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Life Cycle Analysis in Manufacturing Industry - A Case Study

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ABSTRACT

The method used in this project is LCA and the study is performed from gate (beginning of the company) to gate (end of the Company). LCA is a method to assess the potential environmental impacts associated with a specific product or service. All stages in the life cycle are taken into account and use of natural resources, transportation, energy consumption, waste and emissions are considered. LCA can be used for identification of improvement possibilities, decision-making etc. but has also an important application in learning about environmental impacts caused by substances and processes used in the life cycle. This is mainly what is done in this study.
Keywords: Environmental Impacts, NBC, ISO, LCIA, LCA, GWP, LCI

I. INTRODUCTION

The increasing environmental concern in today's society puts lot of pressure on the industry to produce less environmental damaging products. At this point, this is principally experienced by industries producing consumer goods but these industries are in their turn increasing the pressure on their suppliers. So far it is in most cases questions about environmental management systems but the nature of the questions are slowly changing and becoming more product-related. Questions about LCA work and performed LCAs are becoming more frequent. With this as a background I decided that it was time to perform an LCA on one of key products of NBC.

In recent years Life Cycle Assessment (LCA) has become one of many useful tools in assessing the environmental aspects and potential impacts associated with a product. In LCA the product is followed from the cradle to the grave, i.e. from raw material acquisition, through production, use and waste disposal. LCA is multidisciplinary and deals with the social system, the technical system, the natural system and their relationships.

The LCA method provides researchers or companies with quantitative data for their current products. By looking at a product's life from the raw material extraction to its disposal, the environmental impact of each process and material can be analysed. The LCA allows analysts to determine and analyse the technological, economic, environmental, and social aspects of a product or process necessary to manage the complete life cycle. With this quantitative data, desired changes can be justified with respect to the cost and environmental impacts of a product or process.

LCA is an increasingly important tool for environmental policy, and even for industry. Analysts are also interested in forecasting future materials/energy fluxes on regional and global scales, as a function of various economic growth and regulatory scenarios. A fundamental tenet of LCA is that every material product must eventually become a waste. To choose the 'greener' of two products or policies it is necessary to take into account its environmental impacts from 'cradle to grave'. This includes not only indirect inputs to the production process, and associated wastes and emissions, but also the future (downstream) fate of a product. The first stage in the analysis is quantitative comparisons of materials flows and transformations. Energy fluxes are important insofar as they involve materials (e.g., fuels, combustion products). This can be an extremely valuable exercise, if done carefully. However, the data required to accomplish this first step are not normally available from published sources. Theoretical process descriptions from open sources may not correspond to actual practice.

The purpose of the thesis is to investigate the environmental properties of NBC's ball bearing 6210. This is to be done from the starting of the factory gate to the end gate. The purpose is further to identify parameters and processes that causes major environmental impact. Every product has its impact on the environment depending upon the type of material of that product and the manufacturing techniques used in formation of that product. Resources are consumed in formation of product and to produce those resources human being exploit the natural resources which is having a negative impact on the surrounding and environment.

Through life cycle assessment it is possible to find out that how much amount of wastages or unwanted material has been emitted during the desired manufacturing process. Environment can be effected through many ways such as emission to air, water, land, eutrophication emission of photochemical smog etc. by LCA we are capable of find out the exact amount of wastage that has been produced or emitted out. Apart from this LCA also enables us to find out that which of the environment category is badly effected for e.g. by an chemical forming industry the wastage in water resources is far more than air emission which led to human toxicity and water and land eutrophication. So by LCA we can analyse the level of severity of that particular category and try to find out the required measure to protect the same either by changing the type of material used or by changing the type of energy resource or manufacturing process.

The major objective is to quantify the amount of emission in each environmental category and then to compare it with existing emission data of other company which makes the same product. Through this we will be able to find out that whether the company is environmental friendly or it is emitting more than the required standards. After finding out the hot spots of manufacturing process desired suggestion or remedies should be proposed in order to mitigate the unwanted environmental impacts.

The methodology used for fulfilling the purpose of this study is an LCA based on quantitative data. This study deals with the life cycle, from start gate to end gate, of the bearing. Use of natural resources, transportation, energy consumption, waste and emissions to air and water are considered. In the study the production and the use of the bearing takes place in Jaipur. The main production plant for NBC is located in Jaipur but the bearings are sold worldwide. Alternative processes will not be studied.

LCA in general

An LCA is a comparison between different stages life cycles or between different parts of the life cycle. LCA has advantage as a categorizing tool to identify major and minor environmental impacts from each other. Thus defining the "hot spots" [1] which means the areas which are creating more impacts as compared to others.

With the use of LCA it is possible to identify which kind of environmental impact will be affected by different choice of alternatives. This can be applied to present situations as well as changes that are to be made to be future. LCA is intended to provide information that may be used for environmental improvements but can also be used to identify processes, substances and systems in a life cycle that are major contributors to environmental impacts [2]. These stages can later be studied in detail with the help of other tools such as economical or technical tools.

The three main stages in an LCA study are shown in Figure 2 below and are also described in the following sections[3].

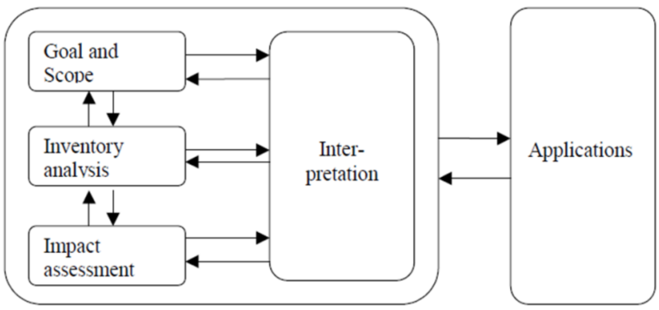
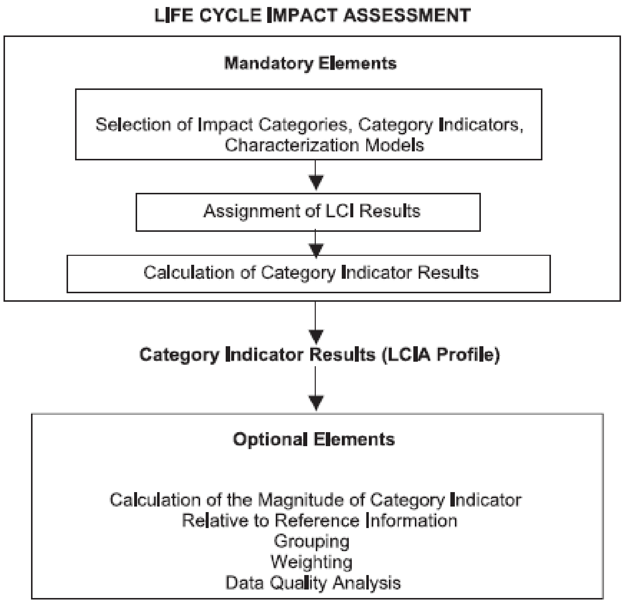


Figure 1: The three main stages in an LCA study according to ISO 14040 *(Soucrce : ISO 14040, 1997)*

The next paragraph shows the key issues of these LCIA parts—starting with an overview of classification and characterisation, discussion of modelling issues, and then out show differences compared to other common impact assessment approaches [4]. It summarises the models and associated indicators that currently exist for characterisation for commonly adopted impact categories. Given all the indicators for the different impact categories, outlines how indicator results can be compared, or condensed, across impact categories using social science techniques when direct comparisons using natural science are not feasible or are considered undesirable[5].

Figure 2: Elements of LCA (*Source: ISO 14042, 2000)*



1. Goal and scope definition

Defining the goal of the study includes stating the intended application of the Study, the reasons for carrying it out and to who the results are intended to be communicated. LCA is an iterative process and some choices may have to be made at a later stage in the study, they are however still seen as part of the goal and scope definition.

The goal and scope definition shall include [6] [7]:

- Functional unit, which will be used as a reference unit for all data.
- System boundaries, e.g. which processes to include in the analysed system.
- Types of impacts being considered and thus choice of for which parameters data will be collected in the inventory analysis.
- Level of detail in the study and thus the data requirements.
- Whether or not to perform a critical review and if so of what type.

2. Functional unit

Since manufactured product needs to be expressed in quantitative terms. This is done by a functional unit. Elaboration and choice of functional unit is one of the most critical activities in first stage. The functional unit shoes the function, benefit, quality and performance of the product. It also made a base in the evaluation and comparison of different alternatives. The functional unit must be clearly defined, measurable and related to input and output data in manufacturing unit.[8][9].

Example: suppose if the purpose of the study is to collate various types of flooring material the function is to protect the floor. One clear difference between various flooring materials is the durability of the material i.e. the time it will last. In this example the functional unit should be: *One square meter of protected floor area*.

3. System boundaries

To assess the environmental impacts loads from a certain process there are a few things that need to be verified and clearly stated. The environmental loads can vary depending on various parameters. Therefore system boundaries need to be clearly shown [10].the final system boundary is between the technological system and natural world. Theoretically, all the inputs and outputs necessary to the function of a product that should be followed upstream and downstream to flows of energy or material: (a) from natural system to the technological system; and (b) from the technological system to natural system [11][12].

(a) Boundaries in relation to natural systems

The starting point of the life cycle is the extraction of raw materials from the nature. Sometimes it is very hard to draw the line between the natural and the technical systems, and thus to decide what to include in the inventory analysis and what to include in the impact assessment [13]. This is one of the reasons why it is difficult to describe the impacts of land use in LCA terms.

(b) Geographical boundaries

Different parts of a products life cycle may occur in different geographical areas and this needs to be specified since the sensitivity to pollutants etc. may vary a lot between these areas. The infrastructure such as electricity production, waste management and transport systems often vary from region to region and if the region which contains the activity is not specified it may have consequences for the result of the study. Are site specific or generic data to be used? If generic data are to be used, which geographic area should they cover? Due to what has been mentioned above the answers to these questions can have an impact on the results [14].

Depending on weather the LCA is done to investigate the environmental load from the production of a product or to investigate the difference between processes average or marginal data can be used. A change in the production is most likely to effect the margin and is therefore probably best estimated by marginal data. If the average data are to be used there are other things to be consider like which type of data is used and it is associated with which process [15].

Example: If the electricity needed for a process is to be estimated with average data the geographic region covered by the data can influence the results considerably. In Sweden electricity mainly originates from water- and nuclear power. The average data for electricity production in Sweden will clearly differ from average data for electricity production in Europe where electricity produced with nuclear power and combustion of fossil fuel is most common. When using weighting methods the indices may be specific for the geographical area. Some methods used today are based on political goals for example reduction targets in the public environmental policy, and are therefore specific for each country[16].

(c) Time boundaries

The time boundaries are depending on the goal of the LCA study. If the goal is to investigate what environmental impacts the product can be held responsible for, it can be answered by an LCA with bookkeeping perspective, i.e. retrospective. If the goal instead is to investigate the impacts of changes in material or processes etc. it is probably better achieved by a change-oriented LCA that looks forward in time and tries to find alternative ways of action [17]. The applicability of the results from the LCA may depend on the time period represented by the gathered data. If, for example, the production has been changed it is very important to know whether the data are based on production before or after the change was completed. The result can also have a "best before date" if process changes are being planned for the future. Some impact categories or rather methods to calculate potential impacts are time dependent, for example Global Warming Potentials (GWP) and Ozone Depletion Potentials (ODP) [18].

(d) Boundaries within the technical system Cut-off criteria

While performing an LCA a decision to cut off the life cycle, and not follow a flow further upstream or downstream, may be based on the assumption that the contribution to environmental loads from the excluded processes is negligible in relation to the rest of the life cycle. The decision to cut off the life cycle while performing a change LCA may be based on what is relevant, i.e. what processes will be affected of the changes. Processes that will not be affected need not be included in the LCA[19]. Sometimes the LCA is not done from the cradle to the grave but the system is only studied from cradle-to-gate, gate-to-gate or gate-to-grave. This also means cutting off processes within the life cycle[20].

Allocation

There are situations when several products share the same process or process chain. If the environmental load is to be expressed in relation to only one of the products an allocation problem arises. There are three basic cases when allocation problems are encountered [21]:

- Processes which have outputs of many products
- Waste treatment processes that have inputs of many different products
- Open loop recycling, i.e. when a product is recycled into a different product.

Allocations can sometimes be avoided through increasing the level of detail of the model or through system expansion. Where allocation cannot be avoided the environmental loads are to be partitioned between the different functions of the system. A good base for this is physical relationships. If the physical relationships cannot be used, relationships, such as economic value between products can be used[22]. One should always be careful when using allocation models because of the differences in result one might get from using different basis for the allocation.

Inventory analysis (LCI)

Inventory analysis is the second stage of the LCA and here a system is built according to the requirements specified in the goal and scope definition. The model may be described as an incomplete mass and energy balance over the system, taking only environmental relevant flows into account.

The inventory analysis should include [23]:

- Construction of a flow model according to the system boundaries – The flow model is usually documented as a flow chart showing the activities included in the analysed system and the product flows between these activities.
- Data collection for all activities in the product system - These data should include inputs and outputs of all activities, i.e.:
  - Raw materials, including energy carriers
  - Products
  - Solid waste and emissions to air, ground and water
- Calculation of environmental loads of the system in relation to the functional unit.

Technical systems and processes often fulfil more than one function, which can make the inventory modelling complicated. In these cases the environmental loads of such a process have to be partitioned i.e. allocated between its different products or functions [24].

4. Impact assessment (LCIA)

The life cycle impact assessment (LCIA) phase, focusing on the key attributes of the supporting models and methodologies. These models and methodologies provide LCA practitioners with the factors they need for calculating and cross-comparing indicators of the potential impact contributions associated with the wastes, the emissions and the resources consumed that are attributable to the provision of the product in a study[25].

- Selection of the impact categories of interest, the indicators for each impact category and, although often implicitly considered by practitioners, the underlying models (a procedure also considered in the initial goal and scope phase of an LCA).
- Assignment of the inventory data to the chosen impact categories (classification).
- Calculation of impact category indicators using characterisation factors (characterisation).
- Calculation of category indicator results relative to reference values(s) (normalisation, optional).
- Grouping and/or weighting the results (optional, weighting not being allowed when following ISO14042 in comparative assertions disclosed to the public).
- Data quality analysis (mandatory in comparative assertions disclosed to the public, according to ISO14042, but receiving little attention in current practice).

5. Impact Categories and Areas of Protection (AoPs)

LCIA standard, there are three broad groups of impact categories that should be taken into account when defining the scope of an LCA study. Impact categories include climate change, stratospheric ozone depletion, photo oxidant formation (smog), eutrophication, acidification, water use, noise, etc. The three broad groups are commonly referred to as AoPs [26]:

- Resource use
- Human health consequences
- Ecological consequences

In some of the recent proposals [27]. The suggested AoPs are now:

- human health
- natural environment (resources and life support functions—climate regulation, soil fertility)
- man-made environment (monuments, forest plantations)

1) Characterization

Given Equation provides an example for outpouring data of how indicators for each impact category can be willingly calculated from the inventory data of a product using general characterisation factors [28]. Characterisation factors are typically the yield of characterisation models. The factors which are made accessible to practitioners in the literature, in various other form of databases, as well as in available LCA support tools. Similar general equations and data exist for wastes and resource emaciation [29].

Category Indicator $= \sum_s Characterisation\ Factor * Emission\ Inventory$

Where subscript s denotes the type of chemical used.

The emissions inventory data are shown in terms of the mass ransom into the environment such as 1 kg per functional unit. The characterisations factors from above equation therefore are linearly shown the hand out to an impact category of a unit mass (1 kg) of an emission to the environment. As an example, the correlative contributions of different natural gaes to climate change are usually compared in terms of carbon dioxide equivalents using Global Warming Potentials (GWPs). A Global warming potential500 of 100 implies that 1 kg of the substance has the same progressive climate change effect as 100 kg of carbon dioxide through, a 500 year time period.

2) Normalization

The main priority of normalisation is typically two-fold [30] to place Life cycle inventory assessment indicator results into a wider context and to adjust the results to have common units [31].

The addition of each category indicator result is then divided by a reference point,

$N_k = S_k / R_k$

Where k denotes the impact category, N shows normalised indicator, S is the category indicator which comes from the characterisation phase and R is the reference value.

The reference system is usually chosen using overall indicator results for a specific region, for example a nation, and for a specific time (year), such as the annual national US hand out to climate change in terms of GWPs. Space related scale, time related scale, a defined system (e.g. a region or an economic sector) and a per capita basis are all examples of characteristics that could be taken into account while choosing the reference value [32].

3) Grouping

Grouping is a qualitative, or semi-quantitative, which includes sorting and/or ranking results across various impact categories. Grouping may give result in a broad ranking, or hierarchy family, of impact categories with respect to their importance. Such a ranking can provide help in making conclusions on the relative importance of various impact categories [33]. For example, categories could be grouped in terms of high importance, medium importance and very low important issues. Some methods which include grouping are the verbal-argumentative perspective described by [34], as further developed by Schmitz and Paulini (1999), and the ranking method is given by Volkwein et al. (1996).

4) Weighting

Weighting is also sometimes cited to as ‘‘valuation’ ’in some Life-cycle assessment circles which refers to using numerical factors based on value choices to facilitate differentiation across impact category indicators (or normalised results)[35]. Weighting is usually applied in the form of linear weighting factors[36]:

$$EI = \sum V_K * N_K \text{ or } EI = \sum V_K * S_K$$

where EI is the overall environmental impact indicator, Vk is the weighting factor for given impact category k, N is the normalised indicator and S is the category indicator from the characterisation phase.

Weighting remains a disputable part of LCA, as in other assessments—mainly because it includes social, political and moral value choices [37]. Not only are there values involved when selecting weighting factors, but also when selecting which type of method is to be use, and even in the choice of whether to use a weighting method at all or not. However, every weighting method contains a scientific aspect not only from natural sciences, but also from social and etiquette sciences as well as from economics. For example, techniques, knowledge and theories developed by decision analysis and environmental economics can be manipulate for weighting in Life-cycle assessment [38].

Methods for weighting can be classified in different ways [39]:

- ✓ A distinction can be made between methods based on impact indicators defined early (at midpoints) or late (e.g. at endpoints or for areas of protection), in the impact chain, as described in Section 5.
- ✓ A second distinction is between three major groups of methods:
  - Monetisation (here used as an umbrella term for all methods which have a monetary measure involved in the weighting factors)
  - Panel (a group of methods where the relative importance of damages, impact categories or interventions is derived from a group of people through surveys)
  - Distance to target (where characterisation results are related to target levels)
- ✓ A third contrast exists between shown preference methods and revealed preference methods. Panel methods, as well as some monetisation methods,

are based on expressed preferences. People are asked their preferences (for example, willingness-to-pay). On the other hand, some monetisation methods are based on revealed preferences. These monetised weighting factors are derived from reactions to different situations of individuals and/or organisations, such as insurance payouts, health care expenditures, fines, costs incurred for environmental cleanups and ecotaxes[40]. provided an overview of monetisation in the context of LCA and human health.

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