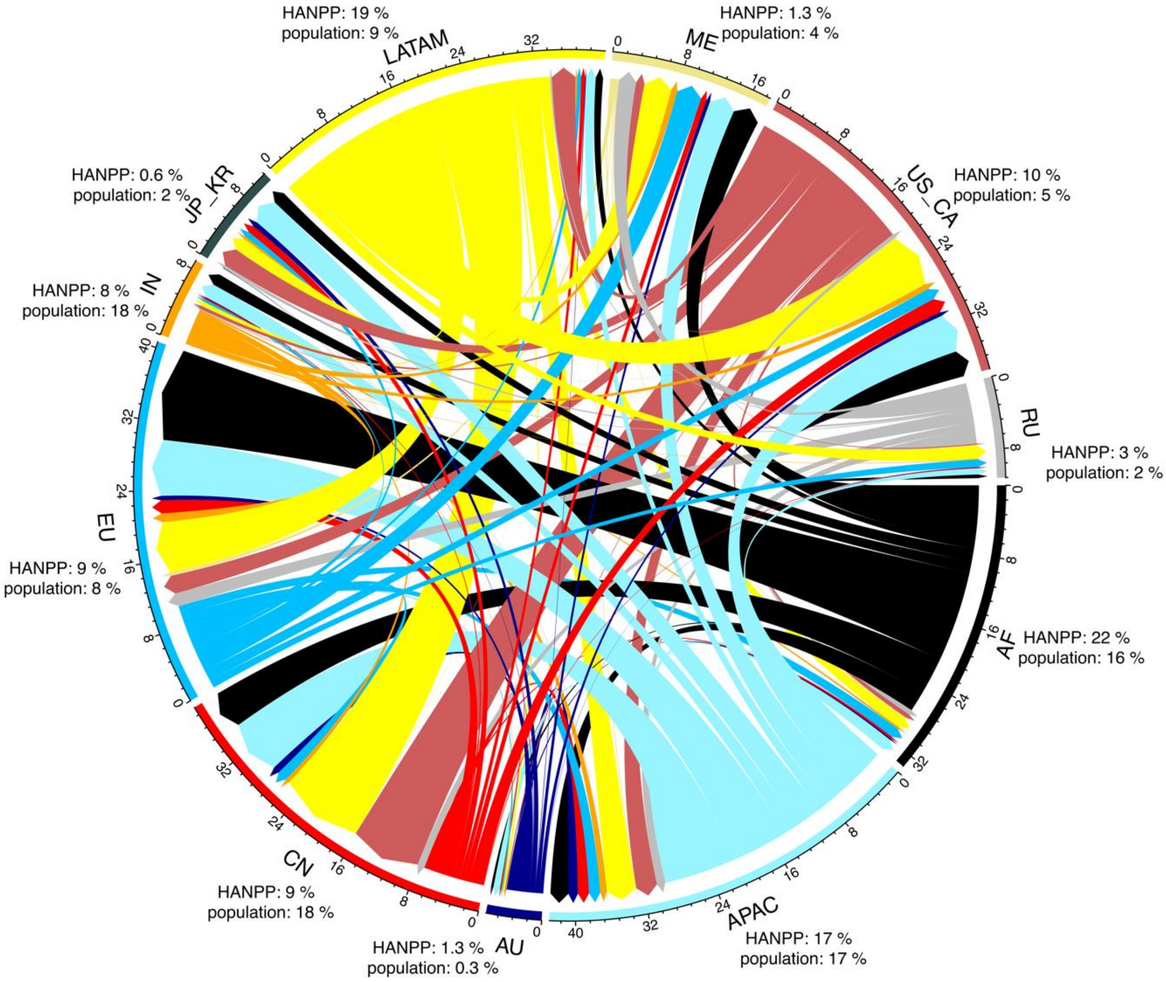

Fig. A. 2. Embodied HANPP flows between world regions as directed arrows in 2015. Values in the circular network plot are given in exajoules [EJ]. Annotated text gives shares of global HANPP and population respectively. LATAM = Latin America, ME = Middle East, US_CA = USA and Canada; RU = Russia, AF = Africa, APAC = Asia and Pacific, AU = Australia, CN = China, EU = Europe, IN = India, JP_KR = Japan and South Korea.

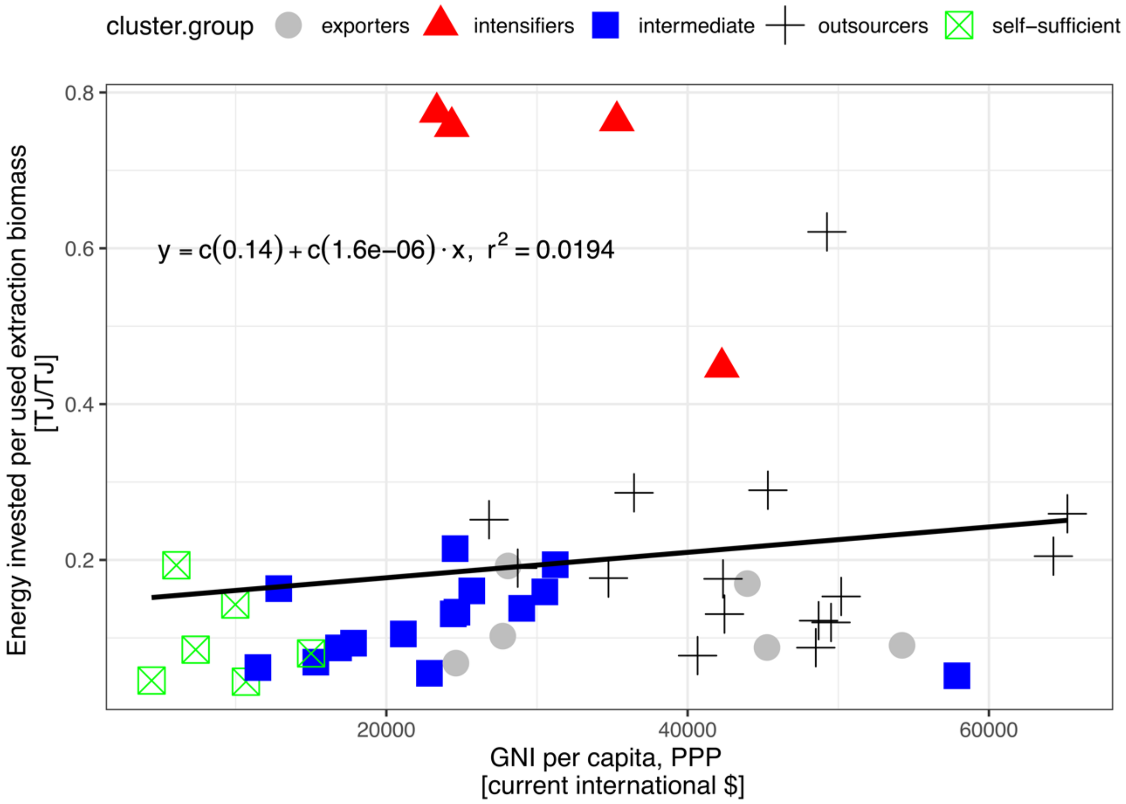

Fig. A. 3 Linear regression analysis with GNI per cap (PPP, current international $) as the predictor and the variable 'energy invested per biomass used extraction' as the response variable. Predictor: mean = 31,348; sd = 15,744. Respondent: mean = 0.20; sd = 0.18; F = 0.87. With a p-value of 0.36 the regression is not significant. N = 46, df = 44.

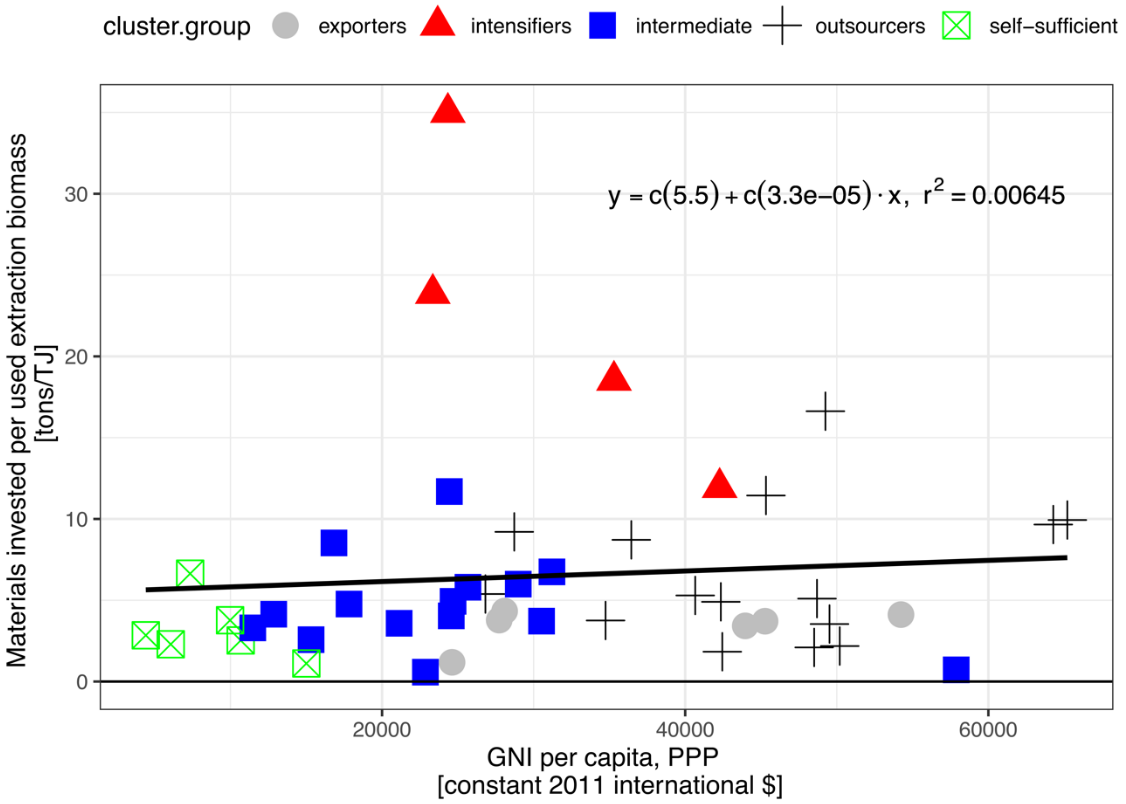

Fig. A. 4. Linear regression analysis with GNI per cap (PPP, current international $) as the predictor and the variable 'materials invested per biomass used extraction' as the response variable. Predictor: mean = 31,348; sd = 15,744. Respondent: mean = 6.52; sd = 6.39; F = 0.29. With a p-value of 0.60 the regression is not significant. N = 46, df = 44.

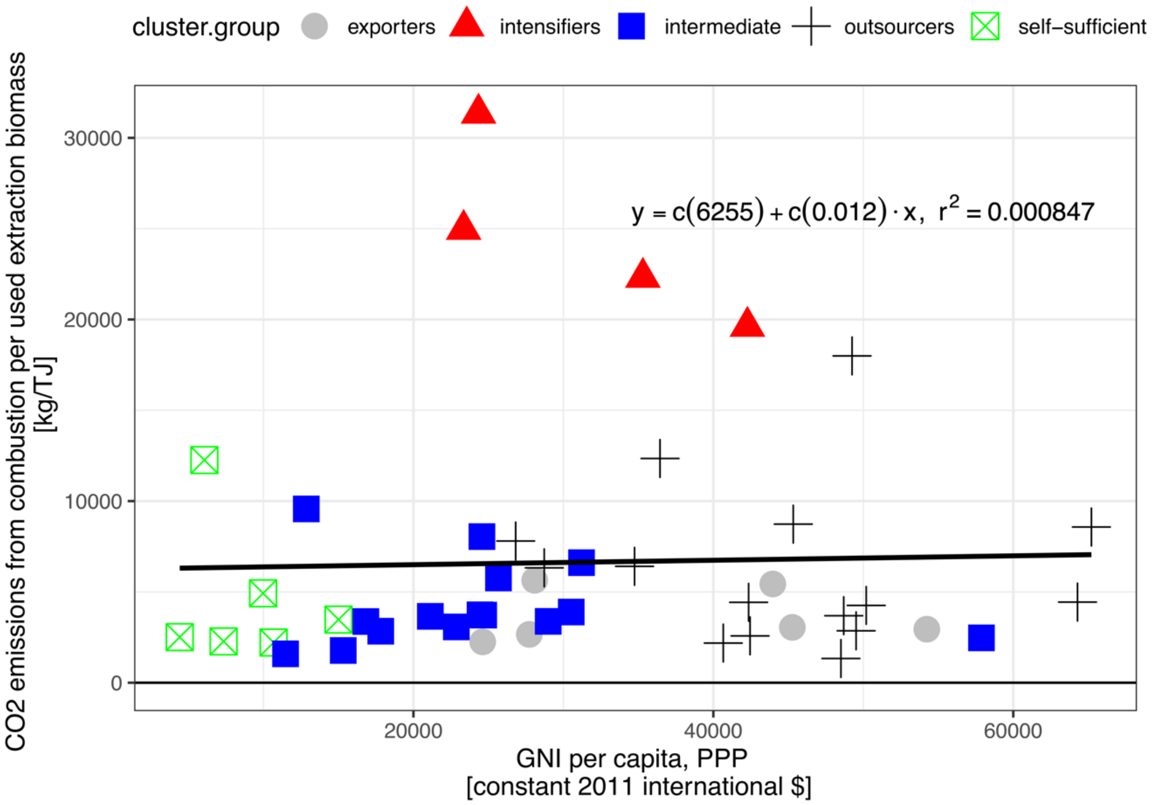

Fig. A. 5. Linear regression analysis with GNI per cap (PPP, current international \$) as the predictor and the variable 'CO_2 emissions from combustion per biomass used extraction' as the response variable. Predictor: mean = 31,348; sd = 15,744. Respondent: mean = 6,637; sd = 6,597; F = 0.04. With a p-value of 0.85 the regression is not significant. N = 46, df = 44.

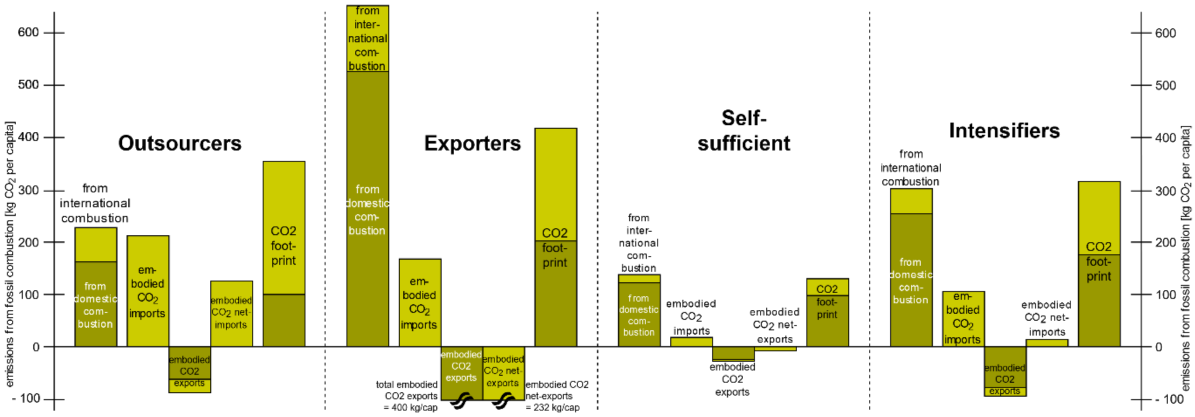

Fig. A. 7. Barplots indicating embodied CO_2 emission flows from combustion which are due to the economic activities of the land-use system for the year 2015. That is, the CO_2 emissions occurring from combustion to appropriate domestic NPP and those embodied in traded biomass. The first stacked bar of each group distinguishes the origin of the emissions occurring from domestic biomass production (domestic vs. international). The subsequent bars show the emissions embodied in biomass imports and exports. Their subtraction yields the net-trade and finally the footprint, which are the domestic emissions plus net-trade. Note that each bar captures the same process, i.e., the first bar of each group presents the process of NPP appropriation and the emissions involved, the second row the biomass imports and the emissions embodied in those imports, etc. All values are given on per capita levels. The share of domestic emissions exported is calculated by assuming an equal distribution of domestic and international emissions for domestic consumption and exports.

Table A. 6. HANPP and embodied resource flow data for clusters as used in Fig. 5, year 2015.

	Domestic land-use			Imports	Exports	Net-trade	Footprint
HANPP flows [GJ per capita]	HANPP	NPP_{eco}		eHANPP imports	eHANPP exports	eHANPP net-trade	eHANPP footprint
Outsourcers	65	85		83	19	64	129
Exporters	313	2,468		72	173	-100	213
Self-sufficient	62	120		10	14	-4	58
Intensifiers	15	34		58	1	57	72
Intermediate	142	618		28	49	-20	121
Labor inputs [hours per capita]	Direct domestic labor	Indirect domestic labor	Indirect inter-national labor	Embodied labor imports	Embodied labor exports	Embodied labor net-trade	Labor footprint
Outsourcers	24	6	27	336	21	315	371
Exporters	26	12	36	305	45	259	333
Self-sufficient	372	7	5	32	94	-62	323
Intensifiers	35	8	25	200	18	182	250
Intermediate	87	11	9	98	39	60	165
Energy inputs [GJ per capita]	From domestic use	From international use		Embodied energy imports	Embodied energy exports	Embodied energy net-trade	Energy footprint
Outsourcers	5	3		6	3	3	11
Exporters	14	6		5	12	-8	12
Self-sufficient	2	2		1	1	0	3
Intensifiers	5	2		3	2	1	8
Intermediate	4	2		2	2	0	6
Material inputs [kg per capita]	From domestic extraction	From international extraction		Embodied material imports	Embodied material exports	Embodied material net-trade	Material footprint
Outsourcers	80	164		239	89	150	395
Exporters	240	329		195	350	-154	415
Self-sufficient	36	56		22	30	-7	84
Intensifiers	146	159		120	103	17	323
Intermediate	175	91		74	95	-21	245
Emissions from fossil combustion [kg CO_2 per capita]	From domestic combustion	from international combustion		Embodied CO_2 imports	Embodied CO_2 exports	Embodied CO_2 net-trade	CO_2 footprint
Outsourcers	162	66		212	86	127	354
Exporters	525	126		168	400	-232	419
Self-sufficient	122	16		19	26	-7	130
Intensifiers	254	49		107	93	13	316
Intermediate	176	37		63	70	-7	206