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Life Cycle Assessment of Tyre Manufacturing Process

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ABSTRACT

Due to the phenomenal growth in the transport sector as a part of rapid urbanization, especially in the Indian sub-continent where transportation of goods and people are essentially done through the existing road associated with production of tyres and to identify the grey areas in which enough network, tyre industries have seen a rapid growth. In view of this, it is important that sustainability of tyre industry is maintained without its adverse effect on the environment. The objectives of this particular study are to identify and quantify the potential environmental impacts scope is there for further improvements. Life cycle assessment is a tool to evaluate the environmental impacts of any product or a process. In this work, life cycle assessment has been used to identify the environmental impacts associated with the tyre manufacturing process. The gate-to-gate approach has been used for this study of tyre production. The detailed data required for this study were obtained from MRF Industries, Usgao, Goa, India. Computations of the life cycle impact assessment results are achieved using SimaPro software with IMPACT 2002+ method. From the results it is noted that there is a significant impact on the environment due to emissions from the generation of electrical energy and steam in the plant under study along with emissions due to various operations in the tyre production process. The major environmental impact categories which are affected due to these processes are respiratory inorganics, aquatic acidification, terrestrial acidification/nitrification and to some extent aquatic eutrophication. Further, it is also observed that there is significant emission of particulate matter from the Banbary section of the tyre production process. This study reveals that the emissions of particulate matter, sulphur dioxide and nitrogen dioxide from tyre production process are significant. The life cycle assessment results obtained for the MRF tyre are compared with the life cycle assessment results of the Tweel tyre invented by Michelin, Bridgestone tyre, Goodyear tyre, Nokia tyre and comparative life cycle assessment results for a conventional tyre and a guayule rubber-based tyre. From a comparison among all above mentioned case studies, it is observed that major environmental impacts of tyres depend primarily on product design and usage. Significant reduction in environmental impact due to tyre production is possible if the source of electricity is nonconventional. Reduction in weight and rolling resistance of the tyre will also lead in significant reduction in greenhouse gas emissions during its use.

KEYWORDS

Tyre production, Life cycle assessment, Respiratory inorganics, IMPACT 2002+, Impact assessment.

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INTRODUCTION

Millions of tyres (car, truck, two wheelers, cycles, tractors, etc.) are currently manufactured per day in India [1]. There are several tyre manufacturing industries in India, e.g., MRF tyres, JK tyres, Apollo tyres, Birla tyres, Ralson India Ltd, CEAT, etc. Pneumatic tyres are manufactured in about 450 tyre factories around the world. Over one billion tyres are manufactured annually, making the tyre industry a major consumer of natural rubber [2]. Every year around six lakh tons of used tyres are replaced with the same number of new tyres [3].

The quantification of the environmental effects and minimizing the same can be demonstrated on the basis of high knowledge of this interaction. Life Cycle Assessment (LCA) involves the estimation of impacts of the manufacture of a product/process and especially the impact on the environment of any service/product or process over its entire life cycle right from the extraction of the raw material, to its use and finally its eventual disposal. Sometimes it is also known as "Life Cycle Analysis", "Eco-balance" and "Life Cycle Approach [4]. Life Cycle Inventory (LCI) which includes all the input and output materials, describes the interaction with the environment in terms of Life Cycle Impact Assessment (LCIA) [5].

The information on LCA studies of tyre industry is very scanty. A sustainable issue of natural rubber industry has been studied thorough LCA approach [6]. In this paper, the study was focused on rubber manufacturing processes. The LCA of a Tweel tyre assembly from manufacturing, through use and disposal was carried out and the results were compared to available information on conventional tyres. The results concluded that there is 10% fuel savings in case of Tweel tyre use on a vehicle. However, emissions of carbon dioxide (CO_2) and carbon monoxide (CO) increased by 10% and 100%, respectively, in case of Tweel tyres. The authors have not suggested any specific improvements in the production process of conventional tyres [7]. The comparison of the environmental impacts of the raw material extraction, transportation and manufacturing of a conventional and a guayule rubber based passenger tyre was carried out using LCA. This study was emphasized more on the use of guayule rubber as a substitute for available natural and synthetic rubbers. The author has stated that the guayule rubber has the potential to replace the available natural and synthetic rubbers. There is no mention of improvements in the conventional tyre manufacturing process [8].

The LCA approach was used on the tyres used yearly by a vehicle fleet travelling on the Egyptian road network. The IMPACT 2002+ approach was utilized to evaluate the environmental impacts associated with Egyptian road tyres [9]. The LCA methodology was used to estimate diverse environmental impacts of different usage alternatives for worn-out tyres. The authors compared various scenarios for assessment of best option in terms of environmental emissions for the management of worn-out tyres [10]. End of Life Tyre (ELT) treatment technologies were compared using LCA approach [11]. The authors have estimated environmental impacts associated with the newly developed Carbonized by Forced Convection (CFC) method and compared the results with conventional pyrolysis method. Their study revealed that the CFC is better compared to conventional pyrolysis method in terms of environmental performance.

A comparative study of the environmental impacts associated with the tyres considering different scenarios for the end of life of the textile fiber material was presented by Landi *et al.* [12]. They considered various options for end of tyres such as landfill, incineration and reuse and concluded that each has a different environmental impact.

As a part of waste management in China, LCA study for the production of ground rubber from scrap tyres was carried out. The authors have concluded that improvements in equipment, energy efficiency and use of clean energy are effective measures to improve the environmental performance of the process [13]. Theoretical studies, using LCA software, was carried out to estimate carbon emissions for tyre plant with carbon black and with graphene as raw materials. Theoretical studies indicated that carbon emission will be reduced in case of graphene as compared to carbon black [14].

The study, comparing the carbon footprint of a new and a retread tyre for use by light commercial vehicles, shows that a 17.5" new tyre produces 86.9 kg CO_2 emissions compared to 60.5 kg CO_2 for an equivalent retread tyre. Process of retreading effectively increases the number of cycles for a tyre casing [15].

The report [16] presents key features that are essential to understand the tyre manufacturing industry. This primarily includes the production process and the costs associated with production of rubber tyres, and environmental concerns associated with the manufacturing process, along with the industry's current situation. The report also contains information on the specific facilities identified in the likely maximum control technology (P-MACT) document.

The properties of rubber compounds produced by blending virgin natural rubber with ground rubber tyre which was modified using a readily available, environmentally friendly, low-cost amino compound were evaluated and presented in the research article [17]. This study revealed that the amino compound acts as a devulcanising/reclaiming agent for ground rubber tyre. Further it is observed that rubber compounds prepared by blending virgin natural rubber with novel retrieved rubber revealed higher stock viscosity, lower scorch resistance, and lower hysteresis in comparison with the control compounds.

Bridgestone's Technical Center Europe has implemented a Product-Oriented Environmental Management System to fine-tune the design of its tyres processes. The LCA was performed on acar tyre throughout its entire life cycle. This study considered resource usage and emissions, from raw materials extraction and manufacturing through transportation and distribution to use, re-use maintenance and recycling or final disposal. The study revealed that the environmental impact of tyres depends primarily on product design and usage. Using this analysis, the company, at pilot scale level, investigated the effect of various design features that affect environmental aspects. These include the implications of material selection and tyre geometry on external noise, rolling resistance and wear. Further management system ensures that the environmental impact of Bridgestone's tyres is consistently controlled at all stages of product design [18].

Goodyear carried out a LCA of a passenger car tyre and the result showed that ~94% of the total Greenhouse Gas (GHG) emissions are from product use phase. It also concluded that tyres with low rolling resistance reduce GHG emissions. This claim is aligned with the LCA results of other industries. Further, this study revealed that a low rolling resistance tyre could reduce fuel consumption by 0.47 L/100 km [19].

The LCA approach is being used by Nokia tyres for environmental protection. This LCA study revealed that major environmental impacts during the tyre's life cycle are caused during its use. Reduction in tyre's weight and rolling resistance will cause reduction in fuel consumption which will lead to decrease in exhaust gas emissions and the formation of GHG's. Tyre production affects odour, dust emissions, noise, waste, energy consumption and solvent emissions (VOC emissions). The most significant of these impacts are VOC emissions and odour. Nokia tyres continually strive to reduce the mentioned impacts by way of improving operations, tracking emissions and correcting identified deviations [20].

From literature survey it is noted that most researchers across the world have been focusing on new raw materials, improvements in tyre design, recycling and disposal of used tyres. A few researchers have investigated alternative processes for the production of tyres. The available information on LCA studies and improvements in operations of conventional tyre manufacturing process is very scanty. Tyre industry being a very important part of economic development of all the countries, efforts must be made to not only find alternative ways to manufacture the tyres but also to improve the existing process by way of best management practices. In view of this, the present study was undertaken to identify the environmental impacts associated with the conventional tyre manufacturing process using LCA. The objectives of the study were:

- Study of the material and energy flows in the various stages of a tyre's production;
- Quantification and evaluation of waste streams;
- Identification of the primary impact on the environment during the manufacture of a tyre.

The detailed data required for this study was obtained from MRF Industries, Usgao, Goa, India. Computations of the LCIA results are obtained using SimaPro software with IMPACT 2002+ method.

LIFE CYCLE ASSESSMENT

LCA is an efficient and comprehensive tool to estimate the life cycle environmental impacts of products and services [21]. LCA can be used throughout product's life cycle, starting with raw material extraction, its transportation, processing, manufacturing and transportation of product, its use and disposal as shown in Figure 1. This is called a cradle-to-grave approach. The cradle-to-gate approach is from raw material extraction through product manufacturing only. The gate-to-gate approach is only related to product manufacturing.

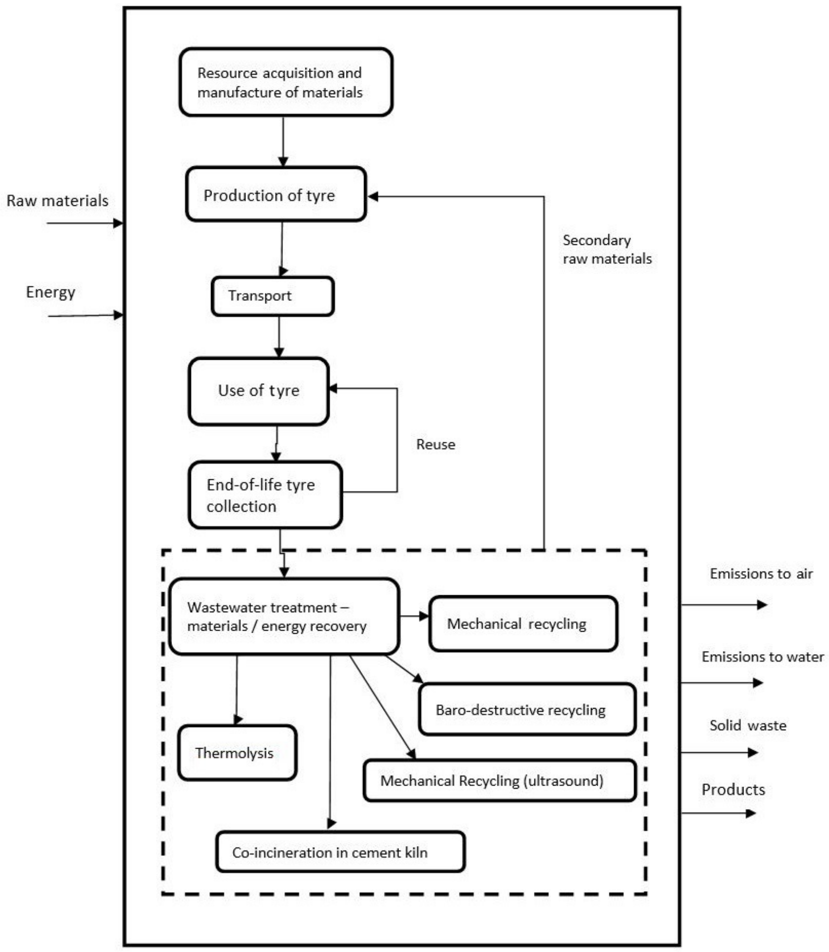

Figure 1. Whole life cycle of the product with boundary as indicated by outer dark solid line

In this study LCA was used to assess the production of conventional tyres. A gate-to-gate LCA approach was used to analyze tyre manufacturing process as shown in Figure 2. Raw material extraction, transportation, use phase and end-of life phase are not incorporated in this study as the focus is primarily on possible improvements in tyre manufacturing process. LCA study has assisted us with the following:

- Identified opportunities to improve the environmental performance of the product during the production stage;
- This study has revealed to tyre manufacturers the changes which can be made in their supply chain and production practices;
- Detailed compiled inventory of inputs and outputs would help the tyre industry to control probable changes in environmental impacts associated with changes in production.

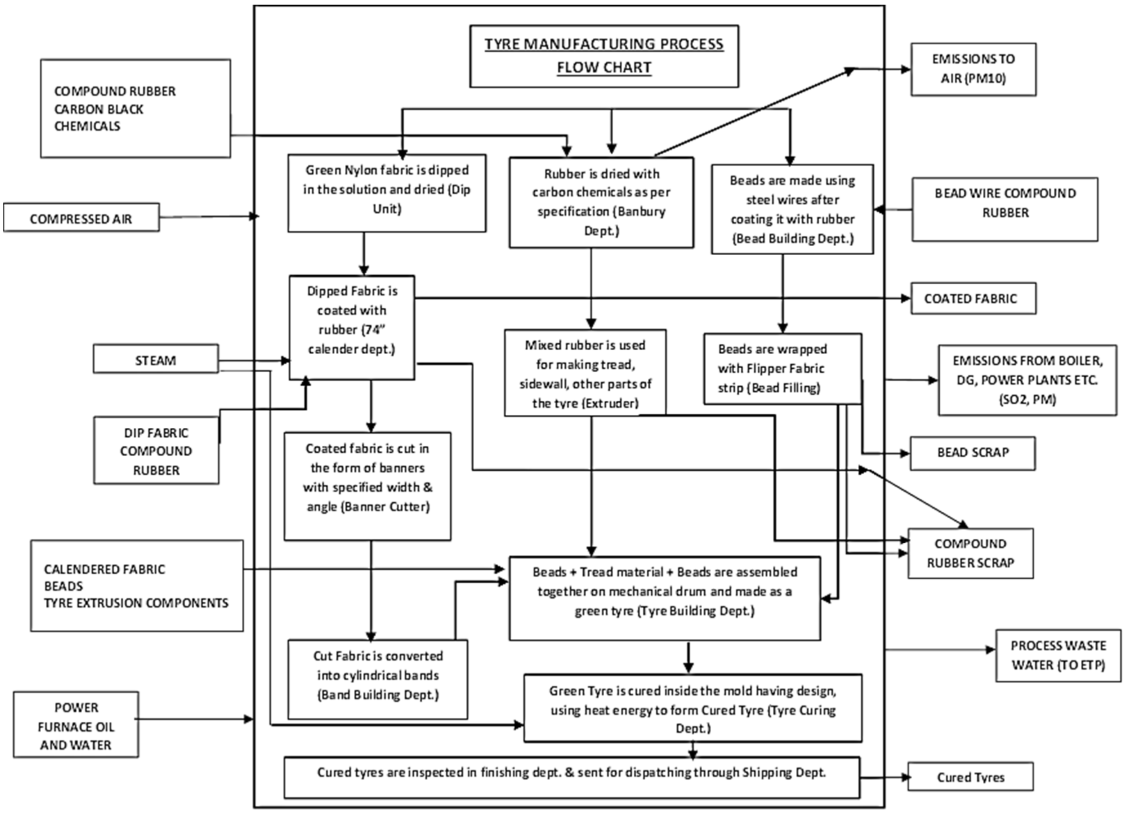

Figure 2. Tyre manufacturing process (gate-to-gate approach for LCA study)

Life Cycle Assessment methods

The LCA process is a systematic, phased approach and has got four components [22] as mentioned below:

- Goal definition and scoping;
- Inventory analysis;
- Impact assessment;
- Interpretation.

Goal and scope of the study

The goal of this study was to estimate environmental impacts associated with the tyre manufacturing process in the MRF Industry, Usgao, Goa, India and to identify the areas where improvement is possible or necessary. Gate-to-gate approach has been considered for this study in which only tyre manufacturing process has been considered. The goal of the study is mentioned in introduction section.

Functional unit. The functional unit is stated as a basis for comparison of a product before and after improvement. In this work, LCA study has been carried on the basis of one tyre (with an approx. weight of 50 kg) manufactured.

Tyre manufacturing process. MRF tyre company manufactures rubber products including tyres, treads, tubes and conveyor belts, paints and toys. Raw materials required for tyre industry include natural and synthetic rubbers, oil, carbon black, zinc oxide, sulphur and other chemicals. The process of manufacturing tyre is a complex process and involves many steps. The sequential steps involved in the process are banbury, dipping, calendaring, extrusion, tyre building, tyre curing and finishing as shown in Figure 2.

Inventory analysis

Various inputs, outputs and emissions at every stage of the process are estimated and provided in though Tables 1 to 3.

Table 1. Material and utility required for tyre manufacturing process

S. No.	Material	Total consumption per 1 Mt of tyre manufactured	Total consumption per 1 No. of tyre (50 kg) manufactured
1	Rubber [kg]		23.1
2	Carbon black [kg]		8.47
3	Fabric [kg]		6.93
4	Bead wire [kg]		2
5	Chemicals [kg]		7.2
6	Others [kg]		2.3
7	Power consumption [kWh]	757.93	37.90
8	Furnace Oil (FO) for process [L]	2.12	0.106
9	Furnace Oil (FO) for power generation [L]	128	6.4
10	High Speed Diesel (HSD) for power consumption [L]	6.79	0.3395
11	Water consumption [kL]	4.79	0.24
12	Total steam consumption [t]	1.37	0.07
13	Compressed air (100 psi) [kscf]	13.06	0.65
14	Compressed air (150 psi) [kscf]	4.77	0.24

Table 2. Scrap material generated during the manufacturing process

S. No.	Material	Quantity of waste generated per Mt of tyre [kg]	Quantity of waste generated per 1 tyre [kg]	Mode of disposal
1	Compound stock	0.4	0.02	Sold to other rubber processing units
2	Coated fabric	7.5	0.375	Given to scrap dealers
3	Beads	20.4	1.02	Given for recycling

The data collected as part of the inventory has been recalculated with respect the functional unit considered for this study and the same is given in Table 3.

Table 3. Material generated during the manufacture of one tyre (50 kg) at MRF Industries

Output materials	Amount
Particulate matter [g]	55.5
Sulphur dioxide [g]	420.37
Nitrogen dioxides [g]	31.35
Hydrocarbons [g]	0.34
Chemical Oxygen Demand (COD) [mg/L]	12.92
Biochemical Oxygen Demand (BOD) [mg/L]	1.6
Suspended solids [mg/L]	1.33
Oil and grease [mg/L]	0.667
Chloride [mg/L]	3.73
Wastewater generation [L]	0.211
Suspended particulate matter generated [g]	1.8E–03
Other gases [g]	1.72E–05

Impact assessment

Impact assessment method has four steps namely selection of impact categories, classification, characterization and normalization. Gate to gate approach has been used to carry LCA of tyre production. The impact method used is IMPACT 2002+. IMPACT 2002+ is life cycle impact assessment methodology that proposes a feasible implementation of a combined midpoint approach, linking all types of life cycle inventory results via 14 midpoint categories to four damage categories [23]. All midpoint scores are expressed in units of reference substance and related to the four damage categories viz., human health, ecosystem quality, climate change, and resources [24].

The main difference between LCA methodologies lies in the use of different approaches in modelling the effect of emissions (midpoint, endpoint and combined approaches). Midpoint approach methodology can be chosen when the environmental effects are of interest to the reported results. Endpoint approach methodology can be chosen when the final damages that occur to human health, Eco system and resources are of interest to the reported results. However, midpoint categories are considered as less relevant to decision makers. Similarly higher model and parameter uncertainty makes endpoint approach less certain. The combined approach takes advantage of both mid-point and endpoint approaches, that is, to align both indicators along the same environmental mechanism.

Based on the inputs made into the LCA software, the major inputs and outputs are shown in the flow chart in Figure 3 and Figure 4.

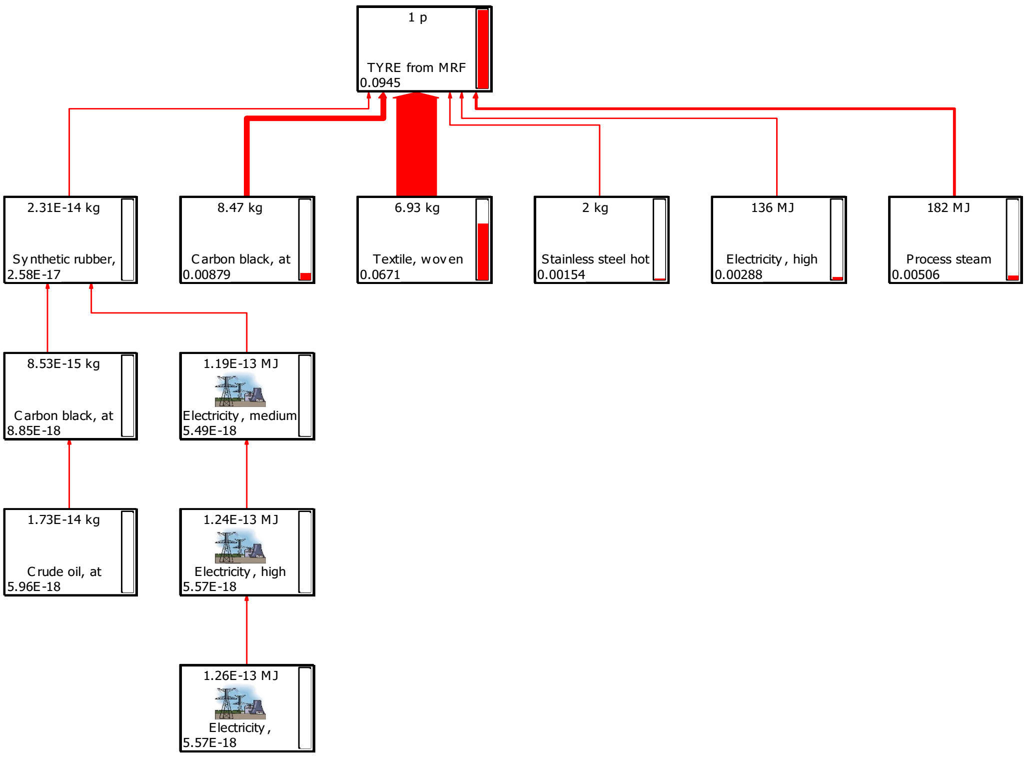

Figure 3. Flow diagram obtained from the LCA software in gate-to-gate approach (MRF Industry)

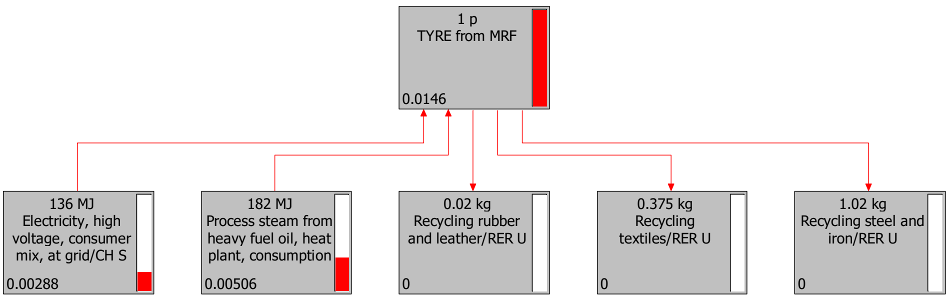

Figure 4. Figure showing the major inputs and outputs at MRF Industry

RESULTS AND DISCUSSION

The environmental impact associated with tyre manufacturing process at MRF tyre Goa, has been estimated. The basis considered for this study was production of 1 tyre with approximately 50 kg weight, using IMPACT 2002+ method.

The results obtained using the SimaPro 7.2 are presented through the Figures 5-8. Identification of impact categories for the tyre production process in gate-to-gate approach has been shown in Figure 5. It is observed that emissions from tyre production contributes to non-carcinogen inorganics, respiratory inorganics, aquatic ecotoxicity, terrestrial acidification/nitrification, aquatic acidifications, global warming, depletion of non-renewable energy sources, health and ozone layer depletion. From Figure 5 it is evident that most of the pollution contribution is due to electricity generation followed by steam generation and from tyre manufacturing process. The impact categories affected by the tyre production are respiratory inorganics, aquatic acidification, terrestrial acidification and to some extent aquatic eutrophication.

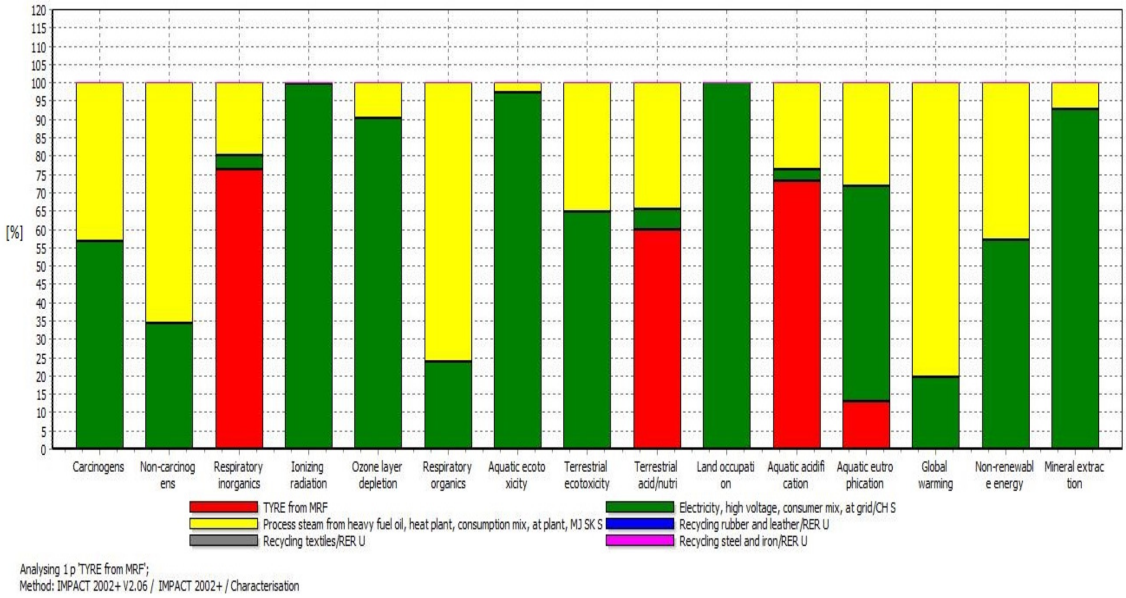

Figure 5. Identification of impact categories for the tyre production process (MRF Industries)

The LCA results obtained for MRF tyre are compared with the LCA results of Tweel tyre invented by Michelin, Bridgestone tyre, Goodyear tyre, Nokia tyre and comparative LCA results for a conventional tyre and a guayule rubber-based tyre.

Tweel tyre is made through the use of conventional tyre materials and commercially available polyurethanes. From the comparative study of above mentioned tyres, it is revealed that around 10% fuel saving in case of Tweel tyre use on a vehicle is possible. However, emissions of carbon dioxide and carbon monoxide increased by 10% and 100%, respectively, during the production of this tyre. Further it is also noted that the production of Tweel tyre significantly contributes in environmental parameters such as respiratory inorganics, global warming and depletion of natural resources. This is very similar to that of MRF tyre contribution. The environmental performance of MRF tyre in the production stage is better than environmental performance of Tweel tyre. The Tweel production process is slightly more environmentally harmful due to the effects of polyurethane and the additives need to mold it.

Results of comparative LCA studies for a conventional tyre and a guayule rubber-based tyre showed that raw material extraction contributed in the majority of impacts for both the tyres, whereas the production of guayule rubber and synthetic rubber

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were the main contributors for guayule and for conventional tyres, respectively. Finally the study concluded that reduction in impacts of raw material extraction can significantly improve a tyre's environmental footprint, along with utilization of co-products produced during the production of guayule and hevea rubber. The study further revealed that improvements in guayule agriculture and transport could make guayule as a promising source of natural rubber. Major impacts resulted from electricity use in the production of both guayule and conventional tyres. The similar trends are observed in MRF tyre and Tweel tyre manufacturing. From comparison among Bridgstone, Goodyear and Nokia it observed that major environmental impacts of tyres depend primarily on product design and usage. Significant reduction in environmental impact due to tyre production is possible if the source of electricity is non-conventional. Reduction in tyre's weight and rolling resistance will also lead in significant reduction in GHG emissions during its usage.

Figure 6 presents the damage assessment in tyre production process. The purpose of damage assessment is to group the various midpoint indicators with common outcome (endpoint indicator). For example, in the IMPACT 2002+ method used in the present study, the mid-point indicators such as human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, and photochemical oxidation are grouped as human health. As such, all the 14 mid-point indicators can be grouped into four endpoints, namely, human health, ecosystem quality, climate change and resources.

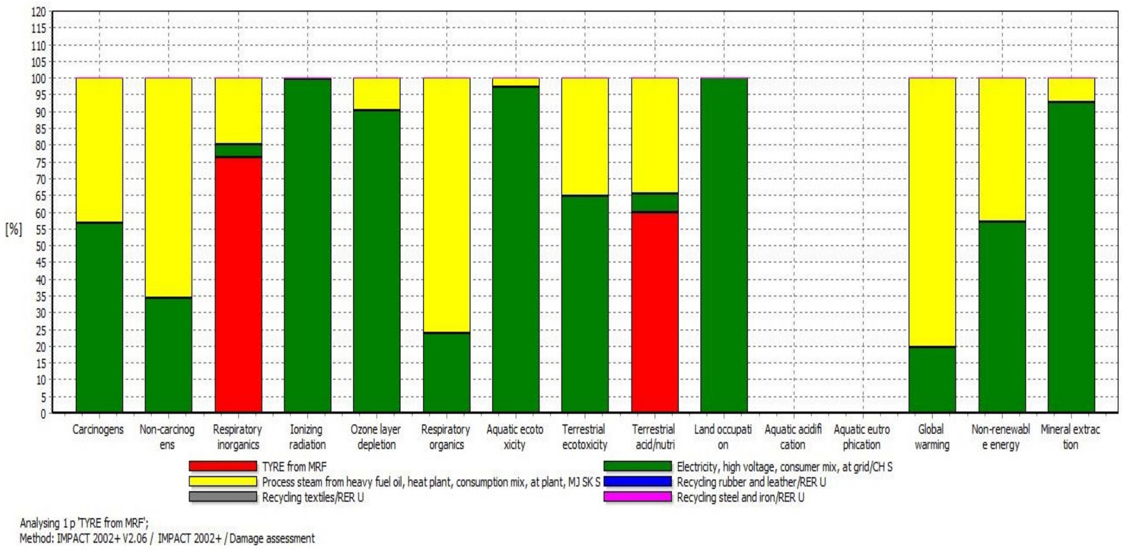

Figure 6. Damage assessment in the tyre production (MRF Industries)

In Figure 7 normalization of impact categories has been done with reference to eco-invent data base. Normalization helps to understand the impacts in a better way. The normalization factor represents the real or potential magnitude of the corresponding impact category for a geographic area for a certain time span. Normalization solves the discrepancy of units. Normalization displays to what level an impact category indicator result has a relatively high or a relatively low value compared to a reference. Selection of reference system plays an important role and should help decision makers to understand the impacts. Reference values could be annual national contribution to climate change in terms of global warming potentials, total emissions, resource use for a given area on a per capita basis, etc. The selected reference system should be in agreement with the goal and scope of any study.

From the Figure 7 it is clear that respiratory inorganic is the major impact category affected among the impact categories affected as mentioned above in tyre production.

This may be attributed to the fact that emissions of particulate matter, sulphur dioxide (SO_2), and nitrogen oxides (NO_x), from tyre production process directly contributes in respiratory inorganics. Global warming and depletion of energy sources are also affected compared to other impact categories. This may be due to the fact that Goa state gets a larger percentage of its electricity from coal plants, which directly affects the environmental impact of tyre production. Release of GHG, such as CO_2 and nitrous oxide (N_2O) during electricity production affects the global warming. Since coal is consumed for the electricity production which leads to depletion of energy sources.

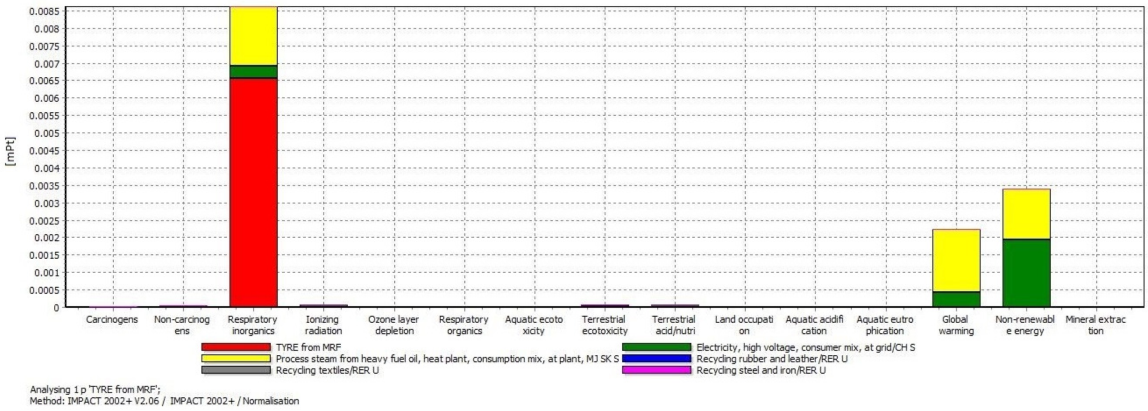

Figure 7. Normalization of impact categories identified in tyre production (MRF Industries)

As mentioned above, these results are compared with the LCA results of Tweel tyre [7]. From the comparison it is noted that the production of Tweel tyre also significantly contributes in environmental parameters such as respiratory inorganics, global warming and depletion of natural resources. This study was conducted in United States (U.S.). U.S. also gets a larger percentage of its electricity from coal plants which affect the environmental impact of tyre production which require large amount of electricity.

Figure 8 presents the weighing of emission data. This step represents the relative importance of each impact category to the environment. The weighing factors are subjective and can vary according to the location. From Figure 8, it is seen that human health is the most affected impact category. This may be attributed to the fact that high rates of particulate emissions affect the human health through the respiratory effects. Several studies have been published citing the various health effects due to exposure to particulate matter. Goa being the tourist place, health is the priority. From Figure 8 it is observed that human health is the primary concern followed by resource depletion and global warming.

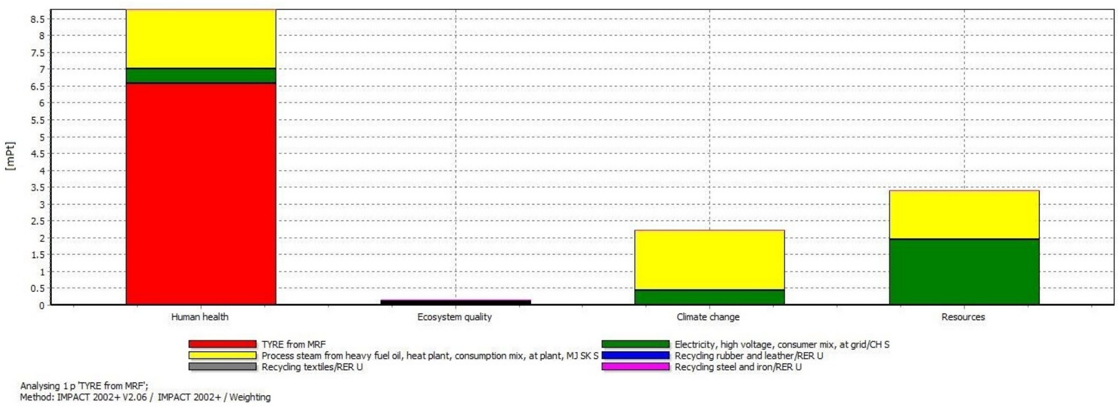

Figure 8. Weighing of emission data in the tyre production (MRF Industries)

INTERPRETATION OF THE LIFE CYCLE ASSESSMENT RESULTS

From the result it is noted that in gate to gate approach, electricity and steam generation during the tyre manufacturing process are major contributor to environmental pollution. It can be interpreted that more than the production processes, it is the energy generation which adds to the pollution problems. Further it is noted that tyre production process has a significant impact on the environment in terms of contribution to respiratory inorganics, global warming and depletion of natural resources. This study reveals the need for the improvement in tyre production process as well as the need for sustainable and green energy sources.

CONCLUSIONS

The environmental impact assessment of tyre production at MRF Industries at Usgao, Goa has been studied and presented here. The gate-to-gate approach was considered for the said study and tyre production plant data from MRF tyres, Usgao, Goa has been used.

The LCA results obtained for MRF tyre have been compared with LCA results of Tweel tyre invented by Michelin, Bridgestone tyre, Goodyear tyre, Nokia tyre and comparative LCA results for a conventional tyre and a guayule rubber-based tyre. From comparative study it is noted that environmental impacts are result mainly during raw material extraction stage, electricity use in tyre production process and type of tyre design. Tyre production affects odor, dust emissions, noise, waste, energy consumption and solvent emissions (VOC emissions). Reduction in tyre’s weight and rolling resistance will cause reduction in fuel consumption which will lead to decrease in exhaust gas emissions and the formation of GHG’s.

This study has provided valuable insights into the tyre production process at MRF Industries, Usgao, Goa, identifying the main sources of impact. As mentioned above, the major environmental impact is from electricity use and steam production during tyre production process. As a part of tyre production process, the banbary section is the major contributor of particulate pollutants. Among the pollutants emitted from tyre production processes, major pollutants are particulate matter, SO_2, NO_x, hydrocarbons and organic pollutants.

To reduce the emissions of the said pollutants, the detailed study of each unit operation in tyre manufacturing should be carried out along with use of energy integration to reduce the energy requirement. There is a need for upgradation of the existing tyre manufacturing process including various tyre design aspects. Further it concluded that alternative energy source should be identified in order to reduce the environmental impacts of the tyre production process.

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