Abstract

Emergy (i.e., embodied energy) is defined as an energy term involving all the energy of one kind previously used up directly and indirectly in making a product or service in energy transfer processes, and the emergy value corresponds to how many solar-energy units are used to create a product that is degraded in energy transformation processes. Non-emergy approaches to the evaluation of ecological, sociopolitical-economic, and industrial processes most often evaluate only non-renewable resources depending on what human technologies are able to extract from them. The environment service is of non-monetary flow, and it is free and usually omitted from an economic assessment model. But it can be included easily in the emergy accounting framework. Emergy synthesis measures material, energy, commodity or money flows. It can easily quantify the value of both energy and material resources to humans and non-human systems within a common framework.

Historically most of the economist just simply used the economic method to evaluate the material and energy flows; they ignore the important ecological function of the natural ecosystems. If the economic activities are only quantified in terms of ecological approach, it is also dissatisfied. The emergy synthesis has evidently advantages comparing to the single ecological or economical methods and linking them together. In this study, we attempt to employ the emergy synthesis method to address the development rules of Macao in the past 30 years.

The emergy indicators show in 2004, the non-renewable environmental resources (N) of Macao was 3.60 $\times 10^{20}$ sej, and the renewable resources has the emergy of only 2.71×10^{19}sej, the emergy used (U) for Macao was 245.2×10^{20}sej, and the imported emergy (F) was 241.3×10^{20}sej, while the exported emergy (Y) was 136.3×10^{20}sej. The mainly trend of emergy flows increased with the urban evolution from 1983 to 2004. There was an evidence peak in around 1993 while Macao reclaiming the land and importing large amount of the sands and stone, thereby drawn up the imported emergy. But the monetary measuring could not appear the obviously peak that implied the emergy more exactly than the money term in measuring the materials flow. The

correlation analysis showed that most of the indicators relative to tourism increased accompanying the development of Macao, except for the *Em/$* ratio. The *Em/$* ratio declined from 8.76×10^{12} sej/$ in 1983 to 2.38×10^{12} sej/$ in 2004, which is because the money flows of the economy rose more quickly than the emergy flow of the natural resource from 1983 to 2004.

Brown and Ulgiati (1997) proposed an accepted equation, $Y=F+N+R$. Brown and Ulgiati (2001) proposed that the sustainable development is related to positive net emergy, and the sustainability is suggested to be relative with the emergy trade balance. The term of "net emergy" appeared from Odum (1996), Brown and Ulgiati (1997) expanded the concept to a system. If the development is sustainable, the net emergy (*NE*) of the system must be positive in the long run. Because high net emergy ratio may capture too much resource in the outer systems, and injure its life support systems, a lower positive net emergy ratio (*NER*) is better for systems than a higher one from the sustainable principle of the large scope regions.

Combining with the net emergy concept we proposed a reasonable equation, i.e, $NE = F+R-Y$, to measure the net emergy, here N was excluded in the equation because N is only used inside the boundary of the system and could not change the inner emergy storage, nevertheless F and R came from the outer boundary.

The researches in Italy, Sweden and Guangzhou have testified that the time series emergy synthesis is a good approach to depict the change and development of region's sustainability (Lei and Wang, 2008).The time series emergy synthesis have shown that there is a yearly positive net emergy in the ecological economic systems of Macao. The net emergy of Macao is originated mainly from two processes: 1) exchanging material and service with Macao's trading partner; the biggest net emergy came from China; 2) exchanging between Macao's tourism industry and the enormous tourists. The net emergy increased from 21.8×10^{20} sej of 1983, reaching its peak of 110.5×10^{20} sej of 1993, and increasing continuously to 63.6×10^{20} sej of 2004.

After 2000, emergy analysis has been used to analyze tourism (Brown and Ulgiati, 2001; Abel T., 2003). According to the published papers of tourism field in the last decade, most authors treat the emergy of tourism monetary incomes as a kind of outer

investment to the tour region, this treatment seems not reasonable in emergy synthesis. In Macao a large quantity of money is used to purchase fuels, goods, and services from the outer systems and that has be accounted as the imported emergy, so the money paid by tourists should not be accounted in U without double counting. We believe that tourism should be treated as another "export" industry, with goods and services leaving host region and going to "Tourists". By now the previous calculating method was just suitable for tour resort or island with few local people. But Macao is an international tourist's destination with dense population. Therefore, different calculating method must be devised. We proposed two promoting approaches to address the emergy of tourist industry in Macao:

1) The imported life-support resources were shared by local residents and tourists, based on the estimating that tourists' consumption (M_t) could be measured as a definite proportion of the emergy used (U), the equation $M_t = R_t U$ was proposed, where R_t expresses the proportion of the emergy consumption by tourists in a systems, and it can be deduced from large statistical data and by a serious survey.
2) Distinguishing the emergy that the tourist consumption (M_t) against the equivalent emergy that tourists spend (T_m). They flow in opposite direction and have very different values, and previous researcher usually confused these two conceptions.

The tourism emergy (T_m) increased from 11.1×10^{20} sej in 1983 to 134.6×10^{20} sej in 2004. During the same period, tourist consumption (M_t) increased from 9.56×10^{20} sej to 42.6×10^{20} sej. Tourism net emergy was small between 1983 (1.5×10^{20} sej) and 1988 (0.63×10^{20} sej), then rose quickly to 42.4×10^{20} sej in 1997, and finally increased to a peak of 92.0×10^{20} sej in 2004. Emergy exchange ratio *(EER)* is the ratio of emergy received to emergy given in exchanging processes, and always expressed relative to one or the two trading partners and is a measuring indicator of the relative trade advantage of one partner over the other (Odum, 1996). In a tourism-dominated city such as Macao, the emergy contribution and the impacts correlated to tourists should be seriously studied; we thought *EER* is a good indicator to address this issue. In 2004, the emergy exchange ratio for Macao's tourism was 3.16. Which depicted that a tourists will consume only partly of his spend.

We also found that the result of emergy accounting for tourist's spending was different from that of the conventional money accounting, and usually occupied a lower percentage. The percentage of GDP accounted for by tourism was 78.6 percent in 2004. But in emergy basis the percentage of the tourism in the emergy used (U) was only 54.9 percent. The proportions of tourism income were higher in monetary terms than that on emergy terms; This is because the environmental resource has been fully accounted for in emergy synthesis so widening the accounting denominator. These two percentages steadily increased from 1983 to 2004 except 1997 to 1999. In Macao tourism earned the equivalent emergy to 39.4 percent of the emergy used in 2004.

Since 1992 Macao's municipal solid waste (MSW) have been incinerating to reduce the volume. And since 1997 municipal wastewater has also been treating with the biological treatment process so as to decrease the environmental damages for the surrounding sea. If we consider wastes to be byproducts of all activities, wastes will contain all the emergy used for the generation of these resources. The emergy in wastes totaled 49.7×10^{20} sej, which amounts to nearly 20.3 percent of the emergy used by Macao in 2004.

An important concept in emergy analysis is Solar Transformity, defined as the solar energy required in making 1 J of a service or product. Following the collecting, transferring and the incinerating procedures of the solid wastes, the emergy of the emission gaseous (47.6×10^{20} sej) was calculated by adding the service and the input of the energy. It has been calculated that the transformity was 3.79×10^{6} sej/J for discharged sewage, 5.11×10^{11} sej/g for fly ash, and 6.01×10^{10} sej/g for slag in wastes treatment process of 2004 in Macao.

Our analysis also found the emergy input for the treatment of wastes: 1)was just a small portion comparing to its embodied emergy, 2) it can decreased the environmental impact while increasing its transformity. High transformity indicates a high potential environmental impact (Odum, 1996); it implies that Odum's conclusion is suitable only for production and assimilation processes but not for the waste treatment or dissimilation processes.