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Full Length Research Paper

Empirical research on constructing Taiwan's eco-environmental stress indicators system

Han-Shen Chen[1,2] and Tsuifang Hsieh[3,4]*

[1]School of Health Diet and Industry Management, Chung Shan Medical University, Taiwan.
[2]Department of Medical Management, Chung Shan Medical University Hospital, Taiwan.
[3]Department of Business Administration, National Dong Hwa University, Taiwan.
[4]Department of Hospitality Management, Taiwan Hospitality and Tourism College, Taiwan.

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In this paper, the material flow indicators and ecological footprint approach structured are adopted to construct eco-environmental stress indicators. We use relevant data to proceed with the empirical analyses on environmental stress and ecological impacts in Taiwan between the years of 1998 and 2007. Analysis of research results brings several important findings. (1) Taiwan's economic activities are highly dependent on imported materials, in which fossil fuel represents the largest percentage; and that increases in greenhouse gas emission are at almost a constant rate of economic growth. (2) The average growth in the ecological footprint of the Taiwanese people is a response to an increase in demand for energy land and grazing land, and a reflection of change in the consumer and industrial structure. (3) At 3.774, Taiwan's ecological overshoot indicator shows that its ecological system is in a state of overshoot. Therefore, if proper measures are not adopted in time, the current weak sustainability will lead into the vicious circle which departs from sustainable development.

Key words: Sustainable development (SD), eco-environmental stress indicators (ESI), environmental stress, environmental load.

INTRODUCTION

Over a long period of time, human beings have over exploited the natural environment, exceeding the natural system's load capacity so far that our established and balanced ecological foundation got damaged and destabilized pushing us into a vicious cycle that causes reduced resource production and degraded the environment's quality for sustaining natural healthy life. Since the Industrial Revolution, a large proportion of human beings have concentrated their efforts on economic growth and ignored the protection of the natural environment. This negligence causes exhaustion of resources and gradual deterioration of environmental quality. The greenhouse effect, acid rain, destruction of ozonosphere, the El Nino phenomenon and natural disasters have increased awareness of the dangerous threat resulting from natural counterattack. The international society thus began to realize its threat to the survival of humanity and its urgency. Therefore, how to measure economic developmental stress towards the eco-environment, how to reduce such stress, and how to coordinate with beneficial results in economic, ecology and the environment become important issues for studies of sustainable development.

Previous analyses have been made by directly aiming at the contents and features of every item of the sustainable development indicators and its statistical approach to the world's current sustainable development position. There are three major categories to consider. The first is the indicator system, which could be further classified into the Pressure-State-Response (PSR) indicator system, which was established by the Organization for Economic Cooperation and Development (OECD); and the Driving force-State-Response (DSR) indicator system, which was an amendment based on the thinking behind the PSR System and was presented by the United Nations Commission on Sustainable Development(UNCSD). The second is a single-item integrated indicators built

*Corresponding author. E-mail: thsieh@ms10.hinet.net. Tel: +886-935-658055. Fax: +886-3-8652000.

according to external costs calculated by environmental economic and accountancy.

Examples include Green GDP, the Indicators of Sustainable Economic Welfare (ISEW), genuine savings, the Genuine Progress Indicators (GPI) and National Wealth. The third is a concrete assessment indicators of biological physics. These include the concepts and methods of calculation of Wackernagel's Ecological Footprints (EF), Odum's Energy Analysis (EA) and Material Flows (MF) (Hardi and Barg, 1997; Neumayer, 2004; Chen et al., 2009). Most strive for sustainable development in factors including society, economics, ecology and the environment, but problems have been revealed through analysis of assessment indicators or measurement models:

(1) In order to express the contents of sustainable development, some assessment indicators or measurement models are over-complicated. Only a few dynamic indicators are able to show changes in sustainable development.
(2) Some of those assessment indicators or measurement models do not establish their own methods based on a comprehensive indicator system; therefore, there are quantified and operational difficulties.
(3) Because assessment indicators or measurement models are often difficult to acquire, they are difficult to apply in an actual model.

Seeing that traditional economics cannot give consideration to biophysical viewpoints when it applies currency value to the assessment of natural resources; therefore, the study uses the Material Flow and the Ecological Footprint Model in Ecological Economics to assess sustainable development in Taiwan. These two models use the biophysics perspective as the main system of measure: The Material Flow Model evaluates different kinds of resource utilization of the Material Flow, including direct utilization and indirect input (the hidden flow).

On the other hand, the Ecological Footprint Model uses land area as a transit basis for the carrying capacity of productivity and wastes and evaluates the necessary land area (resource amount) for the population in a specific region. The weight unit and the land area can be considered as the superficial characteristics of the amount of resource. As the perspective of obtainable difficulty and integrity of basic research integrity, the weight unit and the land area correlation statistical data are easier to collect. Moreover, using land area or weight unit as a weighting basis also makes it easier to understand the advantages of indicator information. However, the aforementioned models also have weaknesses: the Material Flow Model is based on weight, so it cannot show the quality difference of the impact from using different resources and emitting different kinds of waste; furthermore, the limited number of resources it evaluates hinders the applicability of its evaluation results.

The Ecological Footprint Model requires relatively more detailed information, such as resource productivity per unit land and the required types and area of land/water to support such productivity. Therefore, this study integrates indicators of the two models to construct eco-environmental stress indicators for Taiwan, and utilizes relevant data to conduct an empirical analysis on Taiwan's environmental stress and ecological impact situation between 1998 and 2007.

FOUNDATION OF THE THEORY

Material flow model

Material flow (MF) is based on the "material balance principle" and "industrial metabolism mechanism", and calculates the flow and quantity of substances within a certain area. It uses real objects as a measurement unit for quantified input and output, and analyzes the usage state of substances and material flow situation within a certain area, avoiding the problem of subjective price variance when assessing external cost in traditional Green GDP calculation, while showing true and specific economic development and environment usage situations. Therefore, it can be used as a basic tool for evaluating the environment's usage efficiency and resource distribution efficiency.

Wernick and Ausubel (1995) proposed a complete calculation structure for material flow balance in the U.S., dividing material flow into four steps: input, output, trade and extractive wastes. The metric ton is used as the unit for estimating the usage quantity of national energy, architecture mineral substances, industrial mineral substances, metallic mineral substances, forest products and agriculture products, and the recycling quantity of domestic supplies, air pollution, waste emission and dissipated substances. WRI in 1997 combined researchers from the U.S., Japan, Germany and Holland, used the calculation structure material flow balance in the U.S., and announced comparison results of cross-country material flow analysis. In addition, Eurostat, European Environmental Agency (EEA) and European Communities (EC) all researched the material flow model and analyzed material flow in the European Union's 15 members (European Communities, 2001). Indicators and basic relationships in MFA, relevant to this paper, are presented in Table 1.

Ecological footprint model

Ecological footprint model is proposed by a Canadian ecological economist Rees (1992) and becomes gradually complete after being improved by relevant researches (Wackernagel and Rees, 1996; Wackernagel

Table 1. Material flow foundation indicators and calculated relations.

Indicators		Accountancy principle	Indicators connection
Input	Direct material input (DMI)	DMI=domestic resource excavation+Import	DMI =DPO+NAS+export =DMO+NAS
	Total material requirement (TMR)	TMR=DMI+HF(or IF)	
	Domestic hidden flow (HF) or Foreign hidden flow (IF)	HF=IF=domestic hidden flow+foreign hidden flow (import)	
Output	Domestic processed output (DPO)	DPO=output+discard	
	Total domestic output (TDO)	TDO=DPO+domestic hidden flow	
	Direct material output (DMO)	DMO=DPO+export	
Consumption	Domestic material consumption (DMC)	DMC=DMI-export	
	Net additions to stocks (NAS)	NAS=DMI-DPO-export	NAS=DMC-DPO
	Physical trade balance (PTB)	PTB=import -export	

Source: European Communities (2001).

et al., 2004a; Wackernagel et al., 2004b; 2006). EF uses corresponding biological productive land to estimate the resource consumption and waste absorption area of a specific population or economy. Wackernagel and Rees (1996) believe that the size of ecological footprints is the direct proportion of environmental impact, the larger the ecological footprint the larger the environmental impact; the size of ecological footprints is the inverse proportion of biological productive land per person, the larger the ecological footprint the smaller the biological productive land per person.

The calculation of ecological footprints can measure the different types of biological productive land (and water) a specific population requires to support its energy and resource consumption and to absorb the waste it produces. If countries, regions and cities can monitor load capacity and ecological footprint each year and announce GDP at the same time, they will be able to understand economic trends and ecological changes, implementing nature conservation and sustainable development concepts into the society's overall operation and feedback mechanism, and further providing a judgment standard and action direction for the future of mankind.

Having advantages such as easy and comprehensive approach, lively expression and comparable outcome etc, ecological footprint can be adopted as an assessment indicator of sustainable development of ecology. At present, directions in the research of ecological footprint mainly consist of balance factors, rational adjustment of output factors (Erb, 2004; Venetoulis and Talberth, 2008), increase of syndrome count accounts (Jenerette and Larsen, 2006), computation of greenhouse emission (Lenzen et al., 2007; McGregor et al., 2008), calculation of ecological footprint of environmental pollution (Song et al., 2005; Bai et al., 2008), time sequence footprint model (Wackernagel et.al., 2004a ; Wackernagel et. al., 2004b; van Vuuren and Bouwman ,2005; Yue et al., 2006), footprint model combining context model (Senbel et al., 2003; van Vuuren and Bouwman., 2005), input-output footprint model (Bicknell et al., 1998; McGregor et al., 2008; Sánchez-Chóliz et al., 2006; Moran et al., 2008), life cycle footprint model (Monfreda et al., 2004), footprint model combining energy analysis (Zhao et al., 2005; Chen and Chen, 2007) and land interference footprint model (Lenzen and Murray, 2001; Lenzen et al., 2007) etc. The above models have promoted and developed the theories and calculation method of ecological footprint in different levels. However, the accuracy and completeness of the computation of ecological footprint still need further improvement. Many literatures have explored the theoretical hypotheses, basic concepts, calculating methods, empirical applications and deficiency improvements of ecological footprint model, so this paper will not go further on these topics here. (Nguyen and Yamamoto, 2007; Cuadra and Bjrklund, 2007; Chen and Chen, 2007; Li et al., 2008; Zhang and Zhang, 2007; Gu et al., 2007; Turner et al., 2007; Wiedmann and Manfred, 2007; Wiedmann and Manfred, 2007).

To sum up the subjects explored by the above researches, some are due to misunderstanding or high expectations of the nature of ecological footprint; others indicate where the ecological footprint indicators need to be improved. Calculation of ecological footprint itself is not a prediction model but what is used to assess the current status. Its designed function lies in providing ecological camera to photograph the utilization of nature by human beings (Rees, 1996). In terms of the world or a

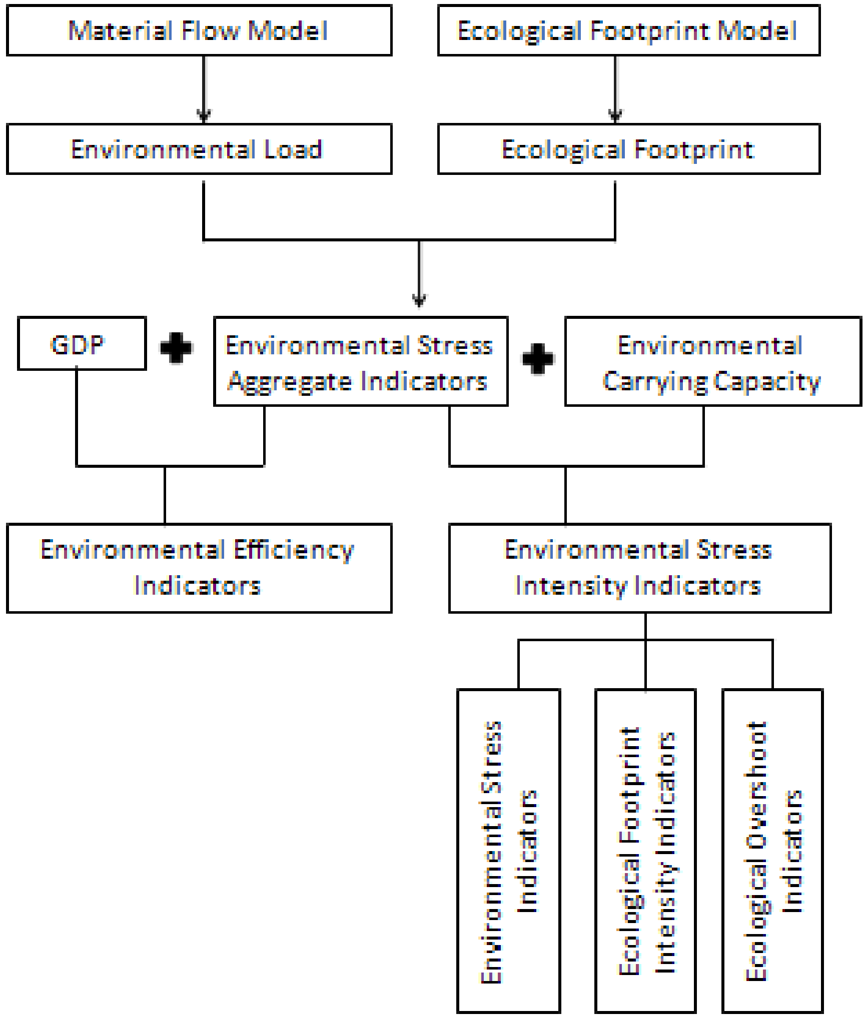

Figure 1. Research framework.

country, ecological footprint studies focus on comparing every country's consumption of ecological carrying capacity or analyzing the appropriation of ecological carrying capacity by trade; in terms of cities, ecological footprint is used to check the contrast to average national value or to assess sustainable strategies; in terms of household unit, calculation or simple questionnaire is used to investigate individual consumption, compare the impact of selection process and gradually increasing consumption items. Therefore, this study aims to find out the impact factors of Taiwan's sustainable development through empirical analysis of ecological footprint in Taiwan and based on this, to further provide a reference for working out the policies of Taiwan's sustainable development.

RESEARCH DESIGN

Research framework

This study will use the two models mentioned above to evaluate sustainable development for the environment in Taiwan, and analyze the issues reflected by their indicator value to construct a system of ecological environment stress indicators, the research structure is as shown in Figure 1. In which environmental load indicators and ecological footprint indicators comprise total environmental stress indicators; environmental stress intensity indicators, ecological footprint intensity indicators and ecological overshoot indicators comprise environmental stress intensity indicators. Environmental load indicators are absolute quantities constructed from material flow indicators to reflect the total environmental stress caused by a nation's social metabolism; environmental stress intensity indicators are the intensity of stress a nation's environment has to bear, which is the load per unit land, and a relative quantity compared with the environment's total land area; ecological footprint indicators indicate the ecological resource quantity required by a nation's production and consumption (mainly biological production and energy consumption), and measures the absolute quantity of environmental stress from another perspective; ecological footprint intensity indicators are similar to environmental stress intensity, it indicates the intensity of stress a nation's environment is under, and is a relative quantity compared with ecological footprints and land area with ecological carrying capacity; ecological overshoot indicators show the degree that a nation's environmental stress (ecological footprints) is exceeding its capacity (land area with carrying capacity). It can be told from the above that this study is an innovative expansion and combination of material flow calculation and ecological footprint methods and indicators.

Environmental stress aggregate indicators

Every material flow indicators in Table 1 refers to the measurement of environmental stress according to different aspects. In the input aspect, domestic material input (DMI) is about the stress that the direct material output of a country's economic system causes to the natural environment (mainly referring to resources). Total material requirement (TMR) is about the stress that the direct material output and indirect interruption (that is, excavation and arrangement of hidden flow) bring about in the environment. From the aspect of output, domestic processed output (DPO) and total domestic output (TDO) explain environmental stress that direct output and total output generate during ecological processes. The unit of the above-mentioned measurement is weight, whose function towards the environment is equal to the load force placed on a tested object in a mechanical experiment. This indicator is called the "Environmental Load."

The total environmental load (TEL) that a country's economic activities cause is defined as the total amount of direct and indirect material flow in input and output aspects. In Equation (1)

$$TEL=TMR+TDO=DMI+DPO+2\ HF+IF \quad (1)$$

where: TEL; total environmental load, TMR; total material requirement, TDO; total domestic output, DMI; domestic material input, DPO; domestic processed output, HF; hidden flow, IF; indirect flow.

Owing to foreign trade, TEL's receivers include the domestic environment and foreign environment which are marked as TEL_d and TEL_e respectively. TEL_e is the stress that the domestic economy causes to foreign environment and can be thus called as an environmental load output which is transferred from environmental stress resulting from trade.

$$TEL_d = TEL\text{-}IF\text{-}I = DMI + DOP + 2HF\text{-}I \quad (2)$$

$$TEL_e = IF + I \quad (3)$$

where: I; Imports.

Environmental stress intensity indicators

Not only does a country's environmental situation and possible transforming tendencies rely on the total amount of carried environmental stress, it also depends on the country's environmental carrying capacity. Therefore, a country's indicators of total environmental stress and carrying capacity needs to be considered and constructed in order to measure the intensity of carried stress in the environment. Such a measurement can reveal the situation of whether the country's environment can bear the environmental stress. This paper adopts a conception of mechanical stress and regards the carried environmental load of every unit land size of a country as "environmental stress." Environmental stress calculated by a country's land size is recorded as TES_g (total environmental stress). The formula is as follows:

$$TES_g = TEL_d/A_g = (DMI+DPO+2HF\text{-}I)/A_g \quad (4)$$

where: A_g is the total land area hectares of a country.

To calculate a country's actual environmental carrying capacity, it is suggested that land size of very low or zero carrying capacity (for example, desert) should be deducted. "Net ecological size" marked as A_n is used to calculate environmental stress as follows:

$$TES_n = TEL_d/A_n = (DMI+DPO+2HF\text{-}I)/A_n \quad (5)$$

Owing to differentiation of natural conditions, environmental carrying capacity differs between every country and type of land. We first need to transform every type of land (or water) size into a "standardized size." Environmental stress can be used to measure a country's burden of environmental stress. The ecological footprint approach is also an important measurement tool.

In the ecological footprint indicators calculation, all resources and energy consumption items can be categorized into six kinds of biological productive land types, such as cultivated land, grassland, forestry land, construction-use land, fossil energy land, and ocean (waters). To calculate results to compare the transformation of "equivalence factor," "yield indicators," and size of a specific population or district's ecological resources' ecological carrying capacity (EC) is measured. The global hectare is the "standard ecological size" with a unified measure unit marked as A_s.

$$A_s = \sum_{k=1}^{6} s_k \gamma_k \lambda_k \quad (6)$$

In the formula: A_s is a standard ecological size of a country's land. S_k is the country's physical size of the k-category land. γ_k is an equivalence factor of the k-category land; λ_k is a yield indicator of the k-category land. γ_k is equal to the ratio of average yield of global k-category land to that of land of the world's six categories and will not change with space (country), but will change with time. λ_k is equal to the ratio of averaged yield of a studied country's k-category land to that of the world's same-category land and changes with space (country) and time.

Ecological stress that a standard ecological size is used to calculate is marked as TES_s whose formula for calculation is as follows:

$$TES_s = TEL_d/A_s = (DMI+DPO+2HF\text{-}I)/A_s \quad (7)$$

From the above-mentioned calculated Formulas (4) (5) (7), it can be observed that TES_g, TES_n and TES_s can help construct a country's total carried environmental stress via the material flow indicators.

Ecological footprint intensity indicators and ecological overshoot indicators

The ecological footprint and environmental load belong to the total environmental stress indicators, but have different measurement units. Therefore, the ecological footprint of carrying unit size can measure the intensity of environmental stress. This paper defines the domestic footprint on a country's unit of environmental carrying capacity size as the country's Ecological Footprint Intensity Indicators (EFII). In Equation (8):

$$EFI = \frac{EF_d}{A_s} \quad (8)$$

The difference between a country's domestic footprint and environmental carrying capacity size (the former one minus the latter one) can be defined as domestic ecological deficit which is recorded as ED_d. If ED_d is greater than zero, it shows that a country's yield and consumption used in the domestic ecological resource is greater than a possessed ecological resource. This means that the "ecological overshoot" happens. ED_d is an overshoot amount. If one would like to measure ecological overshoot levels, one needs to calculate the domestic deficit in a unit of carrying capacity size. The domestic deficit is called the Ecological Overshoot Indicators (EOI) and is calculated as follows: in Equations (9) and (10):

$$ED_d = EF_d - A_s \quad (9)$$

$$EOI = \frac{ED_d}{A_s} = \frac{EF_d - A_s}{A_s} \quad (10)$$

While EOI is greater than zero, the higher it is, the more serious is the ecological overshoot level of a studied country. When the EOI is equal to zero, a studied country's environment is in an ecologically balanced situation. If EOI is less than zero, it shows that a studied country's environment is in an ecological profit state and EOI is the ecological surplus indicators. Between EFI and EOI is a fixed relationship:

$$EOI = EFI - 1 \quad (11)$$

Environmental (ecological) impact-resistance intensity of an economic system

The environmental load and ecological footprint are indicators measuring total environmental stress. To distinguish one from the other, this paper uses an efficiency indicator, in which the ecological footprint indicators are constructed, as the ecological efficiency of an economic system. Domestic environmental efficiency (EV_d) is GDP that yields units of TEL_d in a country's economic system. Domestic ecological efficiency (EE_d) is GDP that yields units of the ecological footprint (EF_d) in a country's economic system, and is calculated by:

$$EV_d = GDP/TEL_d \quad (12)$$

$$EE_d = GDP/EF_d \quad (13)$$

EMPIRICAL ANALYSIS

Material flow indicators analysis

This study applies the Material Flow Indicators Project of the European Union and its computing mode (Table 2) to evaluate the condition of Material Flow in Taiwan during 1998 to 2007. From the result, the trend of direct material input (DMI) in Taiwan, especially the demand for structural materials, is comparatively unstable and dependent on imports.

Pollution emissions are the major material output because of large and increasing greenhouse gas emissions which have caused annual growth in the domestic process output (DOP). DMC and NAS (net additions to stocks), material consumption and inventory formality are unstable as well. In addition, the physical trade balance (PTB) indicates that supply exceeds demand and that there is an occasional shortage of building materials. The result of the 2007 Material Flow indicator in Taiwan was that DMI was 4.27 hundred million/metric ton, DPO was 3.55 million/metric ton, DMC was 4.09 million/metric ton, NAS was 0.54 million/metric ton and PTB was 2.06 million/metric ton.

Ecological footprint indicators analysis

This study applies the Ecological Footprints measurement structure to compared the ecological footprints and ecological carrying capability during 1998 to 2007 in Taiwan, as shown in Table 3. The 2007 per capita Ecological Demand footprint in Taiwan is 8.0252 hm^2, making the Ecological Deficit per capita 6.3441 hm^2. The figures reflect that productivity and life intensity of residents have exceeded the carrying capacity of Taiwan's ecological economic system. The regional ecological economic system is under the pressure of over development, whereas the 1:477 ratio of ecological supply and demand shows how serious the conflict is between supply and demand. In order to maintain the entire system's balanced development, we must input large quantities of energy and materials from other regions or consume natural resources to satisfy the current level of production and living requirements within our region. In addition, the occupation of ecological footprints per 10000 NT dollar GDP may express the utilization benefit of economic development to land resources. More occupation of ecological footprints per 10000 NT dollar GDP means lower utilization benefit of its resources, and the occupation of ecological footprints per 10000 NT dollar GDP in Taiwan is decreasing because of economic development and technical advances, as well as importance of resource utilization benefits.

Empirical analysis of eco-environmental stress indicators

Environmental stress aggregate indicators analysis

Results from applying the above mentioned material flow indicators to the calculation of Taiwan's total environmental load (TEL), domestic environmental load (TEL_d) and environmental load output (TEL_e) between 1998 and 2007 are as shown in Table 4. During this period, the total environmental load cause by Taiwan's economic development was roughly 1278 to 1988×10^8 tons and the domestic environment load was roughly 544-918 to 10^8 tons. Domestic environmental load grew about 4.3% in the duration of this study, two stages can be observed in its changes: Taiwan's environmental load during 1998 until 2001 had a decreasing trend, whereas that after 2001, it stably increased. The scale of materials of social metabolism is a crucial reason for environmental load and is also a function of a country's economic scale and economic systematic environmental efficiency. Owing to a slackening of global economic prosperity as well as the Asian financial storm and Taiwan's political upheaval during 1998 and 2001, where economic growth was very slow. GDP fell from 6.30% in 1996 to 4.55% in 1998 and minus 2.17% in 2001. Such slow and impeded economic growth could possibly be the reason why environmental load decreased. At the end of 2001, the global economy gradually improved – GDP going up from minus 2.17% in 2001 to 5.70% in 2007. This situation made for a gradual increase of environmental load.

In addition, waste emission is directly related to direct material input. This study defines the ratio of domestic processed output and direct material input as the economic system's domestic production emission coefficient. Taiwan's domestic production emission coefficient from 1998 to 2007 was between 0.55 and 0.84 and averaging at 0.72. This means that 0.72 tons of waste is produced whenever an extra ton of resources is used. Results show that the domestic production emission coefficient is increasing year by year, which means that more and more waste is being produced from the use of a single ton of resources; waste is becoming a heavier burden to the environment.

Environmental stress indicators analysis

The above-mentioned domestic total environmental load, TEL_d,

Table 2. Material flow in Taiwan during 1998 to 2007.

Indicators		1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Input	DMI	440.42	426.63	402.67	352.25	390.46	397.21	417.26	382.42	400.46	427.03
	IF	536.69	583.95	619.98	573.87	657.83	696.90	723.11	752.86	796.38	845.79
	HF	93.97	92.96	81.54	41.97	83.59	103.79	128.46	142.85	158.63	180.31
	TMR	1,071.07	1,103.54	1,104.18	968.09	1,131.88	1,197.91	1268.83	1278.13	1355.47	1453.13
Output	DPO	241.99	241.55	257.50	268.39	268.45	294.10	304.97	315.08	336.84	355.26
	DMO	255.01	256.95	273.63	288.08	292.00	322.47	333.09	346.21	357.73	373.41
	TDO	335.95	334.51	339.04	310.36	352.03	397.89	433.43	457.93	495.47	535.57
Consumption	NAS	185.41	168.67	129.04	64.17	98.45	74.75	84.17	36.21	42.73	53.62
	DMC	427.40	411.22	386.54	332.56	366.90	368.84	389.14	351.29	379.57	408.88
	PTB	131.56	136.45	147.20	140.58	152.72	160.75	190.19	194.80	198.43	205.85

* Unit: million tons.

Table 3. Comparison between per capita ecological footprint, per capita ecological carrying capacity and ecological footprints per 10,000 NT Dollar GDP in Taiwan.

Year	Ecological footprint EF(10^6hm^2)	Ecological carrying capacity EC(10^6hm^2)	Ecological deficit ED(10^6hm^2)	Per capita ecological footprints (hm^2/person)	Ecological carrying capacity per capita (hm^2/person)	Ecological deficit per capita (hm^2/person)	Ecological footprints per 10000 NT dollar GDP (hm^2/thousand dollar GDP)
1998	83.1144	35.7124	47.4020	3.7903	1.6218	2.1685	3.983
1999	85.8398	36.3126	49.5272	3.8856	1.6426	2.2430	3.884
2000	89.0612	36.9216	52.1396	3.9981	1.6537	2.3444	3.856
2001	91.2005	37.5214	53.6791	4.0705	1.6732	2.3973	3.801
2002	94.3450	37.9727	56.3723	4.1892	1.6861	2.5031	3.783
2003	96.8209	38.0849	58.6535	4.2585	1.6848	2.5737	3.647
2004	117.7877	38.1674	79.6203	5.1914	1.6822	3.5092	3.601
2005	148.8976	38.3059	110.5917	6.5392	1.6823	4.8569	3.597
2006	162.6354	38.4197	124.2157	7.1093	1.6794	5.4299	3.564
2007	184.2446	38.5945	145.6501	8.0252	1.6811	6.3441	3.497

ecological carrying capacity size, EC (that is, standard ecological size, A_s) a country's land size, A_g, and net ecological size, A_n, are used to calculate Taiwan's environmental stress, TES_s, TES_g and TES_n, between 1998 and 2007. The results are shown in Table 5. We can observe two stages of Taiwan's environment stress during the period of this research: the downward trend from 1998 to 2001 and the stable increase after 2001. The characteristic of this change is consistent with environ-mental load, but with different margins. Furthermore, from the calculation results we know that environmental stress grew synchronously with GPD, meaning that increase in GDP is

Table 4. Taiwan's environmental load during 1998 until 2007.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Direct material input (DMI)	440.42	426.63	402.67	352.25	390.46	397.21	417.26	382.42	400.46	427.03
Domestic processed output (DPO)	241.99	241.55	257.50	268.39	268.45	294.10	304.97	315.08	336.84	355.26
Production emission coefficient DPO/ DMI	0.549	0.566	0.639	0.762	0.688	0.740	0.731	0.824	0.841	0.832
Hidden flow (HF)	93.97	92.96	81.54	41.97	83.59	103.79	128.46	142.85	158.63	180.31
Import (I)	144.57	151.85	163.33	160.27	176.28	189.12	218.31	225.93	219.32	224
Foreign hidden flow (IF)	536.69	583.95	619.98	573.87	657.83	696.90	723.11	752.86	796.38	845.79
Total environmental load (TEL)	1407.04	1438.05	1443.23	1278.45	1483.92	1595.79	1702.26	1736.06	1850.94	1988.7
Domestic environmental load (TEL_d)	725.78	702.25	659.92	544.31	649.81	709.77	760.84	757.27	835.24	918.91
Environmental load output(TEL_e)	681.26	735.80	783.31	734.14	834.11	886.02	941.42	978.79	1015.7	1069.79

* Unit: million tons.

Table 5. Taiwan's environmental stress during 1998 until 2007.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
TES_g	20.03	19.37	18.17	14.99	17.81	19.46	21.6	21.38	23.05	25.36
TES_n	36.49	34.83	32.17	25.76	29.77	31.84	34.36	32.71	34.29	35.54
TES_s	20.29	19.3	17.82	14.46	16.97	18.49	20.48	20.19	21.43	21.97

bound to result in the growth of TES_g, TES_e and TES_s.

Ecological footprint intensity indicators and ecological overshoot indicators analysis

The results calculated in Taiwan's ecological footprint intensity (EFI) indicators between 1998 and 2007 are shown in Table 6. During these eight years, EFI indicators were between 2.327 and 4.774. After 2002, EFI indicators increased slowly within a slight undulation of periodicity: EFI indicators increased from 2.48 of 2002 to 4.774 of 2007. After 2002, benefiting from the global economic recovery, Taiwan's economy returned to its prior growth and caused energy footprint to rise again. Especially from 2004 to 2007, flourishing emerging markets and growth in raw material demand and prices also drove a substantial increase in Taiwan's energy intensity.

The threshold from the ecological footprint intensity (EFI) indicators and ecological overshoot indicators (EOI) were 1.0 and 0.0 respectively. If EFI is greater than one (EOI is more than zero), a studied country's domestic environmental carrying stress (that is, its domestic ecological footprint EF_d) outweighs its possessed carryingcapacity (standard ecological size). This means the situation is in an ecological overshoot state. From this calculated result, it is clear that Taiwan's ecological overshoot is getting more and more serious. In 2007, EFII and EOI were 4.774 and 3.774 respectively – the result implying that a piece of land of 3.774 hectares is enough to supply ecological services (offering resources and absorbing discharged wasted materials), although only a land of every hectare is used. If a country's ecological environment stays in an overshoot state for a long period, ecological degeneration and deterioration will happen. In recent years, the greenhouse effect has brought about peculiar global climate change issues such as the expansion of deserts, increasing erosion of land, forests' destruction and development moving towards polar areas, serious drought and flood disasters. Although there are very complex reasons causing these ecological and environmental changes, one thing for sure is that if the eco-environmental system's remains in a serious overshoot state too long, this will cause serious future issues.

Taiwan's ecological environmental efficiency

Combining Taiwan environment load (TEL_d) and ecological footprint (EF_d), which was calculated above, with GDP will bring us to the environmental efficiency (EV_d) and ecological efficiency (EE_d) of Taiwan between 1998 and 2007, as shown in Table 7. Taiwan's domestic environmental efficiency from 1998 until 2007, which is the domestic total yield in units of domestic environmental load, is shown in Table 7. Using Taiwan New Dollars (1US$=NT$33.25) to represent domestic environmental efficiency, it should have been between 12418.36 and 18118.35 $NT \cdot t^{-1}$. That is, every time, a yield value between NT 12418.36 and 18118.35 was made, domestic environmental load of 1 ton would be generated. Domestic environmental load and GDP in this period grew at almost the same speed; domestic environmental efficiency between 1998 and 2001

Table 6. Taiwan's ecological footprint indicators during1998 until 2007.

Year	Ecological footprint intensity indicators	Energy intensity	Cultivatable land intensity	Pasture land intensity	Forest intensity	Architectural lands intensity	Marine area intensity
1998	2.327	1.366	0.319	0.303	0.027	0.035	0.277
1999	2.364	1.416	0.304	0.303	0.027	0.035	0.279
2000	2.412	1.488	0.289	0.306	0.026	0.035	0.267
2001	2.431	1.534	0.272	0.303	0.025	0.036	0.260
2002	2.485	1.605	0.263	0.300	0.025	0.037	0.255
2003	2.542	1.651	0.256	0.300	0.026	0.037	0.272
2004	3.086	2.247	0.246	0.301	0.025	0.037	0.229
2005	3.887	3.043	0.244	0.302	0.022	0.037	0.239
2006	4.233	3.391	0.240	0.302	0.021	0.038	0.241
2007	4.774	3.925	0.239	0.303	0.020	0.038	0.249

Table 7. Taiwan's environmental and ecological efficiency during 1998 until 2007.

Year	GDP/10^9NT	Environmental load $TEL_d/10^9t$	Environmental efficiency NT ˙t^{-1}	Ecological footprint $EF_d/10^9hm^2$	Ecological efficiency /NT$˙$hm^{-2}$
1998	9013	0.72578	12418.36	0.0831146	108441.42
1999	9531	0.70225	13572.09	0.0858398	111032.41
2000	10081	0.65992	15276.09	0.0890612	113191.83
2001	9862	0.54431	18118.35	0.0912005	108135.37
2002	10281	0.64981	15821.55	0.0943450	108972.39
2003	10634	0.70977	14982.32	0.0968209	109831.66
2004	11279	0.76084	14824.40	0.1177877	95757.03
2005	11734	0.75727	15495.13	0.1488976	78805.84
2006	11918	0.70082	14268.95	0.1567854	73280.48
2007	12636	0.72721	13751.07	0.1687658	68582.74

rose, went down between 2001 and 2007. Decreasing domestic environmental efficiency means that the unit economic yielded load amount affecting the domestic environment was increasing. As a result, total amount of domestic environmental load was not decreasing with the increase of total economic amount.

Taiwan's domestic ecological efficiency between 1998 and 2007 is shown in Table 7. Using Taiwan New Dollars to represent domestic ecological efficiency, it should have been between 68582.74 and 113191.83 NT•hm^{-2}. That is, every time that the domestic footprint of one global hectare was generated, a domestic total yield amount of NT$68582.74 to 113191.83 could be made. Ecological efficiency fell from 108441.42 NT•hm^{-2} in 1998 to 68582.74 NT•hm-^{2} in 2007. Decreasing domestic ecological efficiency means that the unit of Taiwan's economic yield's stress towards domestic ecology in the past ten years was gradually increasing. In proportion, the domestic ecological footprint was not decreasing with the increase of total economic volume.

RESULTS DISCUSSION AND CONCLUSION

According to the results:

(1) From the result of material flow analysis, Taiwan's economic activities are highly dependent on imported materials, in which fossil fuel represents the largest percentage; that Taiwan's economic development (GDP) and resource demand (DMI) are highly correlated; and that increases in greenhouse gas emission are at almost a constant rate of economic growth. Therefore, the correlation of imported energy and economic development and the relationship between imported materials and greenhouse gas emission are topics that would benefit from further discussion. In addition, even though the growth of resource demand matches economic growth, emissions of traditional pollutants became "unhooked" with economic growth, with solid waste being the most significant. For future development of technologies for preventing environmental pollution, Taiwan should put more effort into reducing greenhouse gas emissions.

(2) From the result of ecological footprint analysis, using the "ecological benchmark" of 1.7 hectares per person as a standard, the "ecological deficit" per person in Taiwan reaches 6.3441 hectares; in other words, Taiwan's ecological capacity is already very low, which means it has extremely insufficient natural capital, and heavily relies on the import of foreign ecological capacity to support its current ecological footprint, not only using the ecological resources of other countries, but also of the next generation. Moreover, the apparent growth trend of

ecological footprint requirement shows that the ecological space occupied by social and economic development has severely exceeded the ecological service capacity of the region itself. Therefore, we must use the circular economy economic growth model, conserve resources and energy, and implement sustainable development strategies.

(3)From the result of ecological eco-environmental stress indicators analysis, Taiwan's environmental carrying capacity load reaches over 100,000,000,000 tons every year. In 2007, its ecological footprint intensity indicators was 4.774; and its ecological overshoot indicators was 3.774. This demonstrates that Taiwan's ecological system stays in an overshoot state. Taiwan's domestic environmental efficiency and domestic ecological efficiency in the studied period shows both experiencing an obvious decrease. In other words, the exhausted resource amount and the generated environmental stress resulted from the units of economic yield are increasing – a situation which demonstrates that total amount of both resource use and environmental stress still stays in a developmental stage.

(4) In this paper, a discussion about the eco-environmental stress indicators is related to a country's environment as a studied subject. An angle of the environment is used to measure the impact-resistance of the social-economic system on the eco-environmental system. Aspects of social-economic system input and output are considered. Resource exhaustion, environmental population, recycled resources, non-recycled resources, environmental stress, and environmental carrying capacity are fully considered. Also, the total amount of environmental stress and environmental stress intensity are measured. New indicators systems and calculation approaches are applicable, combining and extending material flow assessment and the ecological footprint approach.

Assessment of these indicators shows that growth in economic activities causes increased pollutants and demand on land development and recycled resources. However, the current controls over pollution levels and the self-purification ability of the environment itself cannot bear the current quantity of pollution emissions and cannot ensure environmental quality. For the benefit of sustainable development, we propose several policy suggestions:

(1) Increase improvements in industrial efficiency.
(2) Improve prevention technologies.
(3) Implement the concept of "total quantity control".
(4) Implement reasonable land planning and total quantity control over development to reduce damage to ecology, reduce over-capacity use of resources, and benefit sustainable development.

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