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# ECO-EFFICIENCY OF CONSTRUCTION AND DEMOLITION WASTE RECYCLING IN CHONGQING, CHINA

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**Abstract**

Ongoing urbanization along with increased regeneration of the obsolete city centres makes the recycling of Construction and Demolition Waste (CDW) an ever hot topic to realize China's circular economy strategy in its construction industry. However, the current recycling rate of CDW is only 5% in the country and the recycling industry is in its infant stage. How to recycle the CDW in a more cost effective and environmentally beneficial way, given the opportunity of the underdeveloped CDW recycling system in China, is a key issue to be investigated at this moment.

From a life cycle perspective, eco-efficiency analysis is used in this study to systematically evaluate the potential pros and cons for developing the different types of CDW treatment and recycling systems to be developed in Chongqing. Nowadays, two forces are driving the development of the CDW recycling industry in China: one is from grass-root – e.g. around 20 small private recycling plants have been established in Chongqing in the last decade, and another is from top-down – e.g. billions of Chinese RMB have been spent to build a group of state-owned large CDW recycling centres. The case study shows, properly designed, the eco-efficiency analysis is able to identify the hot spots and trade-offs between economy and environment systems.

**Keywords:**

Construction and Demolition Waste; Eco-efficiency; Chongqing

## 1 INTRODUCTION

The urbanization rate in China is expected to hit 60% by 2018. A great number of Construction and Demolition Waste (CDW) will be produced with the old city regeneration and new city construction. However, direct CDW landfilling is still dominating this country, rendering the recycling of CDW at a rate of 5% and the recycling industry in its infant stage. How to recycle the CDW in a more cost effective and environmentally beneficial way, given the opportunity of the underdeveloped CDW recycling system in China, is a key issue to be investigated at this moment.

Eco-efficiency, first introduced by the World Business Council for Sustainable Development (WBCSD www.wbcsd.org), is considered useful for guiding micro-level actions towards sustainability [1]. The concept describes a vision of creating more goods and services with less resources and waste. It provides a new perspective for the search of cost effective and environmentally sound solutions for the waste management issues. Quite a few Chinese researchers attempted to use the eco-efficiency concept to support waste management decision making. Lu analysed the eco-efficiency of two different recycling strategies of WEEE (Waste Electrical and Electronic Equipment) in China [2]. Zhao applied a quasi-dynamic eco-efficiency model to analyse the municipal solid waste management and concluded that the eco-efficiency of an integrated scenario is potentially better [3]. Huang qualitatively discussed the legal regulation of the reduction and utilization of the

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CDW under the guidance of the principle of eco-efficiency [4]. However, few quantitative eco-efficiency studies, especially well recorded ones, can be found on the CDW treatment in China.

In this paper, we present an eco-efficiency analysis for four CDW treatment scenarios in Chongqing, China, which is quantified by the environmental impact index obtained from life cycle assessment (LCA) and the economic index obtained from life cycle costing (LCC). Based on this, the development direction for eco-efficient recycling CDW in Chongqing is recommended.

## 2 MATERIALS AND METHODS

### 2.1 CDW Treatment Scenarios

According to our field survey, there are three main routes for the CDW treatment in Chongqing at present.

**Route I:** Simple landfill. If landfill sites are close to the construction sites, contractors will send the CDW for direct landfilling to save disposal cost.

**Route II:** Private recycling. Private recycling of CDW in Chongqing has existed since the 1990s. They all run at small scale. Most are located close to the urban centres under regeneration. According to the information provided by Chongqing Wall Materials Industry Association, there are about 20 private enterprises handling CDW recycling in the central urban area of Chongqing. And more than one hundred private enterprises engage in the CDW recycling in Chongqing, whose annual output value is close to 200 million RMB.

**Route III:** State-owned recycling. The plan approved by the municipality includes the construction of 7 CDW recycling centres. Constrained by the land availability, the first two state-owned recycling centres were finally established at the beginning of 2015 in the urban fringe areas. The state-owned waste management company, Chongqing Environment and Sanitation Group, is responsible for the option of both plants. But due to the long transport distance from city centres (50 – 80 km), both plants are suffering from a lack of CDW supply at the moment.

Through interviews with experts and the comparison with several data sources, we find the most reliable estimation of the amount of CDW generation in Chongqing 2014 is 6.1212 million tons, which was treated by landfill (5.0473 million tons; 82.4%), private recycling (0.5739 million tons; 9.4%) and state-owned recycling (0.5 million tons; 8.2%) [5]. According to this proportion we analysed the eco-efficiency of the current CDW treatment status of Shapingba district in Chongqing.

As you can see in Figure 1, four scenarios are analysed based on the above field investigation. In addition to the current CDW treatment status (hybrid), three other scenarios, representing maximizing one of the single CDW treatment route are formulated. In order to make a fair comparison, a basket of function approach is taken, considering the generation of the construction materials (concrete bricks) from the systems under study. The four scenarios are:

(i) Landfill Scenario. Put all CDW into simple landfill, and use conventional concrete bricks in the subsequent construction process.

(ii) Private Recycling Scenario. Put all CDW into private recycling plants, and put some extra new materials in the process of producing recycled concrete bricks, then use the recycled concrete bricks.

(iii) State-owned Recycling Scenario. Put all CDW into state-owned recycling centres, and use the waste material for reproduction as much as possible, then utilize the recycled concrete bricks.

(iv) Hybrid Scenario. Hybrid process includes the above three scenarios (current status).

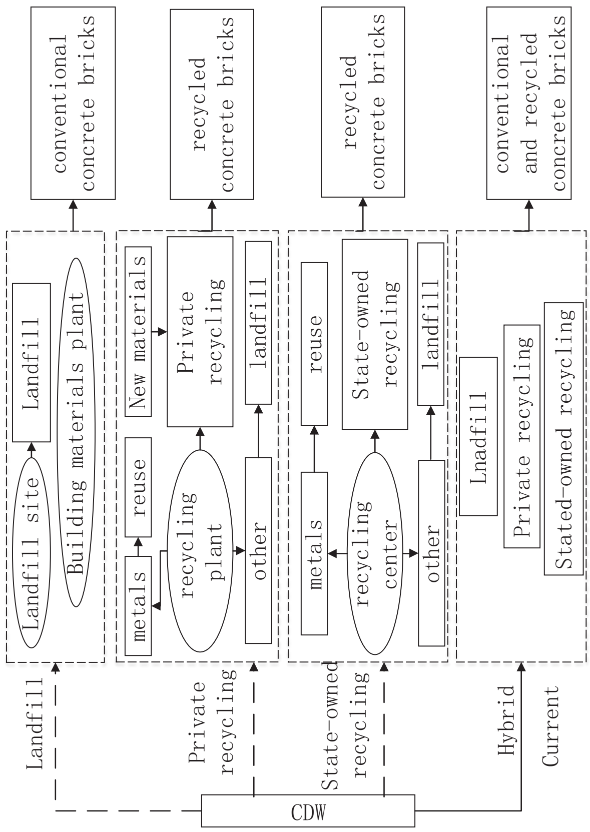


*Fig. 1: Four CDW treatment scenarios in Chongqing.*

### 2.2 System borders

On the condition of treating the same amount of CDW, the output of private recycling plants is much more than the output of state-owned recycling centres because private recycling plants add new materials in the production process of recycled concrete bricks. If the CDW is dumped, we have to use the primary materials to produce conventional concrete bricks. We use the treatment of 0.5739 million tons CDW as the

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base to analyse the eco-efficiency of the CDW treatment scenarios.

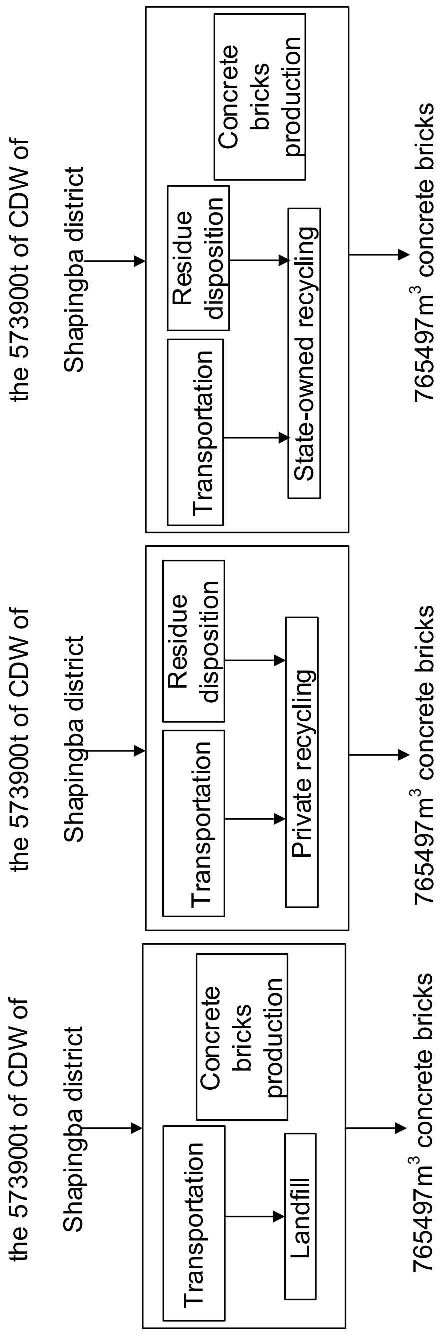


*Fig. 2: The system boundary of the three single scenarios.*

In consideration of the current hybrid CDW treatment scenario in Chongqing, on the basis of analysing the three single scenarios, firstly, we analyse the eco-efficiency of the current scenario.

The determination of system borders is a key to system modelling [6]. In consideration of the function of system which is urban CDW treatment and concrete bricks production simultaneously, we decide to expand the system boundary to analyse environment impacts of different scenarios above. The main processes of every system are transportation, CDW treatment, residue disposition and concrete bricks production. The system boundary of the three single scenarios is shown in figure 2.

### 2.3 Environment impact

Global warming has become a widely concerned problem at present. The data shows that construction industry is one of the world's three largest sources of the greenhouse gases, which consumes 40% of global energy and produces 36% of greenhouse gas emission [7]. However, the greenhouse gas emission in the construction materials production and CDW treatment stage is 18.3% of life cycle emission [8]. How to reduce it has become a problem that cannot be ignored. So we have chosen carbon dioxide equivalent as environmental impact index when using LCA to assess the environment impact of system. The main production data are shown in table 1.

| Category | Landfill | Private recycling | State-owned recycling |
|---|---|---|---|
| CDW（t） | 573900 | 573900 | 573900 |
| recycled concrete bricks（$m^3$） | 0 | 765497 | 196999 |
| conventional concrete bricks（$m^3$） | 765497 | 0 | 568498 |
| residue（kg） | 0 | 54515010 | 55251545 |

*Tab.1: The main production data.*

Metal scraps are main co-products in the systems above. So allocation of environment impact of different products will be discussed. The proportion of metal scraps is only 0.16% in total of CDW. The ratio of recycle of metal scraps and production of concrete bricks is small no matter from the perspectives of economic cost or physical weight during the concrete bricks production. And there is little difference between the two. In addition, the weight of metal scraps has a strong effect on its economic cost. Here we choose to allocate from the perspective of physical weight.

### 2.4 Economic cost

The economic cost of different treatment scenarios was carried out using LCC. According to the characteristics of the CDW production process and the principle of "who produce who responsible for", the economic cost of different treatment scenarios can be divided into internal cost and external cost. The internal cost is counted from the perspective of contractor. The external cost refers to the social and environmental costs caused by treating the CDW.

The internal and external cost structure of different treatment scenarios and the main parameter values are shown in table 2 and table 3. Internal cost of three single scenarios is corresponding transportation fee and the gate fee for contractors. Landfill leads to environmental pollution which can be avoided through recycling. We found that there is a lot of dust emission

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caused by private recycling, but dust emission caused by state-owned recycling is little. We can avoid environmental pollution caused by landfill by using state-owned recycling to instead landfill. So external cost of landfill is conventional concrete bricks production cost and the part of state-owned recycling cost exceeding the gate fee of landfill site. External cost of private recycling is the part of private recycling cost exceeding the gate fee of private recycling plant and environmental cost of air pollution caused by dust. External cost of state-owned recycling is concrete bricks production cost and the part of state-owned recycling cost exceeding the gate fee of state-owned recycling plant.

| Category | Formula | Remarks |
|---|---|---|
| Landfill | | W: amount of CDW |
| | Internal cost: | $D_x$: distance to landfill site |
| | $C_{11}$=W×$D_x$×$T_x$+$R_x$×W | $T_x$: unit transportation cost of landfill site |
| | | $R_x$: the gate fee of landfill site |
| | External cost: | $Z_g$: state-owned recycling unit cost |
| | $C_{12}$=（$Z_g$-$R_x$）×W +$C_z$×$Q_z$ | $C_z$: unit manufacture cost of conventional concrete bricks |
| | | $Q_z$: amount of conventional concrete bricks for landfill |
| Private recycling | Internal cost: | $D_m$: distance to private recycling plant |
| | $C_{21}$= W×$D_m$×$T_m$+ $R_m$×W | $T_m$: unit transportation cost of private recycling plant |
| | | $R_m$: the gate fee of private recycling plant |
| | External cost: | $Z_m$: private recycling unit cost |
| | $C_{22}$=（$Z_m$-$R_m$）×W+$C_a$ | $C_a$: unit environmental cost of air pollution |
| State-owned recycling | Internal cost: | $D_g$: distance to state-owned recycling center |
| | $C_{31}$= W×$D_g$×$T_g$+ $R_g$×W | $T_g$: unit transportation cost of state-owned recycling center |
| | | $R_g$: the gate fee of state-owned recycling center |
| | External cost: | $Z_g$: state-owned recycling unit cost |
| | $C_{32}$=（$Z_g$-$R_g$）×W+ $C_z$×($Q_z$ -$Q_g$) | $Q_g$ amount of concrete bricks for state-owned recycling |

*Tab.2: The cost composition of the three single scenarios.*

The environmental cost of air pollution is calculated with a corrected human capital method. In 2009, the national per capita GDP was 25545.36 RMB, the cost of treatment for each patient suffering from chronic bronchitis was 45272.4 RMB [9]. So on condition of per capita GDP of Chongqing was 48031 RMB in 2014 [5], the cost of treatment for each case of chronic bronchitis was 84441.29 RMB. With the exposure-response relationship function, 934 people can avoid to chronic bronchitis when the PM10 concentration is reduced to threshold, 20 ug/m3 put forward by the World Health Organizationr(WHO). The external health cost caused by air pollution is 78868167.09 RMB.

| Parameters | Values | Unit |
|---|---|---|
| $D_x$ | 20[a] | km |
| $D_m$ | 8[b] | km |
| $D_g$ | 50[b] | km |
| $T_x$ | 1.21[c] | $RMB·t^{-1}·km^{-1}$ |
| $T_g$ | 1.11[c] | $RMB·t^{-1}·km^{-1}$ |
| $T_m$ | 1.48[c] | $RMB·t^{-1}·km^{-1}$ |
| $R_x$ | 2.5[d] | $RMB·t^{-1}$ |
| $R_m$ | 3[b] | $RMB·t^{-2}$ |
| $R_g$ | 25[e] | $RMB·t^{-3}$ |
| $Q_z$ | 765497[b] | $m^3$ |
| $Q_g$ | 196999[e] | $m^3$ |
| $Z_g$ | 64.97[e] | $RMB·t^{-1}$ |
| $Z_m$ | 289.27[b] | $RMB·t^{-2}$ |
| $C_z$ | 302.76[b] | $RMB/m^3$ |
| $C_a$ | 78868167.09 | RMB |

*Tab.3: The main parameter values.*

[a] Site layout planning for landfill station of the main urban area of Chongqing

[b] Field investigation

[c] Converted from building engineering budget ration of Chongqing

[d] Paid service charge management regulation of Urban environmental sanitation of Chongqing

[e] Feasibility study report on CDW treatment project of the main urban area of Chongqing

## 2.5 Eco-efficiency

Eco-efficiency, as a quantitative sustainability analysis tool developed in the field of industrial ecology in recent years, is increasingly applied to the decisions of European Union environmental management [10]. It contains two dimensions of sustainable development of environment and economy, and its purpose is to encourage enterprises to develop production, improve the economic benefit and undertake the responsibility of environment protection to the whole society. All these exactly conform to the development direction of 'Reduction and Recycling' in China.

The formula for calculation is as follow:

$$\text{Eco}-\text{efficiency}=\frac{\text{Environment impact}}{\text{Economic cost}} \quad (1)$$

The environment impact will be assessed with LCA and the economic costs will be given with LCC [11].

The eco-efficiency relative change between different scenarios should be given while using the eco-efficiency analysis to make effective decisions. The eco-efficiency of the above formula is a one-dimensional quantity determined by the environment impact and economic cost. For multiple comparison modes, comprehensive and effective information cannot be shown if we just use the formula. As a result, we use graphic method to compare eco-efficiency of different scenarios [12]. As is shown in figure 5, in order to make the results of the study more helpful for policymakers, one of scenarios is chosen as the benchmark, which is shown with coordinate origin. The value of x-coordinate expresses the relative value in the aspect of environmental impact. The value of y-coordinate expresses the relative value in the aspect of economic cost. Then we can clearly know that the closer to the top right corner of coordinate system the program is, the higher eco-efficiency of the program is.

## 3 RESULTS

### 3.1 LCA of different scenarios

In order to make the result more accurately reflect the reality of China, we use the eBalance software and China Life Cycle Database (CLCD) developed by Sichuan University to calculate the greenhouse gas emission [13]. However, there is no landfill data set in the CLCD, so we invoke the corresponding data set of the Ecoinvent. On the condition of treating 573900t CDW and producing 765497m$^3$ concrete bricks, the greenhouse gas emission of four scenarios is shown in figure 3.

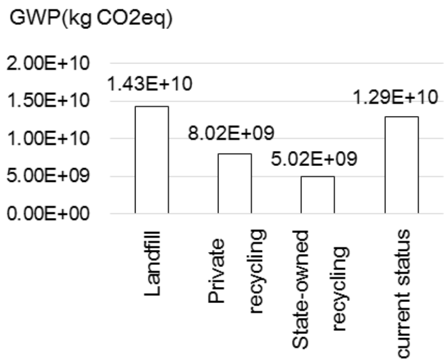


*Fig. 3: The greenhouse gas emission of four scenarios.*

### 3.2 LCC of different scenarios

By substitution of the main parameter values in table 3 into the formula in table 2, the internal and external cost structure of different treatment scenarios is calculated. The result is shown in figure 4.

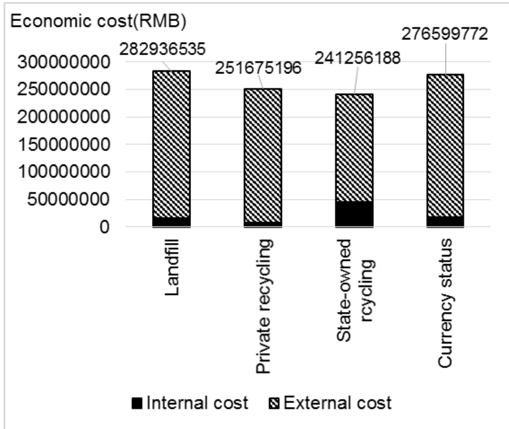


*Fig. 4: The economic cost of four scenarios.*

### 3.3 Eco-efficiency of different scenarios

The current CDW treatment scenario is choose as the benchmark of eco-efficiency analysis and three single scenarios are treated as comparison schemes. Based on the results of LCA and LCC above, the result of eco-efficiency analysis can be shown in figure 5.

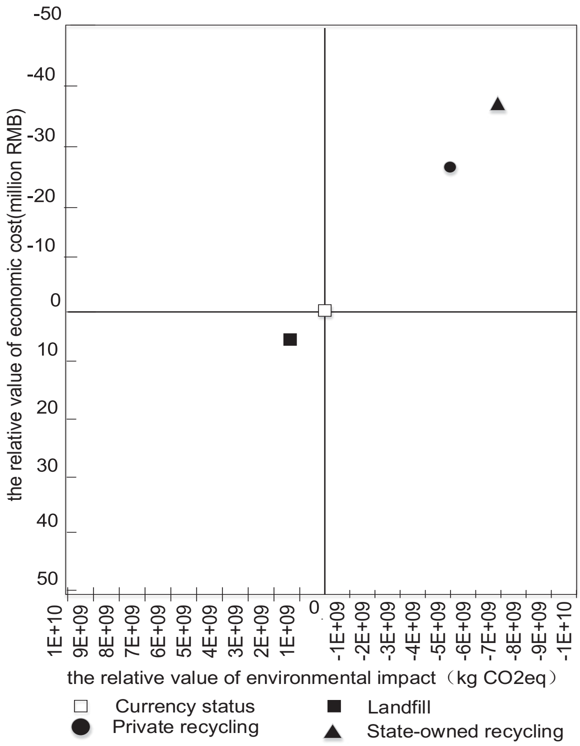


*Fig.5 The result of eco-efficiency analysis.*

## 4 DISCUSSION

Figure 5 shows that the eco-efficiency of recycling is higher than landfill, and the eco-efficiency of state-owned recycling is higher than private recycling. Figure 3 shows the greenhouse gas emission of state-owned recycling is the lowest. Compared with private recycling, the emission of state-owned recycling decreased by 37%. Compared with landfill, the emission of state-owned recycling decreased by 65%. Figure 4 shows that recycling can save tens of million

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RMB than landfill. External cost takes quite a large proportion in economic cost of three scenarios, which is produced by the environmental impact. From the prospective of society, it should be concerned especially in the period of overall ecological civilization construction in China. State-owned recycling makes total cost and external cost decrease simultaneously. However, the internal cost of state-owned recycling is highest for contactors. Its main reason is the difference of transportation distance.

Figure 5 also shows that the level of eco-efficiency of current status is relatively low. Compared with the eco-efficiency of current status and landfill, the eco-efficiency of landfill is lowest. It draws a conclusion that landfill is a route that is not only uneconomic but also environment-polluted. When the CDW recovery rate is improved, the eco-efficiency is also improved. It means that recycling is helpful to improve the eco-efficiency of the CDW treatment. Compared with the eco-efficiency of current status and recycling (private or state-owned recycling), the CDW treatment route still has enough space for improvement in the aspect of eco-efficiency.

## 5 CONCLUSION

After analysing the eco-efficiency of three treatment scenarios and the current status, we can see that the current CDW treatment status in the central urban area of Chongqing is relatively backward, no matter in the aspect of economic cost or environmental impact. By contrast with the results of the early landfill of all and the now recycling of part, it can be seen that there is no doubt that landfill cannot be a future solution to treat the CDW. It has the biggest environmental and cost burden. The results show encouraging both private and state-owned recycling can improve the eco-efficiency of CDW treatment in Chongqing. However, the saving potential of state-owned recycling centre is even bigger. The governors should do more efforts to locate the future state-owned recycling centres closer to future CDW intensive areas and facilitate the current two plants in full use with sufficient supply of CDW. It is also necessary to improve the twenty private recycling plants so that they can be more normative and environment-friendly. Besides, from the vision of those private recycling plants, it’s more profitable if they find out causes of inefficiencies in production.

## 6 REFERENCES


1. Huppes G, and Ishikawa M., Eco-efficiency guiding micro-level actions towards sustainability: Ten basic steps for analysis. Ecological Economics, 2009, 68(6): p. 1687-1700.
2. B. Lu and J. X. Yang, Eco-efficiency analysis of recycling strategies of WEEE in China. Chinese Journal of Environmental Engineering, 2010. 4(1): p. 183-188.
3. W Zhao, Huppes G, Voet E. V. D. Eco-efficiency for greenhouse gas emissions mitigation of municipal solid waste management: A case study of Tianjin, China. Waste Management, 2011, 31(6): p. 1407–1415.
4. X.S. Huang and B.X. Xu, On the Legal Regulation of the Reduction and Utilization of the Construction Waste Based on Eco-Efficiency. Urban Studies, 2011. 18(9): p. 90-94.
5. Chongqing Statistic Bureau, Chongqing Statistical Yearbook-2014. 2014, Beijing: China Statistics Press.
6. J.X. Yang, Methodology and application of life cycle assessment. 2002, Beijing. China: meteorology Press.
7. Change I P O C. Climate Change 2007: Synthesis Report. Environmental Policy Collection, 2007, 27(2):408.
8. S.C. Yin, Study of life-cycle carbon emission in buildings. 2012, Harbin. China: Harbin Institute of Technology.
9. X.Q. An, et al., Evaluation on economic loss of human health induced by Inhalable Particulate Matter in 2009 in China, in 29th Annual Meeting of Chinese meteorological society. 2012: Shenyang, China. p. 2-6.
10. Huppes G. and Ishikawa M., Quantified Eco-Efficiency: An Introduction with Applications. 2007, Dordrecht. Netherlands: Springer Netherlands.
11. Steen B., Environmental costs and benefits in life cycle costing. Management of Environmental Quality: An International Journal. 2005, 16(2): p. 107-118.
12. Huisman J., The QWERTY/EE concept. 2003, Delft, Netherlands: Delft University of Technology.
13. X. L. Liu., et al., Method and basic model for development of Chinese reference life cycle database of fundamental industries. Acta Scientiae Circumstantiae, 2010, 30(10): p. 2136 – 2144.


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