Article

Empirical applications of an environmental stress indicator and the environmental efficiency revolution in Taiwan

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Abstract
In this essay, the first aim is to apply the structure of material flow analysis (MFA) and ecological footprint model to construct an environmental stress indicator. Secondly, an impact, population, affluence and technology (IPAT) analysis is used to resolve indicators related to MFA and resource yield productivity. The research indicates following results: (1) The 2007 per capita ecological deficit in Taiwan is 6.3441hm^2.The figures reflect that productivity and life intensity of residents have exceeded the carrying capacity of Taiwan's ecological economic system. (2) Wealth becomes the most important factor in material needs and pollution discharge. (3) Environmental efficiency and ecological efficiency slowed down dramatically, demonstrating that use of resources and total amount of environmental stress stay at a developmental stage. Therefore, if proper measures are not adopted, the current weak sustainability will lead into the vicious circle which departs from sustainable development.

Keywords material flow; ecological footprint; impact, population, affluence and technology analysis (IPAT).

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1 Introduction

Since the Industrial Revolution, human beings have concentrated on economic growth and ignored protection of the natural environment. This negligence causes exhaustion of resources and gradual deterioration of environmental quality. Greenhouse effect, acid rain, destruction of ozonosphere, the El Nino phenomenon and natural disasters have made people sense the dangerous threat resulting from natural counterattack. The international society thus began to realize its threat to the survival of humanity and its urgency. Since the idea of "Sustainable Development" was revealed by the World Commission on Environment and Development (WCED) in 1987, the issue of sustainable development (SD) has been a principle of Development Strategy in every country. In sustainable development, international communities develop sustainable development assessment models or indicators successively in order to obtain an authentic and effective analysis of ecoenvironment and natural resource depreciation conditions, as well as to modify human economic activities to achieve management objectives though indicator assessment. As a whole, sustainable developmental assessment indices or measurement types that have been developed all have their individual features. The most important factors for sustainable development include; society, economics, ecology and the environment **(**Chen et al., 2009).

Seeing that traditional economics can't give consideration to biophysical viewpoints when it applies currency value to the assessment of natural resources; therefore, this study uses material flow analysis and the ecological footprint model in ecological economics to assess sustainable development in Taiwan. These two models use a 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 u0nit 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. Therefore, further correlation of the two models may be applied to construct an environmental stress indicator and relevant data is used to provide an empirical analysis of Taiwan's environmental stress between 1998 and 2007. Secondly, the IPAT approach is used to explore the relationship between material flow and resource productivity indicators; some wider related issues are also discussed.

2 Foundation of the Theory

2.1 Material flow

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. 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. The World Resources Institute (WRI) in 1997 convened 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. Indicators and basic relationships in MFA, relevant to this essay, are presented in Table 1.

2.2 Ecological footprint

Ecological footprint (EF) model is proposed by a Canadian ecological economist William Rees (1992). 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 EF is in direct proportion to environmental impact, the larger the EF the larger the environmental impact; the size of EF is the inverse proportion of biological productive land per person, the larger the EF the smaller the biological productive land per person. The calculation of EF 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 EF 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 provide a judgment standard and action direction for the future of humankind. 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; Zhang and Zhang, 2007; Gu et al, 2007; Turner et al, 2007; Wiedmann et al, 2007; Wiedmann and Manfred, 2007).

In conclusion, the material flow model directly and indirectly measures resources used and discharged wastes in economic activities by physical unit as the method to observe and estimate the impact of human activities on environment. One of the major features of the model is to indirectly calculate natural resources used in addition to calculating the resource flow used in economic activities (WRI, 1997). The estimation method of physical flow provides the physical perspective that is not noted by those assessment indicators, which are based on pure monetary units and mere logistics that enter into market and economic activity system. It can not only avoid the problem of subjective price difference that will occur when assessing external costs by calculating green GDP, but also truly and concretely present the condition of economic development and environmental application in completeness. Therefore, such estimation model can be adopted as a fundamental computing tool of assessing environmental application and allocation efficiency of resource materials. The feature of ecological footprint is it takes capacity as the theoretical basis, hypothesizes that every energy, material consumption and wastes output needs the productivity or absorption capacity embodied by a certain specific land or water to convert the consumption behavior and the wastes produced by regional population into area of land consumed by each person, so that sustainable development can be assessed. Ecological footprint proposes another thinking perspective to view environmental problems. It emphasizes ecophysical analysis, considers the development and expansion of economic entity are all limited by the volume of ecological capacity; meanwhile, the material and energy consumption required by human being must consider about the restraints that ecological system itself can provide (Wackernagel, 1999).

However, the above model has its defects: material flow model is based on unit of weight, impossible to show the quality differences among impacts of different resource applications and wastes discharges; secondly, the items included in assessing resources are limited and the adaptability to results of assessment will be also reduced. Ecological footprint model needs more detailed relevant data, for example, unit area of land resource productivity and the corresponding land/water body type and area data required. Therefore, this study can further integrate relevant indicators of the two models on the level of application, by analyzing the problems reflected by every indicator value to learn about the dependency and impact between the economic system of human activities and the natural environment, so as to build the environmental stress indicator in Taiwan.

3 Research Design

3.1 Research framework and data source

This study used 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 Fig. 1. The study was performed according to the direct access indicator data from the annual statistics publication of the public sector, evaluations such as those of "Energy balances in Taiwan", "Basic agricultural statistics", "The Statistical Yearbook of Construction and Planning of Taiwan and Fuchien Area", "Yearbook of Environmental Protection Statistics", "Establishment and Renewal of the Greenhouse Gas Inventory", also the websites on "statistics of the Bureau of Mines", "the Customs statistics database", and agricultural related websites to analyze the comprehensive information of material flow and ecological footprints in Taiwan. Moreover, data references of social indicators, such as population and Gross Domestic Product, are from "Statistical Yearbook of the Interior of the Republic of China" and "National Statistics Office ROC," established by the Department of Accounting and Statistics.

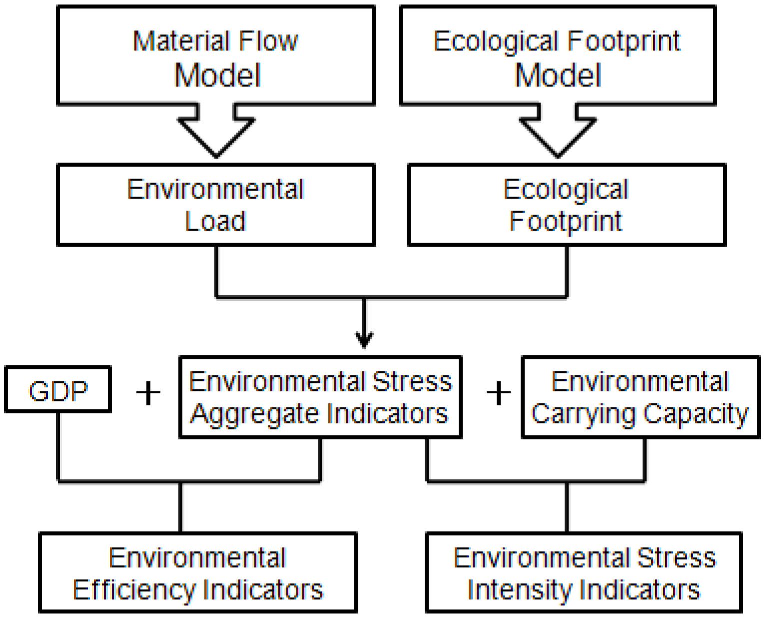

Fig. 1 Research framework.

3.2 Environmental stress indicator (ESI)

Not only does a country's environmental situation and possible transforming tendencies rely on the total amount of carried environmental stress, but they are also brought about by the country's carrying capacity in the environment. Therefore, a country's indicator of total environmental stress and carrying capacity needs to be considered and constructed to measure the intensity of carried stress in the environment. Such measurement can reveal the situation that the country's environment can bear the stress. Every material flow indicator 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 environment is equal to load force placed on a tested object in mechanics experiment. So such an indicator is called the "environmental load".

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

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

where Total Environmental Load (TEL); Total Material Requirement (TMR); Total Domestic Output (TDO); Domestic Material Input (DMI); Domestic Processed Output (DPO); Hidden Flow (HF); Indirect Flow (IF)

Owing to foreign trade, total environmental load (TEL) with respect to 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. The formula is as follows (2) (3):

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

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

where Imports (I).

Table 1 Material flow foundation index of the European Union and calculated relationships.

Index Categories	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)	
	Total Material Input (TMI)	TMI=DMI + domestic hidden flow	TMI=TMO+NAS
	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	
Consum-ption	Direct Material Output (DMO)	DMO = DPO + export	
	Total Material Output (TMO)	TMO = TDO + export	
	Domestic Material Consumption (DMC)	DMC = DMI－export	
	Total Material Consumption (TMC)	TMC = TMR－export－foreign hidden flow (export)	
	Net Additions to Stocks (NAS)	NAS = DMI－DPO－export	NAS = DMC－DPO
	Physical Trade Balance (PTB)	PTB = import－export	

Source: European Communities (2001)

3.3 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 essay 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 follow (4):

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

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

To get close to 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.

$TES_n=TEL_d/A_n=(DMI+DPO+2HF-I)/A_n$ (5)

Owing to differentiation of natural conditions, environmental carrying capacity very much differs in every country and type of land. If we can transform every type of land (or water) size into “standardized size” with some kind of same capacity according to some standard, using the size to calculate environmental stress can truly measure a country’s burden of environmental stress. The ecological footprint approach supplies an important measurement tool here.

In ecological footprint indicator calculation, all resources and energy consumption items can be categorized into six kinds of biological productive land types as follows – cultivated land, grass land, forestry land, construction-use land, fossil energy land, and ocean (waters). To make calculated results comparable with each other, during calculation, through transformation of “equivalence factor” and “yield indicator,” the size of a specific population or district’s ecological resources’ ecological carrying capacity (EC) is measured. Global hectare is “standard ecological size” with a unified measure unit which is marked as As.

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

In the formula: A_s is a standard ecological size of a country land which is studied; 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 averaged yield of the 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 will change 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.

$TES_s=TEL_d/A_s=(DMI+DPO+2HF-I)/A_s$ (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 in Table 1.

3.4 Environmental (ecological) efficiency

Environmental efficiency is generally defined as the economic output that can be obtained by producing unit environmental stress. Environmental load and ecological footprint are indicators measuring total environmental stress. To distinguish one from the other, this essay uses Domestic environmental efficiency (EV_d) is GDP that yields units of TEL_d in a country’s economic system, obtained as follows. Domestic ecological efficiency (EE_d) is GDP that yields units of ecological footprint (EF_d) in a country’s economic system, obtained as follows. The reciprocal of the above environmental efficiencies represents the stress on the environment that the economic system’s economic yield unit makes. It is called the environmental impact-resistance intensity of an economic system. In addition, material intensity of use is an indicator of measuring materialization; its purpose and environmental efficiency is similar to the concept of ‘producing the most service and output from the least input.’ Therefore, this study uses material intensity of use or productivity to measure material use efficiency. The smaller the material intensity of use and the bigger the productivity, the greater the efficiency of material use. Therefore, material intensity of use is a reciprocal of material use. These related indices are shown in Table 2.

$EV_d=GDP/TEL_d$ (8)

$EE_d=GDP/EF_d$ (9)

Table 2 Indexes measuring matters related to resource productivity.

Category	Item	Explanation for Index
Indicators for Intensity of use	Material input per unit service (MIPS)	Required input material (including energy) in every unit service or utility is one of indexes of well-used resources.
	Surface coverage per unit service(FIPS)	Required land surface size in every unit service or utility is to measure intensity of use of land resource.
	Energy intensity (EI)	Required input energy material in every unit service or utility.
	Eco-toxic exposure equivalent per unit service(TOPS)	Eco-toxic exposure equivalent per unit service in every unit service or utility.
Productivity Indicator	Resource productivity(SMI)	Service or utility that every unit input material (including energy) can create directly represents resource productivity and is a reciprocal of MIPS.
	Land productivity (SFI)	Service or utility that every unit input land surface size can create is a reciprocal of index of surface coverage per unit service (FIPS).
	Energy productivity (EP)	Service of utility that every unit input energy can create is a reciprocal of energy intensity index.

Source: “Environmental Indexes” in the website of Bureau of Energy, Ministry of Economic Affairs. R.O.C (2008)

4 Empirical Analysis

4.1 Material flow indicators analysis

This study applies the Material Flow Indicators Project of the European Union and its computing mode (shown in Table 1) to evaluate the condition of Material Flow in Taiwan during 1998~2007. From the result (shown as in Table 3), 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). Domestic Material Consumption (DMC) and Net Additions to Stocks (NAS), 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.

Table 3 Material Flow in Taiwan during 1998~2007.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
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
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
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 4 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 10,000 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

4.2 Ecological footprint indicators analysis

This study applies the Ecological Footprints measurement structure compared the ecological footprints and ecological carrying capability during 1998~2007 in Taiwan, as shown in Table 4. 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 ratio of ecological supply and demand is 1:4.77. Table 4 shows 4.77 ecological spaces are needed to maintain the economic sustainable development in Taiwan with the current economic development model and consumption standard. In other words, the ecological carrying capacity in Taiwan is quite low because of lack of natural resources. Importing most ecological carrying capacity input to support the current ecological footprints in Taiwan not only appropriates the ecological footprint from other countries but also the natural capital from the next generation. 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.

4.3 Empirical analysis of eco-environmental stress indicators

4.3.1 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 5. During this period, the total environmental load cause by Taiwan’s economic development was roughly 1278~1988×10^8 tons and the domestic environment load was roughly 544~918×10^8 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 crisis 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.

Table 5 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 6 Taiwan's environmental stress during 1998 until 2007.

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

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.

4.3.2 Environmental stress indicators analysis

The above-mentioned domestic total environmental load, TEL_d, 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 Table6. 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 environmental 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 bound to result in the growth of TES_g, TES_n and TES_s.

4.4 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$30) to represent domestic environmental efficiency, it should have been between 12418.36 and 18118.35 NT•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 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$68582.74~113191.83 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.

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

Year	GDP /10^9NT	Environmental load $TEL_d/10^9$t	Environmental efficiency NT $\cdot t^{-1}$	Ecological footprint $EF_d/10^9 hm^2$	Ecological efficiency /NT$ $\cdot hm^{-2}$
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

4.5 Exploration of material use and material productivity

Indices for intensity of use adopted in this study include MIPS, Fast Iterative Patterson Squaring (FIPS), EI and TOPS. The numerator, according to different measurements of material, can be different indices. In the MIPS index, DMI and DMC indices can be put in the numerator. FIPS and EI can be put in Taiwan's land size and energy material input amount, respectively. TOPS is originally used to consider the impact of the toxic nature of material and it is replaced here by the DPO index. The replacement indicates the discharge intensity of pollutants. The result is shown in Table 8. As a whole, MIPS shows that variations in domestic material intensity of use are not dramatic: The annual change is between 0.98 and 1.70 kg/US$, which is close to the MIPS value which DMI and DMC are used to calculate. The decreasing trend of FIPS every year indicates that the intensity of land resource use is gradually increasing. That the annual EI value stays in a growing trend means that the intensity of energy material use decreases slightly. Therefore, the degree of dematerialization of domestic land resource only is higher, whereas that of dematerialization in general does not show a notable trend. TOPS shows an annual growing trend. It can be observed that the intensity of domestic discharged pollutants is increasing gradually every year. Calculation approaches of the productivity index include SMI, SFI and EP. The result, shown in Table 8, is that only land productivity has an obvious growing trend, while annual increases in GDP and energy productivity went down. The general material productivity remained around 0.71 to 1.05 US$/kg, a value which does not show any obvious variation. In addition, there is a certain trend towards a degree of dematerialization. Resource productivity does not have any dramatic improvement. The possible reason could be that displays of DMI and DMC indicators are the result of total input of material with every category and there are fixed rules for input amount of material with every category each year. With regard to energy material, annual input amount continues increasing and is, most of the time, imported from foreign countries. Despite annual GDP enjoying obvious growth, the growth range is not as quick as growth in energy material. Therefore, energy material productivity appears to be on a decreasing trend.

Table 8 Material use and material productivity during 1998 until 2007.

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
MIPS-DMI	1.41	1.30	1.16	1.04	1.11	1.09	1.58	1.61	1.64	1.70
MIPS-DMC	1.37	1.25	1.11	0.98	1.04	1.01	1.49	1.52	1.55	1.61
FIPS	0.12	0.11	0.10	0.11	0.10	0.10	0.10	0.10	0.09	0.09
TOPS	0.91	0.82	0.82	0.92	0.83	0.91	0.98	1.02	1.04	1.07
EI	0.27	0.27	0.32	0.29	0.28	0.34	0.55	0.61	0.63	0.67
SMI-DMI	0.71	0.77	0.86	0.97	0.90	0.92	0.94	0.96	0.98	1.04
SMI-DMC	0.73	0.80	0.90	1.02	0.96	0.99	0.98	1.01	1.03	1.05
SFI	7.01	7.45	7.81	7.36	7.82	7.72	7.83	7.74	7.80	7.86
EP	5.54	4.87	2.92	2.93	3.01	2.12	1.96	1.10	1.08	1.05

The unit of materials intensity is kilogram per $US dollar, such as MIPS, TOPS, and EI; the unit of fast iterative Patterson squaring (FIPS) is square kilometer per $million US dollars.

The unit of productivity indicators is $US per kilogram, such as SMI and FP, and the SFI is $US 1 million per square kilometer.

The area of Taiwan is 36,006 km^2

Table 9 Material input and yield of IPAT analysis.

Year	DMI	DOP	P(Population)	GDP/P	MIPS (DMI/GDP)	TOPS (DPO/GDP)
(A)1998-1999	0.987	0.997	0.916	1.143	0.942	0.951
(B)2000-2001	0.952	1.044	1.006	0.973	0.973	1.067
(C)2002-2003	1.049	1.097	1.004	1.030	1.014	1.060
(D)2004-2005	1.015	1.096	1.004	1.037	0.975	1.053
(E)2006-2007	1.067	1.106	1.006	1.168	1.008	1.072

4.6 Decomposition analysis of IPAT equation

IPAT equation is an identical equation among environmental impact, population, affluence and technical factors proposed by Ehrlich in 1970. It is later utilized in data analysis in the form of mathematical model and is a kind of analysis tool in the field of energy utilization and its wastes discharge. The equation separates the impact and pressure of human economic development on resource and environment into three parts including population growth, wealth increase and technical competence, which can be briefly expressed in the formula, I ＝P×A×T.

This study makes use of DMI and DPO, the accounting indices of MF, to represent the material pressure caused by economic activities. Along with social economic statistical indicators, e.g. population and GDP, it divides DMI and DPO into factors of population, economy and techniques. According to the changes of above factors, it analyzes their different contributions to material metabolism of economic system.

$$I = P \times (GDP/P) \times (I/GDP) \quad (10)$$

In formula (10), I refers to environmental stress indicator and can be represented by DIM or DPO; P refers to population, GDP/P refers to per capita GDP, indicating social affluence and public welfare degree; I/GDP is the environmental indicator formed by unit GDP, indicating the material utilization efficiency (DMI/GDP) or material output efficiency (DPO/GDP) of economic system, for the purpose of measuring technical levels.

The material flow period is between 1998 and 2007 which is divided into four stages: (A) 1998-1999, (B) 2000-2001, (C) 2002-2003，(D) 2004-2005 and (E) 2006-2007. Being calculated in different periods, degree of change of a variable shows an increase if it is more than one and shows a decrease if less than one. The result is shown in Table 9. During 1998-1999, population decreased by 8.4%; average income per head population increased by 14.3%; and MIPS went down by 5.8%. Average income per head population during 2000-2001 reduced by 2.7%; that during 2002-2003 is improved by 3.0%; that during 2004-2005 is increased by 3.7%. MIPS has the most increase during 2002-2003 and increased by 1.4%. Average income per head population during 2006-2007 increased by 16.8%; and MIPS went up by 0.8%. In 1998-2007, DMI increased by 37.3%; population, by 3.8%; average income per head population, 24.3%; and MIPS, 6.4%. It shows that material use efficiency slowed down. In this, it is found that the change rate of the population is not higher. Trend of DMI is basically the same as that of MIPS. So reducing DMI value is beneficial to MIPS value because impact-resistance towards the environment can be reduced.

Yield indicator DPO of material flow analysis directly shows impact-resistance, marked by the letter “I.” Marian (2000) indicates impact-resistance on environment that every unit product generates can reflect production techniques, marked as “T.” “T” is represented by pollution discharge intensity. In TOPS indicator estimated in this study, change rate of every variable during the periods from (A) to (D) is also calculated and is shown in Table 4. In the period (A), DOP and POP show their negative growth. In the periods (B) to (D), DOP and POP show their growing trend. DOP’s increasing range is between 4.4% and 9.7%; and POP, between 4% and 6%. Except (A) where TOPS has a decreasing rate, has the most growth in the period (A) and increased by 14.3%; it shows negative growth in the period (B); it increased by 3% and 3.7% in the periods (C) and (D) respectively. TOPS has an increasing rate between 5.3% and 6.7% in all the periods from (B) to (D), except (A) where TOPS has a decreasing rate. During 1998-2007, DOP grows by 42.6%; population, by 3.8%; average income per head population, by 24.3%; and TOPS, by 10.5%. Every variable has a positive influence on DPO, especially the variable related to wealth. In this, it is found that increasing of DPO is related to TOPS and average income per head of population.

In addition to the above-mentioned analysis approach, this study adopts IPAT equation, tries to use different variables to establish a regression equation related to material flow indicator, analyzes the relationship and changing trends between Taiwan’s resource productivity and environmental impact-resistance.

Statistical data of DMI covers the years from 1998 to 2007. Regression equation's R^2 is equal to 0.989. Every variable's coefficient shows its degree of impact. So among all the variables of DMI, average income per head population has the biggest impact. Also every variable has its positive impact. The higher is wealth, the more material needs emerge. If pollution discharge symbolizes degree of environmental impact-resistance, Statistic data of material flow indicator, DPO, covers the years from 1998 to 2007. Number of samples is 8. Regression equation's R^2 is equal to 0.968. From the result, it is found that the most influential variable on changes of Taiwan's DPO indicator is average income per head of population. In other words, the higher is wealth, the more growth DPO achieves. Average income per head population is the most influential variable on DPO. This study resolves the variable into resource productivity and every person's resource use amount which become resolving applicable subjects of energy material indicator and land resource indicator respectively. Regression equation's R^2 is equal to 0.974. MIPS's influence on DPO is very small – a situation which means there is no special relation between resource use and DPO discharge. Among all the variables, population is the most influential and EP and every person's energy use amount is the second most influential. From the above resource productivity analysis, it is found that changes of resource productivity are not obvious. Therefore, the impact of indicators related to energy on DPO discharge is smaller than that of the population. If land resource is used to resolve average income per head population into two items – land productivity (SFI) indicator and every person's land use. Regression equation's R^2 is equal to 0.988. In this equation, variable Log(Land/POP) is not obvious and its change rate is too small. So this Model excludes this variable. Among other variables, population is the most impact. Its impact is positive. But MIPS has a negative impact.

This study adopts material input and output indicators and resource productivity of different materials to be engaged in resolved analysis of IPAT and tries to discuss impact of material use on environmental impact-resistance in Taiwan. Since Taiwan's dematerialization degree is only slight, wealth becomes the most important factor in material needs and pollution discharge. In other words, the higher average income per head population is, the higher DMI and DOP become. In addition, because energy and land resource productivity has no dramatic change, it is unlikely to explain whether these two kinds of resource lead to changes of DPO or not. After all factors are considered and compared, population growth possibly becomes the main influential factor.

5 Results and Discussion

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; 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, for future development of technologies for preventing environmental pollution, Taiwan should put more effort into reducing greenhouse gas emissions.

(2) The Ecological Deficit per capita 6.3441 hm^2 shows that its ecological system is in a state of overshoot.

(3) Taiwan's Domestic environmental efficiency and Ecological efficiency in the studied period shows an obvious decrease, that is, unit economic output and exhausted resource amount and generated environmental stress are on increasing. This situation shows that total amount of resource use and environmental stress stay in a developmental stage.

(4) This study uses analysis of material intensity of use and resource productivity indicators. The result shows that Taiwan's general dematerialization degree does not have fixed trends and resource productivity does not have obvious improvement. If individual resources are discussed, the dematerialization degree of land resource is the highest and pollutant discharge intensity remains with a growing trend. The reason why Taiwan's

material use does not have efficiency is perhaps instability of amount of domestic needs for every material. This unstable phenomenon leads to higher change degree in DMI or DMC. For example, construction material occupies the biggest proportion in material needs, and also changes the most. Also, owing to lack of domestic natural resources, the instability of self-yielded product supplies, and the annual gradual increasing pollutant discharge, domestic resource productivity cannot be improved.

(5) This essay adopts the establishment of regression equations to discuss the relation between material flow indicator and resource productivity. The study result shows MIPS is still not a factor influencing DMI or DPO. Wealth is the main influence. Energy material and land resource are brought into further resolved analysis to find that population growth is the main factor increasing DPO. Because MIPS is a backward variable affecting environmental impact-resistance, only enhancing resource productivity and reducing material intensity of use can effectively cut down environmental impact-resistance.

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