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Emergy evaluation perspectives on the natural environment and economy of Seoul

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An emergy evaluation of the natural environment and economy of Seoul revealed that Seoul used 1.27 E23 sej/yr of emergy in 1997. The emergy input from the Han River accounted for most of the renewable emergy sources. Emergy imported from foreign countries and other parts of Korea accounted for 97% of the total emergy use in Seoul in 1997, revealing that the economy of Seoul is more dependent on outside emergy sources than the entire Korean economy. The emergy use per unit area(2.09 E14 sej/m^2/yr) was higher than that for the entire country or Pusan, whereas the emergy use per capita(1.22 E16 sej/person/yr) was lower than that for the entire country or Pusan. These results reflect the overcrowded conditions in Seoul where about one fourth of the Korean population now live. They also seem to indicate a lower living standard in Seoul than the average in Korea. The quality of living in Seoul could also be judged by a high environmental loading ratio and a low sustainability index. All these indices suggest that people in Seoul live under a higher environmental stress than the average person in Korea.

Key words : emergy, Seoul, environment, economy

1. Introduction

Like many other big cities all over the world, Seoul is a center of economic activities, receiving energy and materials from surrounding areas, and thus supports a high density of population and economic activities. The goods and services produced in Seoul spread over the surrounding area, thereby providing a basis for new economic activities. Seoul has grown rapidly due to growth-oriented economic development policies since 1960s. About one fourth of the Korean population now lives in Seoul, and almost all economic activities converge on this city.

However, the impact of urbanization on the surrounding environment and the people living in Seoul has been neglected due to an emphasis on the economic and engineering aspects of the urbanization. Accordingly, Seoul is now experiencing the same problems as most other major cities in the world, such as overcrowding, deterioration of city functions, environmental degradation and destruction, excessive expansion and unorganized development, and a resultant deterioration in the standard of living.

Recent efforts have been made in other parts of the world to balance the development of cities and their surrounding environment under the concept of environmentally friendly development. Yet, a balance between development and conservation cannot be achieved without a sound evaluation of the contribution of the natural environment surrounding such cities. Sound evaluations of the real values of the surrounding environment to the economy can provide guidelines in judging the benefits and costs of various alternative city development proposals.

Until recently, the contribution of the natural environment to the economy has only been evaluated in terms of market price. Market price,

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however, cannot correctly evaluate the true contribution of the natural environment and resources to the real wealth of an economy[1]. Traditional economic evaluations have only considered the direct contribution of the natural environment to the economy. However, recent researches have revealed substantial contributions that cannot easily be translated into a monetary value.

In this study, the concept of "emergy"(spelled with an "m") is used to provide a new insight into the natural environment and economy of Seoul. The emergy concept, based on the assumption that the value of a resource is proportional to the energy required to produce it[1,2], is an effort to evaluate the real wealth contribution of the natural environment from a whole systems perspective. The emergy concept uses energy as a common currency to compare vastly different resources.

Emergy is defined as "the available energy of one kind previously required directly and indirectly to make a product or service", with its unit being emjoule[1]. Solar emergy is "the available solar energy used up directly and indirectly to make a service or product". Its unit is solar emjoule or sej[1].

The emergy concept recognizes that different types of energies have different abilities to do work. This is reflected in the transformity, which is defined as "the quotient of a product's emergy divided by its energy"[1]. The higher the transformity, the higher the energy quality. Solar transformity is the solar emergy required to make one joule of a service or product, with its unit being solar emjoule/joule(sej/J).

Emergy evaluations on the natural environment and economy have provided new perspectives on conservation and development controversies related to the natural environment[1]. Emergy evaluations of cities in other countries include evaluations of Miami[3], Hongkong[4], and Taipei[5~9]. These evaluations have assessed the carrying capacity of the cities and provided new perspectives on the coexistence of nature and humanity through simulation models of city development.

Several previous studies in Korea have used the emergy concept to evaluate the entire Korea[10], Korean fisheries[11], the carrying capacity of Korean fisheries[12], dam constructions[13,14], and some Korean cities[15~18]. However, the previous emergy evaluations of Seoul[15,16] were incorrectly connected to an evaluation of the entire country, and the emergy evaluations did not include energy systems diagrams.

This study attempts to provide a new perspective for establishing policies on the sustainable development of Seoul in an age of diminishing resources based on a more accurate emergy evaluation of the natural environment and economy of Seoul.

2. Methods

2.1. Energy systems diagram

An emergy evaluation is a top-down systems approach and starts with diagramming the system of interest based on verbal descriptions. The emergy evaluation models were constructed using the energy systems language, a symbolic modeling language that presents the network properties of systems holistically using symbols with predefined specific meanings[1,2,19]. As a top-down modeling, energy systems diagramming helps researchers to understand the network organization of the system of interest and identify the important flows and interactions most relevant to the problem under investigation.

The construction of an energy systems model starts with the definition of the system boundary, followed by the identification of the important external sources. Next, the principal components and main processes of production and consumption within the boundary are identified. An energy systems diagram is drawn by properly arranging the external sources and internal components and connecting them according to energy, material, and money flows.

2.2. Emergy evaluation table

Emergy evaluation tables were constructed from the energy systems models. The raw data for these tables were obtained from literature and statistical references on Korea and Seoul. The transformities of the various items were obtained from previous emergy evaluation studies[1]. The emergy of each input was obtained by multiplying the raw data with its transformity. The macroeconomic values in the table indicate the total amount of money circulating in the entire economy as a result of an emergy flow. Using these emergy evaluation tables, emergy indices were then calculated to provide a new perspective on the economies of Korea and Seoul.

Two different scales of emergy evaluation were performed because the economic activities of Seoul contribute to and are affected by the entire economy of Korea. The entire country of Korea was evaluated first, then the emergy evaluation of Seoul was conducted based on the emergy evaluation of Korea.

3. Results and Discussion

3.1. Country overview

Figure 1 is an aggregated diagram of Korea showing the external energy inputs. These energies that support production within Korea are diagrammed in the order of an increasing energy quality from left to right. Production within the country included coastal ecosystems, forests, and agriculture, along with industry and commerce. Industry and commerce utilized natural resources and were managed by people.

Table 1. Emergy flows of Korea in 1997

No.	Item	Raw Units		Solar Tranfomity (sej/unit)	Solar Emergy (sej/yr)	Macroeconomic value, 1997 US$
RENEWABLE RESOURCES :						
1	Sun	1.23E+21	J	1	1.23E+21	7.39E+08
2	Wind, kinetic energy	2.00E+17	J	1496	2.99E+20	1.80E+08
3	Rain, geopotential	1.92E+17	J	10400	2.00E+21	1.20E+09
4	Rain, chemical	2.12E+18	J	15444	3.27E+22	1.97E+10
5	Tide	2.54E+17	J	23564	5.99E+21	3.61E+09
6	Waves	2.03E+17	J	25889	5.25E+21	3.16E+09
7	Earth cycle	9.94E+16	J	34377	3.42E+21	2.06E+09
INDIGENOUS RENEWABLE ENERGY :						
8	Hydroelectricity	1.95E+16	J	1.59E+05	3.09E+21	1.86E+09
9	Agricultural Production	2.59E+17	J	2.00E+05	5.19E+22	3.12E+10
10	Livestock Production	2.80E+16	J	2.00E+06	5.59E+22	3.37E+10
11	Fisheries Production	8.07E+15	J	2.00E+06	1.61E+22	9.72E+09
12	Fuelwood Production	2.29E+15	J	3.49E+04	7.99E+19	4.82E+07
13	Forest Extraction	8.09E+16	J	3.49E+04	2.82E+21	1.70E+09
NONRENEWABLE SOURCE USE FROM WITHIN SYSTEM :						
14	Coal production	1.31E+17	J	4.00E+04	5.23E+21	3.15E+09
15	Metallic Minerals	6.66E+11	g	8.55E+08	5.70E+20	3.43E+08
16	Inustrial Minerals	1.01E+14	g	1.00E+09	1.01E+23	6.08E+10
17	Top Soil	1.91E+16	J	7.40E+04	1.42E+21	8.53E+08
IMPORTS AND OUTSIDE SOURCES :						
18	Coal	1.44E+18	J	4.00E+04	5.78E+22	3.48E+10
19	Oil, crude	5.48E+18	J	5.30E+04	2.91E+23	1.75E+11
20	Petroleum Products	1.20E+18	J	6.60E+04	7.90E+22	4.76E+10
21	Metallic Minerals	4.08E+13	g	1.00E+09	4.08E+22	2.46E+10
22	Industrial Minerals	5.12E+12	g	1.00E+09	5.12E+21	3.08E+09
23	Natural Gas	6.17E+16	J	4.80E+04	2.96E+21	1.78E+09
24	Goods & Services	1.18E+11	$	1.24E+12	1.46E+23	8.82E+10
EXPORTS :						
25	Goods & Services	1.36E+11	$	1.62E+12	2.21E+23	1.33E+11

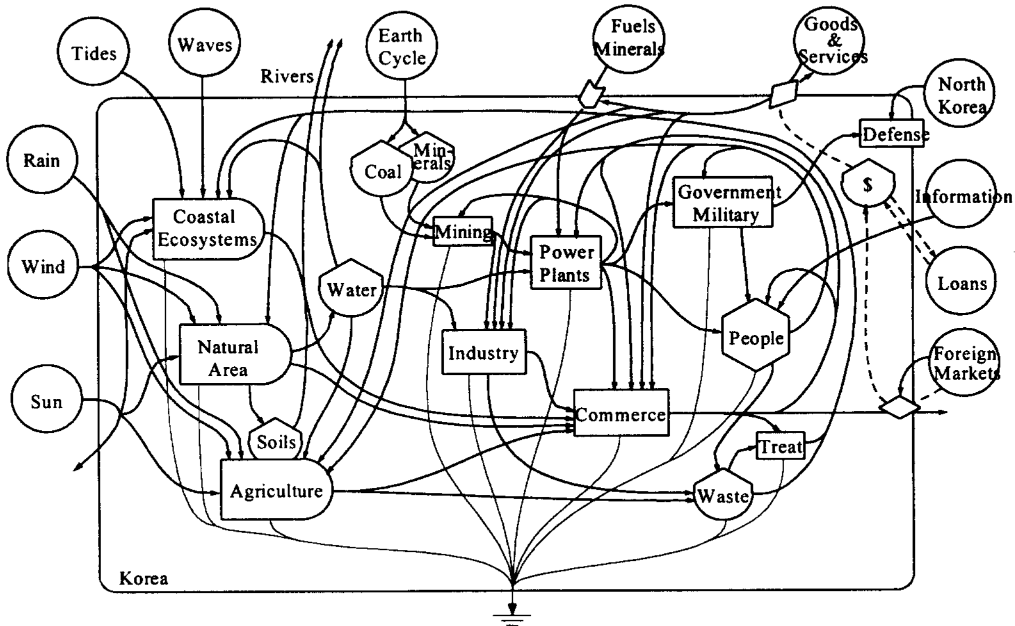

Fig. 1. Energy systems diagram of Korea.

An emergy evaluation of the environmental resources and economy of Korea is presented in Table 1. The chemical potential of rain was the most important renewable resource, whereas agriculture and fisheries were important renewable production entities. The most important indigenous nonrenewable resources were minerals. Crude oil was the most important imported emergy, followed by goods and services.

The emergy evaluation in Table 1 is summarized in Table 2 and Figure 2. Figure 2 aggregates the emergy inputs to the Korean economy into renewable resources(R), nonrenewable resources derived from within Korea(N), and imported fuels, goods, and services(F, P2I). It then aggregates all export flows from the economy into one flow (P1E).

Using the values in Table 2 and Figure 2, overview emergy indices for Korea were calculated as shown in Table 3. The emergy indices for Korea were close to those for other developed countries, thereby reflecting Korea's economic status in the world economy. The total emergy use by the Korean economy in 1997 was 7.69 E23 sej/yr. About 19% of the total emergy use in the Korean economy was derived from within the country, while 81% was imported. This reflects the heavy dependence of the Korean economy on international trade.

Table 2. Summary flows for Korea in 1997

Letter in Figure 2	Item	Numerical value
R	Renewable sources used, sej/yr	3.87E+22
N	Nonrenewable sources flow from within Korea, sej/yr	1.08E+23
F	Imported minerals and fuels, sej/yr	4.76E+23
P2I	Imported goods and services, sej/yr	1.46E+23
I	Dollar paid for imports, $/yr	1.45E+11
E	Dollar paid for exports, $/yr	1.36E+11
P1E	Exported goods and services, sej/yr	2.21E+23
X	Gross national product, $/yr	4.74E+11
P2	Ratio emergy to dollar of imports(sej/$)	1.24E+12
P1	Ratio emergy to dollar within the country and for its exports, sej/$	1.62E+12

Only 5% of the total emergy use was locally renewable.

Even though Korea had a deficit in its balance of payments in 1997, the country had a net emergy surplus from trade. The ratio of imported emergy to exported emergy was 2.82/1.

The emergy yield ratio(EYR) represents the

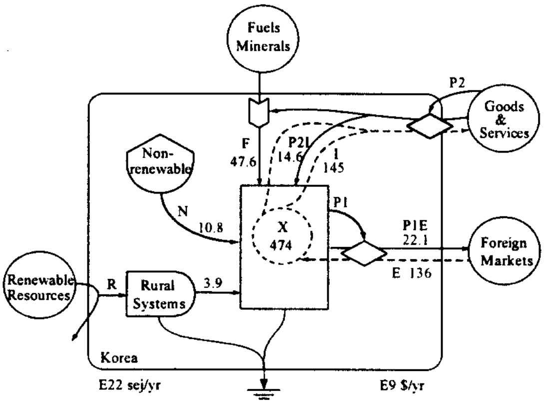

Fig. 2. Summary diagram of emergy flows of Korea in 1997. Emergy flows are in E22 sej/yr, and money flows in E9 $/yr. Letters refer to flows in Table 2.

contribution of emergies purchased from outside to the economy of Korea. In 1997, the Korean economy showed a low EYR(1.24/1), reflecting the heavy dependence of the Korean economy on emergy inputs from outside compared to internal emergy sources.

The emergy use per unit area is usually low in underdeveloped countries and large countries. The annual emergy use per unit area for Korea was very high at 7.74 E12 sej/m^2/yr. This reflects the heavy dependence of the Korean economy on international trade in addition to a very high population density in a small area.

The emergy use per capita may be a better measure for living standards than the per capita GNP, because it takes account of all the emergy sources that contribute to the real wealth of an economy. In 1997, the emergy use per capita for Korea was 1.67 E16 sej/person/yr, approaching those of developed countries. For example, the emergy use per capita for the USA was 2.9 E16 sej/person/yr, and that for Australia was 5.9 E16 sej/person/yr, whereas the emergy use per capita for China was 7.0 E15 sej/person/yr and that for India was 1.0 E15 sej/person/yr[1].

The renewable emergy carrying capacity at the present living standard is the number of people that can be supported by locally renewable emergy. As such, this is a measure of the long-term, sustainable carrying capacity of an economy. In 1997, this was only 2.31 million people or about 5% of the Korean population. The developed carrying capacity, based on the assumption that the development of the Korean economy would be close to that characteristic of developed nations, was 18.5 million people or 40% of the population of Korea in 1997.

The environmental impact of an economic activity can be measured using an environmental loading ratio that is the ratio of nonrenewable emergy(indigenous nonrenewable emergy and purchased emergy from outside) to renewable emergy. High environmental loading ratios suggest greater loading or stress on the environment. The Korean economy imposes a substantial loading on

Table 3. Emergy indices for overview of Korea

Name of Index	Expression	Value
Renewable emergy flow	R	3.87E+22
Flow from indigenous nonrenewable reserves	N	1.08E+23
Flow of imported emergy	F+P2I	6.23E+23
Total emergy inflow	R+N+F+P2I	7.69E+23
Total emergy used	U=N+R+F+P2I	7.69E+23
Total exported emergy	P1E	2.21E+23
Fraction of emergy used derived from home sources	(N+R)/U	0.19
Imports minus exports	(F+P2I)-P1E	4.02E+23
Ratio of imports to exports	(F+P2I)/P1E	2.82
Fraction used, locally renewable	R/U	0.05
Fraction of emergy used purchased(imports)	(F+P2I)/U	0.81
Use per unit area (9.94 E10 m^2)	U/(area)	7.74E+12
Use per capita (4.599 E7 people)	U/(population)	1.67E+16
Renewable carrying capacity at present living standard	(R/U)*(population)	2.31E+06
Developed carrying capacity at present living standard	8(R/U)*(population)	1.85E+07
Emergy to money ratio	P1=U/GNP	1.62E+12
Environmental loading ratio(ELR)	(N+F+P2I)/R	18.89
EmergyYield Ratio (EYR)	U/(F+P2I)	1.24
Sustainability Index (SI)	EYR/ELR	0.07

its environment with an environmental loading ratio of 18.89/1. This is also reflected in the sustainability index, which is the ratio between the emergy yield ratio and the environmental loading ratio. The sustainability index for Korea in 1997 was only 0.07.

3.2. Emergy evaluation of Seoul

Figure 3 is an energy systems diagram of the environment and economy of Seoul. The economy of Seoul is dependent on the interactions of renewable resources(including sun, wind, rain, and the Han river), indigenous nonrenewable resources (such as soil and groundwater), and imported sources from abroad and other regions in Korea (such as fuel, electricity, and goods and services).

Forest and agriculture were the major primary producers for the city of Seoul. Industry and commerce utilized imported goods and services as well as products from forests and agriculture to produce goods and services used within the city and also exported outside the system. The money received from the export of goods and services was used to buy raw materials for the economy of Seoul and support the people and economic structure of Seoul. People living in Seoul participated in the production processes.

Using Figure 3, an emergy evaluation of Seoul was performed in Table 4 based on the emergy evaluation of Korea presented in the previous section. Data on the economic activities in 1997 were used for the emergy evaluation of Seoul.

Table 4. Emergy Flows of Seoul in 1997

No.	Item	Raw Units		Solar Tranfomity (sej/unit)	Solar Emergy (sej/yr)	Macroeconomic value, 1997 US$
RENEWABLE RESOURCES :						
1	Sunlight	1.80E+18	J	1	1.80E+18	1.05E+06
2	Wind, kinetic energy	1.39E+15	J	1496	2.08E+18	1.21E+06
3	Rain, geopotential	1.98E+14	J	10400	2.06E+18	1.19E+06
4	Rain, chemical	1.63E+15	J	15444	2.52E+19	1.46E+07
5	River, geopotential	8.53E+14	J	27874	2.38E+19	1.38E+07
6	River, chemical	7.13E+16	J	48459	3.46E+21	2.01E+09
INDIGENOUS RENEWABLE ENERGY :						
7	Agricultural Production	5.49E+14	J	2.00E+05	1.10E+20	6.38E+07
8	Livestock Production	1.04E+12	J	2.00E+06	2.08E+18	1.21E+06
NONRENEWABLE SOURCE USE FROM WITHIN SYSTEM :						
9	Groundwater	2.21E+14	J	4.10E+04	9.07E+18	5.28E+06
10	Top Soil	4.10E+13	J	7.40E+04	3.04E+18	1.77E+06
IMPORTS AND OUTSIDE SOURCES :						
11	Coal	8.47E+15	J	4.00E+04	3.39E+20	1.97E+08
12	Oil	6.12E+17	J	5.30E+04	3.24E+22	1.88E+10
13	Natural Gas	1.61E+17	J	4.80E+04	7.71E+21	4.48E+09
14	Electricity	9.15E+16	J	2.00E+05	1.83E+22	1.06E+10
15	Goods & Services	4.96E+10	$		6.44E+22	3.74E+10
	Other countries	4.22E+10	$	1.24E+12	5.23E+22	3.04E+10
	Other parts of Korea	6.39E+09	$	1.62E+12	1.04E+22	6.03E+09
	National benefit to Seoul	1.02E+09	$	1.62E+12	1.66E+21	9.63E+08
EXPORTS						
16	Goods & Services	5.97E+10	$	1.83E+12	1.09E+23	6.35E+10

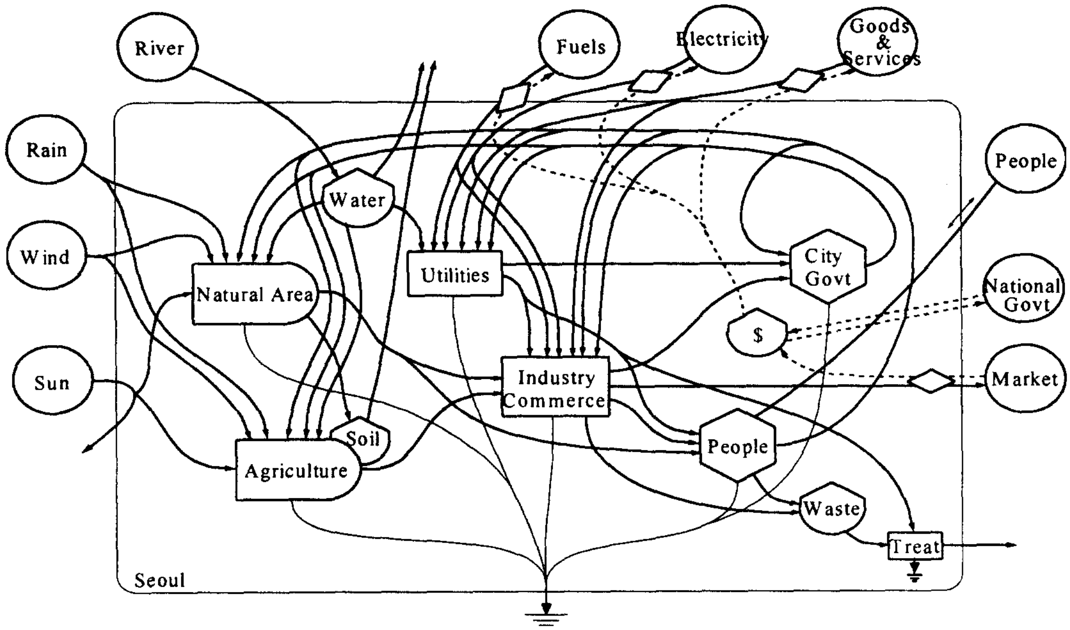

Fig. 3. Energy systems diagram of Seoul.

Unlike the emergy evaluation of the entire country, the import and export emergies included both international trade and trade with other parts of Korea. Data on international trade was obtained from statistical references, however these sources did not include trade data between different parts of Korea. Therefore, the trade between Seoul and other parts of Korea was calculated using the percentage of employees in each economic sector of Seoul out of the total number of employees in the same sector throughout Korea[20].

In 1997, the total emergy use by the economy of Seoul was 1.27 E23 sej/yr. The chemical potential of the Han river was the most important renewable emergy source, contributing 3.46 E21 sej/yr, followed by the geopotential of the Han river and the chemical potential of rain. The indigenous nonrenewable emergy sources included groundwater and soil with a higher emergy contribution from groundwater. The emergy purchased from outside included goods and services, petroleum products, and electricity.

The emergy flows supporting the economy of Seoul are summarized in Figure 4, where the emergy inflows are classified into purchased fuels and electricity from outside(F), purchased goods and services from outside(P2I), indigenous renewable sources(R), and indigenous nonrenewable sources(N). To avoid any double counting, the chemical potential of the river water and rain was only included in the emergy contribution of renewable sources to the economy of Seoul. The data in Figure 4 are tabulated in Table 5.

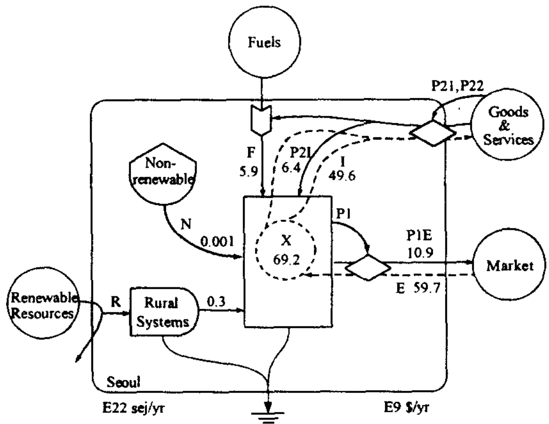

Fig. 4. Summary diagram of emergy flows of Seoul in 1997. Emergy flows are in E22 sej/yr, and money flows in E9 $/yr. Letters refer to flows in Table 5.

Using the data in Figure 4 and Table 5, emergy indices were calculated for Seoul, as presented in

Table 5. Summary flows for Seoul in 1997

Letter in Figure 4	Item	Numerical value
R	Renewable sources used, sej/yr	3.48E+21
N	Nonrenewable sources flow from within Seoul, sej/yr	1.21E+19
F	Imported minerals, fuels, and electricity, sej/yr	5.88E+22
P2I	Imported goods and services, sej/yr	6.44E+22
I	Dollar paid for imports, $/yr	4.96E+10
E	Dollar paid for exports, $/yr	5.97E+10
P1E	Exported goods and services, sej/yr	1.09E+23
X	Gross regional domestic product, $/yr	6.92E+10
P21	Ratio of emergy to dollar of imports from abroad, sej/$	1.24E+12
P22	Ratio of emergy to dollar of imports from other parts of Korea, sej/$	1.62E+12
P1	Ratio of emergy to dollar within Seoul and for its exports, sej/$	1.83E+12

Table 6. The emergy-money ratio for Seoul was 1.83 E12 sej/$. This was higher than that for Korea, as presented in the previous section, yet similar to that for Pusan[18].

The internal emergy sources(R and N in Figure 4) in Seoul contributed only 3% of the total emergy use in 1997, whereas the inputs purchased from outside(P2I) contributed most of the emergy use (97%). The ratio of the emergy inflows to the outflows for Seoul was 1.13/1, thereby indicating an emergy surplus for the economy of Seoul in 1997, similar to the Korean economy.

The emergy yield ratio(EYR) of the economy of Seoul was 1.03, reflecting the fact that the economy of Seoul had to purchase most energies and materials from outside as the internal emergy contribution was only 3% of the total emergy use. This was also reflected in the emergy investment ratio(36.3), that is the ratio of purchased emergy from outside (F+P2I in Figure 4) to internal emergy contributions(R+N).

The emergy use per unit area for Seoul was 2.09 E14 sej/m^2/yr, which was much higher than

Table 6. Emergy indices for overview of Seoul

Name of Index	Expression	Value
Renewable emergy flow	R	3.48E+21
Flow from indigenous nonrenewable reserves	N	1.21E+19
Flow of imported emergy	F+P2I	1.23E+23
Total emergy inflow	R+N+F+P2I	1.27E+23
Total emergy used	U=N+R+F+P2I	1.27E+23
Total exported emergy	P1E	1.09E+23
Fraction of emergy used derived from home sources	(N+R)/U	0.03
Imports minus exports	(F+P2I)-P1E	1.39E+22
Ratio of imports to exports	(F+P2I)/P1E	1.13
Fraction used, locally renewable	R/U	0.03
Fraction of emergy used purchased(imports)	(F+P2I)/U	0.97
Use per unit area (6.06 E8 m^2)	U/(area)	2.09E+14
Use per capita (1.04 E7 people)	U/(population)	1.22E+16
Renewable carrying capacity at present living standard	(R/U)*(population)	2.86E+05
Developed carrying capacity at present living standard	8(R/U)*(population)	2.29E+06
Emergy to money ratio	P1=U/GRDP	1.83E+12
Environmental loading ratio(ELR)	(N+F+P2I)/R	35.36
EmergyYield Ratio(EYR)	U/(F+P2I)	1.03
Sustainability Index (SI)	EYR/ELR	0.03

that for Korea (7.74 E12 sej/m^2/yr), and also higher than that for Pusan[18] (7.08 E13 sej/m^2/yr in 1995). This reflects the fact that about one fourth of the Korean population lives within the rather limited city area of Seoul and most major economic activities in Korea are concentrated in this city.

In 1997, the emergy use per capita for Seoul was 1.22 E16 sej/person/yr, which was lower than those for Korea (1.67 E16 sej/preson/yr) and Pusan(1.36 E16 sej/person/yr in 1995). The high emergy use per unit area, yet low emergy use per capita seems to underscore the overpopulation of Seoul.

The renewable emergy carrying capacity at a present living standard for Seoul was only 286,000 people or about 2.8% of the population(10.4 million people) of Seoul in 1997. The developed carrying capacity was 2.29 million people, 22% of the population of Seoul in 1997. These indices indicate that the population of Seoul has already exceeded the carrying capacity that can be supported by its environment.

4. Conclusion

To perform an emergy evaluation of the environment and economy of Seoul, an emergy evaluation of Korea was conducted first. The total emergy use by the Korean economy in 1997 was 7.69 E23 sej/yr, with 81% of emergy being purchased from other countries. Even though Korea had a deficit in its balance of payments in 1997, the country had a net emergy surplus from trade. Korea had a high emergy use per unit area(7.74 E12 sej/m^2/yr) due to a small area and heavy dependence on trade with foreign countries. The emergy use per capita for Korea(1.67 E16 sej/person/yr) approached those for other developed countries. The renewable carrying capacity of Korea was 2.31 million people and the developed carrying capacity was 18.5 million people, thereby indicating that the current population of Korea is over the carrying capacity that its environment can support. The environmental loading ratio and sustainability index also showed that the Korean economy imposes a great stress on its environment.

The emergy evaluation of the environment and economy of Seoul, based on that of Korea, revealed that the economy of Seoul used 1.27 E23 sej/yr of emergy in 1997. The emergy input from the Han River accounted for most of the renewable emergy inflows. The purchased emergy inputs to the economy of Seoul accounted for 97% of the total emergy use in 1997, indicating a higher dependence of the economy of Seoul on outside emergy sources. The emergy use per unit area was much higher than those for Korea and Pusan, whereas the emergy use per capita was lower than those for Korea and Pusan. This indicates overpopulation and thus a lower standard of living for the people in Seoul in terms of emergy. The renewable carrying capacity was 286,000 people and the developed carrying capacity was 2.29 million people, thereby indicating that the polulation of Seoul is already over the carrying capacity of its environment. The quality of living in Seoul was also reflected in a high environmental loading ratio and a low sustainability index. As such, people in Seoul are living in an environment that is under very high stress compared to the average for the entire country.

These results may provide insights for policies of the economy and population of Seoul. Since Seoul has a population above the level that the surrounding environment can support, policies are needed to reduce rate of population increase and particularly control the population concentration in this city. The population of Seoul is already above its carrying capacity, therefore the establishment and implementation of policies that can manage and utilize environmental resources more efficiently are urgently needed. Emergy indices, such as the environmental loading ratio and sustainability index, could be calculated for alternative policies to help determine those with less environmental stress. The concentration of economic activities in Seoul also needs to be solved. The over-concentration of economic activities in Seoul imposes a great stress on the environment in this city and adjacent areas, thereby decreasing the quality of life for Seoul residents.

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