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Ecosystem, environmental quality and ecotechnology in the Taipei metropolitan region

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Abstract

The "self-design" capability of a natural environment is ignored in currently practiced environmental technology and urban planning professionals. Therefore, we propose an ecological engineering approach to conduct scenarios for environmental management in the metropolitan region of Taipei. Ecological energetic analysis is applied to assess the ecological economic status and the role and contribution of solid waste and water resources in the Taipei metropolitan region. The benefit of an ecological engineering approach to the environmental quality and sustainable development of the metropolitan region is evaluated using emergy synthesis. The results indicate that Taipei metropolitan region operates its activity mainly on the imported fuels and goods and services, which account for 90% of total emergy used. The treatment of waste as resources and the use of the self-design capability of the natural environment according to the ecological engineering approach can generate positive contribution and aid the environmental quality and productive potential of the ecological economic system. It is concluded that ecological sustainability should be used as a reference of environmental quality for urban development policy.

Keywords: Ecotechnology; Emergy synthesis; Environmental quality; Solid waste management; Sustainable development; Waste-water system

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1. Introduction

Nearly half the world's population will live in urban areas by the turn of the century (WCED, 1987). People are beginning to recognize that the way these urban areas are developed determines our success or failure in overcoming

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environmental challenges. Environmental concerns generally receive little attention in urban policy, except when they are constraining the goals of economic development. An OECD study of *Environmental Policies for Cities in the 1990s* raised the attention that environmental issues matter to economic development in cities (OECD, 1990). This transformation of attitudes owes much to the publication of the Brundtland report (WCED, 1987) that expressed the environmental challenge to metropolitan areas. Many people mistakenly use the term "sustainable development" to mean simply environmental protection or economic growth (Roseland, 1991). Sustainable development is defined in the Brundtland report as "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". The challenge posed by this concept requires that those responsible for the development of and within cities always frame their short-term policies in this long-term perspective.

Innovation in the field of environmental quality has typically concentrated on the construction of waste treatment facilities in the short term and on the introduction of new man-made technical fixes for environmental problems for the longer term. Is such environmental technology the answer to the solution of urban environmental problems? Are there alternatives? Although billions of dollars have been invested in Taiwan on abatement technologies for pollution problems that have been widely recognized since 1970s, we are still far from an acceptable solution to many serious environmental problems. We must acknowledge that there are millions more people on this island and that both the non-renewable and renewable resources are less available now than 20 years ago.

The option of introducing ecologically sound techniques has long been advocated but it is still rarely implemented. If development is to be sustainable, it must encompass a full appreciation of the value of the natural and built environments in terms of their contributions both to present societal well-being and for intergenerational equity. Hence the valuation of natural capital of the metropolitan region must be undertaken as correctly as possible so that the full value of the services provided by it to the urban system is accounted for. Sustainable urban environments are those that develop and grow in harmony with, and can reinforce the productive potential of, their life-support environments, ranging from local and regional to global ecosystems.

Defining environmental qualities in an urban setting is a complex challenge. Cities are dynamic entities and their composite environments are determined not only by fulfillment of the material needs of their citizens, but also by providing environmental quality conditions. Sustainable urban development must be more than merely "protecting" the environment; it requires socioeconomic adjustment to diminish the need for environmental protection. The OECD (1990) proposed two principles of sustainable urban development: the principles of "functional and self-regulatory growth" and of "minimum waste". The first principle emphasizes that economic growth should be valued against the net contribution it makes to the system as a whole, that is, to the urban area and its total life-support environment. A feedback mechanism is needed to maintain the balance of the total system. The second principle of minimum waste is related to the functions of natural ecosys-

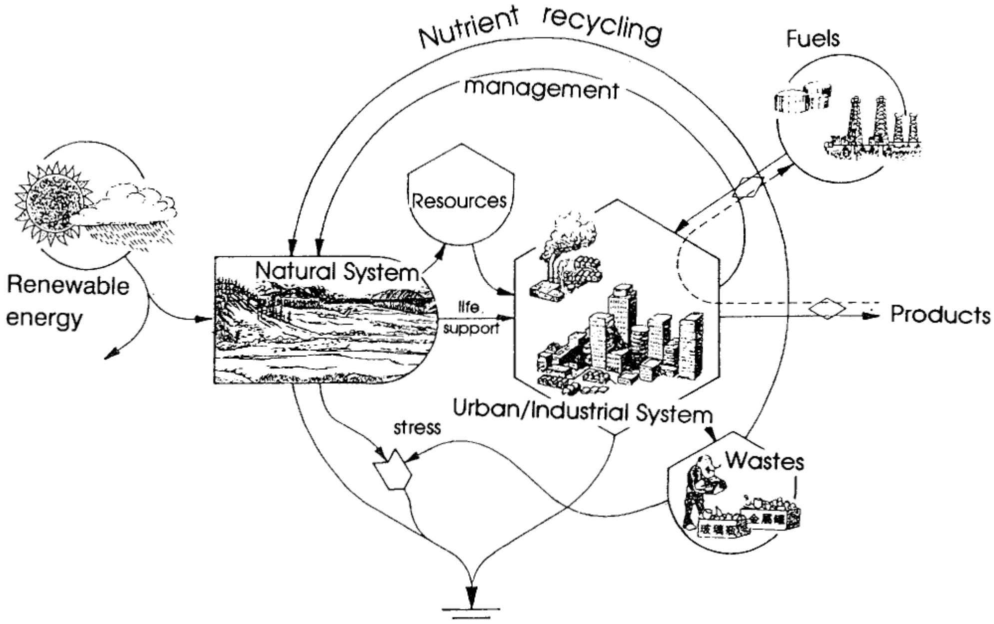

Fig. 1. Conceptual diagram of urban ecological economic system.

tems, where efficient recycling of materials such as essential nutrients should be incorporated with ecological processes.

The definition of urban environmental quality can be and is interpreted in various ways. The narrowest interpretation is concerned primarily with the level of pollution, such as of air and water and from noise, and with waste disposal. A broader definition extends this to subjective judgement and human preference toward the physical properties of the urban environment. We provide an even broader definition concerned with the sustainability of the urban environment as a whole. Natural environments are resources providing commodities and life-support services of value to human societies (Fig. 1). These include raw materials and energy, which are the basis for producing outputs with well-defined commercial values, and assimilative functions to purify air and water through recycling. If the wastes are improperly treated, they result in stress to the life-support functions of the natural environment.

The lack of market for the essentially free services provided by the ecosystem has favored not only excessive demand for consumption of resources but also the development of technologies that produce excessive waste. It has also been recognized that "zero discharges" cannot be achieved because of finite supply of renewable resources and transfer characteristics of pollutants. Diminishing resource depletion for sustainable provision of life-support services to human society requires initiatives in waste reduction and recycling. Ecotechnology or so-called ecological engineering alternatives have been proposed and applied to cope with pollution problems by recognizing the self-designing properties of natural ecosystems (Mitsch and Jørgensen, 1989).

The purpose of this article is to use Taipei metropolitan region as a case study to address the importance of natural environment in providing life-support services and to evaluate of the natural environment's contribution to an urban economic system for the management of urban environmental quality. The first section describes the Taipei metropolitan region; this is followed by a brief introduction to emergy synthesis. In the next section this method is applied to evaluate resource flows to and from the metropolitan region. Thereafter we suggest alternative management strategies of waste water and solid waste treatment based on ecological engineering principles, and compare them with conventional measures, through emergy synthesis. We are asking whether such ecological engineering techniques should be initiated and implemented in planning and management of urban development.

2. Taipei metropolitan region

Today, nearly four-fifths of the population of Taiwan live in urban areas. Cities have evolved into complex economic and social structures due to the diversity of economic activity generated by benefits of agglomeration economies afforded by cities. Environmental conditions in a metropolitan region, such as Taipei, are a source of critical concern to environmental groups, because urban populations are particularly exposed to combined effects of air and water pollution, problems of waste disposal, etc. These problems, which are exacerbating in the Taipei areas, are generally accompanied by a lack of open space and greenery.

Located in the northern portion of the island, Taipei is the key urban center of Taiwan (see Fig. 2). The Taipei metropolitan region, an area of about 1900 km^2, consists of Taipei City and outlying areas of Taipei County. Administratively, the metropolitan region comprises 25 municipalities. Taipei Basin is in the central portion and is surrounded by hillslope areas. The total population of the metropolitan region in 1990 was approximately 5.7 million, having increased by about 25% during the past ten years. Because of the rapid economic growth and urban development, Taipei has become more congested and polluted, and the quality of life is significantly diminished for urban residents. Evidently, there is no single public policy or program to improve environmental quality in the Taipei metropolitan region. Current programs to control various sectoral activities that effect environmental quality are implemented as problems occur or when it is considered to be politically opportune to treat them. Those initiatives are seldom sufficiently integrated, the result being that adequate ecological economic interfaces are not realized and accounted for on the regional or global level. The degrading urban environmental quality clearly indicates that Taipei is not making its full potential contribution to achieving global sustainable development.

The case study of the Taipei metropolitan region is an attempt to integrate, to some degree, the interdependencies between the urban system and the natural

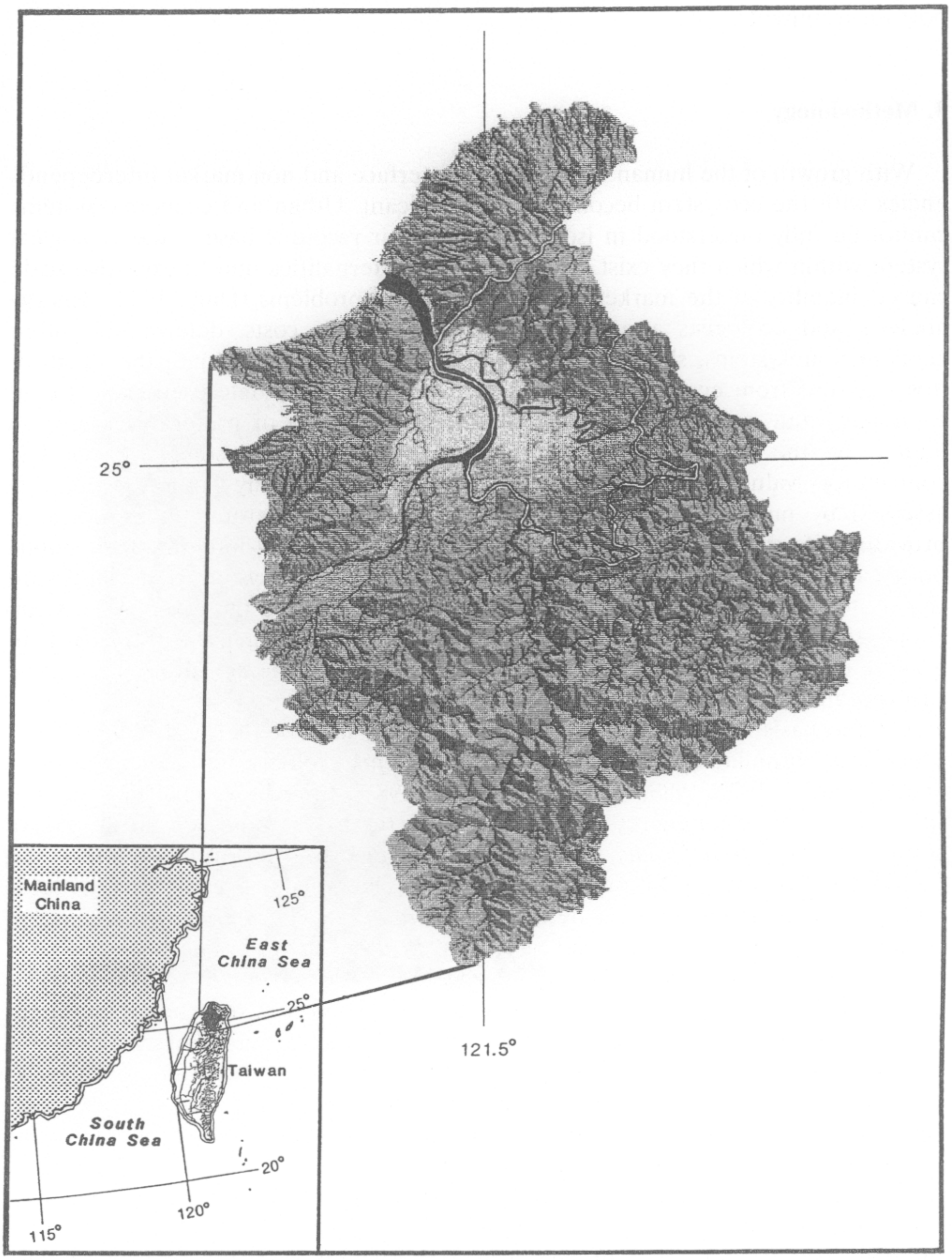

Fig. 2. Regional context of Taipei metropolitan region.

system. In order to compare, by integrating the worth of various inputs from the natural system and products from human economy on the urban system, it is necessary to use some common measure to link the urban system and its life-support environments.

3. Methodology

With growth of the human economy, the interface and non-market interdependencies with the ecosystem become more significant. Urban and economic systems cannot be fully understood in isolation from their resource base – the ecological system within which they exist. The increasing externalities due to excessive scale caused inability of the market to solve allocation problems (Daly, 1984). Energy analysts and ecologists argue that neither prices nor costs, determined within economic subsystems, should be the only measure used to evaluate the worth of flows to and from ecosystems. Market prices, the most widely used indicator of economic value and resource availability, are a function of preferences, endowments and the cost of various alternatives (Maxwell and Costanza, 1989). The contributory value of an ecosystem to urban economic activity cannot be properly assessed by market prices. The intrinsic value of the natural environment in providing life-support services needs to be appreciated and integrated for public policy analysis. This condition requires a new accounting system that can assure the contribution of a non-marketed natural environment to the economic system. Biophysically based energy analysis can provide a comprehensive framework to analyze economic and ecological systems that allows non-market information to be incorporated more easily.

On the basis of general systems principles and laws of thermodynamics, H.T. Odum has formulated a unifying theory of systems ecology and energy theory of values (Odum, 1971, 1988; Odum and Odum, 1981). In order to take into account the varied qualities of energy inherent in the hierarchy of systems components, two terminologies – *transformity* (previously called energy transformation ratio) and *emergy* (spelled with an M; previously known as embodied energy) – were initiated by H.T. Odum. Transformity is defined as *the ratio of energy of one type required to produce a unit of energy of another type*. Emergy is *the energy of one type required in transformation to generate a flow or a storage*. With the concept of transformity, we have a scale of energy quality that indicates the position in the energy hierarchy: the greater the quality of energy, the greater is the transformity. Solar emergy of a flow or storage is the solar equivalent energy required to generate that flow or storage. Its units are solar emergy joules (sej). After the energy content (e.g. joule) of a flow has been estimated, it can be multiplied by its solar transformity to obtain its solar emergy. Emergy indices such as per capita emergy use, fraction of indigenous emergy used, emergy import–export ratio, etc., can be calculated to illustrate the ecological–economic interface. Macro-economic dollar values of each energy flow and storage can be derived by dividing its emergy value by the emergy–dollar ratio. Further details on the procedure of emergy analysis can be found in Odum et al. (1987) and Huang and Odum (1991). Despite the objection and criticism on the concept of emergy and on the calculation of transformity (e.g., see Herendeen, 1992), emergy synthesis can be used to represent the quantity of energy that any input or product of the economy represents. Furthermore, the emergy concept offers a complementary viewpoint of value on the biophysical nature of human activity. It broadens the perspective to include the work of the natural environment.

Data from various sources of geographical or economic information and statistics of the Taipei metropolitan region are collected and interpreted: (1) to understand its ecological economic network; (2) to calculate energy flows to and from, and within the metropolitan region; and (3) to assess the significance of ecotechnology for metropolitan management.

4. Results

Based on the preliminary understanding of the ecological economic system of the Taipei metropolitan region (Huang and Liao, 1991), evaluation of principal emergy flows and emergy indices can provide quantitative measures of the ecological economic interface and the consequence of rapid urban development.

4.1. Resource supply and dependence

Because of limited natural resources, emergy flows from renewable sources (R) and locally non-renewable sources (N) to the urban economy in the Taipei metropolitan region are relatively small (see Fig. 3 and Table 1). However, the ability to attract outside high emergy in fuels, goods and services depends on being able to match these inputs with environmental interactions. According to our examination of the aggregated emergy flows of the Taipei metropolitan region, it becomes apparent that imported fuels and goods and services are the principal sources of urban activities in Taipei. Specifically, Taipei metropolitan region operates its activity on 1.5% renewable sources, 8.5% locally non-renewable resources, and 90% imported fuels and goods and services (see item 6, 7, and 8 of Table 1).

A high emergy–dollar ratio is seen as a measure of the real purchasing power of currency and the ability of labor to compare in attracting labor-intensive economic activity (Odum et al., 1987; Huang and Odum, 1991). A higher emergy–dollar ratio is found in a less developed region in which more emergy to support the economy comes directly from the natural environment without payment of money. As the economic activity in the Taipei metropolitan region is driven mainly by imported emergy of fuels and goods and services, its emergy–dollar ratio is relatively small, 1.33×10^{12} sej/\$ (item 9 of Table 1), compared to the world average approximately 2.00×10^{12} sej/\$. The free subsidy from the environment that made smaller wages possible has decreased.

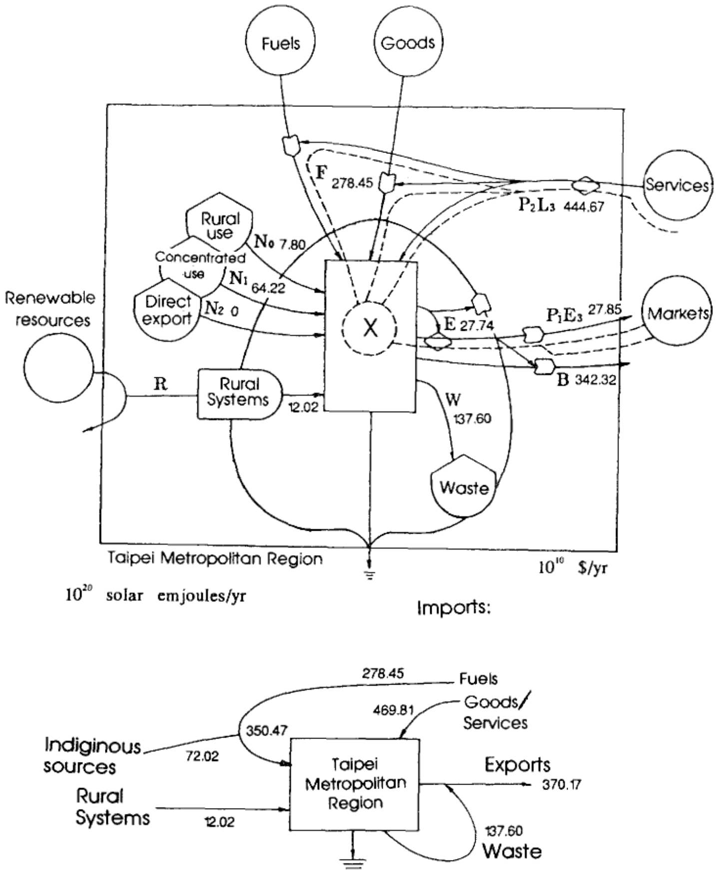

Fig. 3. Aggregated emergy diagram for the Taipei metropolitan region in 1990.

The emergy investment ratio (item 11 of Table 1) is the ratio of the emergy fed back from the economy (including resources within and imported) to the emergy from the free, locally available renewable resources (R), such as sun, rain, wind, etc. A highly developed region has a higher investment ratio. As shown by Table 1, the emergy investment ratio of the Taipei metropolitan region, 66.14, is significantly greater than that of Taiwan (9.04) as a whole. The reason of this high emergy investment ratio in the Taipei region is its limited renewable emergy flow and the necessity of importing emergy of fuels and goods and services to maintain its economic viability. From an ecological economic system viewpoint, the economy in the Taipei metropolitan region can be regarded as a less self-sufficient status.

4.2. Stress from pollution

The higher investment ratio is not merely whether it is economical or not but also a concern for environmental degradation. This measure can be seen as an

Table 1
Emergy indices overview of the ecological economic system of the Taipei metropolitan region

Item	Name of index	Expression	Quantity
1.	Renewable emergy flow ($\times 10^{20}$ sej/yr)	R	12.02
2.	Flow from indigenous non-renewable reserves ($\times 10^{20}$ sej/yr)	N	72.02
3.	Flow of imported emergy ($\times 10^{20}$ sej/yr)	F + G + P2I3	723.12
4.	Total emergy used ($\times 10^{20}$ sej/yr)	U = R + N + F + G + P2I3	807.16
5.	Total exported emergy ($\times 10^{20}$ sej/yr)	B + P1E3	370.17
6.	Fraction of emergy used derived from home sources	(N0 + N1 + R)/U	0.10
7.	Fraction used, locally renewable	R/U	0.015
8.	Fraction of use purchased	(F + G + P2I3)/U	0.90
9.	Ratio of use to GDP, emergy/dollar ratio ($\times 10^{12}$ sej/\$)	P1 = U/GDP	1.33
10.	Ratio of waste to renewable	W/R	11.45
11.	Emergy investment ratio	(F + G + P2I3 + N0 + N1)/R	66.14

Source: Huang and Liao, 1991, p. 32.
B: Exported product: $(2.57 \times 10^{10}\ \$)(1.33 \times 10^{12}\ \text{sej}/\$) = 342.32 \times 10^{10}$ sej
E3: Dollars in exported service: 2.09×10^{19} \$
F: Imported fuels: petroleum products 219.29×10^{20} sej, coal 6.18×10^{20} sej, and natural gas 7.12×10^{20} sej
G: Imported goods: $(2.06 \times 10^{10}\ \$)(1.98 \times 10^{12}\ \text{sej}/\$) = 408.27 \times 10^{20}$ sej
I3: Dollars paid for imported services: $(22.46 \times 10^{9}\ \$)(1.98 \times 10^{12}\ \text{sej}/\$) = 444.67 \times 10^{20}$sej
N: Indigenous non-renewable flows: N0 + N1
  N0: Dispersal rural: soil loss 240 ton/km^2
    $(240\ \text{ton/km}^2)(1895.5\ \text{km}^2)(1.71 \times 10^{15}\ \text{sej/ton}) = 7.8 \times 10^{20}$ sej
  N1: Concentrated use: hydroelectricity, thermal power plant, and copper
    hydroelectricity: $(2.75 \times 10^{8}\ \text{kWh})(3.606 \times 10^{6}\ \text{J/kWh})(159000\ \text{sej/J}) = 1.57 \times 10^{20}$ sej
    thermal power plant: $(5.82 \times 10^{9}\ \text{kWh})(3.606 \times 10^{6}\ \text{J/kWh})(159000\ \text{sej/J}) = 33.37 \times 10^{20}$ sej
    copper: $(4.32 \times 10^{9}\ \text{g})(6.77 \times 10^{10}\ \text{sej/g}) = 29.27 \times 10^{20}$ sej
P1: Ratio of use to GDP: $U/GDP = 807.16 \times 10^{20}\ \text{sej}/6.05 \times 10^{10}\ \$ = 1.33 \times 10^{12}\ \text{sej}/\$$
P2: World emergy/dollar ratio: 1.98×10^{20} sej/\$ (see Huang and Odum, 1991)
R: Renewable emergy flows: wind + tide
  wind: $(30\ \text{watt/m}^2)(10^6\ \text{m}^2/\text{km}^2)(1895.5\ \text{km}^2)(31536000\ \text{sec/yr})(623\ \text{sej/J}) = 11.17 \times 10^{20}$ sej
  tide (assumed 50% absorbed): coastal area 2.544×10^{8} m^2, av. height 2 m
  $(2.544 \times 10^{8}\ \text{m}^2)(0.5)(706/\text{yr})(2\text{m})(9.8\ \text{m/sec}^2)(1.025 \times 10^{3}\ \text{kg/m}^3)(23564\ \text{sej/J}) = 0.85 \times 10^{20}$ sej
U: Total emergy used: R + N + F + G + P2 I3
W: Waste: waste water and solid waste
  waste water: $(8.17 \times 10^{8}\ \text{m}^3)(10^6\ \text{g/m}^3)(5\ \text{J/g})(665714\ \text{sej/J}) = 27.20 \times 10^{20}$ sej
  solid waste: $(5688\ \text{ton/day})(365\ \text{day})(4 \times 10^{6}\ \text{BTU/ton})(1055\ \text{J/BTU})(18 \times 10^{5}\ \text{sej/J}) = 157.7 \times 10^{20}$ sej

index of environmental loading of economic activity. Given a finite supply of renewable natural resources, the capability to assimilate waste generated from urban consumption without causing adverse environmental effects is, from a macro perspective, fixed. This pressure of environmental degradation resulting from rapid urban development in the Taipei metropolitan region can be clearly seen from the high ratio of waste to renewable emergy, 11.45 (item 10 of Table 1).

Table 2
Emergy indices of waste treatment of Taipei metropolitan region

Item	Name of index	Expression	Quantity
1.	Ratio of waste water to renewable emergy flow	WW/R	0.71
2.	Ratio of waste water to total emergy used	WW/U	0.01
3.	Fraction of untreated to total waste water	NT/WW	0.88
4.	Ratio of investment on waste water treatment to total emergy used	US + UT + UC/U	0.009
5.	Fraction of recyclable solid	RC/S	0.733
6.	Ratio of solid waste generated to total emergy used	S/U	0.16
7.	Ratio of investment on solid waste treatment to total emergy used	UI/U	0.002

Source: Huang, 1992, p. 98.

Table 2 further explores the problems of waste treatment in the Taipei metropolitan region. Water pollution in combination with a too rapid rate of water withdrawal can cause serious harm to hydrological systems. As indicated by items 3 and 4 of Table 2, only 0.9% of the total emergy flow was allocated to the treatment of waste water, which accounts for only 12% of total waste water generated in the Taipei metropolitan region.

The solid wastes generated in the Taipei area have greatly increased in volume and altered in composition during the past decade. Trends in waste generation are strongly related to variations in the level and structure of consumption which occur in urban areas. It is estimated that the generation of waste in Taipei metropolitan region was about 5850 tons of solid waste per day in 1990. Available data indicate that 73% of the total solid waste could be recycled (item 5 of Table 2). But, landfill still dominates over other treatment facilities in the metropolitan region. The amounts of solid waste generated account for 16% of the total emergy used (item 6 of Table 2), and only 0.2% of the total emergy used was allocated for treatment of solid waste (item 7 of Table 2).

4.3. *Traditional measures versus ecotechnology*

In order to reinforce nutrient-recycling capability within the metropolitan region to alleviate the adverse environmental effects of waste water, we propose the incorporation of wetlands as an ecological engineering technique to aid the treatment of waste water. Wetlands can be built along stream courses and let treated water discharge to them before entering water bodies. A system diagram of the application of wetlands for waste water treatment is presented in Fig. 4. The treated waste water can be discharged to either the stream course or wetlands, depending whether a wetland is close to a treatment plant. The construction and operation of wetlands require investments of goods and services from the urban system. The value of using wetlands as a component of waste-water treatment system is two fold – recycling nutrients to reinforce the production potential of natural system, and generating recreational and amenity opportunities for urban residents.

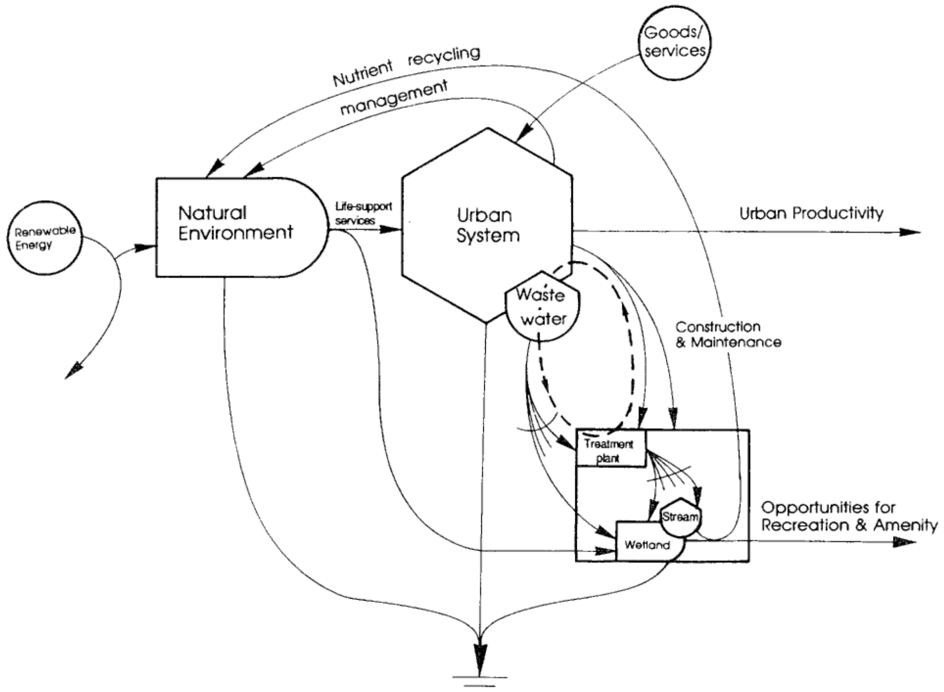

Fig. 4. Ecological engineering system of waste water system.

Using GIS to aid site selection, we hypothesize the locations and capacities of wetlands within the metropolitan region. Emergy synthesis is then applied to evaluate the worth of wetlands to metropolitan management. As indicated in Table 3, the construction of wetlands requires additional costs from the urban economic

Table 3
Macroeconomic value of wetlands (macroeconomic $ $\times 10^6$) [a] for Taipei metropolitan region

Item	Traditional engineering	Ecological engineering (wetland)
Input costs:		
Wetland construction	0	−6.30
Constr. of sewage treatment plant	−5.6	−3.29
Operation & maint. of treat. plants	−877	−188
Subtotal	−882.6	−197.59
Output products:		
Nutrient recycling	0	0.88
Recreation & amenity opportunities	0	172
Subtotal	0	172.88

Source: Huang, 1992, p. 155.
[a] Macroeconomic $: Solar emergy divided by 1.33×10^{12} sej/$.

Table 4
Emergy evaluation of alternative solid waste disposal systems (macroeconomic $·ton^{-1}·yr^{-1})

Item	Alternative disposal system					
	landfill	incinerator + landfill	compost + landfill	reuse + landfill	reuse + incinerator + landfill	reuse + compost + landfill
Input costs:						
1. Goods & services from urban system	−13.74	−138.1	−101.7	−210.6	−239.7	−228.7
2. Solid wastes components	−4308	−861.5	−3509	−791.3	−201.5	−0.2081
Subtotal	−4321.74	−999.6	−3610.7	−1001.9	−441.2	−228.5
Output products:						
3. Land reclaimed	2.09	0.418	1.571	0.489	0.0978	0.001254
4. Electricity	0	2.20×10^{-6}	0	0	7.37×10^{-9}	0
5. Metals reused	0	14.57	7.29×10^{-6}	[a]	[a]	[a]
6. Nutrients recycled	0	0	1175	0	0	1175
7. Reuse	0	0	0	2835	2835	2835
8. Leakage to G.W.	-3.46×10^{-6}	-6.92×10^{-7}	-2.6×10^{-6}	-8.1×10^{-7}	-1.62×10^{-7}	-2.08×10^{-9}
Subtotal	2.09	14.99	1176	2836	2835	4009
Net contribution	−4319.65	−984.61	−2434.7	1834.1	2393.8	3780.5

[a] Included in item 7.

Source: Huang, 1992, p. 122.

system, but the costs of construction and maintenance of treatment plants decrease compared to a traditional engineering approach. Furthermore, wetlands generate a positive value of nutrient recycling and provide potential recreation and amenity opportunities to urban societies.

As cities grow and per-capita consumption increases, many urban areas confront problems of finding new sites for disposal of solid wastes. In addition, NIMBY (not-in-my-backyard) influences the willingness of communities to tolerate creation or extension of waste disposal sites. Urgent action is needed in Taipei to diminish the amount, to increase the recycling and reuse of solid waste and to ensure the proper treatment of future wastes. Waste should be regarded as a by-product within the combined system of man and nature (Mitsch and Jørgensen, 1989).

In addition to currently practiced landfill and incinerators, we propose to incorporate a compost plant and recycling reusable wastes as ecological engineering alternatives for management of solid waste in the Taipei metropolitan region. Emergy evaluation of six alternatives for waste treatment strongly indicates that recycling and compost plants are of great benefit to an urban ecosystem (see Table 4). A solid-waste management system is then designed to recycle and to reuse the so called by-products (see Fig. 5). Evaluation of the ecological engineering alterna-

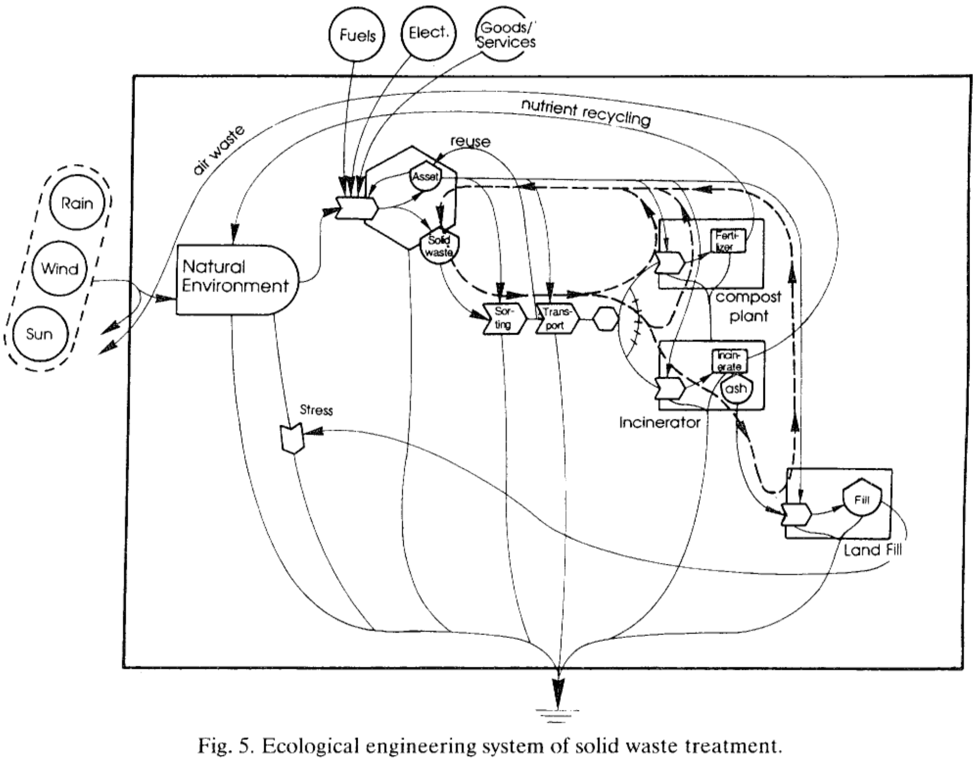

Fig. 5. Ecological engineering system of solid waste treatment.

Table 5
Macroeconomic value (macroeconomic \$) [a] of solid waste management system for Taipei metropolitan region

Item	Traditional engineering	Ecological engineering
Input costs:	-1.966×10^{10}	-6.981×10^{8}
1. Goods and services from urban system	-5.164×10^{7}	-1.691×10^{8}
2. Solid wastes components	-1.991×10^{10}	-5.290×10^{8}
Output products:	2.459×10^{8}	4.859×10^{10}
3. Reuse	8.362×10^{7}	4.572×10^{10}
4. Electricity	1.526×10^{8}	1.818×10^{7}
5. Nutrients recycled	0	2.854×10^{9}
6. Land reclaimed	$9.66\ \times10^{6}$	2.719×10^{5}
7. Leachate	-1.600×10^{1}	-4.505×10^{-1}
Net contribution	-1.972×10^{10}	4.789×10^{10}

Source: Huang, 1992, pp. 180–181.

[a] Macroeconomic \$: solar emergy divided by 1.33×10^{12} sej/\$.

tive indicates that the urban system has to feed back more goods and services to implement the ecotechnology; however, the benefits from fertilizer nutrients and reusable solid waste would be substantial (see Table 5).

5. Discussion

Taipei acts as centers of population, economic production and consumption in northern Taiwan and plays a driving role in the development of the national economy. However, its urban activities also produce great environmental degradation of water, and generate considerable amounts of solid waste. Based on the results presented above, undoubtly, the scale of waste problem is now threatening the viability of Taipei and placing unacceptable burdens on general public health. This is a consequence of the concentration of resources, collected from vast ecosystem, in a small area. Taipei is a throughput system and may be seen as a threat to sustainable development because the environmental problems being generated are not only substantial but also increasing in pace with ongoing urbanization.

There has been a growing public awareness and concern about the limits of environmental damage that can and should be tolerated. In a city like Taipei that accommodates growth, a typical response is to react to an immediate crisis by demand-oriented planning and construction of waste-treatment facilities. The severity of the exponentially increasing costs to treat urban environmental degradation is being raised. Inevitably, this short-term remedy carries with it long-term problems.

We must recognize that an urban area is in some sense a heterotrophic system that has to rely on surrounding landscapes for life-support services (Odum, 1989). Urban areas can never be regarded as self-contained entities. They need to interact economically and environmentally with their surrounding landscapes as an integral dimension of their vitality and growth. Ecological engineering alternatives offer the means not only to sustain the provision of ecological services but also to enhance environmental quality on a metropolitan scale. Hence, there is a need for a strategic plan in the management of urban environmental quality in the Taipei metropolitan region, moving towards distant temporal horizons and away from ad hoc, incremental responses to demand.

6. Conclusions

With the concept of sustainable development placed so high on the global policy agenda of this decade, it is timely to initiate policies according to which urban planners can frame programs and design specific projects. Policies for urban development in Taipei metropolitan region need to be reframed to recognize the importance and necessity of encouraging sustainable development of cities on the basis of an ecological life-support system. Assessing the contributory value of a natural environment to urban societies is of great urgency. We recommend that environmental quality be assessed with regard to ecological sustainability. Ecological engineering approaches are proposed for urban systems to feed back energy to reinforce the productive potential of ecosystems. Using emergy evaluation, we conclude that an ecological engineering approach is of great benefit to both urban economies and ecosystems. Here we provide only results of analysis from a public policy level. Further details on this study are found in Huang (1992). The broad themes that we have discussed here can be further elaborated. In particular, further basic research needs to be undertaken to fully understand, for instance, the nutrient-cycling capabilities of wetlands, the cost of compost plants, etc. Most importantly, the strategies to implement the ecological engineering techniques for planning and management of urban development should be initiated without further delay.

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References

Daly, H.E., 1984. Alternative strategies for integrating economics and ecology. In: A.-M. Jansson (Ed.), Integration of Economy and Ecology – An Outlook for the Eighties. Asko Lab., University of Stockholm, Stockholm, Sweden, pp. 19–29.

Herendeen, R., 1992. Total environmental cost: comparison of efforts and specific comments on emergy analysis. In: Proceedings of 36th Annual Conference of ISSS, General Systems Approaches to Alternative Economics and Values. ISSS, Denver, Colorado, pp. 173–182.

Huang, S.-L., 1992. Ecological Economic System and the Environmental Quality of the Taipei Metropolitan Region. National Science Council, NSC80-0421-P005-02Z, Taipei, Taiwan.

Huang, S.-L. and W.-H. Liao, 1991. Applied emergy synthesis for the preliminary analysis of the ecological-economic system of Taipei metropolitan region. J. City Planning, 18: 19–36. Chinese Institute of Urban Planning, Taipei, Taiwan.

Huang, S.-L. and H.T. Odum, 1991. Ecology and economy: emergy synthesis and public policy in Taiwan. J. Environ. Manage., 32: 13–336.

Maxwell, J. and R. Costanza, 1989. An ecological economics for ecological engineering. In: W.J. Mitsch and S.E. Jørgensen (Eds.), Ecological Engineering: An Introduction to Ecotechnology. Wiley, New York, pp. 57–77.

Mitsch, W.J. and S.E. Jørgensen (Eds.), 1989. Ecological Engineering: An Introduction to Ecotechnology. Wiley, New York.

Odum, E.P., 1989. Ecology and Our Endangered Life-Support Systems. Sinauer Assoc. Inc., Sunderland, MA.

Odum, H.T., 1971. Environment, Power, and Society. Wiley Interscience, New York.

Odum, H.T., 1988. Self-organization, transformity, and information. Science, 242: 1132–1139.

Odum, H.T. and E.C. Odum, 1981. Energy Basis for Man and Nature, 2nd ed. McGraw-Hill, New York.

Odum, H.T., E.C. Odum and M. Blissett, 1987. Ecology and Economy: Emergy Analysis and Public Policy in Texas. Policy Research Project Report No. 78, Lyndon B. Johnson School of Public Affairs, University of Texas, Austin, TX.

OECD, 1990. Environmental Policies in the 1990s. OECD, Paris.

Roseland, M., 1991. Toward sustainable cities. Ecodecision, 3: 48–52.

WCED, 1987. Our Common Future. Oxford University Press, Oxford.