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Any sustainable decoupling in the Finnish economy? A comparison of the pathways and sensitivities of GDP and ecological footprint 2002–2005

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ABSTRACT

Ecological footprint was combined with economic input–output analysis in order to identify the economic structures causing the overuse of biological resources. These structures were analyzed with the use of structural decomposition, path analysis and sensitivity analysis and compared to the structures which drive economic growth. The scope of the analysis was the Finnish national economy during 2002–2005. Based on the results increases in gross domestic product (GDP) and ecological footprint were found to be different subsystems of the economy. This aspect was previously hidden by country level aggregate indicators. Ecological footprint was increased by the production and consumption of primary commodities, such as wood, paper, fish, crops, animal products and energy as well as construction. In contrast, GDP growth was caused mainly by increased demand in service sectors such as renting and owning apartments, trade and business services as well as governmental services, health, education and social work. The two systems overlapped only in dairy products and forest products, which had major influences to both indicators. Ecoefficiency improved overall in the economy between 2002 and 2005 especially in some industries, such as sawmilling and electricity production. However growth in consumption resulted in increased environmental impacts nevertheless.

1. Introduction

The ecological footprint measures the consumption of biological natural resources. It is expressed in productive land area needed to supply the goods and process the wastes of a given entity. Ecological footprint can be calculated for products, organizations and regions, but is most commonly used to estimate the ecological footprint of nations in national footprint accounts (NFAs). The national footprint accounts can be compared with the land area available for a given country (biocapacity) to determine, whether the country is exceeding its ecological limits (consuming more renewable goods than could be sustainably produced). Globally the ecological footprint exceeded the available biocapacity in the beginning of 1980s, resulting in an ecological overshoot which has continued since (Ewing et al., 2008). Population growth and use of fossil fuels have been identified as the main drivers of the overshoot. The ecological footprint has been found to grow continuously with increasing income, therefore negating any hypothesis of decoupling at the global scale (Caviglia-Harris et al., 2009; Bagliani et al., 2008). In spite of the global overshoot, some sparsely populated and bioproductive countries are still below their biocapacity (Ewing et al., 2008).

Finland is one of the few countries, which is not in a state of ecological overshoot. Finland has a low population density with 5.3 million inhabitants and an inland surface area of 34 million hectares. The low population density is combined with production of resource intensive commodities such as pulp and paper, mining, metals and machinery. These commodities are mainly exported, contributing to economic growth but not directly to consumption based ecological footprint. Finland is also an interesting case study from the viewpoint of decoupling. The ecological footprint of Finland decreased by 6.5% from 2002 to 2005 (Global Footprint Network, 2010) while the gross domestic product increased by 9.5% (Statistics Finland, 2007). The ecological footprints of Germany and Netherlands also decreased, but their level of consumption was above their biocapacity (Ewing et al., 2008). Therefore Finland would seem to be a rare example of absolute decoupling at an already sustainable level of consumption.

In recent times there has been a synthesis of ecological indicators used in environmental systems analysis. Ecological footprinting is increasingly being used together with input–output economics to study the production–consumption patterns and subsequent biological resource use (Turner et al., 2007). In the same time, life cycle assessment has merged with environmental input–output analysis (Suh, 2009), enriching the methods in both fields. In this study we apply the rich methodological toolbox of life cycle assessment (LCA) (Guinee et al., 2002) and environmentally extended input–output analysis (EEIO) (Leontief, 1970)

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to the National Footprint Accounts of Finland 2002–2005 (Global Footprint Network, 2010). The aim is to demonstrate the benefits of analyzing the accounts at a detailed subnational process level and to identify the main pathways of change for ecological footprint and economic growth.

2. Materials and methods

2.1. The hybrid input–output model

Input–output analysis was developed to analyze the rich interactions between economic sectors. In order to produce a commodity (output), an industry will need raw materials (input) from other industries. These industries in turn need raw materials from other industries, sometimes including the original industry, resulting in complex cyclical flows. As a result, producing commodities for consumption requires a considerable amount of intermediate production. A key question in both economic and environmental input–output analysis is how much economic activity and environmental impact is caused by different parts of consumption. This information can then be used to identify the impacts of companies, consumers and countries. Of particular importance to ecological footprinting is the use of EEIO to construct consumption based national inventories, where the imported resources are added to the national inventory and resources used for export production are removed (Turner et al., 2007). The use of input–output based inventories is recommended, since the extent of domestic consumption and exports are more accurately followed (Wiedmann and Barrett, 2010).

The analysis was based on a tiered hybrid version of life cycle assessment and input–output analysis (Suh and Huppes, 2005). In this study the model was applied for ecological footprinting:

$$EF = [\,B_d \quad B_i\,]\begin{bmatrix} I-A_d & 0 \\ -A_i & I \end{bmatrix}^{-1}\begin{bmatrix} f_d \\ f_i \end{bmatrix} = B(I-A)^{-1}f \qquad (1)$$

where EF = the ecological footprint (gha); B_d = domestic footprint intensity (gha/M€); B_i = imported footprint intensity (gha/M€); A_d = domestic input coefficient matrix (M€/M€); A_i = imported input coefficient matrix (M€/M€); I = identity matrix; f_d = final demand of domestic products (M€); f_i = final demand of imported products (M€).

The final demand (f) and input coefficient matrices (A) were based on the official national accounts of Finland (Statistics Finland, 2007). The term $(I-A)^{-1}$ is the Leontief inverse, which describes all the intermediate products needed to produce output from an industry when the whole supply chain is taken into account. B is the overall footprint intensity of domestic and imported commodities. The domestic input coefficient matrix was assembled as an industry-by-industry table according to the recommendations of Eurostat (2008) with a resolution of 151 economic sectors. The imported input coefficient matrix was reported as 733 commodity groups. The domestic footprint intensity (B_d) was based on the Finnish National Footprint Accounts (NFA) 2002 and 2005, calculated with the most recent footprint methodology (Global Footprint Network, 2010). The NFA reported the ecological footprint for six subclasses: carbon uptake, cropland, grazing, fishing, built and forest land. For the carbon uptake land, national emission inventories were used instead of NFA results. Therefore the calculation included also methane (CH_4) and dinitrogen monoxide (N_2O) emissions, which were converted to CO_2 equivalents using the most recent global warming potentials (IPCC, 2007).

The current study differs most from previous studies in the analysis of imports (B_i). Most previous studies combining IO and EF have either (a) assumed that imported commodities would be produced with similar emissions than domestic commodities, (b) used multiple region input–output (MRIO) models to estimate imports or (c) used the footprint coefficients from NFAs (Turner et al., 2007). In this study the imported commodities were estimated by combining NFA footprint coefficients with LCA databases on greenhouse gas emissions. NFA data was used for the crop, pasture, forest and fishing grounds embodied in imports, but the imported carbon intensities were based on a combination of life cycle emission inventories for greenhouse gases (Ecoinvent, 2008) and the domestic technology assumption (Seppälä et al., 2009). The use of more detailed life cycle data and the inclusion of other greenhouse gases than carbon dioxide were nonconventional, but acceptable improvements to the current methodology according to the Ecological Footprint Standards (Global Footprint Network, 2009). The NFA import footprint coefficients have been criticized for not including the carbon emissions of imported transport services and being based on inappropriate embodied energy figures (Wiedmann, 2009). The use of hybrid IO-LCA inventories instead of the NFA coefficients resolved these issues, since the LCA data both included transport emissions and was based on actual greenhouse gas emissions instead of embodied energy. Therefore it had the benefits of the MRIO method (Wiedmann, 2009) without adding too much computational complexity.

The NFA results were reported as aggregated totals for six land use classes, but the input–output tables included 151 industries. Therefore the aggregates had to be allocated to industries using national statistics. The carbon footprint was already reported by industry in the national emission inventory, therefore no adjustment was necessary. The aggregated data for croplands were allocated to crop production by using national statistics on the use of agricultural commodities. The crops which were reported as used directly as feed were allocated to integrated animal production, while the crops which were sold to other farmers or to the food and feed industries were classified as crop production. This resulted in 26% of cropland being allocated to animal farming. All grazing land was allocated to animal farming, all fishing land was allocated to fishing and all forest land was allocated to forestry. For built up land the more accurate CORINE 2000 database was used instead of the GAEZ database used in the ecological footprint. Residential areas were allocated to the industry of renting and owning apartments and to households. Industrial areas were allocated to industries based on the amount of material output (Seppälä et al., 2009) of the process industries and the economic output of the service industries. Finally roads, airports and harbors were allocated to the sectors responsible for maintaining roads and other transport areas.

2.2. Analytical methods: sensitivity and structural analysis

Both the GDP and ecological footprint are usually reported in an aggregated form, making it impossible to determine, why the results have increased or decreased. In this study we applied methods from input–output analysis and life cycle assessment to identify relevant model components and subsystems from the network of economic and environmental interactions included in the environmentally extended input–output model (Eq. (1)). To our knowledge, this is the first published application of these tools to ecological footprinting. The tools have been applied to greenhouse gas emissions and energy consumption in other studies.

Sensitivity analysis, or perturbation analysis, is used in life cycle assessment to determine the interactions between processes, which have the most influence on the environmental impacts studied (Heijungs and Suh, 2002). In the input–output model applied in this study, there are approximately 21 000 domestic inter-industry relationships and 20 000 relationships with import products. In the sensitivity analysis, each relationship (defined as an input-coefficient) was changed by 1% and the relative change in the