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Land, carbon and water footprints in Taiwan

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ABSTRACT

The consumer responsibility approach uses footprints as indicators of the total direct and indirect effects of a product or consumption activity. This study used a time-series analysis of three environmental pressures to quantify the total environmental pressures caused by consumption in Taiwan: land footprint, carbon footprint, and water footprint. Land footprint is the pressure from appropriation of biologically productive land and water area. Carbon footprint is the pressure from greenhouse gas emissions. Water footprint is the pressure from freshwater consumption. Conventional carbon footprint is the total CO_2 emitted by a certain activity or the CO_2 accumulation during a product life cycle. This definition cannot be used to convert CO_2 emissions into land units. This study responds to the needs of "CO_2 land" in the footprint family by applying the carbon footprint concept used by GFN. The analytical results showed that consumption by the average Taiwan citizen in 2000 required appropriation of 5.39 gha (hectares of land with global-average biological productivity) and 3.63 gha in 2011 in terms of land footprint. The average Taiwan citizen had a carbon footprint of 3.95 gha in 2000 and 5.94 gha in 2011. These results indicate that separately analyzing the land and carbon footprints enables their trends to be compared and appropriate policies and strategies for different sectors to be proposed accordingly. The average Taiwan citizen had a blue water footprint of 801 m^3 in 2000 and 784 m^3 in 2011. By comparison, their respective global averages were 1.23 gha, 2.36 gha and 163 m^3 blue water in 2011, respectively. Overall, Taiwan revealed higher environmental pressures compared to the rest of the world, demonstrating that Taiwan has become a high footprint state and has appropriated environmental resources from other countries. That is, through its imports of products with embodied pressures and its exports, Taiwan has transferred the environmental pressures from consuming goods and services to other parts of the world, which is an environmental injustice. This study examines the time series trend of land, carbon, and water footprints in Taiwan. However, if these analyses can be downscaled to city/county levels, they will be more useful for examining different sustainability performance of local governments in different regions.

1. Introduction

The environmental pressures from human activities have caused many important transitions in the earth (e.g., climate change) (Galli et al., 2012; The Royal Society, 2014; World Economic Forum, 2014). Consequently, numerous natural hazards—for example drought, inland excess water, and wind erosion—cause social, economic, and environmental problems (Mezosi et al., 2014). Therefore, tools are needed for systematically measuring the impacts of the many environmental effects of human activities (Barnosky et al., 2012; Borucke et al., 2013; Galli et al., 2012; Steen-Olsen et al., 2012; Wackernagel, 2014). To trace environmental pressures, many countries have begun exploring the material flows of energy, water and other goods and services used to satisfy the needs for water, energy, food, shelters and transportation (Chavez and Ramaswami, 2013; Jha et al., 2013; Ramaswami et al., 2012). Most of these material flows are related to the basic infrastructure and are essential for economic productivity. Consequently, a community basic infrastructure footprint is created (Chavez and Ramaswami, 2013). In contrast, the consumption-based footprint is gaining the attention of researchers. Among them, greenhouse gas (GHG) emissions from residential and commercial sectors are not allocated to producers. Rather, they are distributed to end consumers as household expenditures, governmental expenses and entrepreneurial capital investments (Chavez and Ramaswami, 2013).

Of all measurements for estimating consumption-based demands, ecological footprint, carbon footprint, and water footprint are in the "footprint family" of indicators (Fang et al., 2014). The footprint family of indicators can be defined as a set of resource accounting tools characterized by a consumption-based perspective able to track human pressure on the surrounding environment, where pressure is defined as appropriation of biological natural resources and CO_2 uptake, emissions of GHG, and consumption and pollution of global freshwater resources. The three key ecosystem compartments monitored in the footprint family are the biosphere, atmosphere, and hydrosphere

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through the ecological, carbon, and water footprint, respectively (Galli et al., 2011).

Environmental concerns and impact measurements are important to these three ecosystems. Although the three ecosystems have different contexts, they are inter-related, and solving problems in one dimension may cause conflicts in the other two ecosystems (Steen-Olsen et al., 2012; Wackernagel, 2014). Therefore, when drafting public policies and making public investments, lawmakers should consider these three environmental challenges. From the holistic perspective, however, evaluating GHG emissions and human appropriation of land and water is difficult, and many approaches are possible. Because environmental pressures result from the consumption of goods and services, research and pressure indicators usually follow the "consumer responsibility" principle and try to allocate full life-cycle environmental responsibility to products consumed by the end consumers (Steen-Olsen et al., 2012). "Footprints" are used for different environmental pressures so that people can understand the consumer responsibility.

Galli et al. (2012) thoroughly analyzed and defined the three most common footprints. Ecological footprint uses biological productive (bioproductive) lands to measure the embodied biological resources; the measurement unit is global hectare (gha) of average productivity per hectare. Carbon footprint is used as a measure of GHS emissions embodied in the consumption and is usually measured using CO_2 equivalent (tonne). Water footprint uses cubic meters as the measurement unit for direct and indirect water resource demands and is categorized into green water (rainfall absorbed directly by plants), blue water (underground and surface water) and gray water (water resources needed to dilute water pollutants).

Footprint indicators are usually applied at the personal or cooperation assessment level. However, for decision making purposes, footprint indicators should also be assessed at the national or regional level. National footprint accounts reveal the relative importance and context of national impacts and provide a global perspective of the internal driving forces of these impacts. Footprint indicators can also be used to quantify the global consumption of natural resources. Current approaches to calculating national footprints include the Global Footprint Network (GFN), which regularly calculates ecological footprints for most countries worldwide to explore the current situation of land use and CO_2 emissions (Borucke et al., 2013; Ewing et al., 2010a; GFN, 2013; Wackernagel, 2014).

The Water Footprint Network (WFN) similarly estimates water footprint (Hoekstra, 2013; Hoekstra and Mekonnen, 2012). Hertwich and Peters (2009) estimated carbon footprints from a global trade perspective. Peters et al. (2012) then compiled these footprints into internet data. Using consumption-based life cycle accounting approaches, Jones and Kammen (2011) calculated the carbon footprints for various households in 28 cities for six household sizes and 12 income brackets in the U.S. Their results reveal that the size and composition of carbon footprints vary significantly with demographic characteristics among and within different regions.

Estimating the three footprints simultaneously enables a holistic understanding of the dimensions and quantity of the resource consumption and environmental impacts while pursuing social and economic development. Therefore, this study examines the three environmental footprints from 2000 to 2011 in Taiwan. Measuring the three footprint indicators is a consistent approach to evaluating the three different environmental pressures, which provides a more complete picture of how consumption activities cause real pressures on the Taiwan environment and further helps to prevent focusing on only one environmental problem and thus inducing the transfer of environmental pressures.

This study explores land footprint, carbon footprint and blue water footprint in Taiwan. Land footprint is equal to ecological footprint excluding the land for sequestering carbons (i.e., the carbon footprint of CO_2 emissions) (Steen-Olsen et al., 2012; Weinzettel et al., 2013). This study focuses only on the blue water footprint, as several other studies (Hoekstra et al., 2011; Ridoutt and Pfister, 2010; Steen-Olsen et al., 2012), because the gray water footprint measures only water consumed for diluting pollution but excludes direct water consumption. The green water footprint is the direct consumption of rainfall (Galli et al., 2012) and may be double-counted in the land footprint calculation (Ridoutt and Pfister, 2010; Steen-Olsen et al., 2012).

2. Literature review

2.1. Ecological footprint

Land footprint (or actual land requirement) is a widely accepted method of calculating the land resources (domestic or foreign) needed to provide the goods and services finally consumed by a country (Bruckner et al., 2012). Land footprint indicates the dependency of different nations or regions on foreign lands. The virtual land is embodied in import and export products (Giljum et al., 2013).

Since land footprint is defined as EF minus the land needed to sequester CO_2 emissions, this study first analyzes the context of EF. The EF is a measure of the pressure of human activities on nature (Wackernagel, 2014) and connects socio-economic metabolism to land use, which is the main process affecting the "society and nature relationship" of the environmental change (Lammers et al., 2008; Wackernagel and Rees, 1996). The EF is a measure of the land and water area needed to sustain a certain population. Land and water areas provide resources needed for consumption and waste disposal. By calculating the biocapacity of a certain area, human demands on that area can be compared with its natural capital. Therefore, EF is widely used in many academic and practical fields (Borucke et al., 2013; Lammers et al., 2008; Lee and Peng, 2014; Niccolucci et al., 2012; Rendeiro and Ramírez, 2010; Wackernagel, 2014; Wang et al., 2012; Zhou and Liu, 2009).

The EF includes six major land categories: cropland, grazing land, fishing ground, forest land, carbon uptake land and built-up land (Borucke et al., 2013). The size of an EF is positively associated with its environmental impacts. A large EF indicates a large environmental impact. In contrast, the EF size is negatively associated with the bioproductive land area. A large EF indicates a small available bioproductive land area for each person. For example, comparing the EF with the land area of Taiwan reveals that 61 times the area of Taiwan was needed in 2011, indicating an overshooting of the EF of Taiwan and declining sustainability (Lee and Peng, 2014). The consumption of these additional bioproductive lands reveals that, to maintain socio-economic development, Taiwan must appropriate resources from other countries.

From the EF statistical data published by GFN (Ewing et al., 2010a), the global EF comprised only 63% of the resources provided by the biosphere in 1961. In the 1980s, human demands exceeded the biocapacity of the earth. In 2007, the global EF reached 1.52 times that of the biocapacity of the earth. Restated, dramatic annual increases in the global ecological deficit indicate that human overshooting has caused enormous ecological pressures. Humans must face this issue and take the action needed to achieve sustainability.

2.2. Carbon footprint

As noted above, EF is the land and water area consumed to satisfy various human needs. The EF can be conceptualized as a global assets-debt balance sheet. The negative perspective is the consumption of natural resources needed to support human life, such as architecture, transportation, housing, commercial, energy use, forestry and fishery and the consumption of all these activities. From a positive perspective, it is the biocapacity of the environment, being used as the capacity to provide resources and absorb wastes. Using EF has some advantages. From the practical dimension, EF can be used to compare carbon emissions with human needs. For example, goods and services consumed by