Using Life Cycle Assessment to Assess and Identify Improvements of the Environmental Impacts of the Vehicle Leaf Spring

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Abstract

This paper discusses an application of the LCA methodology on the vehicle leaf spring, used on trucks, buses and trailers in Zimbabwe. A look at the whole life cycle of the spring from raw material extraction through manufacturing, use, reuse and final disposal emphasizing the resource consumption, human health and ecosystem quality is done using standard LCA assessment methodology outlined in the ISO 14000 series. SIMAPRO 7 was used to assist in the LCA and also to reduce the complicated and rigorous manual calculations thus eliminating unnecessary errors and enhancing the quality of results obtained.

Keywords:

Environmental Impact; Life Cycle Assessment; Vehicle Leaf Spring

1 INTRODUCTION

The vehicle leaf spring industry is an industry that has often been overlooked in terms of analysis of its function and criticality. The majority of trucks and buses on the road in Zimbabwe today employ leaf springs in their suspension. The suspension is a critical system on any vehicle and its failure amounts to the failure of the whole vehicle. The spring system is necessary in any vehicle and its environmental effects can be great when considered during its manufacture and its life cycle. This paper looks at the leaf spring and its manufacturing processes with the aim of improving its environmental impacts. LCA provides a methodology for considering each stage of a product's life from extraction, through manufacturing and construction, use and disposal/reuse. [1] This can be a 'cradle to the grave' or 'cradle to cradle" approach with environmental consequences being recorded during production, use and afterwards during the disposal and/or reuse. In the steel industry, results of previous LCA work show that iron and steel making produces a very large volume of carbon dioxide, a potent greenhouse gas. [2] It is therefore imperative that the Zimbabwean steel products industries adapt to global practices to enhance exports to green markets through the creation and use good Life Cycle Assessment databases based on international environment standards like the ISO 14000 series, in particular ISO 14040 which deals with LCA. The vehicle leaf spring industry is targeted in this case because it is one of the main users of steel. Adaptations to the data obtained can be used in other countries.

LCA requires that the entire life cycle of the product must be identified and all relevant forms of known environmental interventions should be accounted [3] In the steel processing industry, previous LCA work has been used as a tool for management of environmental issues, generating data for steel plates, coils, bars, wires and for stainless steel with a view of improving eco-efficiency, increasing reusability, improving recycling and extending product life spans. [4] Some studies have focused on mathematical modelling of iron and steel environmental impacts [5]; allocation of gases from steelworks to different products [6]; environmental impact comparisons between steel and concrete structures [7, 8, 9] and between steel and aluminium [10]; and on recycling measures in iron and steel production. [11] This work focuses on the LCA of a steel product, a vehicle leaf spring.

2 METHODOLOGY

The leaf spring manufacturing industry was represented by a detailed case study of Universal Spring Services, Harare which allowed use of some of its manufacturing facilities, expertise and data to enable a realistic LCA to be carried out. Information from the company laboratory facilities and engineering department provided a great deal of the Life Cycle Inventory (LCI) information. The LCA included separate but interrelated components: Goal and scope definition (ISO 14040); Inventory analysis (ISO 14041); Impact assessment (ISO 14042); Interpretation (ISO 14043); and Improvement analysis. Relevant Software, SIMAPRO 7 from Pre Consultants and the PRe Triangle tool were used. Data within the defined system boundaries were included in the software analysis with adaptations to take into account real Zimbabwean data.

3 LIFE CYCLE INVENTORY

Vehicle leaf spring manufacturing involves a number of processes with different environmental impacts. These were analysed as single entities. The main processes involved were; cutting of materials, planning, trimming, hole drilling, furnace heating, tapering, eye forming, furnace heating, quench hardening, tempering, painting assembly and dispatch. The manufacture of springs was as per vehicle specifications and where necessary changes and modifications were implemented by the workshop staff. Manufacture of springs from raw materials and modification of springs were done in the same workshop.

The Life Cycle Inventory (LCI) was found to be very broad hence restrictions were made to the data collection to encompass only critical processes. The materials involved and associated components are shown in Table 1. Table 2 classifies the primary and ancillary materials involved and the decision criteria for the life cycle assessment. From analysis of the spring and looking at the materials that are involved, both primary and ancillary, and also the processes involved the next step was to rank the materials according to criticality and these were to be of major concern in the LCA and analysis with Simapro 7 software. The following materials and processes were the ones selected as the most critical: EN45 and other spring steels; Coal used in the furnace; Used and cooling oil.

Material	Associated component(s)
En 45 SUP9,60Si2Mn steels	Main Leaf and spring blades
NiCrMo6 steel	Clips, rivets and pins
Rubber	Bushes
NiCrMo6	Centre bolts

Table 1: Primary materials with >1% by mass of spring

Materials	Associated components or process	Decision Criteria
Primary materials		
EN45, SUP9,60Si2Mn	Main Leaf, Spring blades	T, Env
NiCrMo6 Steel	Clips, rivets and pins	T, Env
Rubber	Bushes	T, Env
SAE 43430	Centre Bolts	T
Ancillary materials		
Coal	Coal furnace and Forge	E, Env
Used Oil	Quench Hardening	Env
Abrasives	Cutting tools and grinder	T
Cooling Oil	Drilling and cutting	T, Env

Table 2: Primary and ancillary materials or components (Key: T- technology, Env- environment, E- energy criteria)

For the LCA a heavy duty truck spring was selected for analysis and this was assumed to represent the critical environmental impacts of the leaf springs produced in Zimbabwe. The results of the general analysis of the life cycle impacts of the life and disposal of the leaf springs are shown in Table 3.

There is very limited used oil recycling capability in in Zimbabwe. There is no good infrastructure for that and very few companies reprocess used oil. Estimates from inventory data on used oil at the Universal Springs showed that used oil is improperly disposed at most times as shown in Table 4. Through discussions and interviews with company personnel, it could be discerned that there was no concern about the improper disposal of used oil, since the quantities involved were small. However used oil impacts to river systems and aquatic life are very detrimental even in small volume.

The quality of data used at each stage of the life cycle differed greatly. Table 5 indicates this relative difference. Data on the production of steel sections used were collected from the local steel maker. Manufacturing data were the most easy to obtain at the company. The end of life data was the most difficult to obtain.

Vehicle Spring Parameter	Data
Main Spring	
Mass of spring	55kg
Amount of springs in analysis	1
Amount of assembly sent to waste	5%
Amount of assembly disassembled	65%
Amount of springs reused as whole assembly	30%
Type of disposal of springs	Landfill
EN45 steel used in spring	50kg
60CrMnBA steel used in spring	2 kg
NiCrMo6	3kg
Bushes	
Number of bushes	2
Mass of component	0.1kg
Type of disposal	Landfill
Amount sent to disposal	65%
Amount reused	35%
Centre Bolts, Clip bolts, Rivets	
Amount of components	10
Mass of Components	1kg
Type of disposal	Landfill
Amount sent to disposal	85%
Amount reused	15%

Table 3: General Spring Analysis

Used Oil destiny	
Improper Disposal	85%
Collected for Re-cycling	10%
Mixed (Other)	5%

Table 4: Used Oil Disposal

Life Cycle Stage	Relative Data Quality
Upstream	Moderate
Manufacturing	Moderate to High
Use	Moderate to High
End of Life	Low to Moderate
Transport	High

Table 5: Relative Data Quality

4 LCA RESULTS

The results were obtained mainly using the Eco-indicator 99 Method [12]. A simulation of the relative contribution of each part and process was then done by the software and a network generated showing how each process contributed to the leaf spring life cycle. From the network diagram in Figure 1 it can be observed that there are only 12 processes that have been shown instead of the 696 processes identified. A cut off point for processes with less than 5% contribution to the overall life cycle was done since they did not add value to the results. The greatest contribution was from the coal furnace, the transportation of coal and the metals that make up the leaf spring material. Since reuse of the spring is prevalent in the Zimbabwean industry the disposal and reuse part of the network diagram was found to have a relatively greater impact in the overall life cycle of the spring.

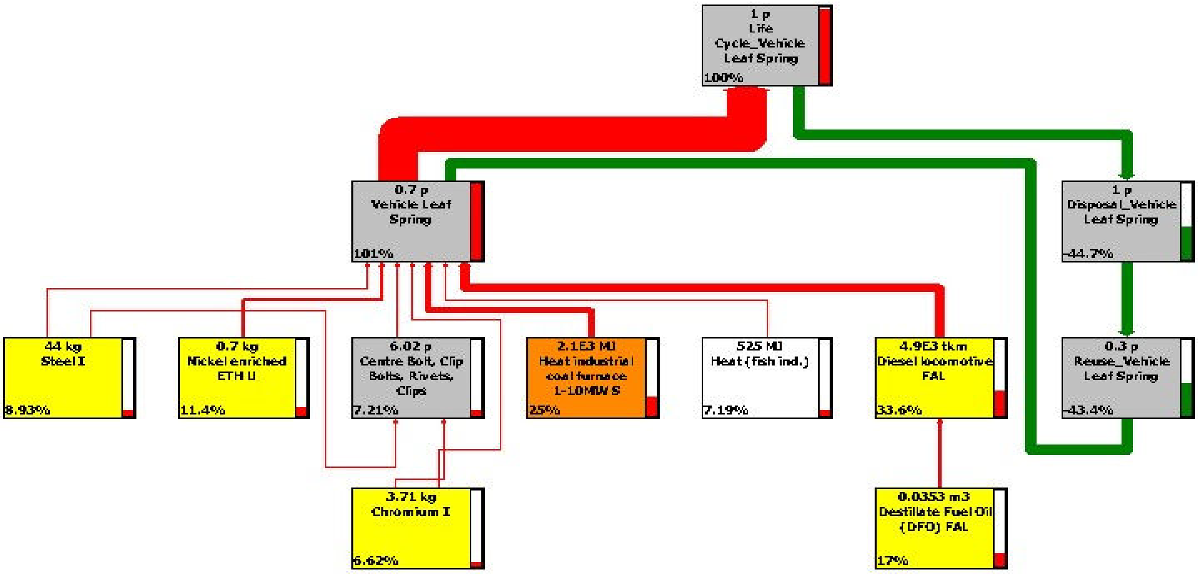

Figure 1: Leaf Spring Process Network

Figure 2 shows the impact assessment weighting results and this contains information on the areas that produce the most environmental impacts. These are: carcinogens; respiratory organics; respiratory inorganics; climate change; radiation; ozone layer; ecotoxicity; acidification/eutrophication; land use; and minerals

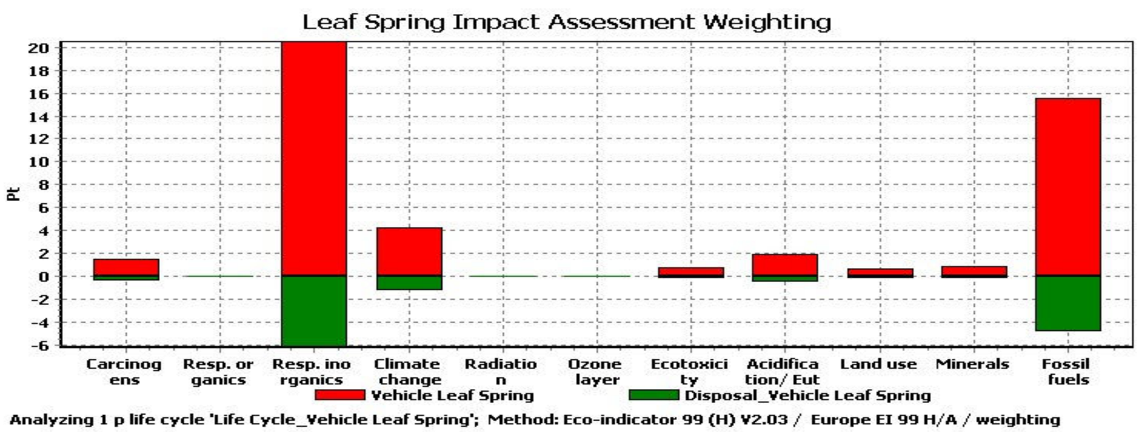

Figure 2: Leaf Spring Impact Assessment Weighting

To help in the weighting of the spring during its use and disposal the Triangle 1.0 tool was used and in this the three major subcategories of concern were: Ecosystem quality; Resources; and Human health. The Triangle Tool is used to illustrate valuation issues, such as comparing the environmental load of two alternative products and processes. Such a comparison usually requires weighting of different aspects but in this case the vehicle leaf spring was assessed in terms of use and disposal. The resulting triangle in Figure 3 shows the weighting of the leaf spring use and disposal and their relative effects. It is seen that the leaf spring use phase has a lower environmental load, consumes 75% of the total resources used and has a strong effect on Human Health (60%). This is characterized by respiratory diseases and damage to water sources. During the use the ecosystem quality is compromised. The leaf spring disposal has a greater impact on the ecosystem quality (100%) in terms of ecotoxicity, acidification and eutrophication but its effect on resources consumed and human health is seen to be considerable.

Each of the processes involved in the leaf spring life cycle was analysed to determine its contribution to the environmental impacts. A cut of point of 3% of the contributions was used and the analysed processes are shown in Figure 4. The values of some of the processes have been estimated in terms of European and American databases as they were the nearest equivalent. The coal furnace processes accounted for the greatest contribution and the diesel locomotive in the transportation of coal is also responsible for a high percentage of the overall contribution.

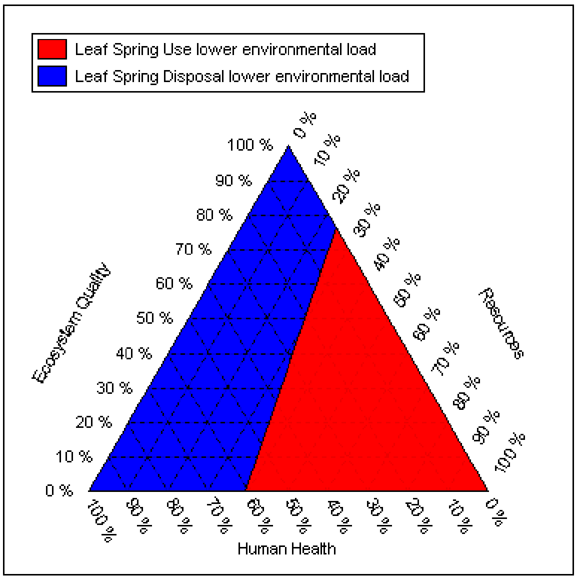

Figure 3: Use and Disposal Comparative Weights

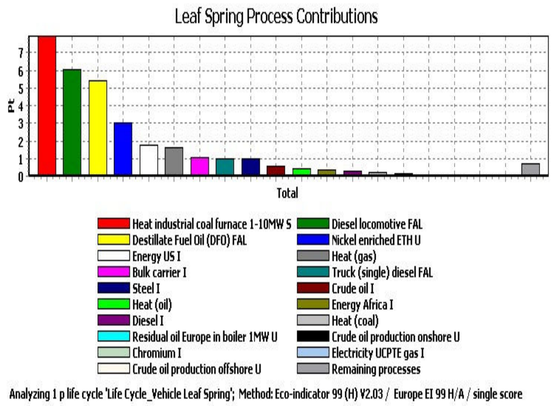

Figure 4: Leaf Spring Process Contributions

A separate impact analysis of used oil was carried out and this was done using some of the information contained in the inventory analysis. Figure 5 shows the relative effects of the used oil in each category of concern. An impact assessment characterization is illustrated giving the percentage contribution to each category. The results show that the minerals (metals like zinc and copper) contained in used oil have a great effect and the carcinogens (85%), ecotoxicity (92%) respiratory inorganics (82%), acidification /eutrophication (78%) and climate change (42%) are the main categories affected by the used oil. If the oil is not disposed of but used for other heating purposes, the figure shows that the greater effect is on radiation (100%), on the ozone layer (98%) and on climate change (52%), affecting the ecosystem quality. The respiratory organic substances (88%) affect human health and the last classification of fossil fuels (68%) (crude oil) shows the level of resource consumption and depletion.

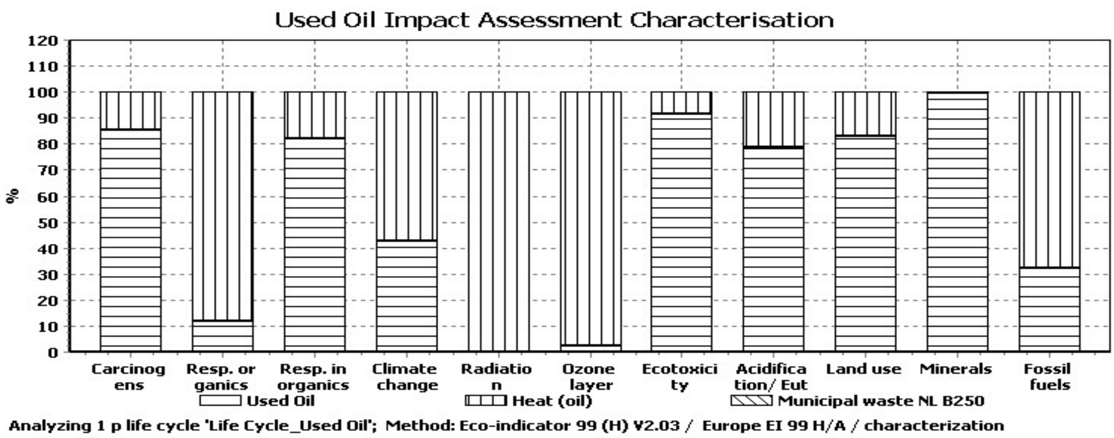

Figure 6: Used Oil Impact Assessment Characterisation

The assessment results give an indication of the life cycle environmental impacts of the vehicle leaf spring. The aspects that contributed most to pollution are the coal furnace activities, the coal transportation, the leaf spring materials and the used oil disposal. Based on this, more informed interventions can be made in order to reduce the potential environmental impacts throughout the life cycle of the vehicle leaf spring. The next section proposes some recommendations in this direction.

5 RECOMMENDATIONS

The greatest impact to the environment using a single score was from coal transportation and use. The industrial coal furnace contributed about 25% of the environmental impacts, while the transportation of coal using the diesel locomotive contributed about 30%. Improvements can be achieved through the use of an electric industrial furnace to heat the steel bars, which are used to make the leaves of the springs. This will reduce the adverse environmental impacts of coal furnaces, avoiding harm to human health (lung diseases), to the ecosystem and contributing less to the depletion of resources. The benefits can be improved further through the use of renewable sources of electricity. Coal use could also be eliminated in the forging processes.

The use of updated, modern and new machinery, equipment and technology could also significantly lower the amount of energy used. Most of the machinery used at the company was 15 to 40 years old, energy in-efficient and more time-consuming. Automated and efficient eye-rollers, cambering presses and painting machinery can be used replacing the cumbersome and energy inefficient manual processes.

The transportation of coal by train (diesel locomotives) from Hwange colliery could in the long-term be improved through the use of electric trains. More than 60% of the 30 electric locomotives of the National Railways of Zimbabwe were non-operational at the time of the study due to lack of foreign currency to buy spares. Also more than 60% of the Railway line to the Colliery has not been electrified yet. When that is done and the electric locomotives are fully operational, environmental impacts are most likely to be reduced.

5.1 Leaf Spring Material Improvements

Steel scrap is produced in the form of off-cuts that result from stripping materials and from cutting materials to required lengths. Scrap can be reduced if steel manufacturers supply material with the required specifications of length and width so as to minimize stripping and cutting. Proper reuse, recycling and disposal of springs can reduce environmental damage potential. Design changes can be made in materials and the leaf spring to minimize use of harmful metals like nickel and chromium, whilst maintaining the required strengths and factors of safety.

5.2 Plant and process improvements

Areas that can be improved in the vehicle leaf spring manufacturing plant were identified. Some of the areas that were identified during this LCA study are:

- The use of the coal furnace should be done at specific times and leaf spring material should be processed in bulk in order to avoid firing the furnaces for single springs throughout the day. Energy in this case is conserved and also emissions to the environment are reduced.
- The use of wet scrubbers and fabric filters can be introduced to trap emissions from the furnaces and forging areas.
- The increase of the height of the furnace and forging chimneys to about twice the current heights would make sure emissions do not affect workers, dispersing them to reduce concentrations at ground level and in the vicinity.
- Analysis of emissions should take place regularly and a laboratory should be set up to properly test the potential environmental harm of the products and processes.
- Proper safety wear should be emphasized for every process in the workshop and regular health check ups for all factory staff is necessary in order to avoid health damage and avoid the long term effects of respiratory gases.
- The used oil should not be disposed into rivers or into other natural environments. Recycling of the oil is strongly recommended as well as use in other applications like heating as long as high burning efficiency is ensured and the resulting emissions are controlled.

5.3 Cleaner production

Adoption of cleaner production strategies within the company policy is recommended. Cleaner production/green manufacturing is the continuous application of integrated preventive environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment. Green Manufacturing emphasizes the pollution prevention through use of less or non hazardous materials, waste reduction, recycling, and process improvement. [13]

5.4 LCA database in Zimbabwe

A major limitation of this study was the scarcity of data. There is a need for the Zimbabwean industry to develop inventory databases for all products, materials, processes and emissions in order to be able to monitor environmental pollution properly. The shortage of data relating to Zimbabwe in this work resulted in the researchers making many assumptions and estimations. The Zimbabwean database can be modelled on the European, American and South African LCA databases. The South African LCA (SALCA) database can be a good reference point in terms of starting such a database. LCA studies like this one can go a long way in enlightening those in industry and policy makers in government to put in place structures to develop an LCA database since they identify the critical data required and provide useful data that can be used. The vehicle leaf spring industry and other industries would benefit as export products produced will be cleaner and more acceptable to the increasingly greener markets. The main difference in the leaf spring manufacturing industry in terms of data relevancy is that the Zimbabwean industry focuses on reuse of a spring and there is little recycling that occurs. Also the methods of disposal are not standardized and this is of major concern because this shows that monitoring by responsible authorities is not is taking place.

5.5 Suggestions for future research

Areas where future research could be conducted to refine and/or continue the use of the results in this study are as follows:

- Gathering more information on energy use in spring manufacturing.
- Developing consistent materials and fuel processing data in a national LCI database that is updated regularly.

- Refining and/or updating some of the leaf spring manufacturing data by taking other manufacturing companies' operational statistics into consideration.
- Collecting more complete end of life data (e.g., remanufacturing data, and primary data for recycling and landfill) to determine better representation of the end of life impacts.
- Collecting more detailed data on other treatment processes, such as water treatment where no impacts were calculated.

6 SUMMARY CONCLUSIONS

This paper has summarised the results of a Life Cycle Assessment of the vehicle leaf spring manufactured in Zimbabwe according to internationally recognized standards and methodologies. Research on the methodology of LCA and on databases that carry information on LCAs was done, improving understanding of the way LCAs are carried out. A comprehensive study of the vehicle industry was carried out and from there inventory data collected, which can be useful in future work in the same area and in related studies. Software tools for LCA were used to carry out the impact assessment and from the results some useful recommendations were made on how the leaf spring industry can improve in reducing its environmental impacts. The main recommendations are on the need to use electrical energy more, particularly power from renewable sources. The use of energy-efficient modern technology, plant and process improvements and cleaner production activities will go a long way to prevent, reduce or eliminate environmental pollution in specific processes. This work has useful extensions that can be adapted and applied to other manufacturing industries in Zimbabwe and in other countries, particularly those in Southern Africa.

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