Implementation of Lean and Sustainable Practices for Reduction of Energy Consumption in a Hydraulic Pump Manufacturing Firm

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Abstract: **This paper explores involvement of lean manufacturing and sustainable practices to reduce the energy consumption in a manufacturing firm. In today's economical condition there is a need for reduction of energy consumption in all the manufacturing firms. Initially, the production line of specific product in the hydraulic pump manufacturing firm was selected using RRS (runners, repeaters, and strangers) analysis. Data has been collected by going from the working processes and the energy consumption reading in the organisation. Based on this data analysis was carried out using lean tools such as kanban, kaizen, and value stream mapping to eliminate the waste. The energy value stream mapping focuses on the energy aspect of the waste and eliminates them. Based on the observation of the work environment, a framework has been designed for the reduction of Carbon footprint in the organisation.**

Keywords -- RRS analysis, Kanban, Kaizen, Value stream mapping, Carbon footprint.

I. INTRODUCTION

Runner Repeaters and Stranger Analysis is a tool for identifying which tasks in a process should have effort dedicated to their improvement.

Value stream mapping is an enterprise improvement technique to visualize an entire production process by representing information and material flow to improve the production process by identifying waste and its sources. This tool is used primarily to identify, demonstrate and decrease waste, as well as create flow in the manufacturing process. VSMs can be created merely using paper and pencil; however more advanced maps are created using Microsoft Visio as well as Microsoft Excel. Energy value stream mapping is a value stream mapping that help in differentiating the non value added energy from the value added energy. Sustainable manufacturing is defined as the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers. Carbon footprint, sometimes also referred to as carbon profile, does not yet has an established definition. Basically, the term is developed to describe the cumulative amount of greenhouse gas (GHG) emissions produced during a product's life cycle. Carbon footprint is a tool which helps to determine the critical life cycle stages causing GHG emissions in a supply chain and pointing out the life cycle stages where the potential to decrease the emissions.

Bhim Singh et.al [1] studied the lean manufacturing technique from an implementation perspective, in their research paper the authors proposed Value stream mapping(VSM) as a lean tool , which provides the information about cycle time, up time or utilization of resources, set-up time or change over time, work in process inventory at the individual stations in the process. They have proposed a simulation model that enhances the impact of lean principles that are used for flow of construction material, found that the lesser the time spent in the value stream, the leaner is a process. **Rahani and Muhammad al-Ashraf [2]** developed a test that was conducted to determine whether the Lean Production principles were helpful for the process sector of an automotive part manufacturing plant. They conclude that there is a significant amount of the time products spent on the production system usually was waiting and non-value added. They identified the Gap that was established between the standardized work and real work which resulted in savings. **Michael Sciortino and Suzanne Watson [3]** propose Energy as ninth waste, the main focus is to reduce cost, Climate Change and Environmental Risk by which

Competitive Advantage can be gained. In this paper the author discus lean principles by adhering to the “Plan/Do/Check/Act” Kaizen methodology. **Vikram Gogula et.al [4]** has discussed the impact of lean tool on energy consumption. This involves the mapping of current and future value stream map, which suggests how much energy is optimized after implementation of lean tools. They determine Contribution of lean implementation in energy saving for achieving a better environmental performance of production systems. **Saskia Reinhardt [5]** developed the methodology that is used in the analysis of the energy flows of a production site, which identify the factory’s key energy consumers and where the greatest amount of energy is wasted, to improve the energy efficiency in total. Author found the types of wastes that are considered are Overproduction (use of surplus energy by an inefficient manufacturing system), Waiting (energy used while production is down), Transportation (inefficient transportation of compressed air), Inventory (storing energy in batteries), Deflects (the energy which was used to manufacture a defective product is wasted), Motion (inefficient transportation of goods), Unused human talent (failure to integrate employees when defining energy efficient process). **Thiede et.al [6]** in their paper suggests the technique for the systematic classification, identification and prioritization of energy consumption in the company. They conclude by improving energy and resource efficiency in manufacturing companies for providing methods for systematic improvement. The method can also be applied to different forms of energy. **Marcello Braglia et.al [7]** presents a case study to formulating and validating the methodology, value stream mapping (VSM) which is an innovative framework for applying to products with complex Bill of Materials. They proposed an approach that integrates Value Stream Mapping with other tools of industrial engineering which is based on seven iterative steps. **Geoff Miller et.al [8]** in their paper presents the disadvantages of lean’s traditional implementation strategies that lead to environmental friendly production company. The company has integrated lean tools and sustainability concepts. They developed discrete event simulation modeling and analyzed with the help of principles of lean manufacturing, we can eliminate the wastage made by the company. **Denise Ravet [9]** studied the corporate sustainability which has been defined as a business approach that creates long-term shareholder value by embracing the opportunities and managing the risks associated with economic, environmental and social developments. This paper reveals the link between sustainable development, global supply chain and the lean paradigm in the international changing competitive environment. **Roosen and Pons [10]** describe the lean method to know the management of waste. Production staff can use the resulting technique to quantify environmental impacts at the level of the individual process and informed about the wastes for the whole value stream. They conclude that a technique was introduced to evaluate the environmental impacts and lean methods. Carbon footprint, perceived impact, cost to remediate, and waste volumes were used for deployment. Program Evaluation Review Technique (PERT) beta distribution is used to collect the ambiguous user estimates of waste quantities.

The work in this paper is divided in three stages. 1) RRS analysis 2) Energy value stream mapping 3) Frame work for Sustainability. Selecting the product by using Runner, Repeater, stranger analysis (RRS) in the hydraulic manufacturing firm. Collection of energy consumption data for each machine in the production line, developing current value stream, identification of the energy guzzlers or the machines consuming above 25Kwh, analyzing the Kaizen burst, developing proposed value stream and suggestions.

The attempt of constructing the energy value stream mapping (EVSM), the connected load reading of each machine in each of the processes were collected. This includes seven machines. All the machining details of these machines were collected and a thorough study was carried out. Suggestions were given to reduce the energy consumption after analyzing the Kaizen burst and cycle time. Using Microsoft Visio, an energy mapping of the manufacturing process of M&M 3036 pump was made. A framework for sustainability is developed by considering the all the parameters that are involved in the manufacturing of product and till the end of the product life cycle. This can be done by using Life cycle approach (LCA) and Carbon footprint approach.

II. METHODOLOGY

RRS Analysis

Runner Repeaters and Stranger Analysis is a tool for identifying which tasks in a process should have effort dedicated to their improvement.

Runners: These are products or services or families of products or services that are made in sufficient volumes to economically justify having facilities and resources dedicated solely to making them. The facilities and resources are used for no other activity.

Repeaters: A product or service or a family of products or services that are made often, but do not have enough volume to justify dedicating facilities and resources exclusively to just them.

Strangers: These are products or services that are done rarely, sporadically, or in low volumes.

As shown in figure M&M 3036 is the runner, PTL 3036 and M&M 4044 are repeater and M&M 3020 is strangers.

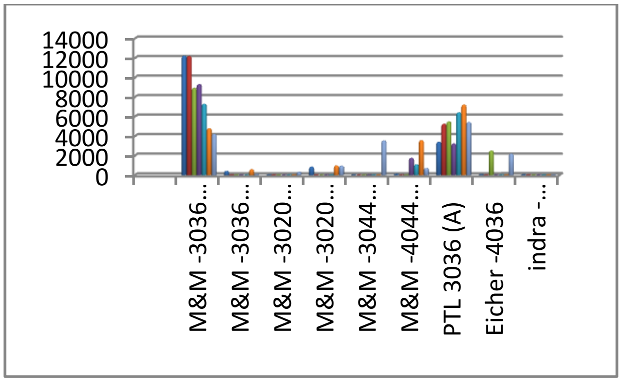

Fig. 1: Outcome of RRS analysis

Data collection

Based on the results of RRS analysis, M&M 3036 pump was selected for the study the data required are collected as follows.

- Going onsite and understanding the work environment, factory layout, and process involved in the hydraulics manufacturing.
- Collecting relevant data through interviewing staff and other internal sources.
- Real time collection of data. Analysis of data using statistical techniques.

Gear section

The data collected from each of the machines in the gear section are as shown in the table 1.

Table 1: Machine details in gear section

M/C	Avg. time/ shift, min	No. of pieces/ Shift	Cycle time /min	Processing time/ piece/ m/c, min	Energy consumed, kWh	Status of machine at lunch time
Grinding x 2 pairs	420	600	1.25	1.4	90	Coolant flow is ON, hydraulics is OFF
Deburring	420	550	1.17	1.5	9.5	switched OFF
Super finishing	420	550	0.83	0.83	28.5	ON with zero load
Washing	420	500-550	0.22	0.22	28.5	ON with zero load

Housing section

The data collected from each of the machines in the housing section are as shown in the table 2.

Table 2: Machine details in housing section

M/c	Avg. time/ shift, min	No. of piece/ shift	Cycle time/ min	Processing time/ piece/ m/c, min	Energy consumed, kWh	Status of machine at lunch time
Size milling	420	500-550	0.66	0.66	28.5	power and hand mode ON, hydraulics OFF
VMM machine	420	100-110	3.75	3.75	33.25	warm up cycle
Manual deburring	420	350-400				
Washing	420	350-400	1.83	1.83	28.5	ON with zero load
Numbering	420	350-400	0.26	0.26	0.1	switched off

Details of Energy Guzzlers

The machines which consume most of the energy in a production line are called energy guzzlers. In Hydraulic manufacturing firm, the machines which have an energy consumption of 25kW or more are referred as "energy guzzlers". The necessary details of the energy guzzlers like operations, components, shifts per day, process time, cycle time, lot size, etc have been summarized in table 5.4. This was carried out in order to analyze the working and studying the energy consumption pattern of the energy guzzlers.

Table 4: Details of energy guzzlers

GEAR GRINDING	Operation	Grinding
	Components	M&M 3036
	No. Of Types	1
	Shift/Day	3
	Process Time	2.8 m/unit
	Cycle Time	2.5 m/unit
	Process Lead time	45 s/unit
GEAR SUPER FINISHING	Operation	Super Finishing
	Components	M&M 3036
	No. Of Types	1
	Shift/Day	3

	Process Time	1.23 m/unit
	Cycle Time	1.23 m/unit
	Process Lead Time	56 s/unit
GEAR WASHING	Operation	Washing
	Components	M&M 3036
	No. Of Types	1
	Shift/Day	3
	Process Time	0.22 m/unit
	Cycle Time	0.22 m/unit
	Process Lead Time	22 s/unit
HOUSING	Operation	Vertical milling
	Components	M&M 3036
	No. Of Types	1
	Shift/Day	3
	Process Time	3.75 m/unit
	Cycle Time	3.75 m/unit
	Process Lead Time	45 s/unit
WASHING	Operation	Washing
	Components	M&M 3036
	No. Of Types	1
	Shift/Day	3
	Process Time	1.83m/unit
	Cycle Time	1.83 m/unit
	Process Lead Time	90 s/unit
FUNCTIONAL TESTING	Operation	Testing
	Components	M&M 3036
	No. Of Types	1
	Shift/Day	3
	Process Time	3 m/unit
	Cycle Time	4 m/unit
	Process Lead Time	50 s/unit

Energy value stream map for M&M 3036 indicating the current state and energy guzzlers

Figure 4 depicts the current value stream and energy guzzlers of the production line. It signifies the various operations performed in the company. The details of the processes and the energy consumptions for various stages also shown in the figure.

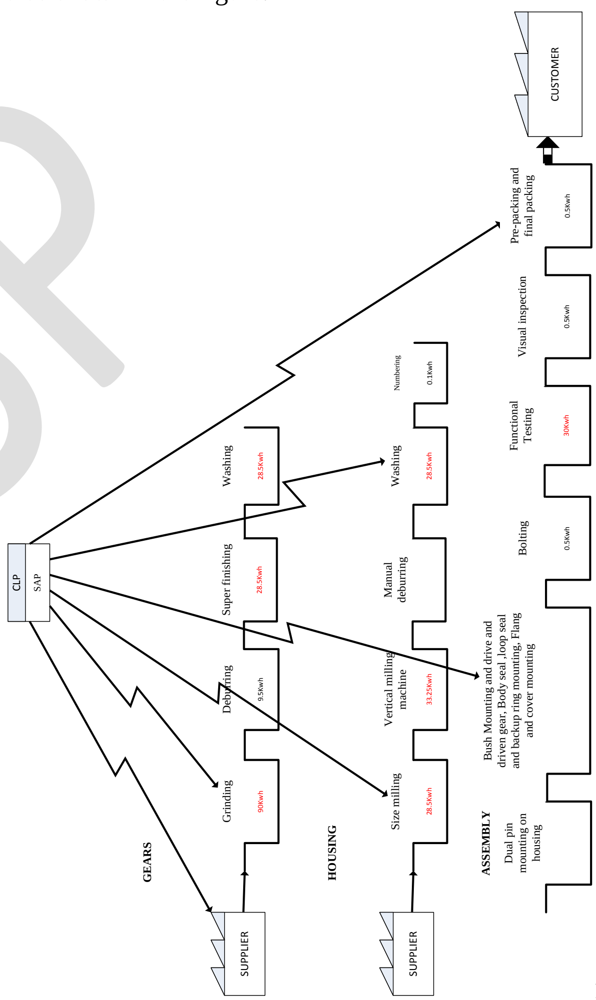

Fig. 5: Energy value stream map for Pump M&M 3036 indicating the energy guzzlers

III. ANALYSIS

After data collection of the charts, tables, etc, the following analysis is carried out to improve productivity and to reduce the unnecessary energy consumption currently present in the production line. Brief calculations have also been shown to compare the current energy consumption and the proposed energy consumption to find out the percentage savings and are shown in terms of money per piece also.

Gears Washing and Housing Washing

Figure 7 describe the Kaizen burst, which shows the area for improvement in washing process. It is observed by the analysis that components are cleaned in a batch of greater than equal to 100. Thus, the other machines in production line have to produce that many parts before it can go for cleaning. Therefore, the machine is idle for a long time till the parts are produced of that quantity.

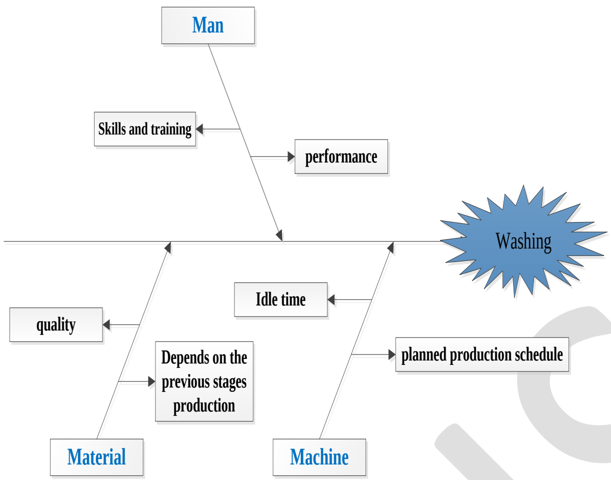

Fig 7: Kaizen burst for Washing

It is observed that the machine is generally idle for 1-2 hours out of working 6 hours per shift. So it is suggested to have a planned production schedule where they can produce all the parts in bulk quantity and store while the Ultrasonic washing machine can be switched off for like one shift and turn it on in next shift to clean all those parts in one go. Thus, it will lead to increase machine efficiency and productivity as well as a huge savings in energy of up to 300-350 kW.

Functional Testing

Figure 8 describe the Kaizen burst, which shows the area for improvement in Functional Testing process. Based on analysis it is observed that machine carries out the operation of testing the functional parameters of the assembled pump. It takes around 4 minutes that can be reduced. The break up is that it takes 1 minute for actual testing and the rest 3 minutes in loading and unloading of the 2 pumps.

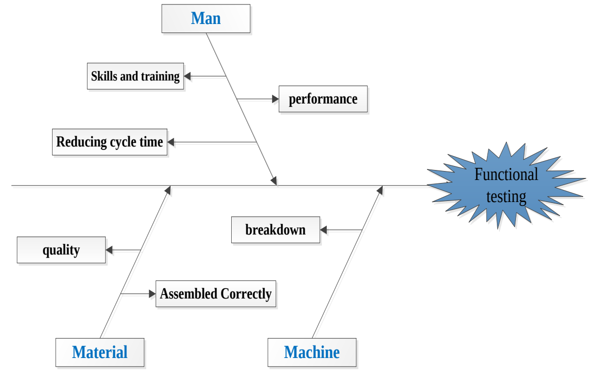

Fig. 8: Kaizen burst for Functional testing

There is a scope to reduce the cycle time because the operator takes the pump from basket or from the preceding machine and then loads into machine and unloads after the test is done. A considerate amount of reduction can be achieved in handling the pumps of up to 60 seconds. It machines around 150 parts a shift and can test 2 parts at a time. So it requires 300 minutes to machine in present scenario. But if they reduce the cycle time by 1 minute, it can helps to save around 100 minutes of machine idle time that leads to energy savings of up to 45 kW per shift.

Size Milling and Vertical Milling Machining

Figure 9 describe the Kaizen burst, which shows the area for improvement in Size Milling and Vertical Milling process. Based on analysis it is observed that in this machines, parts go one after the other for milling and gauging. Loading and unloading of parts are continuous hence we suggest that the operator must stay in the workstation throughout the shift and only move out if it's really necessary like change of tool bit, etc. This is suggested because if the operator goes off somewhere then the machining of already loaded parts stop as a new part has not been loaded and machined part has not been unloaded. Thus, it leads to machine getting idle for a while.

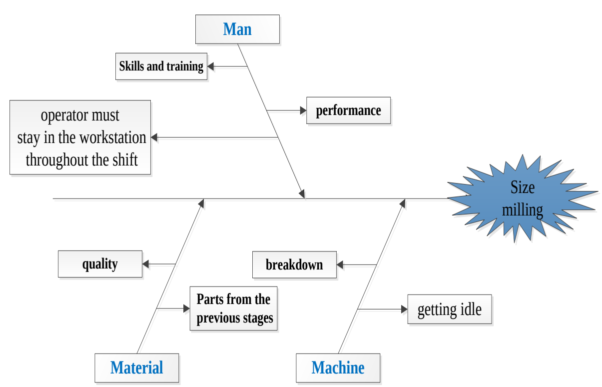

Fig. 9: Kaizen burst for Size milling and Vertical Milling Machining.

Grinding and Super Finishing

Figure 10 describe the Kaizen burst, which shows the area for improvement in Grinding and Super Finishing process. It is observed that after analyzing the data, it is observed that the coolant motor runs continuously throughout the shift. So, we suggest the same reason for Super Finishing machine as it is observed that the coolant keeps flowing continuously even when the machine is not operating

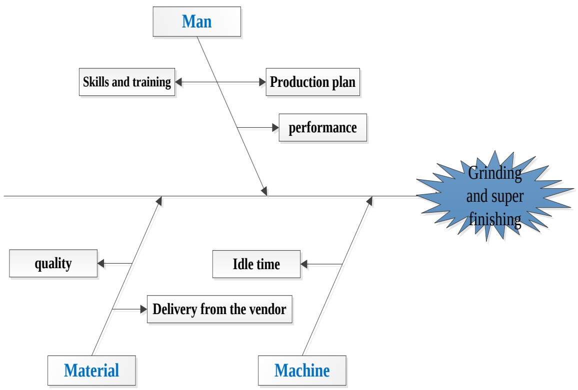

Fig. 10: Kaizen burst for grinding and super finishing.

The other thing found is that they can improve the worker performance where actually great scope to reduce it if they could use the handling of gears in better way. The present practice is that the machining of part takes around 60s. Once, it is done, the operator takes the machined part, inspects and keeps aside if its proper and places the part to be machined after the inspection is over. So, we suggest that the operator can put the part to be machined first as soon as the machining of the previous part is over. He can remove the machined part and fix the fresh part in machine and start the machining process. While, that part is machining, he can inspect during that time which will lead to reduction of cycle time by 5-10s. Here also, they machine around 150 parts a shift thus will lead to savings of energy for about 40 minutes where they can switch it off 40 minutes before the shift gets over. This will help to save energy by 29kW per shift. For grinding this will help to save energy by 17kW per shift.

Energy value stream mapping with kaizen burst and suggestions

Figure 11 show energy value stream map with additional suggestions at different stages of production, and the it helps to find out the area were continuous improvement can be made.

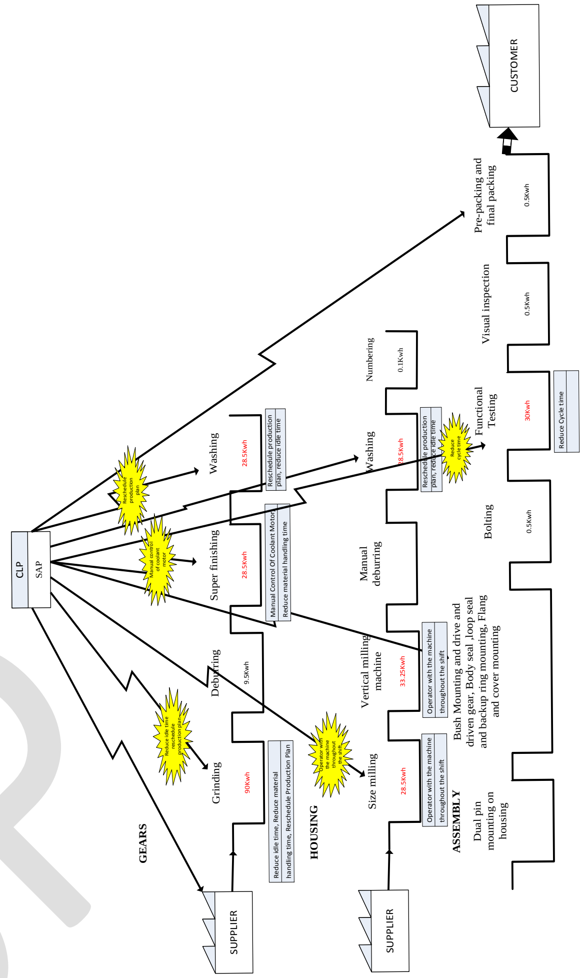

Fig. 11: Future State Energy Value Stream Map for M&M 3036 with kaizen burst and suggestion.

IV. CALCULATIONS

Based on the analysis made the energy saved in turns of the energy cost is calculated as follows.

Production Data for the month of Jan

Particulars	Value
Total production volume	7286
Total energy consumption, kW	51612
Rate of one energy unit, Rs/kW	5.35

Present Value of Energy Consumption In Terms Of Money per Pump

Calculations for energy consumption in terms of money per pump

= (51612*5.35)/7286

= Rs 37.89

Calculations for energy savings

Total savings can be achieved in energy based on analysis = 28.5kWh * 2.5 hr(Washing) + 17(Grinding) + 29(super finishing) + 45 (Functional testing) per shift

= 162.5 *3(3shift per day)

= 486.75 per day

= 12,168.75 per month

Total Savings in energy consumption = 51612 – 12168.75

= 39,443.25 kWh

Percentage savings in energy = (12168.75/51612) * 100

= 23.57%

Thus, Savings in terms of money per month = 12168.75 * 5.35(Unit Price)

= Rs 65,102.81

Proposed value of Energy consumption in terms of Money per pump

Calculations for energy consumption in terms of money per pump

Total production volume for a month = 7286

Total energy consumption for the production after saving = 39,443.25

Thus, energy cost consumption in terms of money per pump= (39,443.25*5.35)/7286

= Rs 28.96

Thus, a saving of Rs8.93 can be achieved per pump. If the nominal production of pumps in a month is 7286, the money saved due to the reduction in energy consumption works out to Rs 65,103.81.

6.7 Carbon footprint framework

It is the framework for issues that should be taken into account when calculating the carbon footprint of manufacturing firm. Like PAS 2050, it is based on the life cycle approach. The framework looks at direct and indirect emissions, carbon sequestration in the firm and in products, the value of bio-energy and the concept of avoided emissions. It is based on ten key elements, which are called the Ten Toes of the carbon footprint. However, the framework allows individual companies to make different choices and does not provide guidance on methodological problems such as how to calculate carbon sequestered in company. The framework is based on the Ten Toes and provides information on calculation methodologies and data sources that can be applied when calculating carbon footprint for manufacturing firm.

6.7.1 Ten Toes of the carbon footprint

- **Carbon sequestration in company** sustainable company management secures the stocks of carbon in company so that they remain neutral or even improve in time.
- **Carbon in company products** a product contains biomass carbon and as long as it is in use, it will keep this biomass carbon from the atmosphere.
- **Greenhouse gas emissions from company product manufacturing facilities** generated from fossil fuel combustion at manufacturing facilities that produce company products, including primary manufacturers and final manufacturing facilities.
- **Greenhouse gas emissions associated with producing components** for virgin components, this includes company management and harvesting, and for recovered components, it includes the collection, sorting and processing of recovered elements before it enters the recycling process.
- **Greenhouse gas emissions associated with producing other raw materials/ fuels** generated during the manufacturing of fuels and non-wood based raw materials (e.g. chemicals and additives) used in manufacturing company products and also direct emissions and emissions associated with electricity purchased to manufacture these raw materials.
- **Greenhouse gas emissions associated with purchased electricity, steam, heat and hot and cold water** emissions associated with purchased electricity, steam and heat used at facilities that manufacture company products. This includes electricity for pollution control equipment used to treat manufacturing-derived wastes and emissions.
- **Transport-related greenhouse gas emissions** greenhouse gas emissions associated with transporting raw materials and products along the value chain. These include emissions from transportation, other raw materials, intermediate products, final products and used products.
- **Emissions associated with product use** emissions that occur when a product is used. It is very uncommon for products to create such emissions. This is a key asset of products comparison.
- **Emissions associated with product end-of-life** – emissions that occur after a product is used. They consist primarily of CH_4 resulting from decomposition or reuse products in landfills.
- **Avoided emissions and offsets** emissions that do not occur (i.e. are avoided) because of an attribute

of the product or an activity of the company making the product.

Currently, Toes 2–8 are included when calculating the carbon footprint of a product for business-to-business purposes (i.e. from cradle to gate) according to PAS 2050. Toe 1 is currently excluded according to PAS and due to a lack of methods. Toe 9 will be included in cases whose scope extends from cradle to grave. Toe 10 is partly taken into account. According to PAS, offsetting is excluded. Offsetting means compensating GHG emissions by e.g. investing in projects that reduce the GHG emissions elsewhere. Offsetting can include e.g. investments in bio based energy projects as shown in Figure 12.

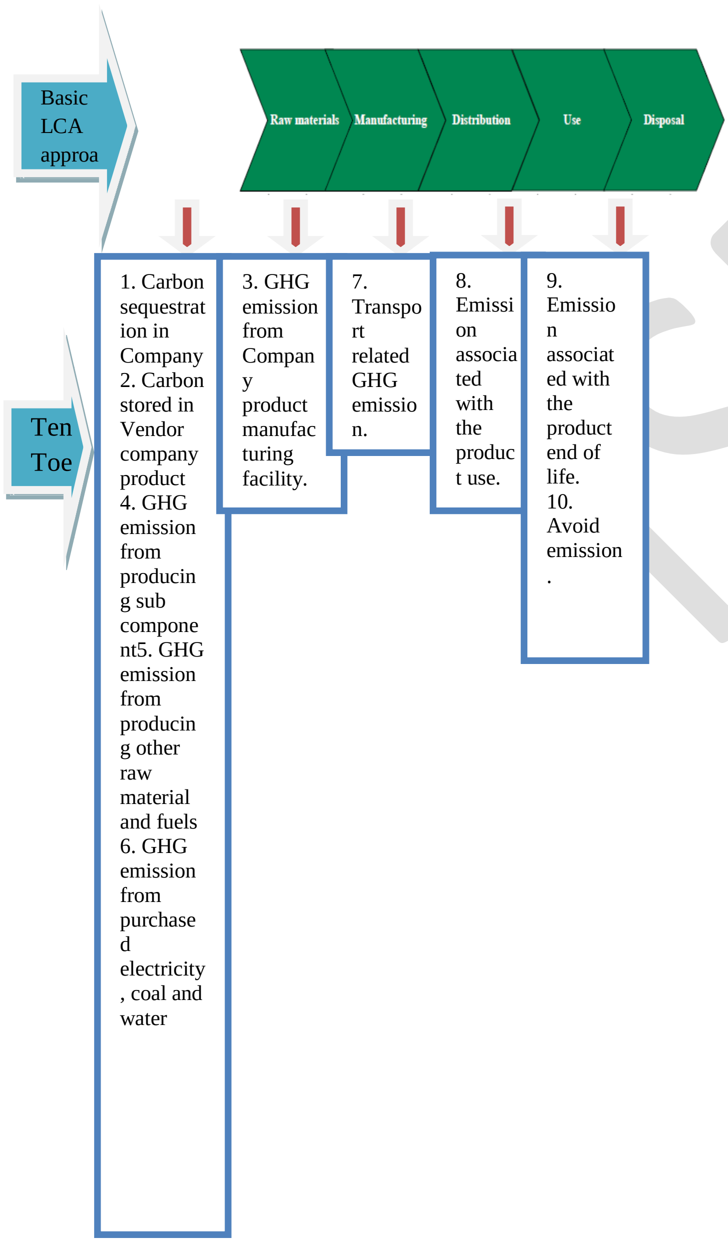

Fig. 12: Framework for carbon footprint

CONCLUSION

The project carried out at Hydraulic manufacturing firm, has been forwarded to the higher management in the form of a report for consideration. Once examined by team, it will be implemented on the production line of M&M 3036 Pump. By comparing the outcomes achieved with the objectives set at the beginning of the project, we can conclude that the non value added activities has been reduced. The company reduces the price of energy consumed for one unit from Rs37.89 to Rs28.96. Thus a saving of **Rs 8.93** can is achieved per pump. This would help the company achieve 23.57%of saving in energy by which the company could save Rs 65,102.81 per month in terms of money.

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