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Ecological footprint of Taiwan: A discussion of its implications for urban and rural sustainable development

Ben-Chaung Wang [a], Fang-Yi Chou [b], Yung-Jaan Lee [c,*]

[a] Department of Architecture, National United University, Taiwan
[b] Center for General Education, National United University, Taiwan
[c] Chung-Hua Institution for Economic Research, 75 Chang-Hsing St., Taipei 106, Taiwan

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ABSTRACT

Ecological footprint is a vital index for measuring whether an area is developing in a sustainable manner. This study calculates and analyzes the ecological footprint of Taiwan from 1994 to 2007. The per capita ecological footprint of Taiwan was 5.09 global hectares in 1994, and increased to 5.52 global hectares in 2005 and 6.54 global hectares in 2007. Based on the 2007 figure an area 42 times the size of Taiwan is needed to sustain the consumption of Taiwan. Moreover, the per capita ecological deficit in Taiwan also worsened during this period, from 3.09 global hectares in 1994 to 3.71 global hectares in 1994 and 4.74 global hectares in 2007, indicating resource overshooting and placing further pressure on the Earth. The calculation of ecological efficiency reveals that the poorest performance occurred in 1997, while performance was improved in 2003.

1. Introduction

The strong economic growth in Taiwan has always been obvious, although it has recently suffered as a result of the global financial problems. Taiwan's gross domestic product, GDP, resumed positive growth in 2010 (Directorate-General of Budget, Accounting and Statistics, DGBAS, 2010a), and the global national competitiveness ranking of Taiwan increased from 23rd in 2009 to eighth in 2010, its highest ever (International Institute for Management Development, IMD, 2010). However, no confirmed conclusions exist regarding the environmental pressures or other impacts associated with economic development. Although some traditional indexes have already identified that economic growth has impacted the environment of Taiwan; for example, indexes on total primary energy use, traffic, and demographics (Lin & Qiu, 2009), few studies have examined the overall environmental impact of economic growth.

"Ecological footprint" measures the pressure that human society has placed on nature (Lammers, Moles, Walsh, & Huijbregts, 2008), which links social and economic metabolism with land use. Land use is one of the key processes influencing the relationship between society and nature and associated environment changes (Wackernagel & Rees, 1996; Haberl, Erb, & Krausmann, 2001; Lammers et al., 2008). Ecological footprint estimates the land and water areas needed to maintain a population using bioproductivity, and estimates the land and water areas needed for the resources necessary for consumption and the generated waste. Through calculating the biocapacity of such areas, the demands placed by humans on these areas can be compared with their natural resources. Ecological footprint has attracted growing importance in both academic and practical circles globally (Bagliani, Bravo, & Dalmazzone, 2008; Haberl et al., 2001; Lammers et al., 2008; McDonald & Patterson, 2004; Renderiro Martín-Cejas & Pablo Ramírez Sánchez, 2010; Zhou & Liu, 2009). Ecological footprint has even become an important reference index that governments use to develop policy on national sustainable development (Barrett, Birch, Cherrett, & Wiedmann, 2005; Erb, 2004).

In 2008, the Global Footprint Network (GFN, 2008) published the latest ecological footprint statistics. Ecological footprint comprises six major categories: cropland footprint, grazing footprint, forest footprint, fishing grounds footprint, carbon footprint, and built-up land. The size of ecological footprint is in direct ratio to environmental impact, with bigger footprint being associated with bigger environmental impact; furthermore, footprint size is in inverse ratio to the land area available for productive biological use by each person, with a bigger footprint meaning less land area available for productive biological use for each person. Table 1 lists global ecological footprints published by GFN in 2009 (GFN, 2009a, 2009b).

Table 1 shows that in 1961, the global ecological footprint accounted for only 62% of the resources that the biosphere was capable of providing. Human demand surpassed the biocapacity of the

* Corresponding author. Tel.: +886 932 352 863.
E-mail addresses: bcwang2001@yahoo.com.tw (B.-C. Wang), vivichou1980@gmail.com (F.-Y. Chou), yungjaanlee@gmail.com (Y.-J. Lee).

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Table 1
Global ecological footprint. Unit: global hectare/person. *Source*: GFN, 2009a.

Item	Year										
	1961	1965	1970	1975	1980	1985	1990	1995	2000	2005	2006
Ecological footprint	2.29	2.43	2.60	2.61	2.63	2.45	2.51	2.41	2.47	2.58	2.59
Biocapacity	3.72	3.45	3.13	2.85	2.62	2.42	2.25	2.09	1.95	1.83	1.81
Ecological deficit	−1.43	−1.02	−0.53	−0.24	0.01	0.03	0.26	0.32	0.52	0.75	0.78

earth in the 1980s, and by 2006 the global ecological footprint exceeded global biocapacity by 1.43 times. That is, the ecological deficit has been increasing rapidly, creating tremendous ecological pressure. Mankind must confront this issue and act responsively to increase the sustainability of urban and rural development.

Calculating the changes in the time series analysis of the ecological footprint makes it possible to inspect whether economic development is becoming more sustainable. Regarding the changes in the time series analysis of ecological footprint, similar research results have been obtained internationally. Take the "Celtic Tiger", Ireland, for example, and its rapid economic development relative to the European Community. Between 1983 and 2001, the ecological footprint of Ireland grew 1.5 times, including a doubling in the energy sector (Lammers et al., 2008). By 2006, the ecological footprint of Ireland reached 8.19 global hectares per capita. While the average ecological footprint of an Austrian was only about 3.4 global hectares in 1926, it subsequently rapidly grew during the 1960s, before leveling off. By 1999 it had reached 4.1 global hectares (Erb, 2004; Haberl et al., 2001), while by 2006 it had reached 4.89 global hectares (GFN, 2009b). In Asia, the average ecological footprint of a Korean was just 1.00 global hectares in 1961 (Wackernagel, Monfreda, Erb, Haberl, & Schulz, 2004), but by 2006 had reached to 3.73 global hectares (GFN, 2009b).

The ecological footprint per person in Taiwan was 2.89 hectares in 1985. By 1990, this had grown rapidly to 4.05 ha, representing a growth rate of up to 140% (Yeh, Huang, & Lin, 1999). Notably, as of 1996, Taiwan's ecological footprint had reached 27.87 times the total area of Taiwan (Lee & Chen, 1998). However, these calculations do not consider the equivalence factor (GFN, 2008), and nor do they explore the relationship between ecological footprint and economic growth. To accumulate data bank on ecological footprint and focus on sustainable development, this study considers the equivalence factor and analyzes the relationship between achievement and environmental protection. This study eventually reveals the implication of ecological footprint for the urban and rural development of Taiwan, and also presents concrete suggestions of sustainable urban development strategies.

2. Ecological footprint

Ecological footprint is a strong and powerful index, capable of indicating the dynamic process of renewable resource use and including environmental pressures in the input (such as, renewable resource) and output (such as, waste materials, CO_2) aspects (Bagliani et al., 2008). The fundamental assumptions of ecological footprint accounting are: (1) The majority of the resources people consume and the wastes they generate can be quantified and tracked. (2) An important subset of these resources and waste flows can be measured in terms of the biologically productive area necessary to maintain flows. Resource and waste flows that cannot be measured are excluded from the assessment, leading to a systematic underestimate of humanity's true ecological footprint. (3) By weighting each area in proportion to its bioproductivity, different types of areas can be converted into the common unit of global hectares, hectares with world average bioproductivity. (4) Because a single global hectare represents a single use, and each global hectare in any given year represents the same amount of bioproductivity, they can be added up to obtain an aggregate indicator of ecological footprint or biocapacity. (5) Human demand, expressed as the ecological footprint, can be directly compared to nature's supply, biocapacity, when both are expressed in global hectares. (6) Area demanded can exceed area supplied if demand on an ecosystem exceeds that ecosystems regenerative capacity (Ewing, Reed, Galli, Kitzes, & Wackernagel, 2010, p. 3). Wackernagel et al. (2002, p. 9266) recognize that "reducing the complexity of humanity's impact on nature to appropriated biomass offers only a partial assessment of global sustainability. It is a necessary, but not sufficient, requirement that human demand does not exceed the globe's biological capacity as measured by our accounts."

Therefore, ecological footprint can measure international ecological dependence from the perspectives of consumers and producers (McDonald & Patterson, 2004). Although some studies question whether ecological footprint can serve as effective measures between environmental impact and economic achievement (such as, Fiala, 2008; van Kooten & Bulte, 2000), relevant investigations note that the value of ecological footprint lies in its being an objective measurement of sustainability, not only scientifically objective but also adjusting its calculation methods based on the results of continuous scientific examinations to more precisely identify the conditions of human resource use (Bagliani et al., 2008; Lammers et al., 2008; Renderiro Martín-Cejas & Pablo Pablo Ramírez Sánchez, 2010). The international ecological footprint monitor proposed by the World Wildlife Fund has become an important instrument for measuring sustainable development (Nie, Ji, & Yang, 2010).

2.1. Methods used to calculate ecological footprint

Wackernagel and Rees (1996) first proposed the idea of ecological footprints in relation to Vancouver, Canada. Wackernagel et al. (1999) began to study ecological footprint statistics on the national level. The above two studies on ecological footprints include six categories of land uses: ocean, forest, farmland, grazing land, built-up land and land used for fossil energy extraction. GFN adjusted the calculation of ecological footprint in 2008. According to the calculation of GFN in 2008, ecological footprint comprises the six main categories of farmland footprint, grazing land footprint, forest footprint, fishing grounds footprint, carbon footprint, and built-up land. Therefore the authors conduct ecological footprint calculation and analyses for Taiwan during 2004–2007 using the ecological footprint calculation methods recently published by GFN. Wackernagel and Rees (1996), Wackernagel et al. (1999) and GFN (2008) presented various methods for calculating ecological footprint, and these methods differ mainly in GFN replacing fossil energy land with carbon footprint. Each category of the methods used to calculate footprint is detailed as follows.

2.1.1. Calculating major and minor production footprint

"Major production" denotes the primary production of specified areas, including the grains, fruits, feed for domestic livestock and wood produced by farmland, grazing land, and by photosynthesis within forests; meanwhile fishery refers to seafood caught from