Improved emergy indices for the evaluation of industrial systems incorporating waste management

Hanfeng Mu, Xiao Feng, Khim Hoong Chu

Abstract

Emergy analysis is able to account for ecosystems’ contribution to industrial activity. Accordingly, it is an ecologically conscious tool useful for assessing the environmental impact and sustainability of industrial systems. The emergy-based approach requires proper system boundary definitions and uses several standard indices. In this article some perspectives on the deficiencies of three standard emergy indicators – environmental loading ratio (ELR), emergy yield ratio (EYR) and emergy index of sustainability (EIS) – when applied to industrial systems involving waste management are put forward and suggestions for overcoming them given. In addition, in order to account for the impact of waste emissions on the environment, a simple impact amplification factor is proposed for inclusion in the improved emergy indicators. To demonstrate their usefulness and highlight their superiority over standard indices, the improved emergy indicators are used to evaluate the interaction between a commercial polyethylene production process incorporating waste management and its surrounding environment.

1. Introduction

Various procedural or analytical tools are available for assessing the environmental impact and sustainability of industrial systems. Examples include life cycle assessment (LCA) (Heijungs et al., 1992), exergy analysis (Erlkman, 1997) and emergy analysis (Odum, 1988). The last-mentioned tool is especially appealing due to its ability to compare different qualities and types of energy or material in terms of a common energetic basis and take account of the contribution of ecosystems to economic activity. Emergy is the amount of available energy in units of one type of energy (usually solar energy) that is required, directly or indirectly, to provide a given flow or storage of energy or matter (Odum, 1988, 1996). Many commonly used analytical tools overlook the critical role that nature’s products and services play in supporting industrial activities (Hau and Bakshi, 2004a). The utilities of these analytical tools may be enhanced if they can be integrated with emergy analysis. For example, attempts have been made to amalgamate emergy analysis with LCA (Pizzigallo et al., 2008), exergy analysis (Hau and Bakshi, 2004b), and pinch analysis (Zhelev, 2007; Zhelev and Ridolfi, 2006).

Emergy analysis was originally proposed by ecologist H.T. Odum (Odum, 1988). Recent publications on emergy analysis describe applications to a wide variety of man-made systems including wastewater treatment (Björklund et al., 2001; Geber and Björklund, 2002; Grönlund et al., 2004; Zhou et al., 2009), electricity production (Brown and Ugliati, 2002), coal processing (Yang et al., 2003), industrial ecosystem and eco-industrial park (Singh and Lou, 2006; Wang et al., 2005, 2006), polyvinyl chloride production (Cao and Feng, 2007), vinyl acetate production (Cao and Feng, 2008), waste management (Cherubini et al., 2008; Marchettini et al., 2007; Zhang et al., 2010) and steel production (Zhang et al., 2009).

Several emergy-based indicators (e.g., emergy yield ratio (EYR), environmental loading ratio (ELR), and emergy index of sustainability (EIS)) have been proposed to analyze and quantify the economic and ecological feasibility as well as sustainability of a system (Brown and Ugliati, 1997; Odum and Peterson, 1996; Ugliati et al., 1995). Because these indicators can reflect the structure, function and efficiency of a complex system and quantitatively analyze the relationship between human and nature, they can be applied to structure the system for better coordination between human, natural resources, and the economy (An et al., 1998; Lan and Qin, 2001; Lu et al., 2005). However, several perspectives on possible inherent weaknesses and inadequacies of traditional emergy analysis and emergy-based indicators in the evaluation of industrial systems have recently been put forward (Yang et al., 2003; Lou et al., 2004). It appears that applying emergy analysis to industrial systems...
systems will require an alternative approach. Some progress in this direction has already been achieved.

As pointed out by Bakshi (2002), one inadequacy is that traditional emergy analysis ignores waste management which is an integral feature of many industrial systems. Although generally attractive, the alternative approach advocated by Bakshi (2002) is somewhat complicated as it requires a joint analysis of emergy and other concepts such as exergy and LCA in order to take into account the impacts of waste management investment and emissions. Ulgiati and Brown (2002) and Vassallo et al. (2009) adopted broad system boundaries in their emergy analyses to incorporate waste management and emissions considerations. However, if the analysis boundary is too broad, the assessment may pose significant demands on data requirements.

Another concern arises from the fact that the emergy of renewable resources (R), a component of the total emergy input, is usually very small or even close to zero for many industrial systems incorporating waste management (Yang et al., 2003). This makes some traditional emergy indicators unrealistically large or small, depending on whether R appears in the numerator or the denominator of the indicator. Consequently, alternative indicators have been proposed for analyzing industrial systems incorporating waste management (Yang et al., 2003; Lou et al., 2004). However, one deficiency of these newly developed indicators is that the recycling of wastes is treated as inputs, resulting in double counting. Remedial methods to dispel this misconception in energy calculation has been addressed elsewhere (Cao and Feng, 2008). A comprehensive exposition of double counting in emergy analysis is available elsewhere (Brown and Herendeen, 1996).

The few initiatives, mentioned above, to develop new indicators capable of analyzing industrial systems involving waste management offer a way forward to the greater understanding of emergy analysis but the quest for indicators with general applicability remains a challenge. The previously proposed indicators, which emphasize the importance of extending and strengthening the traditional indicators, therefore merit further development. The principal contribution of this paper is the formulation of a new set of conceptually and intuitively sound indicators predicated on routinely used energy-based indices for the energy analysis of industrial systems incorporating waste management. The utilities of these newly developed indicators are illustrated by the emergy analysis of a polyethylene production process that is coupled to a waste management system providing treated waste for discharge, reuse and sale as a commercial product.

2. Industrial system boundary definition

Industrial system exploits non-renewable resources and/or renewable resources from nature, processing these resources using goods and services purchased from the economy before putting them on the market. The system boundary should be determined first when evaluating an industrial system of interest. Evaluation methods based on traditional emergy analysis never or rarely consider waste management and emissions. Selecting appropriate system boundary requires careful consideration of the impact of waste emissions on the environment. For example, SO₂ emissions from industrial systems can generate acid rain, which not only has an adverse effect on human health but also results in the death of forests and soil and lake acidification. However, emission impact of this type is beyond the control of a business enterprise or industrial park, it should therefore be considered at a higher level.

Fig. 1 depicts an emergy flow diagram of an industrial–environment complex system. A description of the symbols in Fig. 1 is given in Appendix A. In Fig. 1, the solid lines denote emergy flow while the dotted lines signify money flow. It can be seen that a waste management system is located outside the industrial system boundary. The fates of treated waste depicted in Fig. 1, loosely based on those advocated by Lou et al. (2004), are as follows: treated waste meeting the discharge limits is emitted to the environment, treated waste meeting the criteria for reuse is returned to the industrial system, and treated waste meeting the criteria for sale is sold in the market.

It should be noted that the procedure used by Lou et al. (2004) to calculate the energy of waste reutilization, either through reuse or sale, involved emergy double counting. Cao and Feng (2008) proposed a method to avoid double counting of energy in the loop circuit of process systems. But this method is not suitable for solving the problem of emergy double counting when applied to waste
reutilization. In this paper, the reutilized waste is considered as an internal part of the whole system. Treated waste products for reuse and for sale are both considered as part of the system output. Thus, only four input and output streams are taken into account in this approach, and they are resources input, purchased input, system output and waste for discharge. In this way, the problem of emergy double counting can be avoided.

3. Traditional and improved emergy indicators

3.1. Traditional energy indicators

Fig. 2 depicts an emergy flow diagram of a typical industrial system. As Fig. 2 shows, several emergy indicators have been proposed based on the input and output flows: renewable resources \( R \), nonrenewable resources \( N \), purchased input \( F \) and yield \( Y \). The traditional indicators examined in the present study include the following: emergy yield ratio \( (EYR_{te}) \), environmental loading ratio \( (ELR_{te}) \) and emergy index of sustainability \( (EIS_{te}) \). Note that the subscript ‘te’ is used to indicate that these indicators are the traditional ones. Furthermore, the \( E_w \) term in Fig. 2 denotes the contribution of environmental services to the dilution of the waste of an industrial system. The mathematical definitions of the three traditional emergy indicators are given below (Brown and Ulgiati, 1997; Lan and Qin, 2001; Ulgiati and Brown, 1998).

The first traditional indicator, \( EYR_{te} \), is defined as the yield \( Y \) divided by purchased input \( F \). The yield is the sum of renewable \( (R) \), nonrenewable \( (N) \) and purchased feedback flows of goods and human services from the economy \( (F) \), as shown in Eq. (1):

\[
EYR_{te} = \frac{Y}{F} = \frac{R + N + F}{F} \tag{1}
\]

The \( EYR_{te} \) measures the ability of the industrial processes in Fig. 2 to rely on local resources. A high fraction of locally available energy sources, renewable and nonrenewable \( (R + N) \), will thus lead to a high value of this indicator.

The second traditional indicator, \( ELR_{te} \), is the ratio of nonrenewable \( (N) \) and imported \( (F) \) emergy use to renewable \( (R) \) emergy use:

\[
ELR_{te} = \frac{N + F}{R} \tag{2}
\]

It is an indicator of the stress on the environment due to economic activity. A high value of local renewable resources \( R \) will lead to a small \( ELR_{te} \), suggesting a small environmental stress while a high value of local nonrenewable sources \( N \) will result in a high \( ELR_{te} \), indicating a large environmental stress.

The third traditional indicator, \( EIS_{te} \), measures the emergy yield per unit environmental load:

\[
EIS_{te} = \frac{EYR_{te}}{ELR_{te}} \tag{3}
\]

The industrial processes in Fig. 2 are considered sustainable when they are characterized by a high \( EYR \) and a low \( ELR \), yielding a high \( EIS \). On the contrary, they are deemed unsustainable when the \( EYR \) is low and the \( ELR \) is high, resulting in a low \( EIS \). The \( EIS \) therefore provides a simplistic indication of sustainability for a given process under study.

Note that the traditional emergy indicators mentioned above ignore the waste emergy flow \( W \) in Fig. 2, which is a common characteristic of many industrial systems. As a result, these indicators require modifications before they can be used to account for waste management investment and the impact of emissions.

3.2. Traditional emergy indicators accounting for investment of waste treatment

Fig. 3 depicts an emergy flow diagram of an industrial system that considers both waste management investment and the impact of emissions. The purchased input \( F \) in Fig. 2 is replaced by \( F_1 \) and \( F_2 \). \( F_1 \) denotes the investment in production while \( F_2 \) represents the investment in waste treatment. \( F_2 \) is a necessary input because waste must be treated to meet the standards for discharge. As in Fig. 2, the impact of emissions is denoted by \( W \) in Fig. 3. To
Fig. 3. Input and output emergy flows of an industrial system incorporating waste management investment and emissions. $F_1$, $F_2$ and $F_3$ denote the investment in production, investment in waste management and additional investment in waste management, respectively.

explicitly account for investment in basic waste treatment, the $F$ term in Eqs. (1) and (2) is replaced by $F_1 + F_2$:

$$EYR_{ti} = \frac{R + N + F_1 + F_2}{F_1 + F_2}$$

(4)

$$ELR_{ti} = \frac{N + F_1 + F_2}{R}$$

(5)

In Eqs. (4) and (5), the subscript ‘ti’ is used to indicate that investment of waste treatment is accounted for by the traditional EYR and ELR indicators. Eq. (4) is logical but Eq. (5) is not consistent with the notion that implementing waste management should in principle lead to a smaller environmental stress because the ELR$_{ti}$ calculated from Eq. (5) would be larger than the ELR$_{te}$ calculated from Eq. (2), assuming that $N$ remains unchanged and investment in production is the same for both equations. In addition, $R$ is usually very small or even close to zero for many industrial systems. This would lead to unrealistically large ELR$_{ti}$. Mathematical manipulation of Eq. (6) to resolve these problems is described below.

3.3. Improved emergy indicators accounting for investment of waste treatment

The arithmetic anomaly exhibited by Eq. (5) may be resolved by adding $F_1$ and $F_3$ to the denominator of ELR$_{ti}$:

$$ELR_{ii} = \frac{N + F_1 + F_2}{R + F_1 + F_3}$$

(6)

In Eq. (6), the subscript ‘ii’ is used to indicate that investment of waste treatment is accounted for by the improved ELR indicator. $F_3$ is the additional investment for environmental protection of an enterprise and could express the social responsibility of the enterprise. For example, the discharge standard of COD for petrochemical enterprises is 150 mg/L in China. If the COD concentration of a petrochemical enterprise is lower than 150 mg/L, the investment of the enterprise that the COD concentration of emission can come up to the 150 mg/L should be brought into $F_2$ and other investment that the COD concentration is lower than 150 mg/L should be brought into $F_3$. But $F_3$ is usually zero in actual practice, because the goal of enterprises is to get the best deal. Eq. (6) suggests that the more advanced of a treatment process, the lower the ELR$_{ii}$ in the same treatment effect and the $F_2$ input. This is consistent with the expectation that a larger investment in waste management will lead to a larger reduction in the amount of harmful pollutants discharged to the environment.

Since the EYR$_{ti}$ indicator of Eq. (4) is conceptually sound when investment of waste treatment is considered, it requires no further modification. EYR$_{ii}$ is therefore mathematically equivalent to EYR$_{ti}$:

$$EYR_{ii} = \frac{R + N + F_1 + F_2 + F_3}{F_1 + F_2 + F_3}$$

(7)

3.4. Improved emergy indicators accounting for investment of waste treatment and impact of waste emissions

Eqs. (6) and (7) demonstrate the influence of waste management investment on EYR$_{ii}$ and ELR$_{ii}$ but the impact of waste emissions remains unaddressed. Next, Eqs. (6) and (7) are modified to account for the impact of emissions on the environment. The fates of treated waste as depicted in Fig. 3 are as follows: discharge, reuse and sale in the market. As mentioned previously, the two types of waste reutilization through reuse and sale are treated as internal flows to avoid double counting of emergy. Accordingly, treated waste for discharge is the only emergy flow (W) explicitly accounted for in Fig. 3. The mathematical forms of the ELR$_{ii}$ and EYR$_{ii}$ indicators in Eqs. (6) and (7) are modified in the following manner to take into
calculation of W in Eq. (10) is reasonably straightforward, but the assignment of a value to λ requires assumptions about the impact of emissions. The parameter λ indicates the relative impact of different types of waste emissions. Various methods have been proposed to quantify the impact of emissions which can harm the environment, people and the economy. However, assessing the impact of emissions in terms of emergy (Bakshi, 2002; Zhang et al., 2009) or exergy (Wang and Feng, 2000) is quite challenging and fraught with large uncertainties due to the multitude of factors involved and requirement of detailed information about each emission may not be readily available. In the following sections, the assignment of a value to λ is discussed with reference to a particular case study.

4. Case study

The utilities of the improved indicators are illustrated by the energy analysis of a commercial polyethylene production process known as Unipol developed by Union Carbide (now Dow Chemical). The main energy and material flows of the polyethylene production process incorporating waste management are given in Table 2.

5. Discussion

In energy analysis raw data units (J, kg, m³, $, etc.) are converted to solar emjoules (sej) by solar transformities. Table 2 provides a summary of the conversion of raw data for the polyethylene production process incorporating waste management to solar emergy. The emergy data in Table 2 were used to calculate the traditional and improved EYR, ELR and EIS indicators (Table 1). In addition to the improved indicators developed in this study, the assignment of a value to λ is discussed with reference to a particular case study.

Table 2

<table>
<thead>
<tr>
<th>Item</th>
<th>Data (units/yr)</th>
<th>Transformity (sej/unit)</th>
<th>Solar energy (sej/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonrenewable resources N</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Ethylene, t/yr</td>
<td>8.70E + 08</td>
<td>1.77E + 11</td>
<td>1.54E + 20</td>
</tr>
<tr>
<td>2 Electricity, J/yr</td>
<td>4.32E + 14</td>
<td>8.00E + 04</td>
<td>3.46E + 19</td>
</tr>
<tr>
<td>Total</td>
<td>1.89E + 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Renewable resources R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Water, t/yr</td>
<td>1.86E + 05</td>
<td>6.64E + 11</td>
<td>1.23E + 17</td>
</tr>
<tr>
<td>4 Steam, GJ/yr</td>
<td>3.40E + 06</td>
<td>1.77E + 11</td>
<td>6.02E + 17</td>
</tr>
<tr>
<td>5 Nitrogen, m³/yr</td>
<td>2.80E + 07</td>
<td>6.35E + 11 b</td>
<td>1.78E + 19</td>
</tr>
<tr>
<td>Total</td>
<td>1.85E + 19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchased inputs F₁</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Equipment + construction, ¥/yr</td>
<td>6.07E + 07</td>
<td>1.77E + 11 a</td>
<td>1.07E + 19</td>
</tr>
<tr>
<td>Purchased inputs F₂</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Waste treatment station + water reuse processing system + accident reservoir + pollutant detection system, ¥/yr</td>
<td>1.21E + 07</td>
<td>1.77E + 11 a</td>
<td>2.14E + 18</td>
</tr>
<tr>
<td>Waste W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Waste water, t/yr</td>
<td>1.72E + 05</td>
<td>6.64E + 11 b</td>
<td>1.14E + 17</td>
</tr>
<tr>
<td>9 Waste material, ¥/yr</td>
<td>1.12E + 06</td>
<td>1.77E + 11 a</td>
<td>1.99E + 17</td>
</tr>
<tr>
<td>10 Waste gas, m³/yr</td>
<td>1.17E + 06</td>
<td>6.68E + 10 b</td>
<td>7.80E + 16</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Transformities from Dai (2004).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b Transformities from Lan and Qin (2001).</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
of 4 (Wang et al., 1988). Calculated values of the traditional and improved indicators are listed in Table 3.

As can be seen in Table 3, the calculated magnitude of the traditional EYR, which ignores waste management investment, is appreciably larger than those estimated when waste management investment is taken into consideration. Ignoring the environmental impact of waste will thus inflate the EYR indicator. The calculated magnitude of the traditional ELR, ignoring waste management investment is 10.79. Extending the traditional ELR to include waste management investment increases the value to 10.91 (ELR(w)). The larger ELR suggests that investing in waste management causes more environmental stress. This trend is in conflict with the expectation that investing in waste management would reduce the impact of waste emissions on the environment, resulting in a lower environmental stress and therefore a smaller ELR.

The proposed modification to the traditional ELR indicator, as given by Eq. (6) or (8), can reconcile the concept of ELR with the improved indicators proposed in this study. It is concluded, for stated reasons, that the form of Eq. (11) is insufficient and ineffectual for its intended purposes and that the improved ELR proposed here is a major improvement over the IELR and traditional ELR for the evaluation of industrial systems involving waste management.

In the improved EYR and ELR indicators, the impact of a given emission is assumed to be directly proportional to its emergy. However, different emissions having the same emergy are expected to exert different impacts due to differences in their inherent properties to cause harm. This fact was incorporated in the improved indicators through the use of the parameter $\lambda$, which may be regarded as an impact amplification factor or an environmental penalty factor. The overall impact of a given emission is given by the product $\lambda W$. A value of 4 was assigned to $\lambda$ in the case study. To evaluate the effect of $\lambda$ on the improved indicators, the values of these indicators were computed for the case study using different values of $\lambda$, as shown in Table 4. As expected, the magnitude of EYR decreases and increases, respectively, with increasing $\lambda$. The net effect of these changes is captured through the sustainability indicator $EIS$, which decreases with increasing $\lambda$.

6. Conclusions

Emergy analysis is very useful for evaluating and improving industrial systems because, unlike other analytical tools, it accounts for the contribution of ecosystems to economic activity. Furthermore, it provides useful indicators for evaluating the economic and ecological feasibility as well as sustainability of industrial systems. However, traditional emergy indicators are inadequate for analyzing industrial systems involving waste management. The improved indicators proposed in this study provide a conceptually sound basis to quantify the impacts of waste management investment and emissions. The improved indicators were shown to be consistent with the notion that investing in waste management must be expected to lead to less environmental stress and enhance sustainability.

Acknowledgement

The financial support for this research provided by the National Natural Science Foundation of China under grant 50876079 is gratefully acknowledged.

Table 3

<table>
<thead>
<tr>
<th>Waste investment ignored emissions impact</th>
<th>Waste investment accounted for emissions impact</th>
<th>Improved indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>EYR = 20.39</td>
<td>EYR = 17.16</td>
<td>EYR = 17.16</td>
</tr>
<tr>
<td>ELR = 10.79</td>
<td>ELR = 10.91</td>
<td>ELR = 6.91</td>
</tr>
<tr>
<td>EIS = 1.89</td>
<td>EIS = 1.57</td>
<td>EIS = 2.48</td>
</tr>
</tbody>
</table>

Table 4

<table>
<thead>
<tr>
<th>Improved indicators</th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>EYR</td>
<td>16.65</td>
</tr>
<tr>
<td>ELR</td>
<td>6.93</td>
</tr>
<tr>
<td>EIS</td>
<td>2.40</td>
</tr>
</tbody>
</table>

$\lambda$ is the total investment of a product, and $P$ is the emergy of the process. Eq. (11) suffers from two obvious shortcomings. First, it ignores the role of nonrenewable (N) and renewable (R) resources, which appear in the traditional ELR and are retained in the improved ELR proposed here. Second, the impact of emissions remains unaddressed by Eq. (11), which is accounted for by the product $\lambda W$ in the improved ELR of this study. It is concluded, for stated reasons, that the form of Eq. (11) is insufficient and ineffectual for its intended purposes and that the improved ELR proposed here is a major improvement over the IELR and traditional ELR for the evaluation of industrial systems involving waste management.

Comparison of the traditional and improved EYR, ELR and EIS indicators for polyethylene production incorporating waste management.

$EIS = \lambda W F$
Appendix A. Symbols of the emergy systems language (Odum, 1996)

System frame. A rectangular box is drawn to represent the boundaries that are selected.

Source. Outside source of energy delivering forces according to a program controlled from outside; a forcing function.

Pathway line. Any flow is represented by a line. Solid line indicates energy, material, or information flows; money flow is shown with dashed line.

Heat sink. Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.

Interaction. Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate.

Transaction. A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line).

Tank. A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.

Producer. Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Appendix B. Nomenclature

\[ E_w \] inputs of environmental services

\[ F \] investment in production

\[ F_1 \] investment in waste management

\[ F_2 \] additional investment in waste management

\[ F_i \] waste management investment

\[ i \] \( i \)th type of waste

\[ n \] total number of waste types

\[ N \] nonrenewable resources

\[ R \] renewable resources

\[ W \] energy of waste for discharge

\[ Y \] yield of an industrial process

\[ \lambda \] impact amplification factor

Acronyms

\[ \text{EIS}_{\text{SI}} \] improved index of sustainability accounting for investment of waste treatment

\[ \text{EIS}_{\text{SW}} \] improved index of sustainability accounting for investment of waste treatment and environmental impact of waste

\[ \text{EIS}_{\text{TE}} \] traditional index of sustainability

\[ \text{EIS}_{\text{SI}} \] traditional index of sustainability accounting for investment of waste treatment

\[ \text{ELR}_{\text{RI}} \] improved environmental loading ratio accounting for investment of waste treatment

\[ \text{ELR}_{\text{RW}} \] improved environmental loading ratio accounting for investment of waste treatment and environmental impact of waste

\[ \text{ELR}_{\text{RC}} \] traditional environmental loading ratio

\[ \text{ELR}_{\text{RI}} \] traditional environmental loading ratio accounting for investment of waste treatment

\[ \text{EYR}_{\text{RI}} \] improved energy yield ratio accounting for investment of waste treatment

\[ \text{EYR}_{\text{RW}} \] improved energy yield ratio accounting for investment of waste treatment and environmental impact of waste

\[ \text{EYR}_{\text{RC}} \] traditional energy yield ratio

\[ \text{EYR}_{\text{RI}} \] traditional energy yield ratio accounting for investment of waste treatment

References


学霸图书馆

www.xuebalib.com

本文献由“学霸图书馆-文献云下载”收集自网络，仅供学习交流使用。

学霸图书馆（www.xuebalib.com）是一个“整合众多图书馆数据库资源，提供一站式文献检索和下载服务”的24小时在线不限IP图书馆。

图书馆致力于便利、促进学习与科研，提供最强文献下载服务。

图书馆导航：

图书馆首页  文献云下载  图书馆入口  外文数据库大全  疑难文献辅助工具