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# Implementing Sustainability Criteria in Product Development

E. Lacasa[a,*], J. L. Santolaya[a], L. Fuentes[a], A. C. Majarena[a]

[a]*Design and Manufacturing Engineering Department - EINA(University of Zaragoza), María de Luna 3, Zaragoza (50018), Spain*

**Abstract**

This work analyses the product development process of two different mechanical assemblies in order to put into practice redesign strategies that allow obtaining more sustainable products.
The study of the manufacturing process has been focused on obtaining material and energy consumptions. Sustainable design criteria have been applied preserving the initial specifications of each product. A number of approaches as the material replacement, the reduction of the final product mass and an effective utilization of raw materials have been proposed. A reduction of the environmental impact, which was assessed trough global energy and global warming eco-indicators, has been achieved.


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*Keywords:* sustainable design, product development, eco-indicator

## 1. Introduction

Since several decades, ecological initiatives and industrial models based in the concept of sustainable development have been matter of interest to the governments, in particular of European Union [1, 2], where different specifications of obligatory execution have been established.

The industrial world is increasingly aware of environmental impact of the products it makes, not only along manufacturing phase, but at all stages of the product life cycle [3], from the initial stage of obtaining materials to the waste phase once that the product life has finished. Sustainability has become a requirement for competitive companies, which can also enable them to achieve higher quality products, to improve the company image and to reduce the manufacturing costs.

* Corresponding author. Tel.: +34-976-761-900; fax: +34-976-762-235.
*E-mail address:* enrike_sena@hotmail.com


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In order to integrate environmental considerations into product development, from the design engineering different methods and tools are proposed [4, 5]. The combination of eco-design with life cycle assessment and environmental communication is suggested for obtaining improved products. In addition, a number of tools are currently used to determine the environmental impact of a product. This type of tools employ environmental databases of materials and energy sources and are able to calculate eco-indicators as carbon footprint, global energy or the generation of polluting emissions.

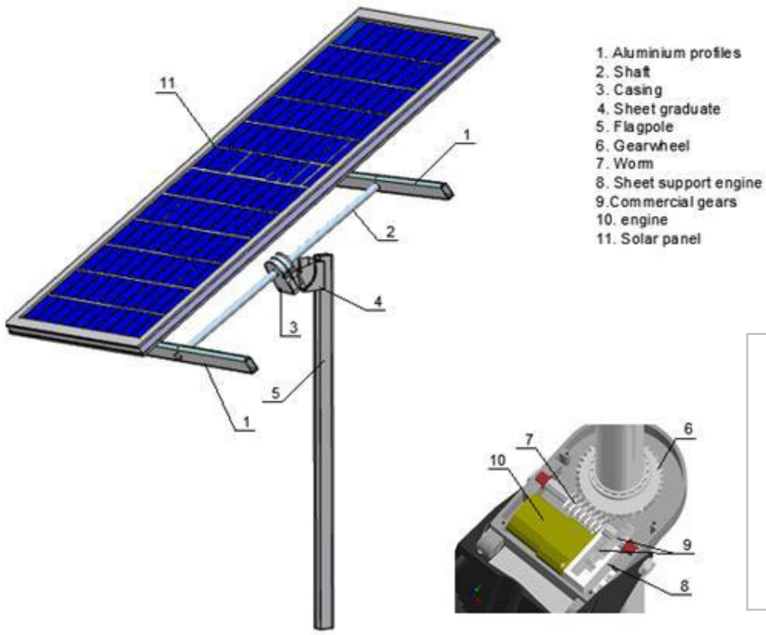
In this paper, a product redesign approach that integrates the study of product specifications, the analysis of design factors [6] and the application of sustainable criteria, is proposed. Initial specifications are preserved in the redesign process. The product manufacturing phase is analysed in detail, particularly, materials and processes.

## 2. Methodology

Two different products have been analysed: a solar tracker for low power installations and an airbrush for precision works. In each case, production drawings, types of materials and initial design specifications are available. The manufacturing processes of both products have been studied. Afterwards, global energy and global warming eco-indicators have been determined and the redesign of products applying sustainability criteria has been carried out. Finally, a comparative study of initial and redesigned products has been performed. The methodology applied is detailed below.

### *2.1. Identification of product specifications*

The first product examined in this work is a single-axis solar tracker for household systems or low power installations. This is shown in Fig. 1. A photovoltaic panel is positioned on an aluminium structure and is programmed to daily follow the motion of the sun. Furthermore, it can be seasonally adjusted in order to obtain an increase of the energy production. The solar tracker must resist exposure to the weather and it should have low maintenance.




Characteristics:
- Solar panel:
  Dimensions: 2x1 m; weight: 20 Kg
- Accurate tracking of the sun:
  Summer: 165°/day
  Winter: 120°/day
- Rotating speed: 15°/h
- Maximum wind speed: 90 Km/h
- Consumption: 5 w

Fig. 1. Solar tracker. Components and specifications.

An exploded view of a double action airbrush and the corresponding parts list is shown in Fig. 2. This device requires high-velocity compressed airflow to spray paint in fine droplets and project it on a surface. The paint is stored in a small reservoir located at the top of the airbrush. The following design specifications were initially established: independent control of air and paint flow rates, different spray paint effects, adaptation to the user's hand and complete disassembly for cleaning and maintenance operations.

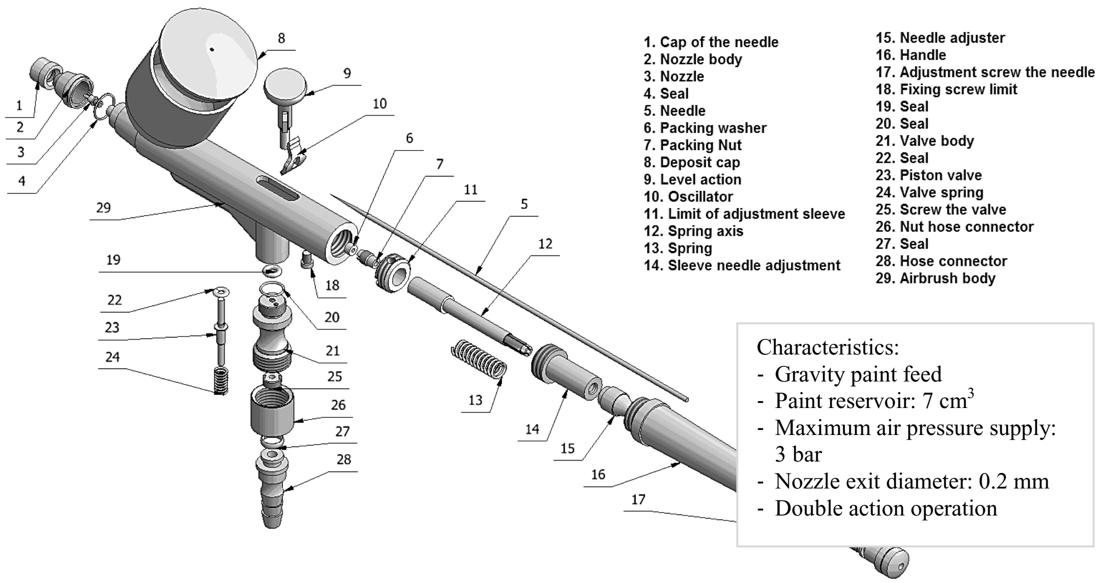



Fig. 2. Airbrush. Components and specifications

### 2.2. Study of the manufacturing process

The sequence of manufacturing operations has been studied for each product. Industrial machinery and raw materials needed for the production have been determined in two cases. Tables 1 and 2 show respectively, for the solar tracker and the airbrush, the listing of machines and materials used along the manufacturing process.

The depth of cut, the radial cutting feed and the cutting speed have been adequately selected for each machined part. From these parameters, the required machine power supply for each productive operation has been calculated. Finally, machining times have been estimated and energy consumptions by machine have been obtained. These are summarized in Tables 1 and 2. In both cases, the mass of raw materials used along the manufacturing process and the mass of the final product are also shown.

Table 1. Solar tracker. Manufacturing process parameters

| Machines | Time (s) | Energy (Kw·s) | Materials | Raw materials (Kg) | Product mass (Kg) |
|---|---|---|---|---|---|
| Saw | 14 | 2.76 | Galvanized Steel | 16.97 | 16.54 |
| CNC Turning | 194 | 32.46 | Stainless Steel | 0.66 | 0.60 |
| CNC Milling | 572 | 425.80 | Steel F-1100 | 0.03 | 0.02 |
| Drill | 34.5 | 9.59 | Aluminum | 1.99 | 1.98 |
| Guillotine | 4.5 | 0.15 | Nylon | 0.06 | 0.03 |
| Folding mach. | 3.5 | 0.2·10-3 | Polypropylene | 0.31 | 0.30 |
| Injection mach. | 240 | 156.58 | Packaging | 2.36 | - |
| Total | 1062.5 | 627.33 | | | 19.47 |

Table 2. Airbrush. Manufacturing process parameters

| Machines | Time (s) | Energy (Kw·s) | Materials | Raw materials (Kg) | Product mass (Kg) |
|---|---|---|---|---|---|
| Saw | 13.4 | 2.16 | Steel AISI 304 | 0.36 | 0.16 |
| CNC Turning | 964 | 72.14 | Brass CW614N | 0.01 | 4.17·10-3 |
| CNC Milling | 209.4 | 27.30 | PTFE | 0.07·10-3 | 0.023·10-3 |
| Drill | 730.3 | 18.20 | Chromium | 0.022 | 7.4·10-3 |
| Guillotine | 4.2 | 0.09 | | | |
| Folding mach. | 3.5 | 0.2·10-3 | | | |
| Pressing mach. | 6.3 | 2.92 | Packaging | 0.35 | - |
| Total | 1931 | 122.85 | | | 0.171 |

As can be seen, the packaging mass has been included in the raw materials list, but no contributes to the final product mass. According to actual operating conditions, an efficiency of 0.8 was assumed for the machine power supply and an increase of 25% was considered for the machining time. Thus, a total increase of 56% was obtained for the energy consumed along the manufacturing process. Energy of non-productive activities has been only estimated for the tool change processes and it has been assessed as 1% of machine maximum power. The high-speed steel consumed in cutting tools has been also estimated in two cases. The consumption per manufactured product is very low. Nevertheless, in the airbrush case represents 8% of the product total mass due to the high number of machining operations.

If Table 1 is examined, we observe that the machine more time used and that more energy consumes along the manufacturing process of a solar tracker is the milling. Looking at the materials, the galvanized steel represents 85% of the product total mass. In the airbrush case, Table 2 shows that turning and milling are the machines with higher energy consumption and the stainless steel AISI 304 is the main material used in the manufacturing process. In both cases, shaped machines have low energy consumption because the sheets that it works have very small thickness.

### *2.3. Calculation of product eco-indicators*

Specific software has been used to calculate eco-indicators of each product. The input data has been structured in the following blocks:

- Product mass, that takes into account the mass of each material making up the final product.
- Manufacturing, that is separated in two groups. On the one hand, product processing, where the energy and high-speed steel consumptions are specified and on the other hand, material removed, where the generated metal shavings is evaluated.
- Packaging. This block includes data of materials used at this stage of the product development process.

Data output are different product eco-indicators. In this work, global energy (GE) and global warming (GW) have been obtained for each product. These eco-indicators represent respectively, the overall energy consumed along the product development process, from the raw materials extraction phase to the packaging phase, and the mass of $CO_2$ emitted to the atmosphere. Values for each input block ant total values are shown in Table 3.

Table 3. Product eco-indicators

| Solar tracker | | | Airbrush | | |
|---|---|---|---|---|---|
| | GE (MJ) | GW (Kg CO2) | | GE (MJ) | GW (Kg CO2) |
| Product mass | 1625.5 | 104.5 | Product mass | 30.2 | 1.9 |
| Product processing | 4.5 | 0.22 | Product processing | 13.9 | 0.68 |
| Material removed | 11.8 | 0.89 | Material removed | 54.2 | 3.14 |
| Packaging | 82.9 | 1.49 | Packaging | 19.8 | 1.05 |
| Total | 1724.8 | 107.1 | Total | 118.2 | 6.8 |

We can observe that the product mass is the most influential factor on solar tracker eco-indicators. Their contribution is over 90%. In the airbrush case, material removed and product mass are the factors that have a major environmental impact. Packaging has a significant contribution in two products. The manufacturing block is much more important in the airbrush case due to this device is made up of small pieces, which are obtained through many machining operations.

Nevertheless, it should be noted that each type of material affects in a different way. Fig. 3 shows the percentage distribution of mass for the two products studied and how each material contributes to elevate the global energy eco-indicator. In the solar tracker case, the aluminium mass is 10% of the total product mass but involves 37.5% of the global energy eco-indicator. Chromium, which is used in the surface finishing process of the airbrush, with only 4.3% of mass, represents 67.4% of the GE eco-indicator. According to this study, redesign strategies will be focused on reducing the product mass and particularly, reducing the mass of specific materials, as galvanized steel and aluminium for the solar tracker and chromium for the airbrush.

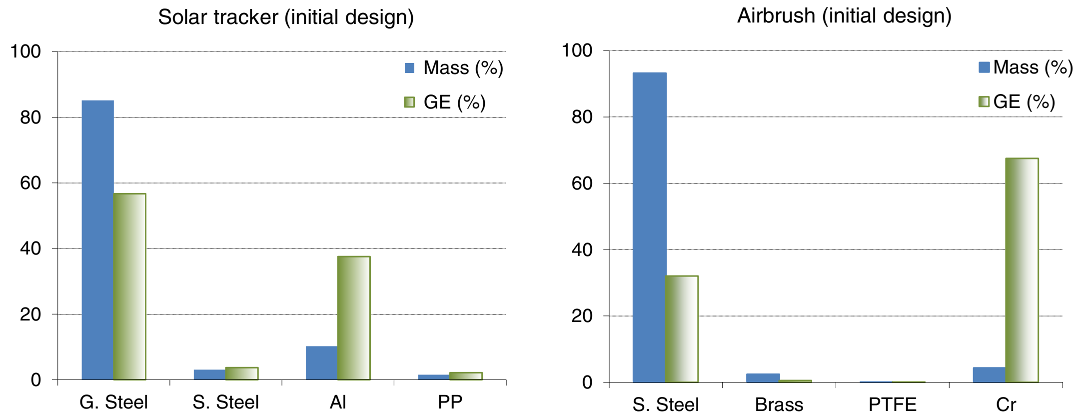



Fig. 3. Percentage distributions of mass and global energy eco-indicators

### *2.4. Application of redesign strategies*

Table 4 shows the series of strategies considered in this work for obtaining more sustainable products. The specifications and product features that were examined in detail and the strategies that were finally applied in each case are also indicated. The reduction of product mass and material removed and the change of materials, manufacturing operations or packaging have been studied.

Among the strategies to improve the environmental impact of the solar tracker, the following have been applied in this work:

- To reduce the overall size of the central shaft (mark 2 in Fig. 1). The length was diminished from 1150 to 1000 mm and the diameter from 30 to 25 mm. The sun tracking was verified.
- To reduce the length and the size of the cross transversal section of the flagpole (mark 5 in Fig. 1). The rectangular profile of 1500x60x40 mm with a thickness of 5 mm was changed by a profile of 1000x60x30 mm with a thickness of 4 mm. The mechanical strength was checked.
- To modify packaging. Because the overall size of the product was reduced, the initial cardboard box of 0.4x0.4x1.6 m used for the packaging has been also reduced to 0.12x0.14x1.1 m. Thus, a notable increase from 9 to 48 was achieved in the number of boxes stored on a pallet.

In addition, a change of materials has been considered. A substantial reduction of the product mass was achieved by the replacement of steel with aluminium. The mechanical strength specification was also verified. However, an improvement of the product eco-indicators was not obtained due to the environmental impact per unit mass of the aluminium is greater than that of the steel (see Fig. 3).

Table 4. Redesign strategies and applications in each product

| Strategy | Solar tracker | Airbrush |
|---|---|---|
| To reduce overall size | The sun tracking has been checked. It has been applied. | It is restricted by the device handling. It not has been applied. |
| To reduce thickness | The mechanical strength has been checked. It has been applied. | It is restricted by the device operation. It not has been applied. |
| To reduce parts number | It is restricted by the device operation. It not has been applied. | It is limited by the total disassembly specification. It not has been applied. |
| To change materials | Replacing steel with aluminum has been studied. The product was not improved. | It is restricted by the corrosion resistance specification. It not has been applied. |
| To reduce material removed | Raw materials have been checked. It not has been applied. | Raw materials have been checked. It has been applied. |
| To change manufacturing operations | Manufacturing operations have been checked. It not has been applied. | The change of sawing + facing operations by grooving was studied. The design was not improved. |
| To change packaging | The overall size of packaging has been changed. It has been applied. | Packaging material has been changed. It has been applied. |
| To change finishing process | Finishing treatment were not used in this product. It not has been applied. | Chromed layer was removed. It has been applied. |

In the case of airbrush, the redesign strategies have been focused on the change of the surface finishing process. The chromed layer is mainly decorative although it also could provide corrosion resistance or increases surface hardness. A polishing process of the stainless steel pieces replaced this layer. Other redesign strategies are summarized in Table 4. The following have been applied:

- To reduce material removed. Each piece was analyzed in detail to optimally select raw materials and manufacturing processes. The use of calibrated bars and tubes was proposed. In this way, some drilling and turning processes have been also removed.
- To change packaging. The initial plastic storage box with suitable receptacle to insert the airbrush and their components has been changed by a wooden box.

## 2.5. Study of the redesign product

The processing times and energy consumptions for the manufacturing processes of each redesigned product have been obtained. These are summarized in Tables 5 and 6. The mass of raw materials and the mass of the final product are also shown.

Table 5. Solar tracker redesigned. Manufacturing process parameters.

| Machines | Time (s) | Energy (Kw-s) | Materials | Raw materials (Kg) | Product mass (Kg) |
|---|---|---|---|---|---|
| Saw | 12.3 | 2.38 | Galvanized Steel | 9 | 8.98 |
| CNC Turning | 194 | 32.21 | Stainless Steel | 0.67 | 0.6 |
| CNC Milling | 548.5 | 424.36 | Steel F-1100 | 0.03 | 0.03 |
| Drill | 31.6 | 8.81 | Aluminum | 1.99 | 1.98 |
| Guillotine | 4.5 | 0.15 | Nylon | 0.06 | 0.03 |
| Folding mach. | 3.5 | $0.2 \cdot 10^{-3}$ | Polypropylene | 0.32 | 0.30 |
| Injection mach. | 240 | 156.58 | Packaging | 0.84 | - |
| Total | 1034.4 | 624.50 | | | 11.89 |

Table 6. Airbrush redesigned. Manufacturing process parameters.

| Machines | Time (s) | Energy (Kw-s) | Materials | Raw materials (Kg) | Product mass (Kg) |
|---|---|---|---|---|---|
| Saw | 13.3 | 2.15 | Steel AISI 304 | 0.31 | 0.16 |
| CNC Turning | 801.4 | 57.57 | Brass CW614N | 0.008 | 4.17·10-3 |
| CNC Milling | 208.3 | 26.38 | PTFE | 0.04·10-3 | 0.023·10-3 |
| Drill | 634.4 | 12.57 | Chromium | 0 | 0 |
| Guillotine | 4.2 | 0.09 | | | |
| Folding mach. | 3.5 | 0.2·10-3 | | | |
| Pressing mach. | 6.3 | 2.92 | Packaging | 0.28 | - |
| Total | 1671 | 101.68 | | | 0.164 |

Results are consistent with redesign strategies previously exposed. A notable reduction of the galvanized steel mass and packaging mass is obtained for the solar tracker redesigned. Meanwhile a significant decrease of the CNC turning energy consumption and the complete elimination of chromium is noted for the airbrush redesigned. In Fig. 4, the total values obtained for the redesigned products are compared with those obtained for the initial designs. A very small change of the total processing time and machine energy consumption is noted for the solar tracker case. However, a decrease of 40% is observed in the product mass. Variation notably different is detected in the airbrush parameters. A reduction around 15% is obtained for the total processing time and machine energy consumption and a slight decrease of the product mass.

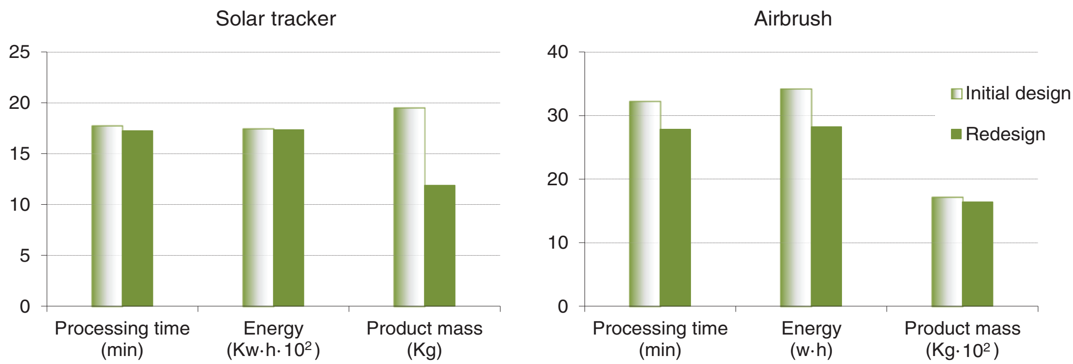



Fig. 4. Variation of manufacturing process parameters

Eco-indicators of each redesigned product have been also determined. Table 7 shows the global energy and global warming values for each input block. In the solar tracker case, it should be noted that eco-indicators obtained for the product mass block experience a reduction around 20% and those obtained for the packaging block a decrease greater than 60%. In the airbrush case, two redesign stages are differentiated: the first stage, where the chromed layer is removed and the second stage where other strategies as the reduction of material removed or the change of packaging, are also applied. A substantial decrease of the eco-indicators for the product mass block is generated in the first stage.

Change in total values is shown in Fig. 5, where product eco-indicators obtained for the redesigned products are compared with those obtained for the initial products. In the solar tracker case, a total reduction around 20% is achieved for global energy and global warming eco-indicators. In the airbrush case, GE and GW drop respectively 59 and 47% in the first stage of product redesign and global decreases of 68 and 57% are achieved for the final redesigned airbrush.

Table 7. Eco-indicators of redesigned products

| | Solar tracker | | Airbrush | | | |
|---|---|---|---|---|---|---|
| | | | Stage 1 | | Stage 2 | |
| | GE (*MJ*) | GW (*Kg* $CO_2$) | GE (*MJ*) | GW (*Kg* $CO_2$) | GE (*MJ*) | GW (*Kg* $CO_2$) |
| Product mass | 1354.6 | 81.9 | 9.8 | 0.98 | 9.8 | 0.98 |
| Product processing | 4.35 | 0.21 | 5.48 | 0.27 | 4.78 | 0.24 |
| Material removed | 11.7 | 0.88 | 12.8 | 1.27 | 9.67 | 0.96 |
| Packaging | 31.4 | 0.53 | 19.8 | 1.05 | 13.5 | 0.73 |
| Total | 1402 | 83.5 | 48 | 3.6 | 37.8 | 2.9 |

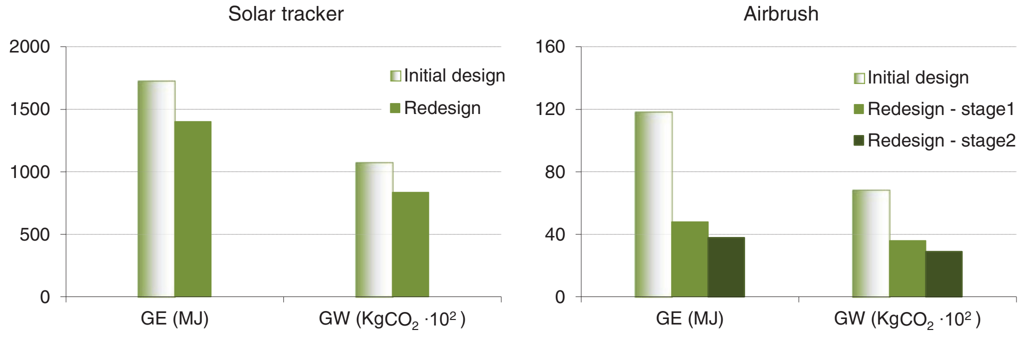



Fig. 5. Modification of product eco-indicators

## 3. Conclusions

In this research work, sustainability criteria have been implemented in the design process of two different products: a solar tracker for low power installations and airbrush for precision works. The study focused on the product development phase. In both cases, total processing times, energy consumptions and material removed along the manufacturing processes have been calculated. From these parameters, the eco-indicators of global energy and global warming have been assessed and a number of sustainable redesign strategies have been proposed. The initial specifications and product features have been checked along the redesign process.

In the solar tracker case, a significant reduction of 40% in the product mass was applied by the size modification of some parts and a drop around 20% of the eco-indicators was achieved. In the airbrush case, redesign strategies have been focused on the optimal use of raw materials and particularly on the elimination of the chromed layer. A substantial improvement of eco-indicators, which were reduced over 50%, was achieved. In order to reduce eco-indicators level, the study in detail of materials and manufacturing operations has been decisive to propose effective redesign strategies in each case.

## 4. References

[1] Decision nº 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme.

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