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Integrated life cycle assessment and activity based life cycle costing approach for an automotive product

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Abstract. The manufacturing organizations are adopting the environmentally friendlier practices to sustain in the competitive business environment. Automotive industries are adopting the environmental management standards to comply with government norms. Life Cycle Assessment (LCA) enables the evaluation of environmental impacts associated with the processes. Life Cycle Costing (LCC) enables the attainment of economic aspect of sustainability. This article presents an integrated approach of LCA-Activity Based LCC to minimize the environmental impact across the life cycle as well as to identify the costs associated with life cycle activities. Different scenarios are being analyzed from the sustainability view point, and critical activities are also being identified so as to improve sustainability.

1. Introduction

Sustainability is an essential winning strategy in the modern manufacturing sector, due to strict government regulations, and customer preference for sustainable products. According to Orsato and Wells [1], automotive industry is facing sustainability challenges that need improvements in life cycle stages of vehicle manufacturing, design, material selection, manufacturing, vehicle use and end of life. For attaining sustainability, the resolution of environmental problem has to proceed along with economical challenges. LCA methodology assess the environmental impact associated with the processes that are involved in realizing a product or service and also to determine the critical part that add environmental impacts significantly [2,3]. LCC is a tool for sustainability assessment which addresses economic dimensions of sustainability [4]. An integrated approach of LCA and Activity Based Life Cycle Costing (ABLCC) is used in this study to identify the opportunities to improve sustainability by determining the environmental impacts and life cycle cost and associated drivers of these impacts. For the selected automotive component, manufacturing process of wheel end possesses highest environmental and economic impact. Activity based analysis showed that raw material consumption and wastage during steel turning process is the hot spot which demand improvements.

The paper emphasizes the need for combining LCA and ABLCC approach to determine the environmental and economic impacts associated with life cycle stage of a product, and also a case study is presented in which the approach of integrated ABLCC and LCA methodology is used for environmental and economic impact analysis of an automotive component. This approach helps to determining the critical processes that necessitate improvements to attain sustainability.

The article is organized in six sections. After

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the introduction section, literature review is discussed. The methodology and case study are detailed in the third and fourth sections and the findings of the case study are discussed in the results section. Conclusions are presented in the final section.

2. Literature review

The literature review has been conducted in the perspective of LCA and LCC.

2.1. Review on Life Cycle Assessment (LCA)

Tukker [5] defined LCA as an analytical tool to assess the environmental impact of the production chain related to the product. He illustrated the statement with case studies from environmental impact assessment of waste management plans, oil desulphurization plant, electricity production plant, and flue gas treatment plant. The author concluded that LCA is the best tool to analyze the environmental impact and is an aid for policy decision making and process alternatives. Hanseen [6] grouped products into five basic types based on the functionality and their applications. LCA study was also conducted for these product groups and concluded that the environmental impact of the products shows a similar pattern according to their life cycle stages. In the study, the raw material preparation and use phase of the product were found as important life cycle stages which influence the environment significantly. Lunghi et al. [7] conducted a case study to compare environmental impact of traditional electricity production system with molten carbon fuel cell system, and then evaluated the advantages and disadvantages of both in a life cycle perspective. The authors pointed out that LCA is a unique approach to assess the environmental impact since it considers all the processes involved in the life cycle stages. Blom et al. [8] applied LCA methodology to quantitatively assess the environmental performance of the use and maintenance phases of heating and ventilation systems. The authors observed that the heat pump causes the highest environmental impact due to electricity usage in the operation phase and high material content of the system. Wang et al. [9] studied the environmental impact of the two materials using a software package for modeling the process of raw material preparation and comparing the carbon footprint index. LCA methodology was used to analyze the mass and energy flows associated with the life cycle of the product. They analyzed the influence of different parameters of the manufacturing system in terms of carbon footprint and selected the best material based on the findings. Vinodh et al. [10] evaluated the sustainability of an automotive product through an integrated approach. They conducted a case study in an automotive industry to select the manufacturing process alternatives based on sustainability performance through product sustainability index, risk/benefit worksheet and LCA integrated approach. They concluded that for sustainability assessment, single approach is not advisory as it deals with economic, social and environmental dimensions.

2.2. Review on Life Cycle Costing (LCC)

Gluch and Baumann [11] discussed theoretical assumptions and the practical usefulness of the LCC approach in making environmentally responsible decisions. LCC links the environmental issues with financial consequences to support the decision makers in making environmental considerations. The authors observed that LCC does not support the decision makers limited ability to make rational decisions under uncertainty. They also pointed out that LCC's practical usefulness is constrained by its oversimplification to a monetary unit, lack of reliable data, and complexity of the process. Witik et al. [12] quantified the life cycle costs and environmental performance of several suitable lightweight polymer composites and compared them against magnesium and steel for a representative component. In their study, they found out that the weight reduction has a positive effect in reducing the environmental impact and life cycle cost. They also mentioned that the combination of LCA and LCC approach is useful for identifying the environmental and economic improvement opportunities. Gunasekaran and Sarhadi [13] discussed the role of Activity Based Costing (ABC) in manufacturing system. Implementation of ABC in manufacturing system helps to identify productivity and quality improvement opportunities by eliminating non-value adding activities. In their study, a framework to implement ABC strategy was proposed and conditions for successful implementation of the model was also established. Emblemsvag and Bras [14] proposed activity based method for tracing of costs, energy consumption and waste generation for usage in life cycle design. The proposed model traces the cost and also analyzes the largest cost contributors. A case study was conducted and evaluated the life cycle cost, energy consumption and waste generation in the operation phase of a platform supply vessel. They remarked that the ABLCC possess the capability of identifying the significant resources that contribute to the life cycle costs extensively. Emblemsvag and Bras [15] combined ABLCC with LCA procedure in order to perform economical and environmental assessment to improve product and process designs in a manufacturing organization. They identified the resources required for the activities involved and established the relationship between activity drivers and design changes using the methodology. They pointed out that the activity based method is effective for better resource utilization and thereby improving the profit of the organization.

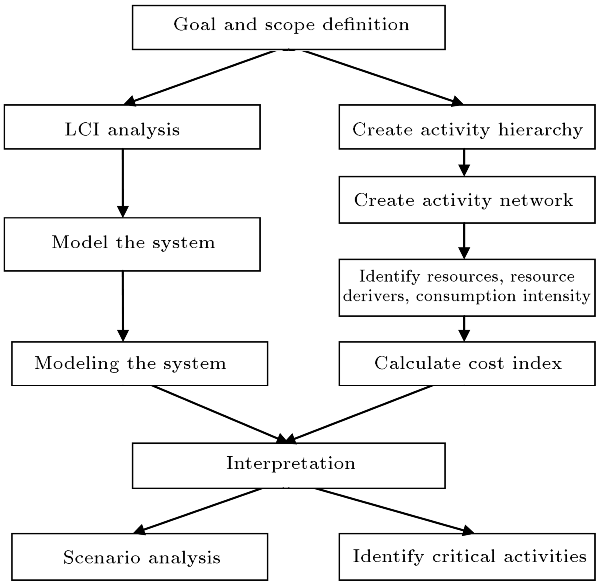

Figure 1. LCA-activity based LCC methodology.

Though many researchers have used LCA and LCC as tools for assessing sustainability, there exists a need for combing the LCA and ABLCC for identifying the environmental and economic impact of processes involved in the life cycle stage of a product and also for determining the critical processes that necessitate improvements to attain sustainability.

3. Methodology

The integrated approach of LCA-Activity Based LCC is developed to analyze the environmental impact across the life cycle stages of the product as well as to identify the costs associated with life cycle activities. The methodology is elaborated in Figure 1.

The methodology starts with identification of objectives, and defining the scope of the study. It is followed by Life Cycle analysis and Activity Based LCC. In the interpretation step, different scenarios can be identified, modeled and analyzed from sustainability view point and critical activities are also being identified from the cost index analysis so as to improve sustainability. The approach not only analyses the environmental impact associated with life cycle stages, but also systematically identifies the critical activities which contribute to life cycle cost. Systematically, different scenarios can be identified and compared based on environmental impacts. Resource based analysis of critical activities gives better view of causes behind the life cycle cost.

4. Case study

The case study is conducted in an automotive component manufacturing organization located at Tiruchirappalli, Tamil Nadu, India. The case organization is the manufacturer of hydraulic power rack and pinion steering gear assembly, integral power steering and power steering pump assembly. The organization aspires to enhance sustainability in their product design and development practices. The case product is a mechanism used in steering assembly. The details of the case study are presented in the following subsections.

4.1. LCA on steering column assembly

LCA consists of mainly four steps: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA) and interpretation according to ISO 14044 [7,16,17].

4.1.1. Goal of LCA

In this study, the objective of the LCA is to analyze the cradle to gate life cycle stages of the steering column assembly based on environmental impacts. The case product consists of 13 components namely, nylon sleeve, head screw, wheel end, bush, rubber bush, external circlip, spacer, lock spacer, protector serrated end, protector wheel end, nut, outer tube, and protector outer tube. Since the analysis of 13 components of the candidate product is beyond the scope, the main components, wheel end and outer tube, are considered for the LCA study. For modeling convenience, LCA is conducted for manufacturing process of a batch of size 50.

4.1.2. LCI Analysis

In this step, energy and raw material flows for each process in the life cycle stages are quantified. The life cycle stages for modeling are outer tube manufacturing, wheel end manufacturing and transportation to the assembly station. The energy and material inflows are collected and modeled using GaBi 5 software package. The life cycle stages and the input flows collected for processes are given in Table 1.

Modeling the system. The database of the GaBi 5 software package was used to incorporate the input

Table 1. Inventory data for LCA of case product.

Stages	Flow	Value	Unit
Machining of outer tube	Steel pipe	50	kg
	Electricity	1.26	MJ
Steel turning	Steel billet	408	kg
	Electricity	992	MJ
Machining of wheel end	Steel parts	300	kg
	Electricity	8.82	MJ
Transportation	Cargo	345	kg
	Diesel	0.249	kg

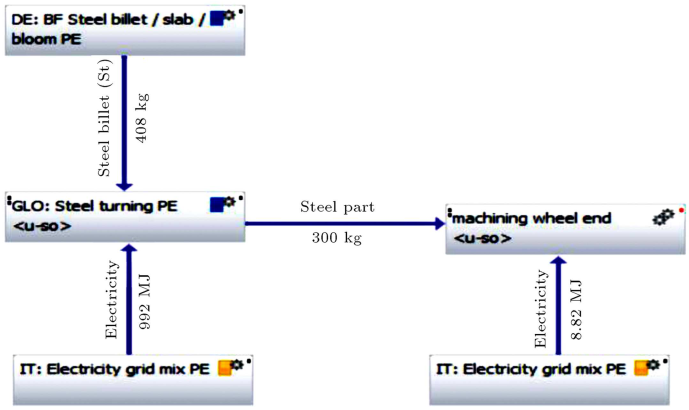

Figure 2. Wheel end manufacturing.

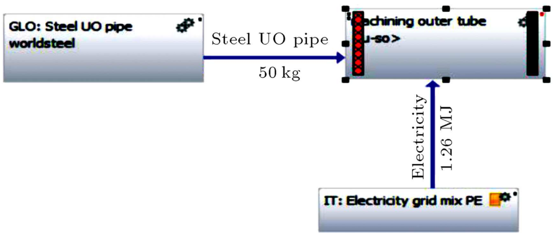

Figure 3. Outer tube manufacturing.

material and to analyze LCA results. Wheel end manufacturing and outer tube manufacturing are modeled as sub plans. The steel scrap wasted during each process is modeled as steel waste for recovery. The source of electrical energy is electricity from hydro power and the truck used to transport is a truck trailer with 4 tonne load capacity. The sub plans are shown in Figures 2 and 3.

The sub plans are incorporated in the existing manufacturing system. The process cargo is created to combine the outer tube and wheel end for shipping. The source of diesel is assumed to be from diesel mix from the refinery. It is shown in Figure 4.

The input output analysis of the material and energy is shown in Table 2.

4.2. *ABLCC on steering column assembly*

Activity based life cycle costing method is used to trace the cost associated with the life cycle stages. The cradle to gate life cycle stages for a batch of 50 outer tubes and 50 wheel end are considered for the study. The End of Life (EoL) activities are also included in the case study. The steps for finding the costs are discussed in the following subsections.

4.2.1. *Creating activity hierarchy and activity network diagram*

The activities and sub activities involved in the life cycle stages are identified and arranged in a network diagram. Five main activities are identified as level 1 activities for the life cycle stages of the case product. They are outer tube manufacturing (A1), wheel end manufacturing (A2), transportation of wheel end, and outer tube to the assembly station (A3), reuse of outer tube (A4), and repair of wheel end (A5). Raw material procurement for outer tube (A11), and machining of outer tube (A12) are the sub activities of A1. The activity A2 consists of raw material procurement (A21), steel turning (A22) and machining of wheel end (A23). For reusing the outer tube, disassembly (A41) and cleaning and inspection (A42) are needed. The activity A5 includes disassembly (A51), cleaning and inspection (A52) and repairing of wheel end (A53). The level 1 activities and level 2 sub activities of the activity hierarchy is given in Table 3 and the created activity network diagram is shown in Figure 5.

4.2.2. *Identifying the resources, resource drivers and consumption intensities*

The resources for the activities are raw material, transportation distance, labor and machines. The resource element considered for the study to measure

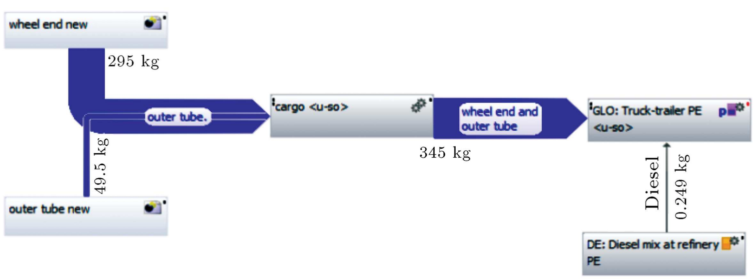

Figure 4. Existing manufacturing system.

Table 2. Inventory analysis for case product.

Input flows		Output flows	
Units in kg equivalent	**Value**	**Units in kg equivalent**	**Value**
Energy resources		Resources	198
Nonrenewable energy resources	478	Emissions to air	4.56E003
Renewable energy resources	0.000621	Emissions to fresh water	9.71E005
Material resources		Emissions to sea water	17.2
Nonrenewable elements	487	Emissions to agriculture soil	7.57E-005
Nonrenewable resources	5.89E003	Emissions to industrial soil	0.00784
renewable resources	9.64E005		

Table 3. Activity hierarchy of case product.

Level 1 activities	Level 2 activities
Outer tube manufacturing (A1)	Raw material procurement (A11) machining (A12)
Wheel end manufacturing (A2)	Raw material procurement (A21) Steel turning (A22) Machining (A23)
Transportation (A3)	
Reuse of outer tube (A4)	Disassembly (A41) Cleaning and inspection (A42)
Repair of wheel end (A5)	Disassembly (A51) Cleaning and inspection (A52) Repair (A53)

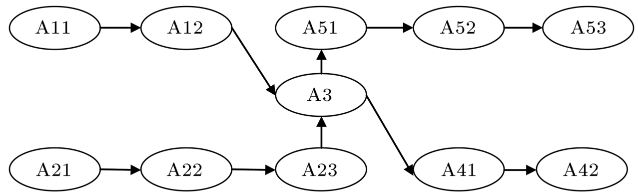

Figure 5. Activity network diagram for case product.

the resources are raw material, labor hours, machine hours, electricity and transportation distance. The raw material for activity A11 is steel pipe and for activity A21 is steel billet. Labor hours keep track on labor cost and distance to be transported is a resource element which keep track on transportation cost. The electricity and machining hours measure the machining cost of the respective activities. The resource driver of each element is the quantity of each resource element used. The consumption intensity of resource driver is cost consumed by unit resource driver. The resource driver and the consumption intensity of each resource element are identified.

4.2.3. Calculating the cost index

The Cost index is determined by multiplying each resource driver by its respective consumption intensity and the cost of each activity is found out by summing the cost indices for the activity [15,18].

$$\text{Cost index} = \text{Resource driver} \times \text{Consumption intensity}. \quad (1)$$

The life cycle cost calculated for steering column is presented in Table 4.

5. Results and discussions

The findings of LCA and ABLCC are discussed in the following sections.

5.1. Environmental impacts of case product

The final steps of LCA are life cycle impact assessment, life cycle improvement and interpretation [7,16]. It is detailed in the following subsections.

5.1.1. LCIA of steering column assembly

LCIA is done based on four indices, namely, Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Ozone Depletion Potential (ODP). GWP is the mass of greenhouse gases estimated to contribute in global warming. It is calculated for 100 years for this study. It compares the amount of heat trapped by a certain

Table 4. Cost indices for case product.

Activity	Resources	Resource driver	Consumption intensity (INR)	Cost index (INR)
A11	Steel pipe	50 kg	54.41	2720.5
	Transportation distance	70 km	8	560
A12	Electricity	0.350 KWh	6	2.1
	Labour hours	0.833 hr	65	54.145
A21	Steel billet	408 kg	27	11016
	Transportation distance	70 km	8	560
A22	Electricity	275.555 KWh	6	1653.333
	Labour hours	6.67 hr	65	433.55
A23	Electricity	2.450 KWh	6	14.7
	Labour hours	5.83 hr	50	291.67
A3	Transportation distance	30 km	8	240
A41	Labour hours	1.25 hr	65	81.25
A42	Labour hours	1.67 hr	65	108.33
A51	Labour hour	2.08 hr	65	135.42
A52	Labour hour	2.5 hr	65	162.5
A53	Labour hour	16.67 hr	65	1083.33
	Machine hours	2.5 hr	25	62.5

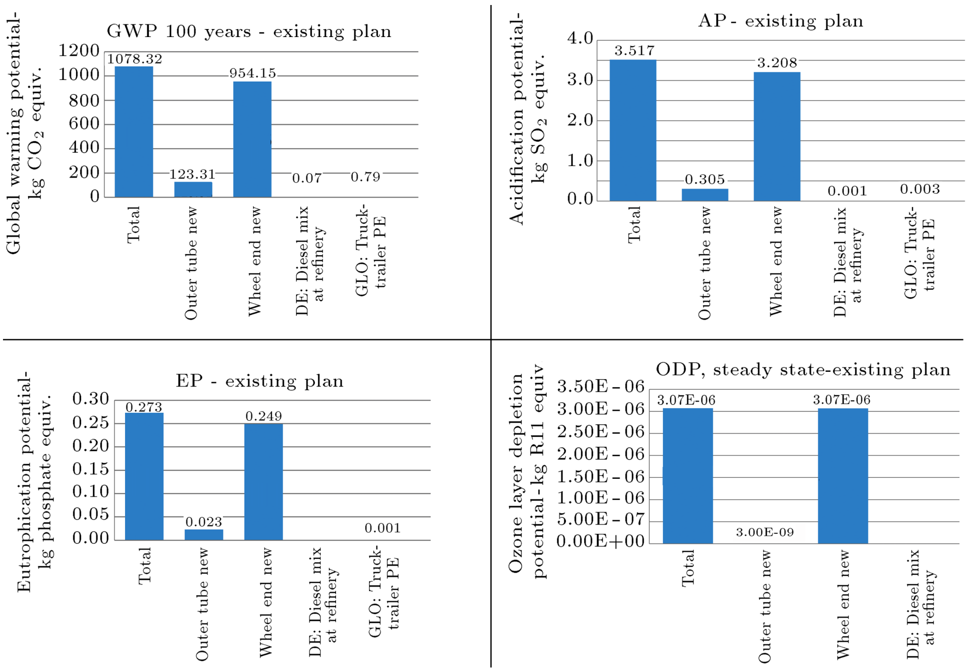

Figure 6. Life cycle impact assessment of case product.

mass of the gas subjected to the amount of heat trapped by a similar mass of carbon dioxide. The ODP category indicates the potential of emissions of chlorofluorohydrocarbons (CFCs) and chlorinated hydrocarbons (HCs) for depleting the ozone layer. In this study, ODP is identified based on trichloromonofluoromethane (R11). AP is calculated based on the contributions of Sulphur dioxide to the potential acid deposition. EP is defined as the potential to cause over-fertilization of water and soil, which can result in increased growth of biomass. Permanganate equivalent is taken as base for calculating EP in this study. The impact of the existing system is shown in Figure 6.

Table 5. Comparison of different scenarios with existing plan.

	GWP (CO_2 equivalent)	EP (permanganate equivalent)	AP (SO_2 equivalent)	ODP (R11 equivalent)
Existing plan	1078.32	.0273	3.517	0.307e-5
Scenario 1	969.37	0.254	3.241	0.312e-5
Scenario 2	1077.94	0.273	3.516	0.306e-5
Scenario 3	1077.46	0.272	3.513	0.307e-5

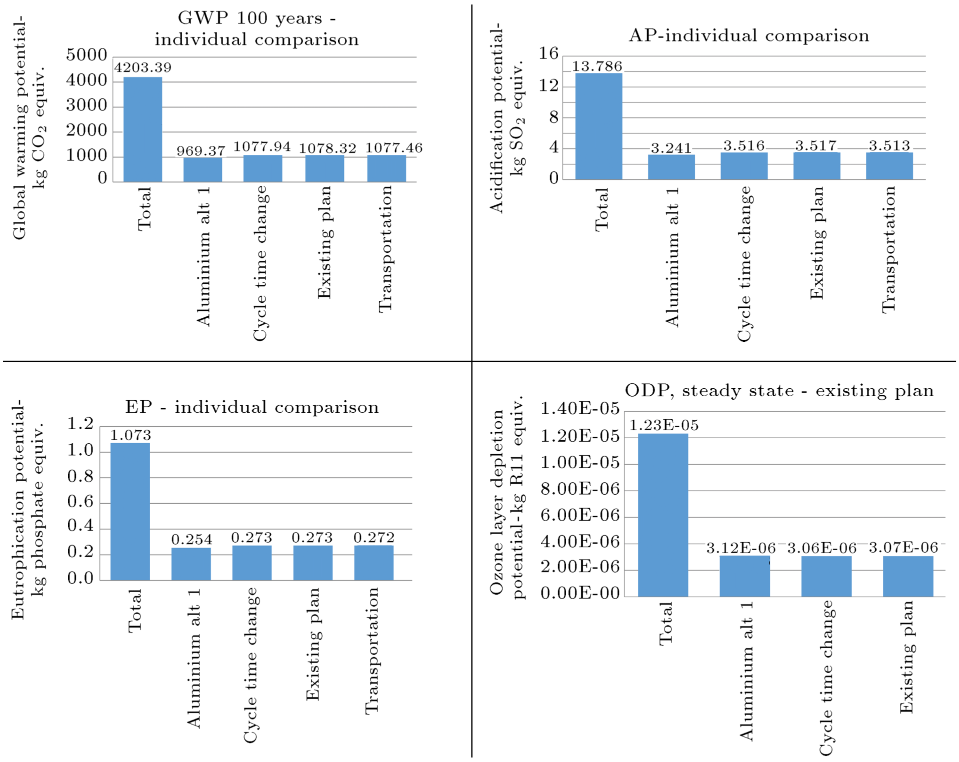

Figure 7. Comparison of different scenarios with existing manufacturing system.

5.1.2. Interpretation

The wheel end manufacturing sub plan has the highest environmental impact based on these four indices. In order to reduce the overall environmental impact, three different scenarios are identified and analyzed.

- Scenario 1: Aluminium can be used as an alternative material for outer tube;
- Scenario 2: The cycle time for wheel end machining can be reduced to five minutes, so that electricity consumption can be reduced;
- Scenario 3: The transportation from machining centre to assembly station can be avoided.

In Scenario 1, aluminum extruded profile is used instead of steel pipe. For 50 outer tubes, required aluminum is 17 kg. In Scenario 2 the electrical energy needed for machining 50 wheel ends is changed from 8.82 MJ to 6.3 MJ. The changes are incorporated in model and analyzed. Table 5 and Figure 7 show the comparison of these three scenarios with the existing plan.

It is found that the material alternative for aluminum has highest contribution in reducing the environmental impact than other scenarios. Scenario 3 will reduce the GWP, AP and EP more in comparison to Scenario 2. The significance of cycle time reduction of wheel end machining is very less in minimizing the environmental impact. The main reason for high environmental impact of wheel end is the raw material. In order to minimize the effect, raw material requirement should be minimized by incorporating design changes, or environmentally friendlier alternative material should be used instead of steel billet.

5.2. ABLCC of case product

The life cycle cost of outer tube and wheel end is calculated by adding the activity costs. For a batch, it is found to be Indian National Rupees (INR) 19179.328. The costs of level 1 activities are presented in Table 6.

The impact of activities on the life cycle cost is analyzed and is shown in Figure 8. Activity A2 is the critical activity. The cost of A2 is very high compared to others due to the raw material cost. 26% of steel is wasted during the turning process. The raw material requirement for A2 is high that consumes more cost. The EoL activity cost is less. The cost of EoL operation of wheel end is high compared to that of outer tube. The repair activity is needed for wheel end to reuse it which consume additional cost. Remanufacturing the product is better strategy because EoL activities consume less cost.

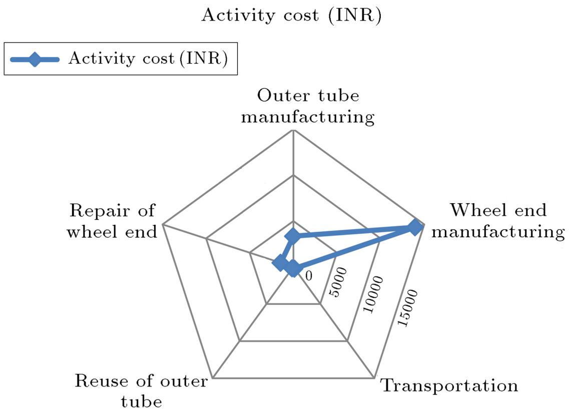

Figure 8. Activity based cost analysis of the product.

Table 6. Costs of level 1 activities.

Activity	Activity cost (INR)
A1	3336.745
A2	13969.253
A3	240
A4	189.58
A5	1443.75

The resources based analysis of life cycle cost is also done and is shown in Figure 9.

The raw material cost is very high compared to other resources. Transportation cost and machining cost have the same impact. In order to overcome this problem, raw material requirement should decrease by incorporating design changes; the wastage of steel in turning process should be minimized or less cost material alternative should be investigated. The labour cost is higher than machining and transportation cost.

5.3. Comparison with other methodologies

The proposed integrated methodology is compared with LCA and ABLCC methodologies and the findings are summarized in Table 7.

6. Conclusions

For modern manufacturing industries, sustainability must be achieved at both product and process levels. An integrated approach is needed for evaluation of

Table 7. Comparison of different methodologies.

Research paper	Objective	Methodology	Findings
Present study	To identify the opportunities to improve sustainability of an automotive component	Integrated LCA-ABLCC approach	Environmental impacts associated with different life cycle stages are analyzed by modeling the system. Different scenarios are compared to minimize these impacts. The critical activities in the life cycle stages are identified by analyzing the resource consumption in the ABLCC approach
Emblemsvag and Bras [15]	To perform economical and environmental assessment to improve product and process designs in a manufacturing organization	Combined ABLCC with life cycle analysis procedure	They identified the resources required for the activities involved and established the relationship between activity drivers and design changes using the methodology.
Witik et al. [12]	To quantify the life cycle costs and environmental performance of several suitable lightweight polymer composites	Combination of LCA and LCC approach	The weight reduction has a positive effect in reducing the environmental impact and life cycle cost.

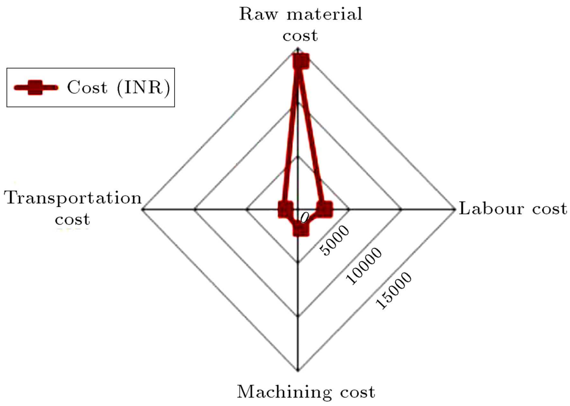

Figure 9. Resource based cost analysis for the case product.

sustainability since it deals with different elements namely economy, environment and society. The proposed approach integrates LCA and ABLCC methodology to identify the improvement opportunities for sustainable products. A case study is conducted for an automotive product. LCA identifies and compare different scenarios to improve environmental performance with existing manufacturing system on a life cycle basis. ABLCC study revealed the activities and resource drivers which consume cost. Based on LCA and ABLCC, wheel end manufacturing is found to be the critical activity which reduces the sustainability.

The following notations are used in this article.

Nomenclature

ABC	Activity Based Costing
ABLCC	Activity Based Life Cycle Costing
AP	Acidification Potential
EP	Eutrophication Potential
EoL	End of Life
GWP	Global Warming Potential
INR	Indian National Rupees
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
ODP	Ozone Depletion Potential

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