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# EMERGY ACCOUNTING OF THE BENEFITS PROVIDED BY THE SCRAP/STEEL SHEET EXCHANGE

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**ABSTRACT**

The steel sheet distributor studied is located in Great São Paulo (Brazil) and has been in operation since 1995. The company trades steel directly purchased from steel plant and resells it to other companies. Up to the beginning of 2003, the company traded only steel sheet. However, after political and economic changes in domestic and international markets, the steel plant chose to export almost all its production. Thus, in order to maintain the domestic market, the steel plant and the distributor have established an agreement: the distributor returns to the steel plant two tons of scrap for each ton of sheet purchased. On the other side, the distributor made a partnership with its clients to assure a scrap stock. Thus, it was established that for each ton of steel sheet supplied four tons of scrap should be returned to the distributor. Thus, the distributor deals with two types of customers: without scrap exchange and with scrap exchange. With the agreement established, the company had to implement an infrastructure for supply the customers who exchange scraps. In the period of four months, the company invested on producing containers, hiring specialized labor force and purchasing trucks for containers transportation. Once the implementation phase ended, the company started to operate with both costumers. In this paper, the energy diagram for the distributor operation and emergy tables (implementation, maintenance and operation) are presented. The data obtained permit to evaluate and compare the emergy benefits of the new system since its implementation.

## 1. INTRODUCTION

The change in the companies behavior concerning the environment started in production and operation areas, where there are large opportunities to reduce the impact of processes. The introduction of environmental issues in production processes compelled many companies to invest in environmental research with the purpose of minimizing environmental impacts without affecting their profit. However, the first environmental evaluations based on traditional financial analysis did not include intangible costs and benefits, such as the cost of the environment necessary to absorb a pollutant.

Since its introduction, emergy analysis [1] has become increasingly important, since it considers both the economic and the environmental resources employed to obtain a product or service. In this study, the emergy analysis of a new system for steel distribution is performed. A graphical tool is employed to assist data interpretation [2].

## 2. MATERIALS AND METHODS

### 2.1. System description

The distributor operates purchasing steel sheets directly from a large steel plant and selling to small companies of the metallurgical sector. The steel plant and the distributor have established an agreement, where the distributor returns two tons of scrap to the steel plant for each ton of material purchased. Thus, the distributor can supply its customers, and the steel plant assures raw material for the manufacture of the sheets.

In order to ensure a scrap stock, it was established that for each ton of material supplied to its customers, the distributor receives four tons in scrap in return. Because this system is new and subjected to market oscillations, some customers preferred to maintain the conventional system. Thus, the company deals with two types of customers: with scrap exchange and without scrap exchange (Fig. 1).

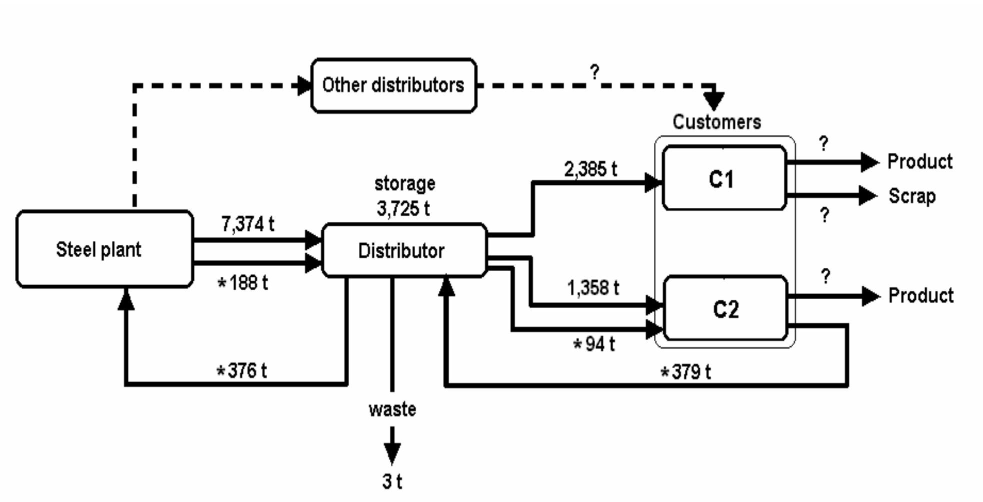


Figure 1. Accounting of the steel/scrap distribution system (data relative to one year operation). C1 – customer without scrap exchange, C2 – customer with scrap exchange, (?) unknown fluxes. Values preceded by (*) are referred to material exchange. Steel sheets constitute all fluxes towards the right direction and all the fluxes towards the left are referred to steel scrap

After the agreement was established, the distributor invested to implement the new system, with the production of containers, the hiring of temporary specialized labor force and the purchase of trucks for containers transportation.

### 2.2. System boundaries and sources of data

Industrial sectors positioned among primary activities, like mining or energy production, have their input flows of renewable and non-renewable resources well defined. However, when the sector is positioned along the productive chain, close to consumers or disposal, the identification of the resources supplied by nature becomes more complex, even if accounted for, indirectly, by the transformity.

In the services sector, for example, most of the resources used are non-renewable or provided by the economy, such as fuel and labor. Hence, the calculation of some traditional indicators of emergy analysis, as ELR (environmental load ratio) and ESI (environmental sustainability index), is less straightforward [1].

The results can also be analyzed with the aim of ternary diagram (figure 2). For the case studied herein, the upper apex of the diagram represents the saved emergy associated to the recovered steel and the apexes in the triangle basis represent: the emergy invested in goods and services (right) and the emergy invested in fuel (left). To evaluate the contribution to the environment of the new distributing system, the emergy saved by the scrap use was determined and compared to the emergy needed to produce the same amount of material. The saved emergy is called herein as "gross benefit". When the scrap is introduced in the production cycle, use, disposal, collection and recycling, it represents the same material continuously flowing. Non-renewable inputs, in this case, are those employed for collection and recycling. Assuming that the emergy employed for steel production from scrap is lesser than that employed for its production from raw material, the net benefit will be given by the saved emergy less the emergy invested in collection. The net benefit should then be considered as a measure of the "renewability" of the input.

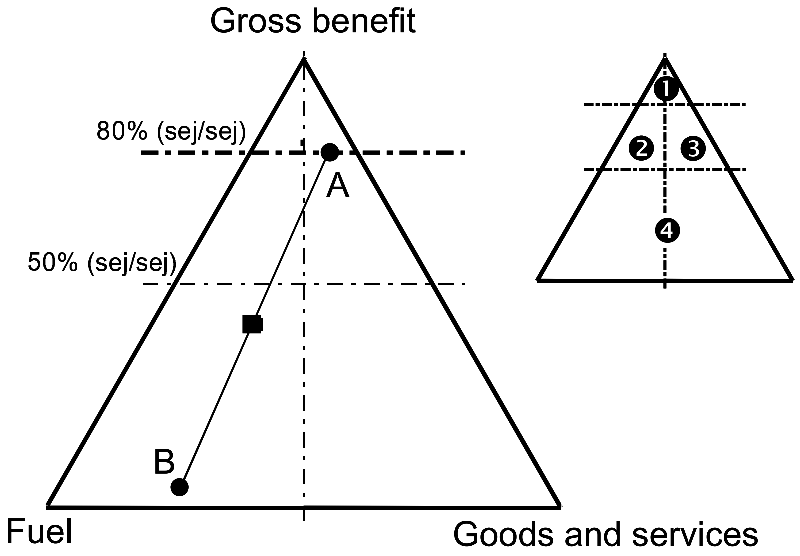

Figure 2. Emergy ternary diagrams where the simergy point (■) represents the combination of points A and B. The diagram on the right shows four classification regions adopted by the authors where: area ❶ excellent, area ❷ and ❸ indicates good performance, but in ❷ fuel consumption is higher than in ❸, and area ❹ indicates that there is no net benefit

Data were collected from the distributor in the period of November 2003 to April 2004. The steel and scrap mass quantities calculated for one-year operation are shown in Figure 1. It is important to remark that the new system is still operating below its full capacity. The useful life was estimated to be 25 years for containers, 10 years for machines and 4 years for trucks.

Electricity flows were allocated according to the quantities of steel sheets bought by each customer, with and without scrap exchange. Thus, 38 % (w/w) of the electricity was distributed to the customers with scrap exchange and the other 62 % (w/w) to the customers without scrap exchange. Direct labor was accounted considering the number of working-hours in each case. Neither administration services nor truck maintenance were accounted. The construction of the facilities was also not considered. The accountancy made herein contemplates only the main differences between both systems (with and without scrap exchange).

### 2.3. Emergy analysis

Emergy is the amount of energy needed, directly or indirectly, to obtain a product (good or service). The use of one single unit, sej (solar energy joule), to which the several kinds of energy are converted permits to sum up all contributions of energy used to obtain a given product or service. Transformities (expressed in sej/J, solar energy joule per joule) and emergies per unit are defined as the amount of solar energy employed, directly and/or indirectly, to obtain one unit of goods or services [1]. Transformity provides a measure of the concentration of emergy and can be considered as an indicator of energy quality. Table 1 presents the transformities and emergies per unit taken from literature.

Table 1.Values of transformities and emergy per unit used in this study

| | Unit | Emergy/unit | Ref. |
|---|---|---|---|
| Diesel | J | 6.60E+04 | [3] |
| Electricity | J | 1.65E+05 (a) | [1] |
| Electrode and welding wire | kg | 1.78E+12 (b) | [1] |
| Labor non qualified (Brazil) | J | 7.66E+05 | [4] |
| Mechanical and transportation equipment | kg | 6.70E+12 | [5] |
| Oxygen | kg | 5.16E+10 | [6] |
| Propane | J | 4.8E+04 (c) | [1] |
| Steel sheets | kg | 4.13E+12 | [7] |
| Synthetic paint | kg | 1.50E+12 | [6] |
| Thinner | kg | 3.80E+11 (d) | [6] |
| Water | J | 1.39E+05 (e) | [8] |

Assuming the same values that (a) hydroelectric (Tucurui, Brazil), (b) iron and steel products, (c) natural gas, (d) chemicals, , (e) drinking water not including distribution (West Palm Beach, U. S. A.).

## 2.4. Emergy ternary diagram and benefits accounting

The emergy ternary diagram [2] is a very useful graphical method, when three variables describe a process or a system. In these diagrams, three fractions or proportions add to 1, or three percentages add to 100. The constant sum constraint means that there are just two independent pieces of information. Hence, it is possible to plot observations in two dimensions within a triangle.

Ternary diagrams show important properties. When two different ternary compositions are mixed, a point, called here “simergy point”, will represent the resulting composition. This point lies on a plane that contains the points that represent each composition accounted (Fig. 2). The simergy point is used to determine the characteristics of the combination of two or more product or processes. A line, which horizontally crosses the diagram in half the height of the triangle, 50% (sej/sej), shows the condition where gross benefits obtained are equal to resources employed (fuel, goods and services). When the resources invested to recover the scrap are lower than the saved emergy, a point above this line should represent the resulting system. In this case, there will be a net benefit equal to the difference between the gross benefit and the resources used (fuel, goods and services). For example, for a gross benefit of 80% (sej/sej), there will be 20% (sej/sej) of investment. Thus the net benefit, or “renewability”, will be 60% (sej/sej). Figure 2 also shows a classification according to the location within the diagram: area ❶ indicates a situation in which the gross benefit is above 80% (sej/sej), area ❷ indicates a condition in which there is a high gross benefit, and fuel consumption is higher than the investment in goods and services, area ❸ indicates gross benefit with higher use of good and services but lower fuel consumption and area ❹ indicates that there is no emergy net benefit, that is fuel, goods and services spent to recover the scrap are higher than the material recovery.

## 3. RESULTS

The conventional and the new system are represented in Figures 3a and 3b, respectively. The diagrams show the main fluxes that enter the distribution process (fuel, goods and services). Once the diagrams are built, it is possible to identify the items in an evaluation table. Table 2 shows the resources used during the implementation and operation phases of the conventional system. The resources employed during implementation and operation of the new system is shown in table 3, which includes the resources used for maintaining the containers constructed especially for scrap storage and transportation. The authors, if requested will supply details of calculations. It can be observed that the higher investment during the implementation phase of the conventional system (Tab. 2) comes from the trucks for container transportation and scrap collection, 45% (sej/sej). During the operation phase fuel is the resource with highest consumption. It represents 85% (sej/sej) of operation and 46% (sej/sej) of the total emergy.

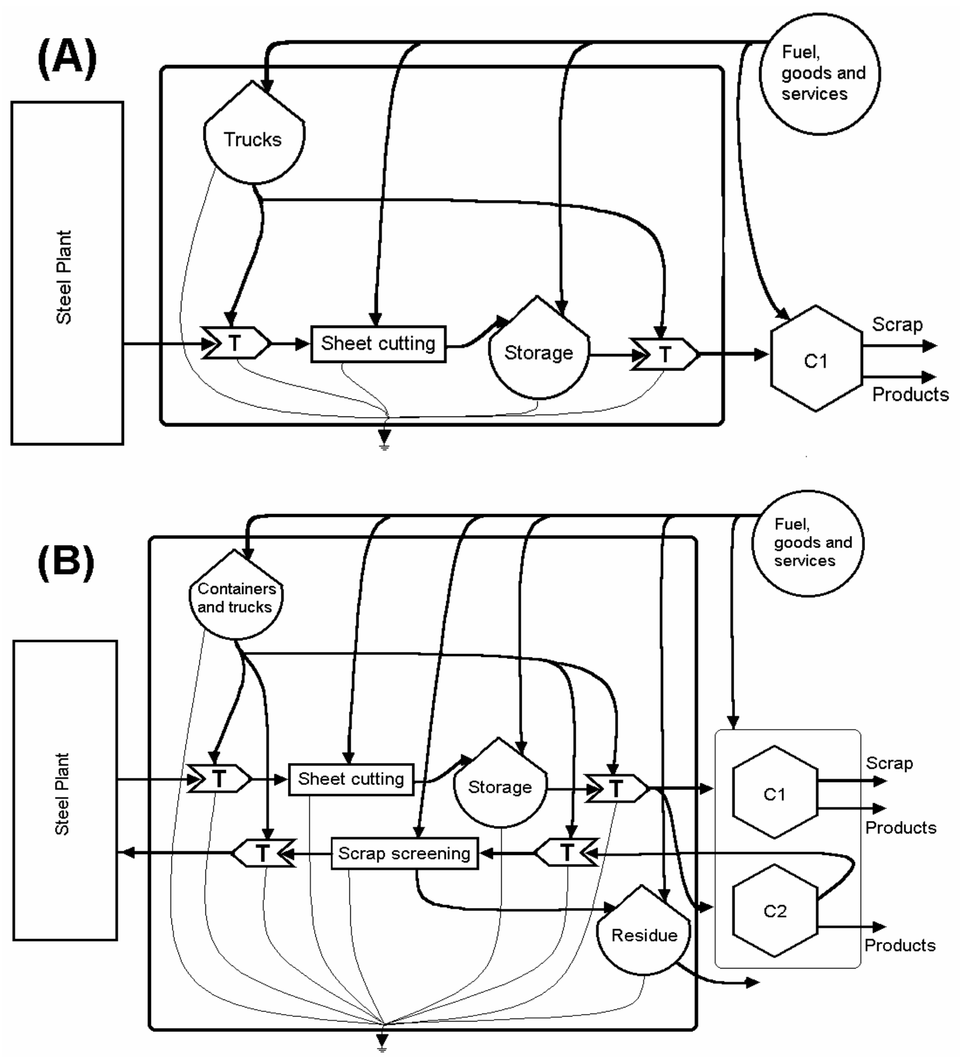


Figure 3. Energy diagrams of (A) conventional system and (B) new system. C1 – customer without scrap exchange, C2 – customer with scrap exchange and T – steel sheet and scrap transport

Table 3 shows the emergy investments needed to supply customers with scrap exchange. The use of steel for container construction contributes with 9% (sej/sej) to the total emergy, and the main investment is due to the purchase of the trucks, 56% (sej/sej) of the total emergy. The emergy balance made for maintenance phase show that steel sheets for containers repair represent 2% (sej/sej) of the total emergy. In the operation phase, labor inputs are 3% (sej/sej) and fuel is the resource used in higher proportion, 28% (sej/sej). In relation to the total emergy employed for the system implemented to attend customers with scrap exchange, the highest contributions come from trucks and fuel.

The emergy of the new system has been calculated as the sum of the emergy of the conventional system (5.93E+16 sej/year) plus the emergy invested (1.30E+17 sej/year) to contemplate customers with scrap exchange, 1.89E+17 sej/year. It is worthy to attention that there was a great enhancement on the emergy invested in the system to implement the scrap exchange system. However, this higher emergy investment permitted the recovery of 3.76 E+5 kg/year of scrap (Fig. 1). Calculating the emergy invested to recover 1 kg of steel (1.30E+17 sej / 3.76E+5 kg = 3.46E+11 sej/kg) with the emergy needed to manufacture 1 kg of steel (4.13E+12 sej/kg) [7] it is noticed that the system implemented uses less resources than those needed to manufacture the same amount of steel.

Table 2. Emergy investment for the conventional system

| | | | | | | Emergy contribution/ (sej/sej) | |
|---|---|---|---|---|---|---|---|
| **Item** | **Description** | Unit | Value / (year) | Emergy per unit/ (sej/unit) | Emergy/ (sej/year) | % of the subtotal | % of the total emergy |
| | IMPLEMENTATION PHASE | | | | | | |
| | *Trucks* | | | | | | |
| 1 | Wagon truck | kg | 4.00E+03 | 6.70E+12 | 2.68E+16 | 100 | 45 |
| | **Subtotal** | | | | **2.68E+16** | | |
| | OPERATION PHASE | | | | | | |
| 2 | Eletric energy | J | 6.43E+09 | 1.65E+05 | 1.06E+15 | 3 | 2 |
| 3 | Labor | J | 2.43E+09 | 7.66E+05 | 1.86E+15 | 6 | 3 |
| 4 | Fuel | J | 4.17E+11 | 6.60E+04 | 2.75E+16 | 85 | 46 |
| 5 | Oxygen | kg | 9.82E+03 | 5.16E+10 | 5.07E+14 | 2 | 1 |
| 6 | Propane | J | 3.13E+10 | 4.80E+04 | 1.50E+15 | 5 | 3 |
| | **Subtotal** | | | | **3.25E+16** | | |
| | **Total emergy** | | | | **5.93E+16** | | |

The location of the points in figure 4 shows the relation between the investment in fuel and goods and services to the amount of scrap recovered.

The emergy ternary diagram shows clearly that system (C1 + C2), resulting from the combination of both types of operation -with scrap exchange (C2) and without scrap exchange (C1) - is located above the line 80% (sej/sej), that is, system (C1+C2) is environmentally beneficial.

The diagram showing the new system (C1+C2) inside area ❶ justifies the implementation of the new structure, which introduces scrap exchange. The "renewability" achieved is nearly 90% (sej/sej).

Table 3. Emergy investment for supplying customers with scrap exchange

| Item | Description | Unit | Value / (year) | Emergy per unit (sej/unit) | Emergy/ (sej/year) | **Emergy contribution / (sej/sej)** % of the subtotal | % of the total emergy |
|---|---|---|---|---|---|---|---|
| | IMPLEMENTATION PHASE | | | | | | |
| | *Material for construction of containers (77 units)* | | | | | | |
| 1 | Steel sheets | kg | 2.77E+03 | 4.13E+12 | 1.14E+16 | 14 | 9 |
| 2 | Electrode | kg | 9.66E+01 | 1.78E+12 | 1.72E+14 | <1 | <1 |
| 3 | Welding iron | kg | 5.44E+01 | 1.78E+12 | 9.68E+13 | <1 | <1 |
| 4 | Machinery | kg | 3.44E+01 | 6.70E+12 | 2.30E+14 | <1 | <1 |
| 5 | Propane | J | 7.63E+08 | 4.80E+04 | 3.66E+13 | <1 | <1 |
| 6 | Oxygen | kg | 2.75E+02 | 5.16E+10 | 1.42E+13 | <1 | <1 |
| 7 | Thinner | kg | 3.08E+00 | 3.80E+11 | 1.17E+12 | <1 | <1 |
| 8 | Synthetic Paint | kg | 6.16E+00 | 1.50E+12 | 9.24E+12 | <1 | <1 |
| 9 | Electric Energy | J | 2.30E+08 | 1.65E+05 | 3.80E+13 | <1 | <1 |
| 10 | Water | J | 1.48E+09 | 1.39E+05 | 2.06E+14 | <1 | <1 |
| 11 | Labor | J | 2.26E+08 | 7.66E+05 | 1.73E+14 | <1 | <1 |
| 12 | Temporary labor | J | 9.72E+07 | 7.66E+05 | 7.45E+13 | <1 | <1 |
| 13 | Fuel | J | 1.06E+09 | 6.60E+04 | 7.00E+13 | <1 | <1 |
| 14 | Fixed container truck | kg | 4.05E+03 | 6.70E+12 | 2.71E+16 | 32 | 21 |
| 15 | Wagon truck | kg | 4.00E+03 | 6.70E+12 | 2.68E+16 | 32 | 21 |
| 16 | Dump truck | kg | 2.65E+03 | 6.70E+12 | 1.78E+16 | 21 | 14 |
| | **Subtotal phase of implantation** | | | | **8.43E+16** | | |
| | CONTAINERS MAINTENANCE PHASE | | | | | | |
| 17 | Steel sheets | kg | 6.93E+02 | 4.13E+12 | 2.86E+15 | 77 | 2 |
| 18 | Electrode | kg | 2.42E+01 | 1.78E+12 | 4.31E+13 | 1 | <1 |
| 19 | Welding iron | kg | 1.36E+01 | 1.78E+12 | 2.42E+13 | 1 | <1 |
| 20 | Propane | J | 4.08E+00 | 4.80E+04 | 1.96E+05 | <1 | <1 |
| 21 | Oxygen | kg | 6.87E+01 | 5.16E+10 | 3.54E+12 | <1 | <1 |
| 22 | Thinner | kg | 2.57E+01 | 3.80E+11 | 9.77E+12 | <1 | <1 |
| 23 | Synthetic Paint | kg | 5.13E+01 | 1.50E+12 | 7.70E+13 | 2 | <1 |
| 24 | Labor | J | 8.09E+08 | 7.66E+05 | 6.20E+14 | 17 | <1 |
| 25 | Electric Energy | J | 5.76E+07 | 1.65E+05 | 9.50E+12 | <1 | <1 |
| 26 | Water | J | 3.71E+08 | 1.39E+05 | 5.16E+13 | 1 | <1 |
| | **Subtotal maintenance phase** | | | | **3.70E+15** | | |
| | OPERATION PHASE | | | | | | |
| 27 | Electric Energy | J | 3.94E+09 | 1.65E+05 | 6.50E+14 | 2 | <1 |
| 28 | Labor | J | 4.86E+09 | 7.66E+05 | 3.72E+15 | 9 | 3 |
| 29 | Fuel | J | 5.53E+11 | 6.60E+04 | 3.65E+16 | 87 | 28 |
| 30 | Oxygen | J | 6.02E+03 | 5.16E+10 | 3.11E+14 | 1 | <1 |
| 31 | Propane | J | 1.92E+10 | 4.80E+04 | 9.22E+14 | 2 | 1 |
| | **Subtotal operation phase** | | | | **4.21E+16** | | |
| | **Total emergy** | | | | **1.30E+17** | | |

The total emergy of the new system equals the sum of the total emergies calculated on tables 2 and 3 (1.89E+17 sej/year).

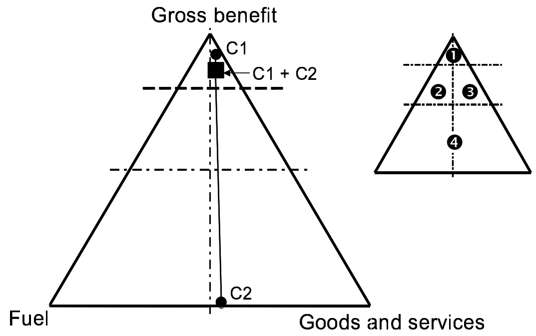


Figure 4. Emergy ternary diagram of the complete distribution system: (C1) customer without scrap exchange, (C2) customer with scrap exchange and system (C1 + C2) representing the combination between (C1) and (C2). The diagram on the right shows four classification regions adopted by the authors where: area ❶ excellent, area ❷ and ❸ indicates good performance, but in ❷ fuel consumption is higher than in ❸, and area ❹ indicates that there is no net benefit

## 5. CONCLUSION

Emergy analysis and emergy ternary diagrams were used to evaluate the performance of a new distribution system for steel sheets, with the collection of scrap. They allowed to highlight that the emergy invested to recover 1kg of steel (3.46E+11 sej/kg) is smaller than that needed to manufacture 1 kg of steel (4.12E+12 sej/kg). The benefit resulting from the new system was classified as excellent, especially because the system was not operating with full capacity during the period of data collection. This study will still be completed with the accounting of $CO_2$ emissions due to the transport of the steel sheets to customers and the transport for the collection of the recovered scrap.

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