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Environmental Effect Estimation of a New Technology Using Total Material Requirement

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It is required for engineers not only to develop a new environmentally conscious technology but also to argue its benefits on the environment. Thus, a basis to represent its benefits on the environment is needed. Though several researches on methods to estimate environment effects have been carried out, selecting appropriate indicators to represent environment effects of technologies especially for material processing has been a research issue. This paper explains how environmental effect estimation is achieved using TMR (Total Material Requirement) concept, describes estimations of two specific new technologies, and discusses the merits and the problems to be solved.

Key words: resource productivity, TMR, environmental effect, effect estimation

1. INTRODUCTION

Over a couple of decades, environmental problems originating from the mass production paradigm widespread in industrialized countries during the last century have been quite serious. Thus, it is indispensable for mankind to keep the balance of material and energy between the humanosphere and the biosphere within global limits by increasing *resource productivity* [1] (See Fig. 1).

On the other hand, in order to tackle the environmental problems, systematic combination of technologies, economic systems, and policies is essential. Therefore, it is crucial for engineers not only to develop a new environmentally conscious technology but also to argue quantitative effects on the environment obtained by applying a new technology under research and development to our society in the near future. Thus, a basis to communicate their benefits along with quantitative effects on the environment is needed.

A promising index for representing the quantitative effects in case that *resource productivity* is focused is *Total Material Requirement* (TMR). Since TMR represents the total amount of materials that are required to move or disturb in order to manufacture a certain product, it is effective for evaluation from the viewpoint of *resource productivity*. Several researches to obtain an environmental profile using TMR have been carried out. For instance, the World Resource Institute [2] have estimated TMR of economic activities originating from four countries including Japan. Also, Wuppertal Institute for Climate, Environment, and Energy have [3] analyzed relations between TMR and economic growth of several countries. However, an effect estimation of new technologies adopting TMR is not seen so far.

This paper aims at demonstrating a TMR concept is effective for environmental effect estimation for material processing technologies. To do so, environmental effect estimation of two new technologies is carried out using TMR.

The rest of this paper consists of the followings. Section 2 explains how environmental effect estimation is achieved using a TMR concept, and Section 3 describes estimations of two specific technologies for material processing. Section 4 makes discussions, and Section 5 concludes the paper.

2. THE METHOD

2.1 TMR

TMR is defined as follows in [2].

$$TMR=S(DMI)+S(IMI)+S(HMF) \qquad (1)$$

DMI (*Direct Material Input*) and IMI (*Indirect Material Input*) are the amounts that enter the industrial economy directly and indirectly, respectively. These together are called *commodity materials flow*. HMF (*Hidden Material Flow*), which is a concept indispensable with TMR, is an amount of materials removed or disturbed along with economic activities but not included in *commodity materials flow*. For instance, HMF includes an amount of rocks and plants removed on mining.

LCA (Life Cycle Assessment), which is one of the most recognized methods to assess environmental impacts, is not essentially replaced with TMR. However, TMR is expected to be a main stressor in LCA. One reason is that TMR has the possibility to represent the potentiality of the environmental effects.

Fig. 2 depicts how TMR for steel is obtained [4]. Thick-framed boxes and boxes framed with broken lines denote DMI and HMF, respectively. Others belong to IMI.

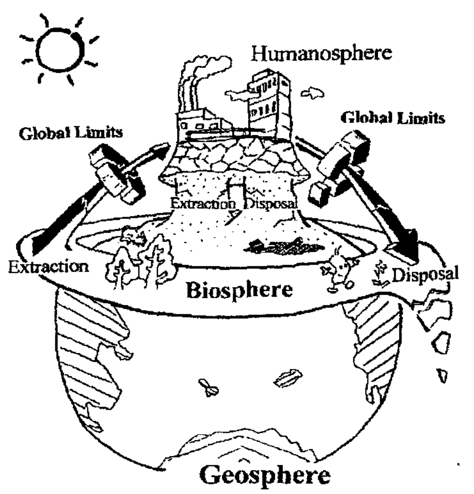

Fig. 1 The relation of the biosphere and the humanosphere [1]

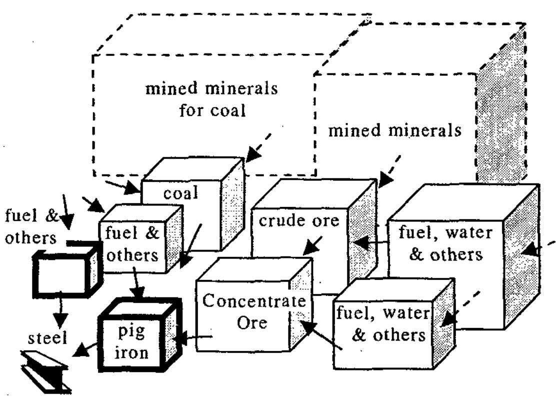

Fig. 2 Calculation of TMR for steel (modified from [4])

2.2 Application of TMR to effect estimation of new technologies

First, the followings are decided; a) temporal point of effect, and b) a scenario on which the technology is applied including a target product and the amount of demand for the product. Second, the life cycles for the product, one of which is in the case the technology would be applied and the other of which is in the case the technology is not applied, are assumed. Third, the difference between the sums of TMR on the two life cycles is obtained. This is depicted by Fig. 3. Note that TMR_{mt}, TMR_{mf}, TMR_{us}, TMR_{dp}, and TMR_{rc} denote TMR of the materials and energies required at the stage of material production, production, usage, waste processing, and recycling, respectively. Also, r means a recycle rate. The sum of TMR on a life cycle, TMR_{lc}, is obtained by the equation (2).

$$TMR_{lc} = TMR_{mt} + TMR_{mf} + TMR_{us} + TMR_{dp} + TMR_{rc} \quad (2)$$

The effect of the new technology is defined by the equation (3). Note that TMR_{lc}(tr) and TMR_{lc} (nw) represent TMR_{lc} in the cases that the technology would be applied and that it is not applied, respectively.

$$\text{(Effect of the new technology)} = TMR_{lc}(\text{tr}) - TMR_{lc}(\text{nw}) \quad (3)$$

Methods enough to assess the impacts of wastes have not been developed so far especially in the field of LCA. This research adopts the method to add the TMR needed for returning the wastes to the biosphere through detoxification.

2.3 Adopted TMR values

Table I shows the values of TMR adopted for the case studies described in Section 3. Note that TMR for iron ore, cupper ore, coal, and oil includes only that for the mining process. TMR for wood is estimated from the ratios of product per felled tree [5] and that per wasted tree and grass [6]. TMR for the electricity in Japan is an average of the multiple means for electricity generation in Japan. TMR for unidentified wastes is TMR for the energy required to process them so that they can be released to the biosphere after detoxification.

Table I Adopted TMR values

Item	Value	Unit	Source
Iron Ore	5.1	[t/t]	[4]
Cupper Ore	300.0	[t/t]	[4]
Wood	5.0	[t/t]	[5, 6]
Coal	12.4	[t/t]	[4]
Oil	9.3	[t/t]	[7]
Electricity in Japan	0.49	[kg/MJ]	[8]
Unidentified Wastes	15.0	[t/t]	[9]

3. CASE STUDIES

3.1 A positive use of Cu contaminants in iron scraps

This technology is for forming Fe-Cu alloy without

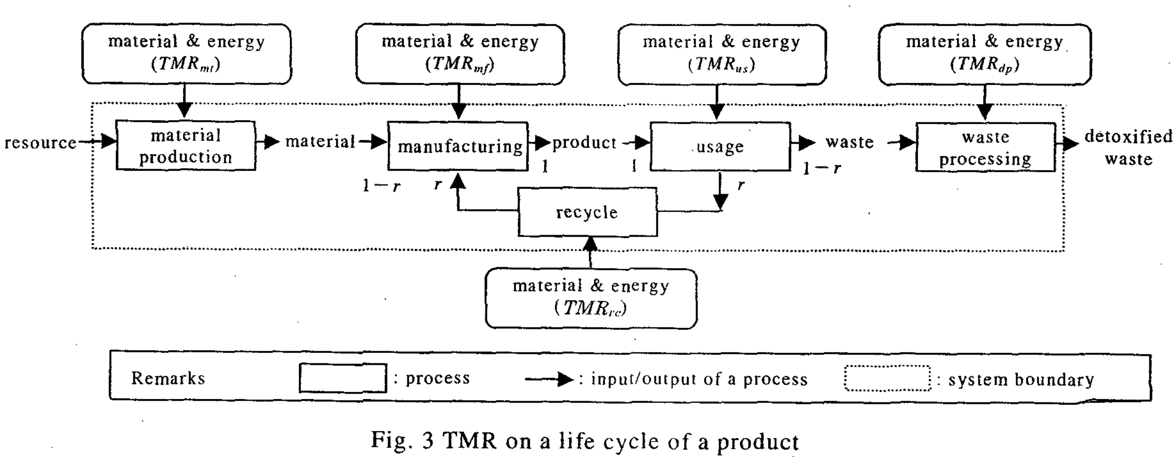

Fig. 3 TMR on a life cycle of a product

the effect of Cu using atomizing process [10]. Some portions of scraps from automobiles are unable to be recycled, since they contain a high content of Cu. This technology is useful for recycling those scraps.

The applied product is an Fe-based mechanical part for such as automobiles and motorbikes, which is now produced by powder sintering in Japan. In the year 2010 in the given scenario, the technology would be applied to all the parts above produced in Japan, while they will be manufactured from virgin materials without the technology.

The TMR for the life cycles with/without the technology are shown in Fig. 4. Note that black rectangle nodes denote that TMR was calculated for the stage, and white ones denote that TMR was not calculated because of no difference between the two cases. Arrows for TMR directed horizontally mean that they are energy oriented, while those directed vertically are for materials. The demand for the product was set to be 66 [kt/yr]. The energies required at the material production stage without the technology and the recycle stage with the technology are obtained from a literature

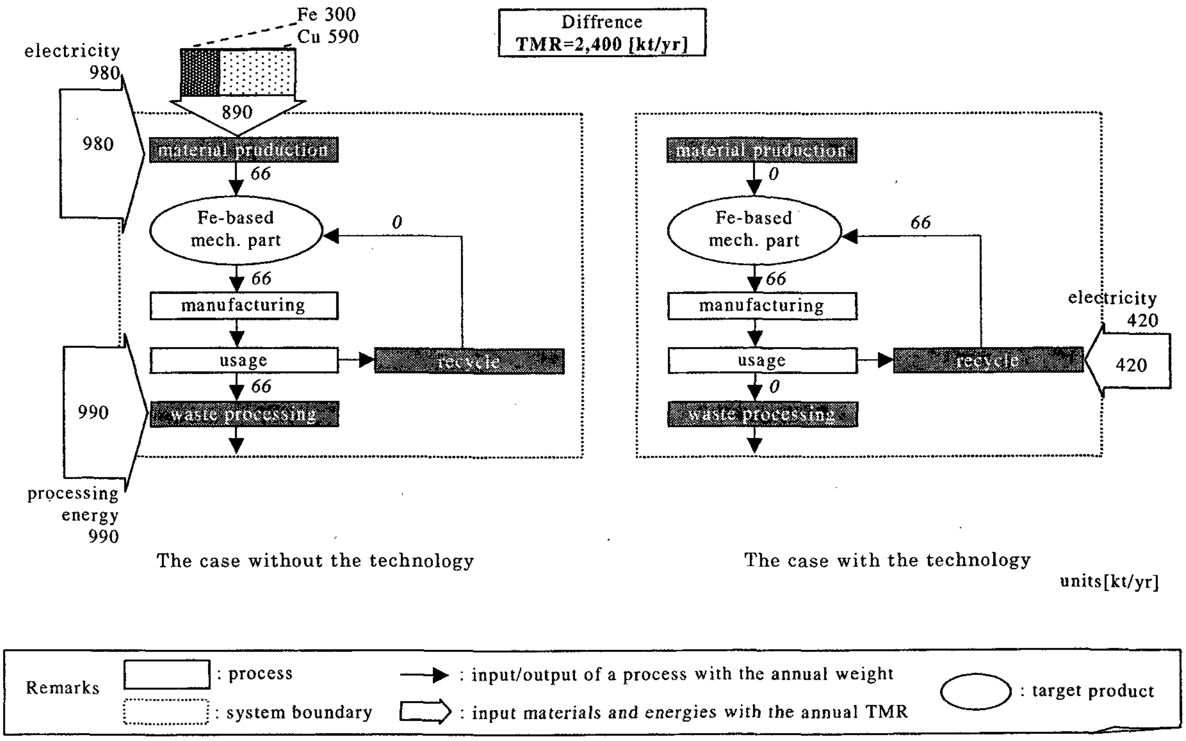

Fig. 4 Effect of the scraps processing technology

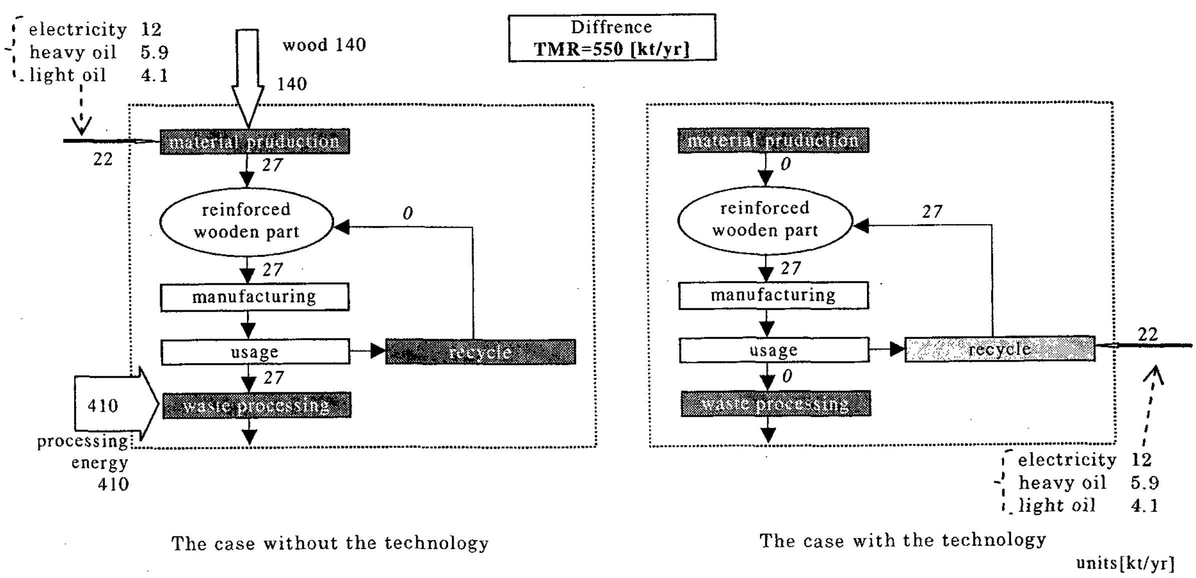

Fig. 5 Effect of the wood wastes processing technology

[11]. The weight ratios of Fe and Cu in the product were set to be 0.9 and 0.03, respectively. TMR required at the waste processing stage without the technology was obtained by applying TMR for processing unidentified wastes. This means the worst case is assumed.

3.2 Producing long-lived and recyclable wooden blocks from wood wastes

This technology is for forming wooden blocks at low temperature and high pressure from wood wastes [12]. Products of this technology are superior in hardness, strength, life time, appearance and recyclability than traditional wooden blocks.

The applied product is a plate shaped part of buildings. In the year 2010 in the given scenario, the technology would be applied to all the parts above in Japan, while they will be manufactured from virgin woods without the technology.

The TMR for the life cycles with/without the technology are shown in Fig. 5. Note that grey rectangle nodes denote that TMR was not calculated but a similar process was substituted for that. The demand for the product was set to weigh 27 [kt/yr]. The energies required at the material production stage without the technology were calculated by prorating the energies for all the wooden boards manufactured in Japan, whose supply amount is $7.8 * 10^4$ [t/yr], according to their supply amounts. Note that all the energies in Japan required for manufacturing wooden boards are $2.0 * 10^7$ [kWh/yr] of electricity, $2.3 * 10^3$ [kl/yr] of heavy oil and, $1.6 * 10^3$ [kl/yr] of light oil [13]. The energies required at the recycle stage with the technology were assumed to be the same as the above because of the data unavailability. TMR required at the waste processing stage without the technology was obtained in the same way as the technology in Section 3.1.

4. DISCUSSIONS

Through the cases in Section 3, a TMR concept was demonstrated to be effective on the following points for environmental effect estimation.

1) representing the relation between the biosphere and the humanosphere

TMR accounts for the amount of the effected part in the entire resource in the biosphere, whose amount is apparently limited. Therefore, it is effective to represent the relation between the biosphere and the humanosphere.

2) contributing to communication with simple information

Since a TMR concept is represented by a one-dimensional parameter, the effect estimation results using TMR can be communicated with simple information. Deriving an environmental impact for wastes by summing TMR for the detoxification energy as described in Section 2.2 contributes to the simple representation. It is also desired that the language for communication among engineers, industry decision makers, and policy makers does not include values of the evaluators, because their values may vary. Thus TMR can work effectively as a parameter describing the results from effect estimation.

In spite of the benefits above, effect estimation with TMR has drawbacks. One of the biggest problems is on their data availability. In the case studies shown in Section 3, TMR for limited processes were summed. For instance, only the mining processes were covered to obtain TMR for steel. Constructing a database for TMR is expected.

5. CONCLUSIONS

This paper demonstrated how environmental effect estimation is achieved using a TMR concept through two specific new technologies, and discussed the merits. Future works include carrying out the effect estimation on more cases for further verification of the method and constructing a database for TMR.

6. ACKNOWLEDGEMENTS

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