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# Estimating the human appropriation of land in Brazil by means of an Input–Output Economic Model and Ecological Footprint analysis

Gabriele Salvo[a,*], Moana S. Simas[b], Sergio A. Pacca[c], Joaquim J.M. Guilhoto[d], Acacio R.G. Tomas[e], Ricardo Abramovay[a]

[a] Socio-Environmental Economics Group (NESA), Faculty of Economics, Administration and Accountancy, University of São Paulo, São Paulo 05508-010, Brazil
[b] Industrial Ecology Program, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim 7491, Norway
[c] Sustainability Program, School of Arts, Sciences and Humanity, University of São Paulo, São Paulo 03705-000, Brazil
[d] Department of Economics, Faculty of Economics, Administration and Accountancy, University of São Paulo, São Paulo 05508-010, Brazil
[e] Fisheries Institute, Advanced Technology Research Center on Marine Fish Agribusiness, 11030-906 Santos, Brazil

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ABSTRACT

As we confront the current environmental crisis, determining the biophysical base (e.g., materials, energy, land, and water) of nations has become paramount. With advanced economies benefiting from the import of resource-intensive primary goods originating from poorer parts of the world, especially emerging nations, these are dilapidating their natural capital. Brazil is one of such emerging economies, whose mining and farming activities, propping up its export-led economic growth, exert great pressure on the environment. In particular, farming has been shown to have one of the world's greatest environmental impacts, especially as a consequence of land use associated with cattle ranching. Since a nation-wide evaluation of land-use types across the whole sectorial spectrum of the country's economy is still lacking, we used the most recently available Input–Output Economic Model for Brazil and the Ecological Footprint method to identify those economic sectors with the greatest potential for appropriating portions of the natural world.

Our results show that: (i) the biggest chunk of Brazil's Ecological Footprint is due to its Carbon Footprint and, in particular, emissions from cattle; (ii) only a few economic sectors exhibit high Ecological Footprint values, chiefly those belonging to livestock farming and energy production based on fossil fuels; (iii) excluding the soybeans and slaughter sectors, export-oriented sectors have below-average Ecological Footprint values; and (iv) the percentage of Brazil's Ecological Footprint due to household consumption (excluding imports) is three times bigger than that attributable to exports, with sectors belonging to livestock farming contributing the most to such disparity.

These results underscore that the environmental impact of the Brazilian economy can be drastically reduced by tackling the emission-intensive production processes of a few sectors only and disincentivizing the domestic consumption of a narrow range of products, especially with respect to the livestock segment.



## 1. Introduction

In the current era of dwindling natural resources and widespread environmental degradation (Brown, 2011), driven by global population growth, rapid industrialization of emerging countries and humanity's increasing level of consumption (Royal Society, 2012), it has become paramount to determine the biophysical bases of nations (Adriaanse et al., 1997; Behrens et al., 2007; Global Footprint Network, 2010; Matthews et al., 2000). As societies grow wealthier, they demand more and more materials and energy to sustain their economic activities and standard of living. From 1900 to 2005, total material extraction of biomass, ores and industrial minerals, construction minerals, and fossil fuels increased eight-fold globally (Krausmann et al., 2009). Not only has global resource consumption expanded, but also there are huge geographical imbalances on how natural resources are used. Advanced economies benefit from major natural capital transfers originating mainly in poorer parts of the world,

* Corresponding author. Tel.: +55 11952997387.
*E-mail address:* corallinus@hotmail.com (G. Salvo).

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where most material extraction takes place and energivorous and highly polluting industries are found (Sustainable Europe Research Institute, GLOBAL 2000, 2009; UNEP, 2011a; Wiedmann et al., 2013). This fact, coupled with rapid population increase in developing countries and growing consumption in emerging economies, has caused the global metabolic rate – the quantity of materials and energy used per capita per year – to start rising again during the last decade (UNEP, 2011b). This metric, in fact, which had been rising since the beginning of the previous century, had reached a fairly stable level between the oil crisis of the 70s and the beginning of the current century. At present, emerging nations display a metabolic rate similar to that of industrial countries in the 1950s and 60s (UNEP, 2011b).

One of such nations is Brazil, whose metabolic rate was close to the world's average in 1970, but had almost doubled by 2005, reaching China's level (Hashimoto et al., 2012). In the period 1975–1995, the most thorough study that has been carried out so far on the material and energy flows of the Brazilian economy has found a tremendous increase in the use of materials, with domestic material extraction growing at 120% over the period, in contrast with a 48% and 68% rise in population and gross domestic product (GDP), respectively (Machado, 1999; Machado et al., 2004). A similar trend was found between 1995 and 2005, with the domestic extraction of materials in the country having expanded from 2310 to 3006 million tonnes over the period (Wiebe et al., 2012). Likewise, between 1970 and 2008, primary energy production in Brazil rose from circa 50 million tonnes of oil equivalents to circa 250 (de Freitas and Kaneko, 2011), whereas population and GDP showed more modest growth rates.

Not only has the absolute amount of extracted materials and energy rocketed in Brazil, but also material intensity (i.e., the quantity of materials embedded in each unit of GDP) and energy intensity (i.e., joules per GDP) have increased substantially. In a study that compared the direct material input per unit of GDP between 1975 and 1995 among different countries, Brazil and Venezuela were the only countries that exhibited an upward trend (Amann et al., 2002). With the exception of Saudi Arabia, Brazil is the country that has reduced its energy intensity the least between 1990 and 2005, as compared to other G20 member states (Abramovay, 2010a).

This spectacular surge in Brazil's metabolic rate can be attributed to the country having become one of the top mining and agricultural powerhouses of the world (Tollefson, 2010). In particular, due to the availability of vast areas of land suitable for crop cultivation and pastures, Brazil has focused on developing farming, making it key to its economic growth strategy (World Bank, 2010). In recent decades, in fact, this nation has acquired a competitive advantage in the production of primary goods and natural-resource-intensive goods (Laplane and Baltar, 2009), with the agribusiness sector contributing to around 25% of the nation's GDP (Martinelli et al., 2010). From the year 2000 to 2007 the role of primary goods in exports grew by nearly 15% (UNEP, 2011a) and from 2006 to 2011 the proportion of exports comprising iron ore, oil, soy, beef, sugar and coffee rose from 28% to 47% (Abramovay, 2012). Beef exports have increased seven-fold on a mass basis during the past decade, making Brazil the world's top exporter of this commodity and the world's second largest producer (Cederberg et al., 2011). With the largest cropped area in the country (23 million ha) occupied by soybeans, Brazil is also one of the world's leading soya exporters (Tollefson, 2010).

Brazil has not only become a net exporter of material- and energy-intensive primary goods, but also, in recent decades, the pollution and emission potential of its exports has risen. From 2002 to 2007 there has been a steady increase in the Linear Acute Human Toxicity Index of exports, with only ten products accounting for 60% of overall toxicity (UNEP, 2011a). In an older study that analyzed the emission- and pollution-intensity of the Brazilian economy in 1985 and 1990–1994, the productive chains associated with exports were found to be "dirtier" than those associated with the domestic market (Young, 2000). Furthermore, such intensities were not distributed homogenously across economic activities, but were concentrated in a few sectors only: metallurgy, paper and cellulose, chemicals, and food products. Similarly, Machado et al. (2001) found that in 1995 each dollar earned with exports embodied 40% more energy and 56% more carbon than each dollar spent on imports. In summary, the revenue from Brazil's exports of primary goods and natural-resource-intensive goods comes at a high environmental cost, in terms of materials/energy used and emissions/pollution produced.

In a study that evaluated six major environmental impacts (water use, greenhouse gas emissions, waste, air pollution, land and water pollution, and land use) for over 1000 primary production and processing region-sectors across the world, land use in South America – caused mainly by cattle ranching in Brazil and the associated appropriation of virgin land and loss of ecosystem services – was one of the categories with the greatest impact on nature (Trucost and TEEB for Business Coalition, 2013). Notably, the expansion of agriculture in Brazil has been accompanied by heavy deforestation, affecting the nation's major biomes: the Amazon Forest, the Atlantic Forest and the Cerrado (Martinelli et al., 2010). In particular, the opening up of the beef and soy industries to foreign markets has been directly linked to the increased rate of deforestation that the Legal Amazon Region (LAR) experienced between 2002 and 2004 (Nepstad et al., 2006). Apart from being responsible for ecosystems' degradation and biodiversity loss, land use and land-use change have also been identified as the main factors contributing to Brazil's greenhouse gas emissions. In fact, land use, land-use change, and forestry (LULUCF) accounted for about two-thirds of Brazil's $CO_2$eq emissions in 2008, with two-thirds of that amount represented by deforestation alone (World Bank, 2010).

Although land use and land-use change have been well studied in Brazil (e.g., Aldrich et al., 2006; de Sá et al., 2012; Gardner et al., 2013; Leite et al., 2012), a nation-wide evaluation of land-use types across the whole sectorial spectrum of the country's economy is still lacking. Most importantly, the amount of land utilized by each Brazilian economic sector per monetary unit of their final demand (i.e., land intensity) is not known. Such information is crucial in order to identify the most land-intensive industries and hence those with the greatest potential (per unit of GDP) for appropriating portions of the natural world. Consequently, the present study was based on a powerful indicator of land-use type, the Ecological Footprint (EF), together with an Input–Output (I-O) Model of the Brazilian economy.

The EF measures the amount of productive land seized by a country in order to support all its economic activities (i.e., the total land required to provide resources to, and absorb emissions from, a country's economy). For Brazil it has been reported from 1961 to 2008 by the Global Footprint Network, showing that although the per capita EF has remained constant throughout the period (at circa three global hectares, gha), due to population growth, per capita biocapacity (i.e., the amount of biologically productive land and sea area available in a country) has declined steadily (from circa twenty-three to eleven gha). Nonetheless, in per capita terms, Brazil's biocapacity remains nearly four times as big as its EF.

The EF of a country, however, is a coarse indicator of natural resource appropriation; a greater level of detail is needed in order to understand which economic activities use the greatest amount of land, both directly and indirectly. Such thoroughness can be achieved by adopting a combined I-O/EF framework. By associating the land-use categories of the Global Footprint Network to the relevant economic sectors of an I-O monetary table, the direct and