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Abstract

Goal,Scope and Background In 2001, a new law on the recycling of end-of-life electric home appliances (EL-EHA) was put into effect in Japan; it was the first legislation of its sort in the world, and deserves to be called the 'Japan model.' This article is concerned with LCIA of alternative life-cycle strategies for EL-EHA, which consist of recycling as prescribed by the law, 'ecodesign' strategies such as the reuse of recovered waste materials and the extension of product life (EPL) with and without ex-post functional upgradability, and the once dominant treatment methods such as landfilling and simple shredding.

Methods We use the waste input-output (WIO) analysis, a new method of hybrid LCIA that was developed by the authors [1]. The WIO extends the conventional input-output analysis to explicitly take into account the interdependence between the flow of goods and the flow of waste in the whole economy, and hence provides an optimal platform for LCIA involving waste treatment and recycling. Furthermore, the WIO enables us to evaluate not only environmental impacts but also economic impacts such as sectoral output and employment. Our analysis is based on the WIO table for 1995 and detailed process data on recycling processes.

Results and Discussion Recycling was found to outperform the 'traditional' treatment strategy with regard to the reduction of CO_2 emission and landfill consumption. Thanks to efficient utilization of the existing retail network system, it was also found to be economically more efficient. Additional implementation of the reuse strategy resulted in a marginal reduction in the environmental impacts. The EPL without upgrading resulted in a significant reduction in the environmental impacts, but also in the level of employment. On the other hand, the EPL with upgrading scenario was found to outperform the recycling strategy in terms of environment impacts without having significant negative economic impacts.

Conclusion and Recommendations Recycling of EL-EHA as prescribed by the Japanese law on the recycling of EL-EHA was found effective in reducing CO2 emission, generation of waste, and landfill consumption provided the rate of retrieval remains at a high level. Our results also support the effectiveness of ecodesign strategy toward the realization of a sustainable economy, provided its implementation in products does not cause a noticeable decline in the material and energy productivity of the manufacturing process.

Keywords end of life home electric appliances, hybrid LCIA, product life, recycling, reuse, upgrading, waste input-output

1 Introduction

In Japan, the number of discarded TV sets, refrigerators, washing machines, and air conditioners amounts to about 2 million units, or 0.73 million tons, annually. Direct landfilling or landfilling after shredding with iron recovery used to be the main treatment method applied to them. With the aim of increasing the recovery of waste materials and reducing the negative environmental impact associated with such treatment, the Japanese government introduced a new law on the recycling of End of Life Electric Home Appliances (EL-EHA) in April 2001. The law makes the manufacturers of electrical home appliances (EHA), TV sets, refrigerators, washing machines, and air conditioners, responsible for the recycling (re-commercializing, to be precise) of specific percentages of EL-EHA, and makes the consumers (disposers) responsible for bearing the cost of recycling and transport. This was the first legislation of its sort in the world, and deserves to be called the "Japan model."

An important element of the Japan model is the "integrated recycling" process [2] under which material components could be recovered from EL-EHA at substantially higher rates than under the conventional shredding processes. With regard to the use pattern of recovered materials, however, the Japan model is still largely characterized by "downcycling" [3] because the original value of the product is destroyed and only some natural resources are recovered.

It is often pointed out that the current manufacturing system represented by the combination of mass production, mass consumption and mass downcycling will not be a sustainable one [4]. The current system is characterized by a loop of product life cycle that is large and open. It is argued that the loop has to be transformed to a small and closed one in order to make the manufacturing system sustainable [5]. Maintenance and upgrading of products to extend their lifetime, and the reuse of disused components, among others, emerge as important strategies for achieving this transformation.

This article is concerned with the evaluation of the environmental and economic effects of these alternative life-cycle strategies by use of the waste input-output (WIO) analysis [1]. A combined use of input-output analysis (IOA) and the life-cycle inventory assessment (LCIA) based on process modeling has become a standard tool of LCIA owing primarily to the public availability of data, ease of computation, and the well defined system boundary [6] [7]. IOA, however, is not appropriate to deal with issues related to waste management, because it does not consider the flow of waste. The WIO is an extended form of IOA that takes into account the interdependence between the flow of both goods (and services) and waste. Using the WIO we can evaluate the impact of alternative product life-cycle strategies on emissions such as CO_2, landfill consumption, and economic activity such as sectoral output and employment.

Assocaited wtih EL-EHA recycling is a complicated flow of goods, recovered waste materials, and residues among a large number of different sectors of the economy, which consist of the EL-EHA treatment sector, the users of recovered materials, and the treatment sector of residues. Furthermore, EL-EHA can be treated in several different ways, each of which is characterized by different combinations and types of inputs, recovered resources and residues. For a LCIA of EL-EHA, it is thus of great importance to properly take into account this interdpendence between the flow of goods and waste over different sectors of the economy. The advantage of WIO-LCIA conists in that it is based on a consistent accountig system (WIO table) that describes this interdpendence.

Prior to the introduction of the recycling law in 2001, there was a worry about a possible increase in the illegal dumping of EL-EHA. Japanese experiences of the past months, however, indicate that this worry did not materialize [8]. In this paper, we assume that all the EL-EHA are retrieved, and focus attention on the effects that result from the application of alternative treatment processes.

The article is structured as follows. First, we give in Section 2 a brief summary of WIO. Section 3 then describes the setup of alternative life-cycle scenarios and the associated material recovery and use patterns. Empirical results of our WIO analysis are presented in Section 4. Discussion of its implications and the limitations of analysis closes the article.

2 LCIA by WIO

Let there be n^{I} goods- and service-producing sectors (henceforth "goods sector"), n^{II} waste treatment sectors, and n^{W} waste types. For ease of exposition, we define the sets of natural numbers referring to each of these sectors and waste types by $N^{\text{I}} := \{1,\dots,n^{\text{I}}\}$, $N^{\text{II}} := \{n^{\text{I}}+1,\dots,n^{\text{I}}+n^{\text{II}}\}$, $N := N^{\text{I}} \cup N^{\text{II}}$, and $N^{\text{W}} := \{1,\dots,n^{\text{W}}\}$. Let x_{I} be an $n^{\text{I}} \times 1$ vector, the i-th component of which is the output of goods sector $i \in N^{\text{I}}$, and x_{II} be an $n^{\text{II}} \times 1$ vector, the $(i - n^{\text{I}})$-th component of after shredding with iron recovery used to be the main treatment method applied to them. With the aim of increasing the recovery of waste materials and reducing the negative environmental impact associated with such treatment, the Japanese government introduced a new law on the recycling of End of Life Electric Home Appliances (EL-EHA) in April 2001. The law makes the manufacturers of electrical home appliances (EHA), TV sets, refrigerators, washing machines, and air conditioners, responsible for the recycling (re-commercializing, to be precise) of specific percentages of EL-EHA, and makes the consumers (disposers) responsible for bearing the cost of recycling and transport. This was the first legislation of its sort in the world, and deserves to be called the "Japan model."

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Let $A_{I,II}$ be an $n^{I} \times n^{II}$ matrix of input coefficients the (i, j) component of which refers to the input of good $i \in N^{I}$ per unit of output of $j \in N^{II}$, and $G_{\cdot,I}$ be an $n^{W} \times n^{I}$ matrix of net waste generation coefficients the (k, j) component of which refers to the net generation (generation net of recycling) of waste $k \in N^{W}$ per unit of output of sector $j \in N^{I}$. $A_{I,I}$ and $G_{\cdot,II}$ are defined in a similar manner. Finally, let S be an $n^{II} \times n^{W}$ non-negative matrix whose (j, k)-component s_{jk} represents the share of waste $k \in N^{W}$ that is treated by treatment method $j \in N^{II}$.

The WIO then gives a simple representation of the relationship between the level of industrial output x_I and waste treatment x_{II}, the structure of technology represented by $A_{I,I}$, $A_{I,II}$, $G_{\cdot,I}$, and $G_{\cdot,II}$, and the life style of final consumers represented by $X_{I,F}$ and $W_{\cdot,F}$ [1]:

$$\begin{bmatrix} A_{I,I} & A_{I,II} \\ SG_{\cdot,I} & SG_{\cdot,II} \end{bmatrix} \begin{bmatrix} x_I \\ x_{II} \end{bmatrix} + \begin{bmatrix} X_{I,F} \\ SW_{\cdot,F} \end{bmatrix} = \begin{bmatrix} x_I \\ x_{II} \end{bmatrix}, \tag{1}$$

or

$$\begin{bmatrix} x_I \\ x_{II} \end{bmatrix} = \left(I_n - \begin{bmatrix} A_{I,I} & A_{I,II} \\ SG_{\cdot,I} & SG_{\cdot,II} \end{bmatrix} \right)^{-1} \begin{bmatrix} X_{I,F} \\ SW_{\cdot,F} \end{bmatrix}, \tag{2}$$

where I_n is the identity matrix of order $n := n^{I} + n^{II}$. Let R be an $n^{E} \times n$ matrix of the emission coefficients of environment loading factors with n^{E} referring to the number of loading factors. The emission of loading factors induced by the lifestyle $(X_{I,F}, W_{\cdot,F})$ is then given by

$$R \begin{bmatrix} x_I \\ x_{II} \end{bmatrix} = R \left(I_n - \begin{bmatrix} A_{I,I} & A_{I,II} \\ SG_{\cdot,I} & SG_{\cdot,II} \end{bmatrix} \right)^{-1} \begin{bmatrix} X_{I,F} \\ SW_{\cdot,F} \end{bmatrix}. \tag{3}$$

In (3), the introduction of a new treatment and/or recycling technology occurs as a change in the coefficient matrices $(A_{\cdot,\cdot}, G_{\cdot,\cdot}, R)$, and a change in lifestyle occurs as a change in final demand vectors $(X_{I,F}, W_{\cdot,F})$. For instance, let Δa_{ij}, Δg_{ij} and Δr_{ij} be the incremental changes in input, waste generation, and emission coefficients associated with the introduction of a certain scenario (for simplicity, we ignore the suffixes "I" and "II"). The new set of corresponding input, waste generation, and emission coefficients matrices A', G' and R' are then given by $A' = [a_{ij} + \Delta a_{ij}]$, $G' = [g_{ij} + \Delta g_{ij}]$ and $R' = [r_{ij} + \Delta r_{ij}]$. We can evaluate the impact associated with the scenario by comparing the new solution for (3) based on A', G' and R' with the reference solution based on the coefficients before the change.

In this paper, we used the Japanese WIO table for 1995 [9, 10]. The WIO table comprises eighty industry sectors, five basic treatment methods (composting, gasification, shredding, incineration, and landfilling), and thirty-six waste types, including nine types of bulky waste (see Appendix for detailed classifications). Incineration was further broken down into several types, depending on the size of incinerator, methods of energy recovery, and the treatment of incineration residues. While the WIO model can deal arbitrary number of emissions, due to data constriants only CO_2 is considered in the following.

3 Discard, Recovery and Recycling Scenarios

3.1 Recovery and Use of Waste Materials

Table 1 shows the amount of EL-EHA and their representative material composition. We first consider four scenarios with regard to the recovery and use of material components. They consist of landfilling (**Lf**), shredding (**Sr**), recycling (**Rc**), and reuse (**Ru**), to the explanation of which we now turn.

Landfilling (Lf) EL-EHA are directly landfilled without any pretreatment except for recovery at a recovery rate of 90% and destruction of chlorofluorocarbon (CFC) 12. In all the scenarios we consider, CFC12 is treated this way.

Shredding (Sr) EL-EHA are shredded and their iron component is recovered at a recovery rate of 99%. The shredding process consists of a set of crushers and magnetic separators. Recovered iron scraps are used as material for steel making in electric arc furnaces. Steel from an electric arc furnace is a substitute for converter steel that uses iron produced by a blast furnace. The remaining unrecovered components become shredder dust and are landfilled.

Recycling (Rc) EL-EHA are subjected to a comprehensive recycling process where, besides steel (at a recovery rate of 99.9%), other materials such as plastics (at a recovery rate of 49%), glass (at a recovery rate of 90%), copper (at a recovery rate of 90%) and aluminum (at a recovery rate of 92%) are also recovered [2]. Furthermore, CFC11 contained in the urethane foam of refrigerators is also recovered (at a recovery rate of 90%) and destroyed. The recycling (**Rc**) scenario satisfies the rate of material recovery prescribed by the Japanese EL-EHA recycling law by a wide margin (to be precise, the law prescribes re-commercialization ratios of around 50 to 60%, the satisfaction of which is more stringent than recycling ratios because the recovered materials have to be sold at positive prices).

This process is characterized by the integrated use of a number of elements such as sorting and initial disassembly, cryogenic crushing, low temperature shredding and metallic-plastic compound separation, and copper-aluminum separation, and as well as PCB (printed circuit board) solder recovery [2]. Recovered copper, aluminum, and glass are used respectively for copper elongation, aluminum rolling, and glass making as substitutes for virgin materials. Plastics, however, are used as a reduction agent in place of coke for steel-making in blast furnaces.

Reuse (Ru) Of the materials recovered under the recycling scenario, plastics are characterized by the largest loss of their original value because they are used as a substitute for coke or pulverized coal, whereas other materials are more or less used as substitutes for their virgin counterparts. Under the reuse scenario we consider the case where some portions of plastics are recovered at levels of purity that are high enough to allow for their use in a more valuable manner.

To be specific, we consider a hypothetical case in which 99% of polypropylene (PP) and polystyrene (PS) is recovered at a level of purity that allows them to be reused as materials for industrial plastic products, while the remaining plastics are used (downcycled) as a reduction agent in iron production, as before. Since EHA manufacturing is one of the main users of industrial plastics, this reuse scenario can be considered one form of closed loop circulation of plastics.

Because PP and PS constitute a substantial portion of plastics used in EHA, their recovery at high rates can significantly reduce the generation of shredder dust, the disposal of which is becoming expensive in Japan owing to the shortage of landfill sites and the introduction of stricter regulations regarding its disposal.

The extent to which waste materials can be recovered at high yield rates depends, among others, on the ease of disassembling EL-EHA into their individual components. This is a subject related to the concept of design for disassembly (DfD). We considered the effects of DfD on disassembly work by reducing all the input coefficients related to the shredding activity by 50%. This corresponds to a 50% increase in the efficiency of the disassembling process (improvement of this order is reported for a conceptual model of washing machine [12]).

Implementation of DfD will also change the way EHA are produced, and hence affect the corresponding input and waste generation coefficients. Owing to a lack of relevant information, this point is subject to a high degree of uncertainty. A sensitivity analysis will be performed with regard to this point in the next section.

For lack of sufficient information, the recovery of nonferrous metals other than copper and aluminum, such as lead, was ignored. Furthermore, the recovered printed circuit boards (PCB) were put together with "other plastics."

3.2 Collection and transport

Significant differences exist between the conventional scenarios (**Lf** and **Sr**) and the recycling scenario (**Rc**) with regard to the method of collection and transport distance, which need to be taken into account in our analysis.

First, different subjects are involved in the collection of EL-EHA from individual households. This brings about significant differences in the collection methods. Under **Lf** and **Sr**, EL-EHA are collected by municipalities based on the curbside collection system, whereas under **Rc** they are collected by retailers of EHA. The utilization of existing retail networks in the collection of EL-EHA is an important feature of the Japanese EL-EHA recycling system, which is made possible by the fact that the generation of EL-EHA usually takes place simultaneous with a new purchase (delivery) of EHA. The same vehicle that delivered the new EHA can then be used to collect and transport the EL-EHA to the nearest designated collection depots that are operated by EHA manufacturers (there are about 380 such depots across the country). It was assumed that no extra inputs are required for the collection of EL-EHA under **Rc**. Our specification of the curbside collection system follows [11], where a 4-ton truck manned with three persons runs at the speed of 10 km/h collecting waste at each curbside.

While **Rc** may outperform **Lf** and **Sr** in terms of the efficiency of collection, it may not in terms of the transport of collected EL-EHA to recycling facilities. This is so because the number of recycling facilities is much smaller (there are forty facilities across the country as of October 2002) than landfill sites or conventional shredding facilities; the collected EL-EHA then have to be transported over substantially longer distances. It was assumed that under the landfilling (**Lf**) and shredding (**Sr**) scenarios, collected EL-EHA need to be transported over a one-way distance of 12 km (this value was taken from [11]), whereas under the recycling (**Rc**) scenario they have to be transported over 75 km. We assume that the transport under **Rc** is done by a 10-ton truck manned with one person, the average speed of which is 40 km/h.

Because our specifications of transport distance are hypothetical, a sensitivity analysis will be performed with regard to it in the next section. The characteristics of the above scenarios are summarized in Table 2.

3.3 Extension of product life

The scenarios introduced above are concerned with the recovery and use of EL-EHA components under a given use pattern of EHA on the side of the consumer. An important factor of the use pattern on the side of the consumer is the length of product life. The life of a product has two dimensions: physical life and functional (value) life. It is widely observed, at least in advanced economies, that many products are discarded at the end of their value life, although their physical life still remains, because the consumers find the products they own functionally outdated and for most products the possibility of ex-post (after purchase) functional upgrading is zero.

It then follows that a simple extension of physical life will not be sufficient for extending product life; it will also be necessary for products to be designed to accommodate functional upgradability [4]. Below we consider two scenarios on the extension of product life, which differ from each other with regard to the possibility of functional upgradability.

Extended life with patience (ExP) The first scenario corresponds to the case where the consumers simply use the products (EHA) longer (within the range of the physical lives) even though they may be functionally outdated. To be specific, we consider the case where the life of EHA is extended by 50%. Assuming the stationary situation where both the purchase and discard of EHAs change simultaneously, the new purchase of EHA and the disposal of EL-EHA are reduced by $33.33\%(= 1 - 1/1.5)$, while the expenditure for repair is increased by 50%.

In 1995, Japanese households owned about 271 million units of four types of EHA [14, p. 501], spent 5,610 billion yen on the purchase of new EHA, and about 80 billion yen on their repair [15]. This gives a rough approximation of annual repair expenditure per unit of EHA of about 300 yen. Corresponding to the extension in the product life of EL-EHA, this amount is also increased by 50%. Because this increase in the consumer expenditure for repair is negligibly small compared with the drop in the expenditure for the purchase of new appliances, the total consumer expenditure drops by 0.48%. We use the term "extended life with patience" or **ExP** to represent this scenario because it requires patience on the side of the consumers in the sense that they are asked to use the products over longer periods even though the products are functionally outdated.

Extended life with functional upgrading (ExU) The second scenario corresponds to the case where the extension of product life is accompanied by ex-post functional upgrading. With regard to the extent to which product life is extended, this scenario is the same as **ExP**. The consumers, however, are no longer asked for patience, because the products in their possession are steadily functionally updated. The way this strategy can actually be implemented may greatly differ for individual products and their specifications, and it is difficult to conceive of any omnibus relationship between repair and update expenditure on the one hand and extension of functional life on the other.

For the sake of computation, a simple hypothetical case was considered where the same amount of expenditure for a new purchase that was saved by the extension of product life needs to be spent on repair and update to keep it functionally updated. This results in a 2400% increase in expenditure for repair and maintenance on the side of the consumer. Economically, at least, this scenario is of interest because the total consumer expenditure remains unchanged, whereas under **ExP** it is reduced because there is no corresponding increase in expenditure for repairs that compensates for the decline in expenditure for new purchases. We use the term "extended life with functional upgrading" or **ExU** for this scenario.

Under the "patience" scenario (**ExP**) the total consumer expenditure, the largest component of GDP, is reduced by 0.48%, whereas under the "upgrading" scenario (**ExU**) it remains at the same level, although its composition changes. It is important to note that the repair activity is not free from waste generation; according to the Japanese WIO table [10], activity of one million yen generates, among other things, 7 kg of waste paper, 1 kg of waste plastics and 150 g of iron scrap. It then follows that the increase in repair under **ExU** works counteractively with regard to the reduction of waste. As for the recovery of waste materials from EL-EHA, the recycling process **Rc** is applied.

Before leaving scenario set-ups, an important remark is due on the limitation of our analysis. While we are concerned with an LCIA of durables, we do not consider issues of dynamic adjustments where EHA of different "vintages," with possibly different energy efficiency and material components, become obsolete and are replaced by newer ones. The case we consider corresponds to a sort of stationary state where, within the range of "extended lives," EHA of different vintages, including the newest ones on the market, are exactly the same. The issues related to the timing of the replacement of older products with newer ones which embody possibly more efficient technology are beyond the scope of this article.

3.4 Inventories

Table 3 shows the inventory of major input items of three of the alternative recovery processes in Table 2, their unit prices, and the WIO industry sectors to which these input items correspond. Panel A of Table 4 then shows the major input and emission coefficients for shredding, recycling and reuse processes that are used in the following scenario analysis. Note that for the first four items (from water supply to chemicals) the values are obtained by multiplying the physical input quantities by the corresponding prices in Table 3.

The input of general machinery refers to the annualized value of construction costs (1.1 billion yen for a shredding plant and 2 billion yen for an integrated recycling plant with an annual capacity of 18000 t = 500,000 units × 36 kg per unit) based on the assumption that the plant lasts for 20 years and that general machinery is the sole supplier of the plant facilities.

The inputs of petroleum products and car maintenance refer to the collection and transportation of EL-EHA, the details of which were described above. Employment refers to total labor requirements that include both vehicle drivers and plant operators/workers. Panel **B** below shows the amount of shredder dust that is generated per ton of treatment under each recovery process. Because plastics constitute the largest component of shredder dust, it is no wonder that its generation is the smallest under the reuse scenario (**Ru**) and is the largest under the shredding scenario (**Sh**).

3.5 Implementing the recycling of recovered materials

3.5.1 Iron scrap

We now turn to implementation into the WIO model of the recycling of recovered materials, the patterns of which are given in the right-most column of Table 2. Table 5 describes the recycling of recovered iron components. The electric steel industry operating electric arc furnaces is the largest user of iron scrap: one ton of its output requires 0.95 tons of iron scrap. For the steel producers operating the converter furnace, however, the main input is pig iron from a blast furnace (see h_{31} and h_{32} in the middle panel of Table 5): its input of iron scrap per ton of output only amounts to 0.08 tons. Provided that these input patterns remain constant, the recycling of recovered iron scraps of 0.27 million tons under **Rc** requires, with other things being equal, an increase in the output of electric arc furnace steel of 0.31 million tons (12.5 billion yen in value terms (see Δy_{32} and Δx_{32})) with a corresponding reduction in the output of converter steel (see Δy_{31} and Δx_{31}).

The major user of electric arc and converter steel is the manufacturer of hot-rolled steel. Therefore, the additional recycling of iron scrap in the amount of 0.27 million tons requires a corresponding change in the composition of electric arc and converter steel as input in the production of hot-rolled steel: the input of electric arc steel per unit of hot-rolled steel is increased by 0.00225, whereas the input of converter steel is reduced by 0.00197. Implicit in this is the assumption that both types of steel are substitutable for each other within the range of volumes considered.

3.5.2 Non-ferrous metals and glass

We next turn to the recycling of non-ferrous metal scrap and glass and the reuse of plastics. Table 6 shows the derivation of incremental changes in the relevant input and waste generation coefficients. The use of these recycled materials as substitutes for virgin materials is a well established practice in the industry. The only exception to this is the reuse of plastics, which is still not an established manufacturing process, and hence is purely hypothetical. The required increase in the use of recycled materials was implemented by changing the corresponding input and waste generation coefficients. For instance, the additional use of recovered copper scraps of 0.039 million tons in the copper elongation sector requires a corresponding increase in the input coefficient for copper scraps (0.067 ton per million yen) and a decrease in the input coefficient for virgin copper (0.019 million yen per million yen) in that sector.

The additional recycling of aluminum scraps in the aluminum rolling industry and that of waste glass (glass cullet) in the glass manufacturing industry are implemented in a similar manner by increasing the input coefficient (decreasing the net waste generation coefficient) of recovered waste materials and decreasing the input coefficient of corresponding virgin materials. Here, too, we assume that within the range under consideration virgin materials and the corresponding recycled materials are fully substitutable for each other. Formally, at least, the reuse of plastics is also implemented in exactly the same way; with regard to its content, this is the only case where waste materials are used not for producing materials but for producing final products (plastic products). Furthermore, this is still far from a widely established manufacturing process.

3.5.3 Plastics for chemical recycling

Finally, we turn to the implementation of the injection of waste plastics into blast furnaces in Table 7. This case is remarkable in that it is concerned with the substitution of heterogeneous materials, plastics and coke/pulverized coal, serving the same purpose as reduction agents in the production of iron. It is necessary to convert them into an equivalent unit of measurement. Based on heat capacity, 1 kg of waste plastics is regarded as an equivalent of 1.31 kg of coke [16].

Because coke and plastics have different carbon content (.8856 kg-C/kg and .7288 kg-C/kg), the use of one ton of waste plastics in place of (the heat equivalent quantity of) coke can reduce the emission of CO_2 by $1.31 \times 0.8856 - 0.7288 = 0.4313$ t-C. On the other hand, waste plastics need to be pretreated into forms that are appropriate for injection into blast furnaces. This requires additional electricity of 267 kWh per ton of waste plastics. The amount of maintenance and repair corresponds to the annualized construction cost of a typical pretreatment plant characterized by 44000 yen per ton of capacity and a durability of 10 years. As was the case for Table 4, we regard the general machinery industry as the sole supplier of the whole plant.

4 Results

4.1 Effectiveness of recycling

Table 8 shows the major results in terms of the rate of change in percentage relative to the corresponding values obtained under the landfilling scenario (**Lf**) that serves to provide reference values. The CO_2 emission contains, besides that originating from the burning of fossil fuels and limestone, the GWP100 (global warming potential over 100 years) CO_2-equivalent value of methane originating from biomass fermenting at landfill sites, and the GWP100 CO_2-equivalent value of CFCs ([17]) contained in EL-EHA. Given the modest share (less than 1%) of EL-EHA in the total volume of landfill consumption, it is not surprising that the overall "macro effects" are rather small. Still, Table 8 provides many interesting findings.

First, in terms of the reduction of CO_2 emission (including the GWP100 CO_2-equivalents of CFCs) and landfill consumption in panel **A**, the results of recycling (**Rc**) outperform those of both landfilling (**Lf**) and shredding (**Sh**). The result is robust to the exclusion of the emission of CFC origin. While it may be obvious that increased recycling reduces landfill consumption, its effect on CO_2 emission is not obvious because larger inputs of energy may be necessary to increase recycling.

Pane **B**, in fact, shows that recycling increases the overall demand for power (electricity) by about 0.02%. On the other hand, the increase in recycling of recovered metals reduces the output of copper by 2.3%, pig iron by 0.4%, and aluminum by 0.4%, the production of which is quite energy intensive, and the output of other mining (mostly crude oil and ores) by 0.1%. As a whole, the effect of reducing the emission of CO_2 induced by recycling turned out to be large enough to outweigh the opposite effects that work to augment the emissions. This result on CO_2 emission is consistent with that of [13] and [2], which were obtained by the conventional method of LCIA based on process modeling. The increase in electric steel and the reduction in converter steel reflect the increased use of iron scraps in steel making.

Corresponding to the changes in sectoral output, the major items of which are reported in panel **B**, the level of waste generation and recycling, net waste generation in short, also change. Panel **C** shows major changes in the net generation of waste. The reduced production of metals reduces the generation of slag, waste acid, and waste alkali, among others.

The effect on overall employment in panel **A** will be the only item in our results that could be used as a proxy for macro economic effects. Because the level of GDP (the sum of final demand) is kept constant except for the extended life scenario without upgrading (**ExP**), an increase in overall employment indicates that a larger amount of labor input was required to produce the same level of GDP. This means a decline in the level of overall labor productivity. Under the recycling scenario, the overall employment increases by 0.003%, whereas under the shredding scenario it increases by 0.007%. While this indicates the presence of cost increasing effects under recycling compared to landfilling, its effect is smaller than the shredding scenario due largely to the efficiency of its collection system.

In order to see the extent to which the above results are affected when transport distances are changed, we performed a sort of sensitivity analysis by changing the one-way transport distance of collected EL-EHA under the recycling scenario (**Rc**) from 12 km to 4800 km. Figure 1 shows the results on CO_2 emission and employment. The source of CO_2 emission excludes CFCs. The results indicate that CO_2 emission under the recycling scenario will be smaller than under the shredding scenario even when the transport distance is increased to 1200 km, and that it will be smaller than under landfilling even when it is increased to 2400 km (the full length of the Japanese archipelago is about 3000 km!). The latter would roughly correspond to an extreme case where there is only one recycling facility in the whole country. The advantage of recycling with regard to CO_2 emission over shredding and landfilling thus appears robust to changes in transport distance. While the labor cost tends to increase with the increase in transport distance, it remains at the same level even when it is extended to 600 km.

4.2 Reuse and extension of product life

The column **Ru** in Table 8 refers to the results of the reuse scenario. It indicates that the combination of the recycling scenario with the reuse scenario of plastics can result in a further reduction in the emission of CO_2 and landfill consumption.

The columns **ExP** and **ExU** refer to the extension of product life without and with the possibility of functional upgrading. Because of the reduction in the purchase of new products, the output of household electric appliances, which include EHA, is decreased by 23% under both the scenarios. With regard to the output level of machine repair, however, substantially different effects emerge. Under **ExU**, the reallocation of expenditure from new purchase to repair and maintenance leads to a compensating increase in the output of machine repair by 30%. In the case of **ExP**, however, there is no such compensating increase in the expenditure for repair and maintenance, and the increase in machine repair is kept at a tiny 0.4%. This produces significantly different effects between the two scenarios.

It is obvious that the level of emissions declines with a decline in the level of economic activity. The significant decline in the CO_2 emission of 0.27% (a sixfold increase compared to the recycling scenario **Rc**) under **ExP** is due to the decline in the total consumer expenditure of 0.48%. Also significant is the reduction in incineration of 0.15%. The economic cost associated with these environmental gains, however, is not small, with an almost 0.3% reduction in total employment, which amounts to 0.18 million persons! While "deep ecologists" may feel comfortable with the consequence of this scenario, most people would not. A society plagued by a high unemployment rates would not be "socially sustainable."

Scenario **ExU** deals with an alternative case where the fall in the purchase of new EHA is compensated for by the same amount of increase in the expenditure for repair and maintenance. Because the level of final demand, and hence the level of economic activity, is kept unaltered, it is no wonder that the associated environmental gains become significantly smaller compared with those under **ExP**. Still, in terms of the emission of CO_2 with CFCs, landfill consumption, and the amount of incineration, the results under **ExU** outperform those under **Rc**.

Recall that a reduction in resource inputs with a given level of GDP (final demand) indicates an increase in the overall productivity (efficiency) of the economy because the same level of living standard can then be achieved with a smaller input of resources. The large decline in labor input (employment) obtained under **ExP** is no indication of increase in productivity because the level of GDP was not kept constant but reduced. Of the scenarios where the level of GDP is kept unaltered, we observe the largest rate of decline in the overall level of employment under **ExU**. It then follows that this scenario is the most cost effective among the scenarios that keep the level of economic activity unchanged. The maintenance and upgrade scenario thus emerges as the one that is sound in terms of both environmental effect and economic cost.

Our scenarios on reuse and extended lives are hypothetical and subject to considerable uncertainty. It was assumed aove that the implementation of design for disassembly and extended product life does not cause any change in the manufacturing process of EHA. It is usually the case, however, that the implementation of these design concepts calls for the use of more input: upgradability calls for redundancy, and reusability calls for the use of more durable parts and components. With other things being equal, the use of more input implies a decline in the productivity of the EHA manufacturing sector. In terms of WIO, these occur as an increase in the input coefficients of the EHA manufacturing sector.

In order to have some idea about the extent to which the above results on CO_2 emission remain robust to possible decline in the productivity of the EHA manufacturing sector, a sensitivity analysis was carried out for alternative cases where the input coefficients of the sector are increased from 1% to 5% under both reuse and extended life scenarios. Figure 2 shows the results. In the figure, the bars on the far right refer to the results in Table 8 where there is no decline in the productivity level of the EHA manufacturing sector. It is indicated that the emission-saving effect remains robust to the decline in productivity when it is kept below 4% in the case of extended life with functional upgradability **ExU** and 3% in the case of reuse **Ru**; because the reuse scenario has smaller emission-saving effects than the extended life scenario it is no wonder that the saving effect diminishes at lower rates of productivity decline than the latter. In a similar vein, we also considered the case where under the reuse scenario the productivity of shredding is not increased by 50% as above, but is kept unchanged, and found that the result was negligible.

5 Concluding Remarks

Several important implications can be derived from the above results. Firstly, our result supports the result of [13] (obtained by use of the conventional process based method of LCIA) that the recycling of EL-EHA based on the comprehensive recycling process [2] is an effective means of reducing environmental load in terms of CO_2 emission, generation of waste, and landfill consumption. This implies that the Japanese law on EL-EHA recycling that was put into effect in 2001 is also an effective means of reducing environmental load provided the rate of retrieval remains at a high level.

Secondly, its effect on the reduction of CO_2 emission was found robust to a wide range of changes in transport distances. While the economic cost would rise compared with landfilling, its increase was kept lower than shredding under a reasonable range of transport distance mainly due to the high efficiency of the collection system that makes use of existing retail networks. The efficiency of transport is crucial to make the Japan model of EL-EHA recycling not only environmentally sound but also economically affordable.

Thirdly, the extension of product life where the drop in the expenditure for new purchases is compensated for by increased expenditure on repair and maintenance emerged as a promising strategy for achieving a significant reduction of environmental load without having negative effects on economic activity and employment. Extension of functional product life via maintenance and upgrading constitutes an important element of EcoDesign.

Our results thus support the effectiveness of EcoDesign strategy toward the realization of a sustainable economy, provided its implementation in products does not cause a noticeable decline in the material and energy productivity of the manufacturing process.

Our results were based on hypothetical scenarios, the empirical relevance of which needs to be carefully checked. This applies in particular to the scenarios concerned with reuse and extended life where relevant empirical information is still quite limited due to the still immature state of their implementation in actual product design. Further investigation is required to close the gap between the analytical model and real implementation of EcoDesign strategies in industry and business.

Appendix

Table 9 shows the classification of the eighty goods sectors of the WIO table for Japan 1995. Table 10 shows that of waste types and treatment methods of the table.

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Table 1: Discard and Material Composition of Electric Home Appliances

	TV set	Refrigerator	Washing machine	Air conditioner
Discarded appliances				
Units (10^3)	9031	4071	4530	3023
Weight (10^3 tons)	225.8	240.2	113.3	154.2
Material composition (%)				
Iron	9.7	49.0	55.7	45.9
Copper	1.5	3.4	2.9	18.5
Aluminum	0.3	1.1	1.4	8.6
Other metals	1.4	1.1	0.5	1.5
Plastics: PP & PS[a]	15.0	22.1	28.7	9.3
Plastics: PVC[a]	0.5	3.4	2.0	1.9
Plastics: others	0.5	17.8	4.0	6.4
Glass	62.4	0.0	0.0	0.0
PCB[a]	8.1	0.0	1.5	3.1
CFC11		0.77		
CFC12		0.33		2.0
Others	0.5	1.0	3.3	2.9

Note: Units in parentheses.

[a] PP, PS, PVC, and PCB stand for polypropylene, polystyrene, poly vinyl chloride, and printed circuit boards, respectively.

Source: [2, 13].

Table 2: Recovery and Use/Treatment of Materials under Alternative Recovery Scenarios

Treatment scenarios	A. Rate of material recovery (%)				B. Use/treatment of recovered materials[a]
	(Lf) Landfilling	(Sh) Shredding	(Rc) Recycling	(Ru) Reuse	
Material components					
Iron	0.0	99.0	99.9	99.9	electric arc steel[b]
Copper	0.0	0.0	89.9	89.9	copper elongation (copper)
Aluminum	0.0	0.0	92.2	92.2	aluminum rolling (aluminum)
Other metals	0.0	0.0	0.0	0.0	landfilled
Plastics: PP & PS	0.0	0.0	48.5	99.0	steel (pulverized coke)[c]
Plastics: others[d]	0.0	0.0	48.5	48.5	steel (pulverized coke)
Glass	0.0	0.0	99.0	99.0	glass (silica)
CFC11	0.0	0.0	90.0	90.0	destroyed
CFC12	90.0	90.0	90.0	90.0	destroyed
Others	0.0	0.0	0.0	0.0	incineration and/or landfill
Collection	curbside		retail network		
Distance (km)[e]	12	12	75	75	

Note: See also notes for Table 1.

[a] Recovered materials are used by goods sectors (as substitutes in parentheses), or treated by treatment methods.

[b] The electric arc steel made of iron scrap substitutes for the converter steel made of pig iron.

[c] In the case of "Reuse", PP & PS are used in "Plastic products" sector as substitutes of input from the chemical industry.

[d] Excludes poly vinyl chloride (PVC), which is landfilled.

[e] Transport distance (one way) of collected EL-EHA to treatment facilities.

Source: [2, 13].

Table 3: Inventories of Alternative Recovery Methods

	Unit	Input per ton of EL-EHA (Lf) Landfilling	(Sr) Shredding	(Rc) Recycling	Price (yen/unit)	WIO classification
Water[a]	L	2.2	2.2	38.8	3.0	Water supply
Electricity	kWh	5.9	109.1	135.6	21.0	Electric power
Slaked lime[a]	kg	0.1	0.1	0.3	20.0	Misc. stone and clay products
Liquid nitrogen[b]	kg			85.4	25.0	Chemical industry

Note: See also Table 9 for the WIO classification of sectors.

[a] Used for CFC degradation. [b] Used for low temperature shredding.

Source: [2].

Table 4: Coefficients of Recovery Processes

Scenarios	(Sh) Shredding	(Rc) Recycling	(Ru) Reuse
A. Major input and emission coefficients[a]			
Water supply	0.0007	0.0116	0.0058
Electric power	2.2909	2.8453	1.4226
Misc. stone and clay products	0.0020	0.0060	0.0030
Chemical industry	0.0000	0.0021	0.0011
General machinery	3.0247	5.5556	2.7778
Petroleum refinery products (inc. greases)	0.3339	0.1982	0.1982
Repair of motor vehicles	1.2841	0.3330	0.3330
Employment[b]	0.0057	0.0032	0.0018
CO_2[c]	0.0043	0.0027	0.0027
B. Generation of shredder dust (ton per ton of EHA treated)			
TV set	0.9040	0.1517	0.0758
Refrigerator	0.5039	0.2488	0.1373
Washing machine	0.4486	0.2290	0.0841
Air conditioner	0.5256	0.1759	0.1290

[a] The unit is 10^3 yen per ton of EHA unless otherwise stated.

[b] Person per ton. Includes employment for collection and transport.

[c] Direct emission due to the consumption of petroleum products and lime stone in ton-Carbon.

Table 5: Implementing the Recycling of Iron Scraps in WIO (Shredding Scenario)

Iron scraps to be recycled	270.7 [10^3 ton]	w
Output of "Hot rolled steel" sector	5,526 [10^9 yen]	x_{33}
Input of iron scraps per output of alternative crude steel		
"Crude steel (converters)"	0.0805 [ton/ton]	$h_{31} = p_{31}\, g_{5,31}$
	2.309 [10^{-6} ton/yen]	$g_{5,31}$
"Crude steel (electric furnaces)"	0.9469 [ton/ton]	$h_{32} = p_{32}\, g_{5,32}$
	23.760 [10^{-6} ton/yen]	$g_{5,32}$
Increase in output of crude steel that is necessary to absorb recovered iron scraps		
"Crude steel (converters)"	−312.47 [10^3 ton]	$\Delta y_{31} = w/(h_{31} - h_{32})$
	−10.900 [10^9 yen]	$\Delta x_{31} = p_{31}\, \Delta y_{31}$
"Crude steel (electric furnaces)"	312.47 [10^3 ton]	$\Delta y_{32} = -\Delta y_1$
	12.453 [10^9 yen]	$\Delta x_{32} = p_{32}\, \Delta y_{32}$
Incremental change in input coefficients of "Hot rolled steel" sector		
"Crude steel (converters)"	−0.00197 [yen/yen]	$\Delta a_{31,33} = \Delta x_{31}/x_{33}$
"Crude steel (electric furnaces)"	0.00225 [yen/yen]	$\Delta a_{32,33} = \Delta x_{32}/x_{33}$

Note: The numbers occurring as suffixes in the far right column refer to sectoral classification numbers; 33 for "hot rolled steel", 31 for "crude steel (converters)", 32 for "crude steel (electric furnaces)", and 5 for "iron scraps". See also Tables 9 and 10. $p_{31}(= h_{31}/g_{5,31})$ refers to the price of converter steel and $p_{32}(= h_{32}/g_{5,32})$ refers to the price of electric steel 10^6 yen/ton.

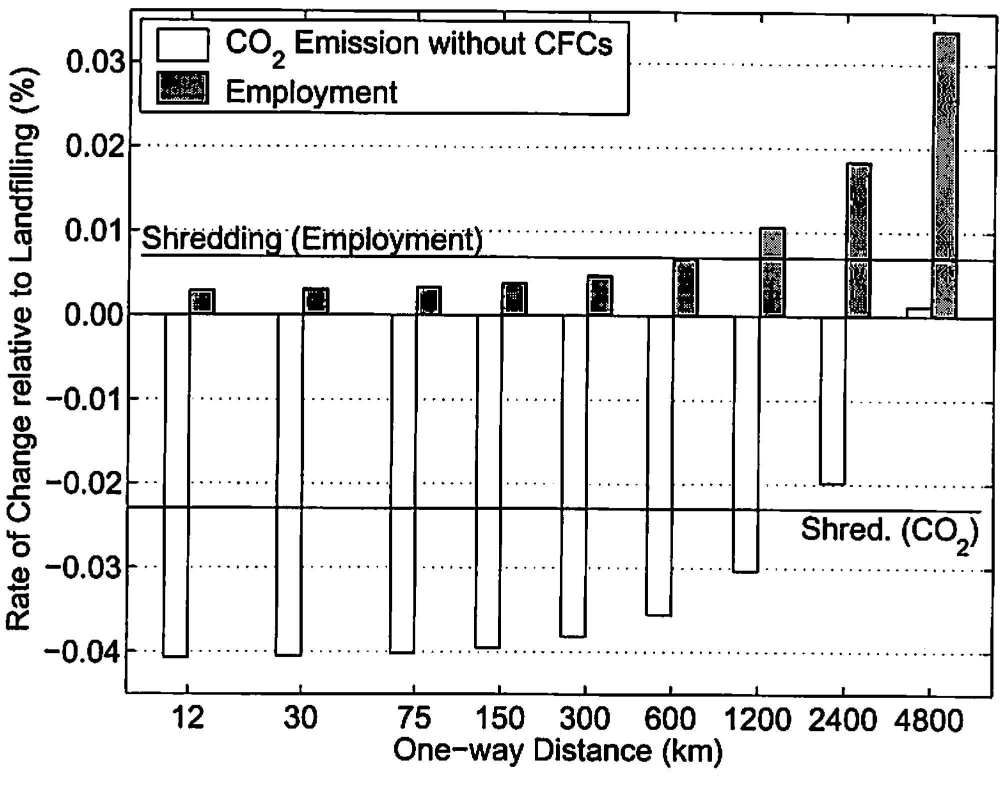

Figure 1: Effects of transport distance on CO_2 emission and labor cost

Table 6: Implementing the Substitution of Virgin Materials by Recycled Materials

Copper ("Recycling" and "Reuse" scenario)		
Copper scraps to be reused	39.0 [10^3 ton]	w
"rolled and drawn copper and copper alloys" sector		
Output	578.1 [10^9 yen]	x_{44}
Price of virgin copper	0.2816 [10^6 yen/ton]	p_{38}
Incremental change in input coefficients of "rolled and drawn copper and copper alloys" sector		
Copper scraps	0.06743 [10^{-6} ton/yen]	$\Delta g_{7,44} = w/x_{44}$
Virgin copper	−0.01899 [yen/yen]	$\Delta a_{38,44} = -p_{38}\,\Delta g_{7,44}$

Aluminum ("Recycling" and "Reuse" scenario)		
Aluminum scraps to be reused	16.7 [10^3 ton]	w
"rolled and drawn aluminum" sector		
Output	1,236 [10^9 yen]	x_{45}
Price of virgin aluminum	0.1985 [10^6 yen/ton]	p_{40}
incremental change in input coefficients of "rolled and drawn aluminum" sector		
Aluminum scraps	0.01355 [10^{-6} ton/yen]	$\Delta g_{8,45} = w/x_{45}$
Virgin aluminum	−0.00269 [yen/yen]	$\Delta a_{40,45} = -p_{40}\,\Delta g_{8,45}$

Glass ("Recycling" and "Reuse" scenario)		
Glass cullet to be reused	139.5 [10^3 ton]	w
"Glass products" sector		
Output	1,745 [10^9 yen]	x_{26}
Price of raw minerals (silica stone)	0.0022 [10^6 yen/ton]	p_5
Incremental change in input coefficients of "glass products" sector		
Glass cullet	0.07992 [10^{-6} ton/yen]	$\Delta g_{10,26} = w/x_{26}$
Raw minerals	−0.00018 [yen/yen]	$\Delta a_{5,26} = -p_5\,\Delta g_{10,26}$

Plastics for reuse ("Reuse" scenario)		
Recovered plastics to be reused		
PP	64.1 [10^3 ton]	$w_{(1)}$
PS	68.4 [10^3 ton]	$w_{(2)}$
Total	132.5 [10^3 ton]	$w = w_{(1)} + w_{(2)}$
"Plastic products" sector		
Output	10,107 [10^9 yen]	x_{23}
Price of virgin plastics		
PP	0.1420 [10^6 yen/ton]	$p_{(1)}$
PS	0.2145 [10^6 yen/ton]	$p_{(2)}$
Average	0.1794 [10^6 yen/ton]	$p_{19} = (p_{(1)}\,w_{(1)} + p_{(2)}\,w_{(2)})/w$
Incremental change in input coefficients of "household electric appliances" sector		
Recovered plastics	0.01311 [10^{-6} ton/yen]	$\Delta g_{4,23} = w/x_{23}$
Virgin plastics	−0.00235 [yen/yen]	$\Delta a_{19,23} = -p_{19}\,\Delta g_{4,23}$

Note: The numbers occurring as suffixes in the far right column refer to sectoral classification numbers. See also Tables 9 and 10.

Table 7: Implementing the Use of Waste Plastics in the Steel Industry ("Recycling" scenario)

Waste plastics to be recycled (injected)	105.2 [10^3 ton]	w
"Pig iron" sector		
Output	1,197 [10^9 yen]	x_{29}
Price of coke	0.0129 [10^6 yen/ton]	p_{21}
Coke to be substituted	137.8 [10^3 ton]	$-\Delta y_{21,29} = 1.31 \times w$
Reduction of CO_2 due to the substitution of plastics for coke	45.4 103 ton-C	$-\Delta e = 0.4313 \times w$
Inputs for shredding of plastics injected		
Electricity	0.58910 [10^9 yen]	$\Delta y_{62,29} = 267\,\text{kWh/ton} \times w$
Machinery (Maintenance and repair)	0.46290 [10^9 yen]	$\Delta x_{52,29} = 0.0044 \times w$
Incremental change in input and emission coefficients of "pig iron" sector		
Coke	−0.00149 [yen/yen]	$\Delta a_{21,29} = p_{21}\,\Delta y_{21,29}/x_{29}$
Electricity	0.00049 [yen/yen]	$\Delta a_{62,29} = p_{62}\,\Delta y_{62,29}/x_{29}$
Machinery	0.00039 [yen/yen]	$\Delta a_{52,29} = \Delta x_{52,29}/x_{29}$
Waste plastics	0.08787 [10^{-6} ton/yen]	$\Delta g_{4,29} = w/x_{29}$
CO_2	−0.03790 [10^{-6} ton-C/yen]	$\Delta r_{29} = \Delta e/x_{29}$

Note: The numbers occurring as suffixes in the far right column refer to sectoral classification numbers. See also Tables 9 and 10. The price of electricity p_{62} is given in Table 3. The inventory data on $\Delta y_{21,29}$ and $\Delta y_{62,29}$ are due to [16].

Table 8: Major Results of WIO on EL-EHA

Scenarios	Recovery/Use			Extended life	
	Shredding (Sr)	Recycling (Rc)	Reuse (Ru)	Patience (ExP)	Upgrading (ExU)
A. Macro effects					
CO_2	−0.023	−0.040	−0.042	−0.266	−0.041
CO_2 with CFC	−0.022	−1.912	−1.914	−2.509	−2.291
Incineration	0.000	−0.002	−0.008	−0.147	−0.063
Landfilling (m^3)	−0.257	−1.006	−1.211	−1.107	−1.079
Employment	0.007	0.003	−0.001	−0.274	−0.015
B. Effects on industrial output					
Materials for ceramics	−0.037	−0.154	−0.154	−0.321	−0.160
Other mining	−0.019	−0.104	−0.107	−0.336	−0.122
Chemical industry	0.001	0.000	−0.117	−0.349	−0.224
Coal products	−0.102	−0.334	−0.203	−0.618	−0.215
Plastic products	0.001	0.001	−0.007	−1.259	−0.976
Rubber products	0.014	0.008	0.002	−0.436	0.300
Glass products	0.001	0.000	−0.008	−0.450	−0.222
Pig iron	−0.373	−0.375	−0.378	−0.770	−0.308
Crude steel (converters)	−0.451	−0.455	−0.457	−0.840	−0.396
Crude steel (electric furnaces)	0.943	0.952	0.949	0.107	0.574
Copper	0.000	−2.316	−2.318	−2.834	−2.484
Aluminum (inc. regenerated aluminum)	0.005	−0.386	−0.390	−1.127	−0.739
Rolled and drawn copper and copper alloys	0.001	0.002	0.000	−2.440	−1.944
Rolled and drawn aluminum	0.001	0.001	−0.002	−0.969	−0.712
General machinery	0.009	0.018	0.008	−0.156	1.585
Household electric appliances	0.000	0.000	0.000	−23.203	−22.542
Electric power	0.016	0.020	0.003	−0.274	0.035
Water supply	0.000	0.000	−0.005	−0.161	−0.039
Repair of motor vehicles	0.015	0.004	0.002	−0.109	0.001
Repair of machines	0.001	−0.002	−0.011	0.377	30.824
C. Effects on net waste emission					
Incineration ash	0.004	0.001	−0.020	−0.320	−0.121
Slag	−0.040	−0.063	−0.079	−2.359	−0.623
Waste oil	0.000	−0.008	−0.038	−0.574	−0.171
Waste acid	−0.003	−0.009	−0.054	−1.283	−0.935
Waste alkali	0.001	−0.048	−0.077	−1.143	−0.777
Molten slag	0.000	−0.005	−0.018	−0.383	−0.216

The numbers refer to the rate of change in percentage relative to the reference value obtained under the landfilling scenario. "Household electrical appliances" include EHA, but other electronic and electric appliances as well.

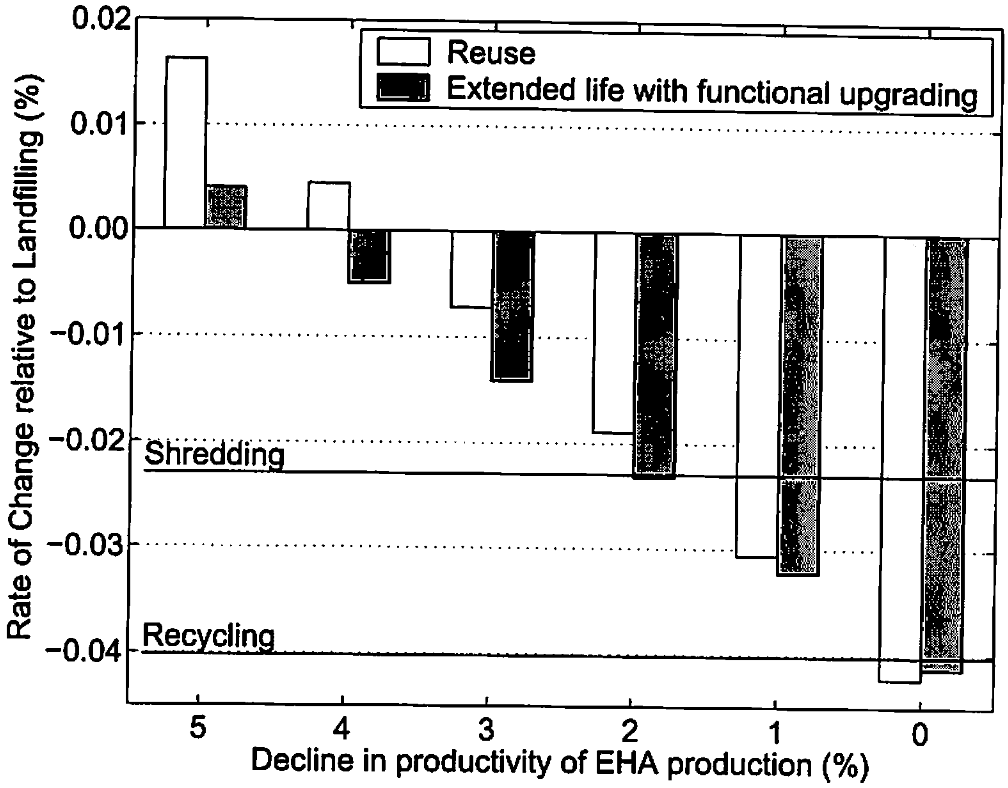

Figure 2: Effects of decline in productivity of EHA manufacturing on CO_2 emission

The light gray bar indicates the effect on overall emission of CO_2 when the productivity of the EHA (electric home appliances) sector is decreased by 5%, 3%, 1%, and 0% under the reuse (design for disassembly) scenario. The dark gray bar indicates the corresponding effect under extended life with the functional upgrading scenario.

Table 9: Classification of Industrial Sectors

No.	Industrial sector	No.	Industrial sector
1.	Agriculture (excl. livestock)	41.	Other non-ferrous metals
2.	Livestock	42.	Electric wires and cables
3.	Forestry	43.	Optical fiber cable
4.	Fishery	44.	Rolled and drawn copper and copper alloys
5.	Materials for ceramics	45.	Rolled and drawn aluminum
6.	Gravel and crushed stones	46.	Non-ferrous metal castings and forgings
7.	Other mining	47.	Nuclear fuels
8.	Foods	48.	Other non-ferrous metal products
9.	Beverage, feeds and tobacco	49.	Metal products for construction
10.	Textile	50.	Metal products for architecture
11.	Textile products	51.	Other metal products
12.	Timber and wooden products	52.	General machinery
13.	Furniture	53.	Household electric appliances
14.	Pulp	54.	Other electric appliances
15.	Paper and paperboard	55.	Passenger motor cars
16.	Paper products	56.	Trucks, buses and other cars
17.	Printing and publishing	57.	Other transportation equipment
18.	Chemical fertilizer	58.	Precision instruments
19.	Chemical industry	59.	Misc. manufacturing products
20.	Petroleum refinery products (inc. greases)	60.	Construction
21.	Coal products	61.	Civil engineering
22.	Paving materials	62.	Electric power
23.	Plastic products	63.	Gas supply
24.	Rubber products	64.	Heat supply
25.	Leather and fur products	65.	Water supply
26.	Glass products	66.	Sewage disposal
27.	Cement	67.	Wholesale trade
28.	Misc. stone and clay products	68.	Retail trade
29.	Pig iron	69.	Railway transport
30.	Ferroalloys	70.	Road transport
31.	Crude steel (converters)	71.	Other transport and communication
32.	Crude steel (electric furnaces)	72.	Public administration
33.	Hot rolled steel	73.	Scientific research institutions
34.	Steel pipes and tubes	74.	Medical service
35.	Cold-finished and coated steel	75.	Repair of motor vehicles
36.	Cast and forged steel products	76.	Repair of machines
37.	Other steel products	77.	Eating and drinking places
38.	Copper	78.	Other services
39.	Lead and zinc (inc. regenerated lead)	79.	Office supplies
40.	Aluminum (inc. regenerated aluminum)	80.	Activities not elsewhere classified

Table 10: Classification of waste types and treatment processes

No.	Waste type
1.	Food waste
2.	Waste paper
3.	Waste textiles
4.	Waste plastics
5.	Iron scraps
6.	Non-ferrous scraps[a]
7.	Copper scraps[a]
8.	Aluminum scraps[a]
9.	Glass bottles
10.	Glass cullet
11.	Waste ceramics
12.	Waste rubber
13.	Animal and vegetable residue
14.	Dust
15.	Incineration ash
16.	Slag
17.	Sawdust and wood chips
18.	Organic sludge
19.	Inorganic sludge
20.	Waste oil
21.	Waste acid
22.	Waste alkali

No.	Waste type
23.	Construction debris
24.	Animal waste
25.	Carcass
26.	Bulky waste: textile products
27.	Bulky waste: wooden furniture
28.	Bicycles and ovens
29.	Small electric appliances
30.	[EHA] TV sets
31.	[EHA] Refrigerators
32.	[EHA] Washing machines
33.	[EHA] Air conditioners
34.	Automobiles
35.	Molten slag
36.	Shredder dust

No.	Treatment method
1.	Incineration[b]
2.	Landfilling
3.	Composting
4.	Biogasification
5.	Shredding[c]

Note: [a] Copper and aluminum scraps are included in Types 7 and 8, respectively, if they are recovered by shredding EHA, and in Type 6 otherwise.

[b] Distinguished by size, utilization of waste heat, and treatment of residue.

[c] Distinguished by feedstock types.