INCORPORATING SUSTAINABLE CONCEPTS FOR PRODUCT DESIGN, DEVELOPMENT AND MANUFACTURING

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Abstract

In the general product design and development process, only the increment of economical benefits has been considered but the effectiveness on the environment or society has not been considered. The responsibility of the manufacture should be focused on a successful product design and development process in order to avoid or minimize harmful or bad ecological, social, and economical effects. Past researches such as Re-considering product design: a practical "road-map" for integration of sustainability issues, Design for sustainability a step by step (Sissel A. Waage, 2006) approach, gives pathways for designers and business decision makers and presents the effectiveness of the world production with the key elements of sustainability. However, these sustainable concepts have not been considered at the right stages of the product design and development process in order to increase the overall sustainability of any manufacturing firm while increasing financial benefits. In order to bridge the gap, this research focuses on incorporating all applicable sustainability concepts at each phase of the product design and development process and other relevant sub functions of manufacturing planning and control namely process planning, facility location, plant layout design etc. The relevant sustainability impacts were identified at each of these stages initially. Later a flow chart was developed for the whole process. Two folded approach was used for validation of the proposed methodology. First, selected household consumer products were manufactured at the faculty workshops to observe adapted sustainability methodology and compared with the existing products in the market. Later several manufacturing industries were selected to study the current product design and development processes and manufacturing processes (Life cycle of the products) and data were collected by conducting a field survey. SimaPro software was used to analyse quantitative effects of the process along with proposed methodology to analyse qualitative information. The worst phase of product lifecycle was identified by eco indicator 99 of SimaPro. It was found that eco indicator 99 of SimaPro only highlights environmental impacts at macro scale and proposed methodology highlights environmental impacts at micro and macro levels and two other bottom lines of sustainability: social and economical aspects. Furthermore, it can be found that all industries considered for this research are at the zero level of sustainability in manufacturing.

Keywords: Design for Sustainability, Product design and development, Manufacturing, Product life cycle

INTRODUCTION

Sustainability is one of the most common areas discuss in many domains. This acts as replacement to environmental degradation which was used in the past. The word sustainability even linked with development and currently that is called as sustainable development which mainly based on triple bottom line of social, environmental and economical aspects than linking economical benefits with the development. The splendour of sustainability is that it not only looks at the economical impacts but considers the environmental and social impacts along with it. On the other hand, every day many new products or the modified versions of the existing products come in to market. These products ultimately lead to economical, social and environmental impacts to the world when consider them as a whole. However, the idea of new product starts in Product Design and Development (PD&D) phase. During this phase, many aspects are taken in to account to come up with a competitive product. Mainly economical impacts and benefits are considered as paramount factors currently. A segment of society concerns about these issues when making choices/decisions due to popularization of sustainability and green concepts. Therefore, incorporating sustainability concepts in PD&D is need of hour, not only by concerning consumer preferences but due to the various global issues such as climate change, environmental pollution, disasters and natural resource depletion etc. since many of the reasons link with PD&D somehow or another. For example, material select for the packaging of consumer products finally creates an environmental pollution or energy efficiency of a consumer product during the user phase leads to climate change.

Already there is a concept called Design for Sustainability (D4S) which up to certain percentage accommodate sustainability concepts in PD&D. However, it is evident from the previous examples that, it is essential to consider whole Life Cycle (LC) of the product during the PD&D phase to eradicate or to minimize social and environmental impacts of a product. Therefore, the main purpose of this research is to design and develop a methodology to incorporate sustainability concepts in PD&D phase by considering the entire LC of the product.

There is some similar kind of researches in this domain in the recent past. Sissel and Waage (2006), M.R.M. Crul and J.C. Diehl (2007) gives pathways for designers and business decision makers and present the effectiveness of the world production with the key elements of sustainability. Jayal et.al., (2010) presents four influencing factors in the product life cycle stages under three sustainability components (Environmental, Economical and social). Though some suggestions such as rating systems have been prepared to increase the sustainability while designing building environments, it is very rear to find any suggestions to increase the sustainability for the product design and development stages. Therefore, this research addresses the issue of presenting a detailed guideline to incorporate sustainability concepts in PD&D phase by considering the LC of the product. Rest of the paper is organized as follows; section 2 presents the methodology or the proposed guideline which encompasses the sustainability concepts in PD&D. This is followed by a case study to test and validate the proposed methodology. This is followed by the discussion and the conclusion remarks including future directions.

METHODOLOGY

The proposed methodology is designed and developed by considering the traditional PD&D process. PD&D consists of number of stages. In the proposed approach, at each stage of PD&D phases are extensively investigated and identified potential sustainability approaches. After that a new flow path for sustainable product design & development was prepared. Figure 1 shows the identified areas at each stage of PD&D. At each of phases, detailed sustainability options are further investigated. Similarly in the process design phase relevant sustainability options are identified at each stage of the process design and they are arranged into a flow chart based on the conditions to be satisfied at each stage. This is shown in Figure 2. In the second phase, key sustainability issues with respect to triple bottom lines are identified and assign numerical values based on severity with respect to sustainability of the issue. If severity is high, higher value is assigned. If there is no severity at all, zero is assigned. There are 6 main indicators in the economical aspects and 9 indicators for social aspects while 8 indicators are identified in environmental aspects. Since phase 1 and 2 do not cover the sustainability impacts during the initial stages of product such as raw material extraction, processing, storage and transportation etc. and usage and disposal stages, it is very difficult to justify sustainability aspects of the life cycle of the product. Therefore, in 3rd phase, LCA analysis is performed with the assistants from SimaPro® software for the two products considered in the case study.

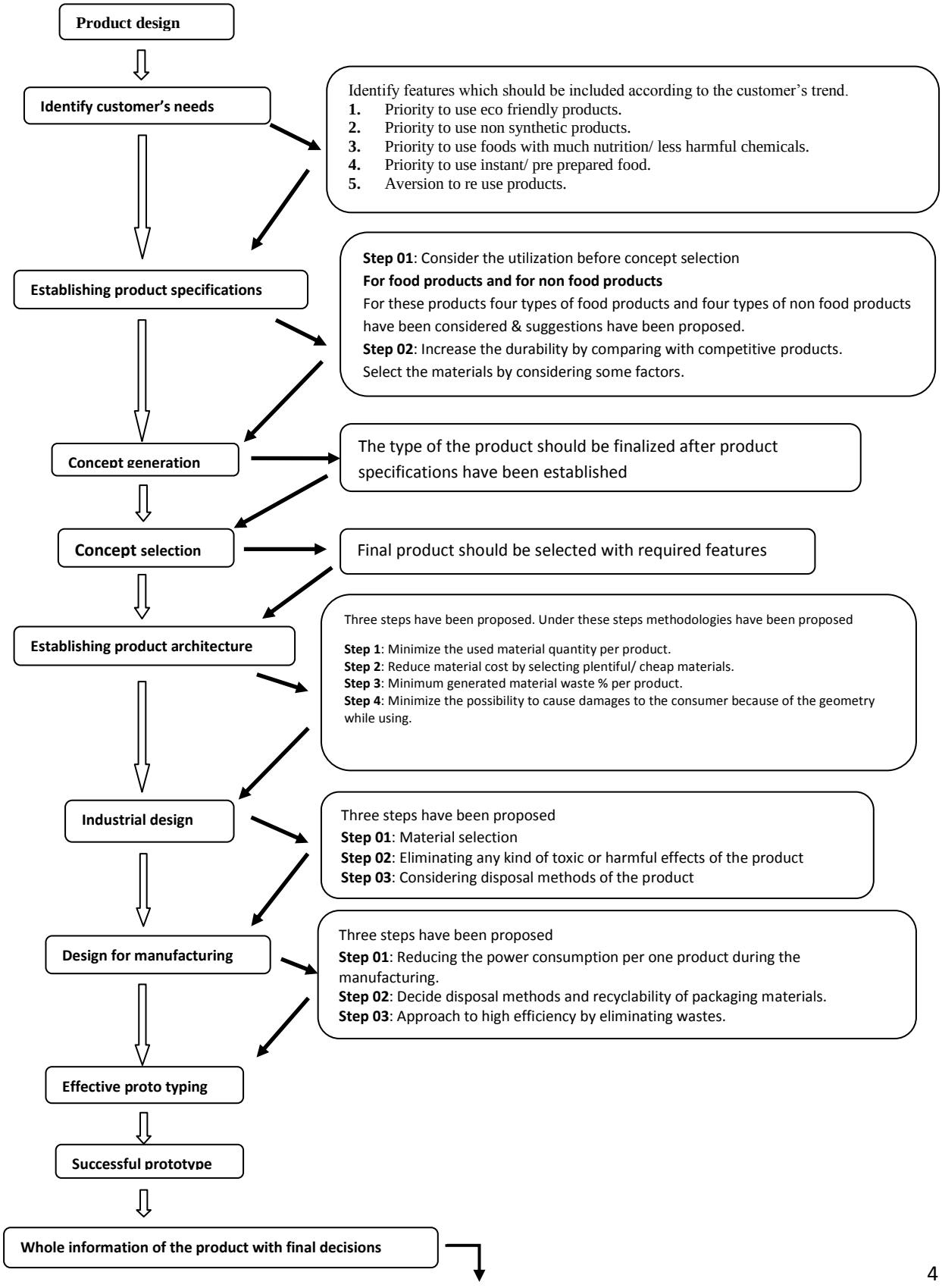
Product design
Identify customer's needs
Identify features which should be included according to the customer's trend.
1. Priority to use eco friendly products.
2. Priority to use non synthetic products.
3. Priority to use foods with much nutrition/ less harmful chemicals.
4. Priority to use instant/ pre prepared food.
5. Aversion to re use products.
Establishing product specifications
Step 01: Consider the utilization before concept selection
For food products and for non food products
For these products four types of food products and four types of non food products have been considered & suggestions have been proposed.
Step 02: Increase the durability by comparing with competitive products.
Select the materials by considering some factors.
Concept generation
The type of the product should be finalized after product specifications have been established
Concept selection
Final product should be selected with required features
Establishing product architecture
Three steps have been proposed. Under these steps methodologies have been proposed
Step 1: Minimize the used material quantity per product.
Step 2: Reduce material cost by selecting plentiful/ cheap materials.
Step 3: Minimum generated material waste % per product.
Step 4: Minimize the possibility to cause damages to the consumer because of the geometry while using.
Industrial design
Three steps have been proposed
Step 01: Material selection
Step 02: Eliminating any kind of toxic or harmful effects of the product
Step 03: Considering disposal methods of the product
Design for manufacturing
Three steps have been proposed
Step 01: Reducing the power consumption per one product during the manufacturing.
Step 02: Decide disposal methods and recyclability of packaging materials.
Step 03: Approach to high efficiency by eliminating wastes.
Effective proto typing
Successful prototype
Whole information of the product with final decisions

Figure 1: Sustainable product design and development flow chart

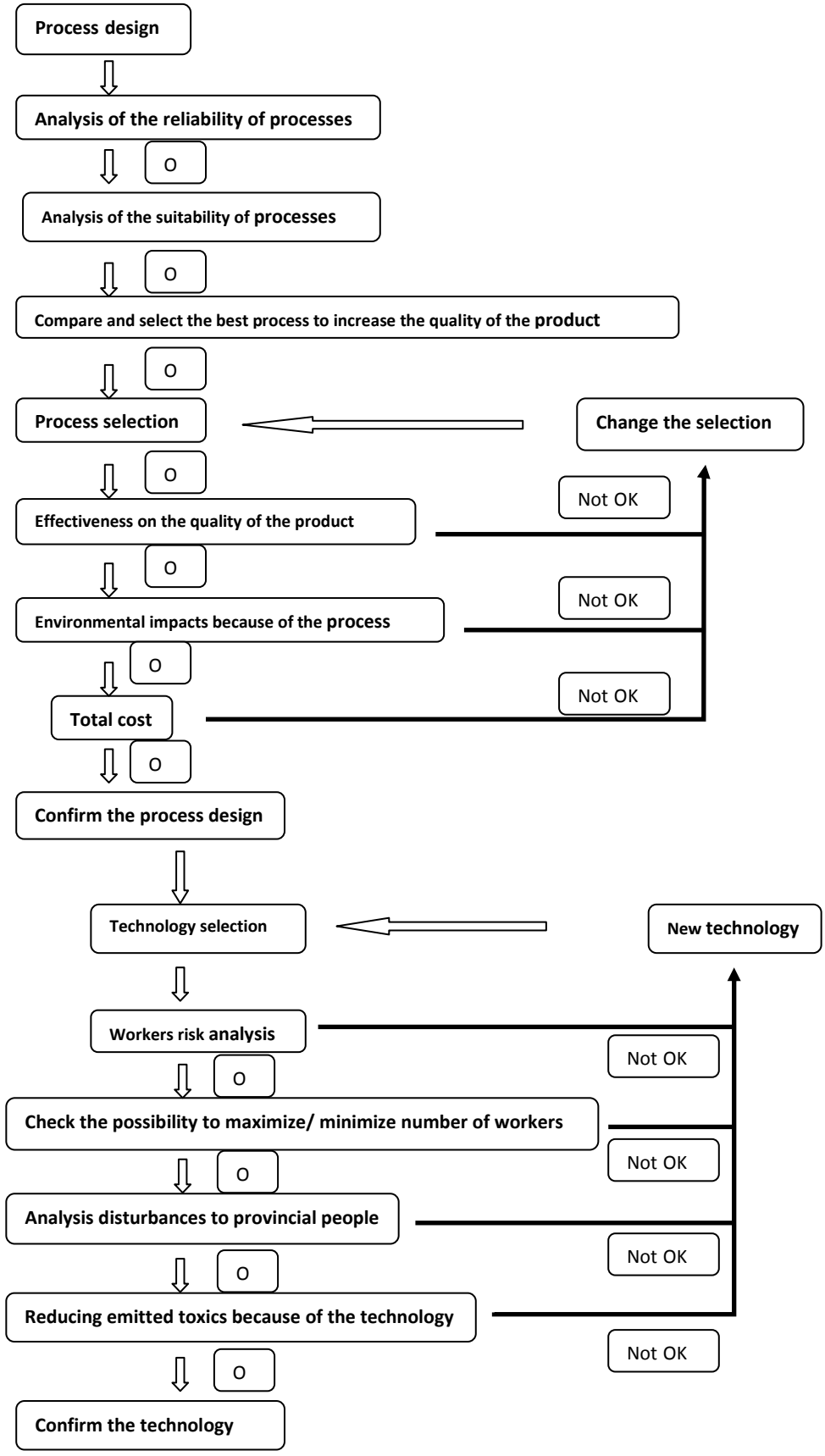

Figure 2: Sustainable Process design to incorporate with product designing and developing

From three bottom lines in sustainability any manufacturing organization considers economical bottom-line as the most significant one, since without economical stability any business could not sustain. However, here these benefits are considered by considering the economical benefits delivered to a country than individually to a company. Same manner, social and environmental aspects also considered.

Table 1: Triple bottom line sustainability indicators

No.	Economical Indicators	Condition	Points
1	Ownership of the industry.	Government or Semi government / Local ownership / Multinational or foreign	0 / 1 / 3
2	Types of employees.	Workers are foreign (Excessive volume) / Local workers (Excessive volume) with less salary / Local workers & salary is enough as the level of country	3 / 1 / 0
3	No of employees (If local).	(Num > 1000) / (1000 > Num >500) / (500 > Num >50) / (50> Num)	0 / 1 / 2 / 3
4	Type of the market.	Foreign & local / Foreign only / Local	0 / 1 / 2
5	Amount of natural resource depletion only for exporting products.	Import semi finished products &export after finishing	0
		Import row materials & export finished products with less natural resource & energy consumption.	1
		Not rare row materials/ resources from locally & export finished products.	2
		Rare local row materials (Limited amount) & exporting finished products.	3
		Not rare row material exporting for productions (*)	4
		Rare row materials exporting for productions (*)	5
6	Amount of annual profit.	Profit is enough to develop the existing process / Profit is enough to carry on the existing process / Not profitable	0 / 1 / 3
No.	**Social Indicators**	**Condition**	**Points**
1	Utility of the product	Very essential product for day today life. Available solutions are rare/ Used to produce other products in industries / Necessary but there are some another options / Useful but not essential / People buy because the availability in the market	0 / 1 / 2 / 3
2	Effectiveness to the health	Not effects to the human body / If a food product, there is useful nutrition / There would be some problems & exactly don't know about effects / If a food product not much nutrition / If the product is a food product it will cause health care problems / Definitely cause illnesses directly because of the product	0 / 0 / 1 / 1 / 3 / 3
3	Types of employees	Workers are foreign. (Excessive volume) / Workers are local people. (Excessive volume) / If local, salary is very low / If local, salary is enough according to their struggle	3 / 1 / 1 / 0
4	No of employees (If local)	Num > 5000 / 5000 > Num >1000 / 1000 > Num >100 / 100> Num	0 / 1 / 2 / 3
5	Human rights	Child labours are used.	3

		Risky job without safety equipments.	3
		Risky job with safety equipments.	1
		There is no any risk.	0
		High risk for illnesses.	3
		Medium risk for illnesses & infirmities.	2
		Health care service is not available inside the industry.	3
		Essential facilities for standard working environments have not supplied.	3
		Collapse of families & relationships because of the busy occupation.	3
6	Land usage quantity	Small area has used (Less than 100 m2) / Medium amount of area has used (Less than 500 m2) / High amount of area has used(Less than 5000 m2) / Very high amount of area has used (Greater than 5000m2)	0 / 1 / 2 / 3
7	Disturbances because of the establishment	There are no effects to day to day lives of neighbours.	0
		Sound of the industry is a disturbance to neighbours / Ground water, water streams have polluted & people cannot use that water / People have turned away when the industry was established / People have to faced illnesses because of polluted emits / There are bad effect to occupations of provincial people	3
8	Workers satisfaction	Less satisfaction of the salary according to the economy / Easiness to female workers / Ability of utilization of disabled workers / Equality between different levels of workers inside the organization	3 / 0 / 0 / 0
9	Job security	All employees are permanent with a pension or welfare salary / Excessive numbers of employees are permanent with a pension or welfare salary / Excessive numbers of workers are not permanent but work with long time agreements / Excessive numbers of workers are casual and work for daily salary	0 / 1 / 2 / 3
No.	**Environmental Indicators**	**Condition**	**Points**
1	Power consumption.	The power resource is 100% natural/ renewable.	0
		>50% out of total power consumption is supplied by a natural/ renewable resource.	1
		Though the existing power resource is renewable, there is another renewable alternative power resource with low cost but up to now it has not used.	2
		There is no way to use natural power resources because of some practical conditions.	1
		Though there is a reasonable possibility to use renewable power resource, the used power resource is not natural or renewable.	5
		There is no way to use renewable power resources because of some practical conditions.	4

		The quantity of disposal waste of the power resource is high or there is a hygienic risk of disposal wastage of the power resource.	5
2	Toxicity (Gaseous)	Existing amount is greater than or equal to the CEA regulations / Existing amount is more than half of the recommended amount / Existing amount is less than the half of the recommended amount / Existing amount is very small compare with the limits / There are no any air pollutants	4 / 3 / 2 / 1 / 0
	Toxicity (Liquid)	Drinking & consumption of polluted water occurs hygiene problems to provincial people / Affects to occupations such as fishing, farming / Affects to trees & wild life	3
	Toxicity (Solid)	There are no secondary usage of this emitted solid / Emitted solid will not perish or will take longer time to perish / Solid toxic will reduce the fertility of the soil / Solid will cause hygiene problems such as increment of the population of mosquitoes, population of fly etc / Particles will damage to human body & will cause illnesses like cancers	3
3	Recyclability.	Whole the product can be recycled easily with low cost / Recycling cost is much higher but possible	0
		Some parts of the product can be recycled easily with low cost	1
		Though recycling is possible but here it is not happened / Recycling is not happened / The product can not be recycled	3
4	Durability (Raw materials are non renewable)	Product is durable comparatively / Comparatively product is not much durable / Product is not durable comparatively / Product is not much durable but after some parts are replaced it can be used again same as previous	0 / 2 / 3 / 1
		Part replacing can be done. No need to dispose whole the product / Easy to repairing and again the product can be used same as previous	0
	Durability (Raw materials are renewable)	Comparatively product is not durable & not plentiful row materials / Renewable raw materials but the much usage occur environmental hazardous like global warming etc	3
		Durable products but raw materials are not plentiful / Raw materials are not recurring within less than the product life time	2
	Durability (Raw materials for food products)	Undue percentage of products are get spoiled regularly / Time to arrive the product to the customer is longer / Always an excessive volume of products in the market or the waiting time at the market before it arrives to the customer is much longer	3
		Product can be kept longer period without getting spoiled, by using additional chemicals.	2
5	Wastage.	Waste material can not be used for a secondary purpose / Waste material is not recyclable & will not perish with the time / It is recyclable but it is not happening / Waste material will not perish or will take longer time to perish / Waste material causes hygiene problems such as increment of mosquitoes, fly etc.	3
		It can be used but here it is not happening.	2
		Waste materials will perish with the time. No recycling process / There is an extra space (a place) for waste material	1

		Waste material is used for a secondary purpose.	0
6	Utilization (Non food products)	Very essential product for day today life. Substitute products are rare/ Used to produce other products / Necessary but there are some another options / Useful but not essential / People buy because the availability in the market	0 / 1 / 2 / 3
	Utilization (Food products)	Provide primary food necessity / Pre prepared food items for additional nutrition / Pre prepared food items without much nutrition / Pre prepared food items without nutrition and cause health care problems	0 / 1 / 2 / 3
7	Resources depletion.	Not rare & renewable row materials are used / Renewable but amount of usage is high. Therefore availability is decreasing with short time period / Raw materials production occur damaging eco systems, erosion etc. / Rare & renewable row materials are used / Rare & non renewable row materials are used	0 / 1 / / 2 / 2 / 3
8	Disposal methods of products & packaging materials. (Packaging material of food products)	Packaging material is not perishing with time / Packaging material occur health problems / Packaging material is perishing with time / It is reusable or recyclable & always packaging materials are collecting to reuse or recycle	2 / 3 / 1 / 0
	Disposal methods of products & packaging materials. (Other products & packaging materials)	Packaging material is perishing with time, but not reusable / Packaging material is not perishing with time / It is reusable & always packaging materials are collected to reuse / Packaging material occur health problems / After the disposing product causes health problems	1 / 3 / 0 / 3 / 3

CASE STUDY

A case study was done to validate the methodology proposed in this paper. The case study consists of two main components. The first one was to investigate sustainability potential of products and processes. In the second component, LCA was done for the two selected products using SimaPro® software in order to identify environmental sustainability impacts of the whole LC of the products. SimaPro® is standard commercially available software used to analysis the LC of each product. It is one of the famous softwares which gives only quantitative effects of the production to the environment from the analysis. However, for a particular process the most critical sub stages cannot be highlighted using SimaPro® software. Therefore, it is important that to have any proper guidance for the PD&D process in order to increase the sustainability of any product.

Two different industries were considered in the case study. Initially, sustainability concepts adapted in the PD&D and Process design were investigated. Next, factors related to triple bottom lines in Sustainability were investigated in these industries based on the guideline designed in the methodology for the two industries. In the latter part, the two different products life cycles were analysed by the SimaPro software to highlight the overall impacts of the products life cycle on quantitative basis. Of the two industries currently none of them practised sustainability options in the PD&D and in the process design stages. However, it was noted that reasonable amount of aspects are being adapted without specifically considering as sustainability options in both industries. Table 2 shows the level of usage/adherence of each sub categories under the triple bottom line of sustainability.

Table 2: Sustainability of Industrial Products in two industries

Product	**: SA 10 Tea rolling machine**		**: : 13200 Ltr. Fuel Bowser Tank**	
Environmental sustainability				
Parameter	Condition	Points	Condition	Points
Power consumption.	Both diesel & Hydro electricity	1	Both Diesel & Hydro electricity.	1
Toxicity.	No.	0	Welding & gas cutting causes small amount of emitted gases. Silica sand is used to blasting. Amount is high.	0,3
Recyclability.	Metals are sold for recycling.	0	Recycling is not happened.	3
Durability.	Durability can be increased with repairs	0	Durability can be increased with repairs.	3
Wastage.	Metal parts are sold for recycling. But not the 100% amount of waste. Considerable percentage has not sold.	2	Waste metal parts are used to machine small metal shapes. An amount is sold. Silica sand is used one time. No secondary purpose.	2,3
Utilization.	Useful product to produce tea powder.	0	Useful to transport liquids.	0
Resources depletion.	Raw materials are (casted parts) imported.	0	Imported metal sheets are used.	0
Disposal methods of products & packaging materials.	Old parts are recycled. No packaging materials for local customers.	0	Secondary purposes like oil storing in small industries, Coconut oil, petroleum distributors, water storing. Considerable amount is not used. No packaging materials.	1
Economical sustainability				
Ownership of the industry.	Multinational	3	Local.	0
Types of employees.	Local. Salary is not enough.	1	Local. Not much low salary.	0
No of employees (If local).	>500	1	>500	1
Type of the market.	Both local & foreign.	0	Local.	3
Amount of natural resource depletion (only for exporting products.)	Less.	0	-	-
Amount of annual profit.	Profit is enough to carry on the existing process.	1	Profit is enough to develop the existing process.	0
Social sustainability				
Utility of the product	Useful product to produce tea powder.	0	Useful.	0
Effectiveness to the health	No.	0	Possibility to cause health problems while manufacturing process.	3
Types of employees	Local. Salary is not enough.	1	Local. Not much low salary.	0
No of employees (If local)	>500	1	< 500	1
Human rights	Accidents are possible. No safety equipments.	3	Risky jobs with safety equipments.	1
Land usage quantity	< 5000m^2	2	> 5000 m^2	2
Disturbances because of the establishment	Noisy.	3	Industrial area. Sound is not affected. Blasted sand particles are carried by the wing. Near to the water board.	3
Workers satisfaction	Less. Necessary facilities are not enough. Low salary.	3	Not much comfortable working environment. But facilities are enough.	0
Job security	Excessive numbers of workers are casual and work for daily salary.	3	Excessive numbers of workers are casual and work for daily salary.	3

When two different industries/ products are compared, bowser manufacturing has less level of sustainability concepts adaptation than the tea roller manufacturing. When triple bottom line wise considers, more sustainability related to environmental bottom line is given by the

tea roller while economics and social bottom lines wise, bowser manufacturing industry has shown better level of sustainability.

In impact assessment of the tea rolling machine characterization, damage assessment, normalization & weighing to the environmental sustainability has presented as figures. Using the eco indicator 99 the percentage of effectiveness to climate change, eco toxicity, radiation land use fossil fuels etc have shown. As the output of the analysis using SimaPro® not only the impact assessment but also other information were presented. Those are Characterization, Damage assessment, Normalization, Single score and Weighing of both tea rolling machine and the bowser. Figure 3, Figure 4 and Figure 5 show the weighing of each processes and network diagrams of both processes.

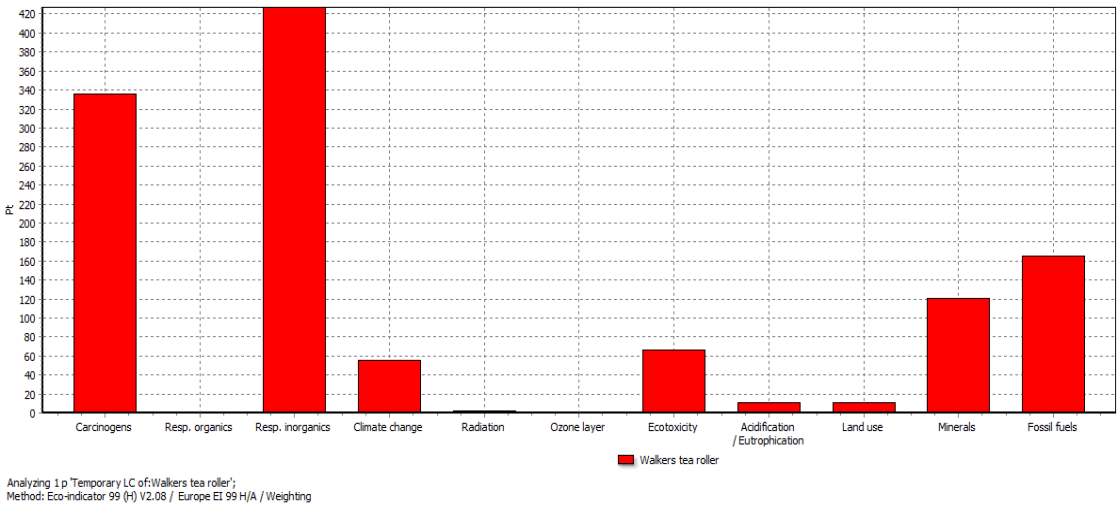

Figure 3: Weighing of the tea roller

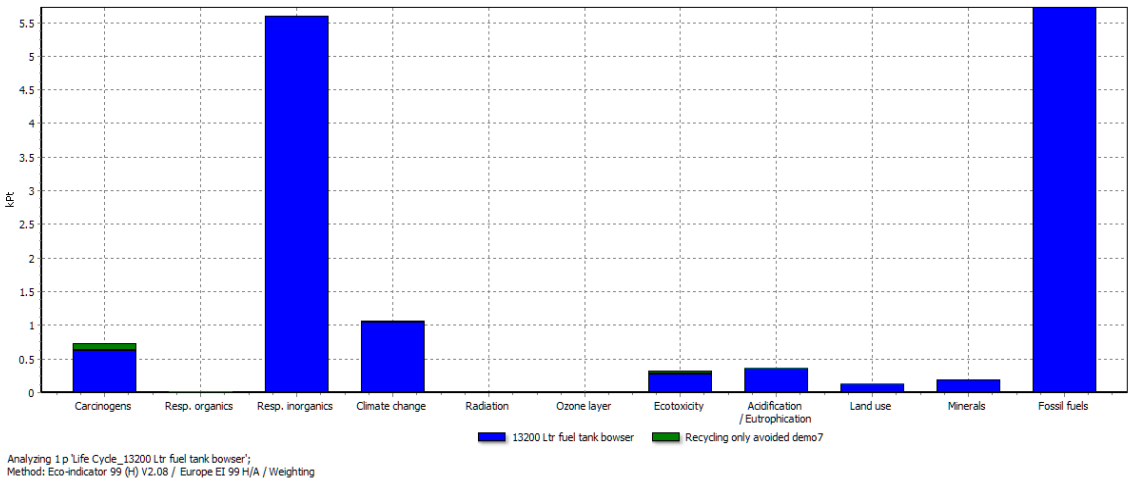

Figure 4: Weighing of the Bowser

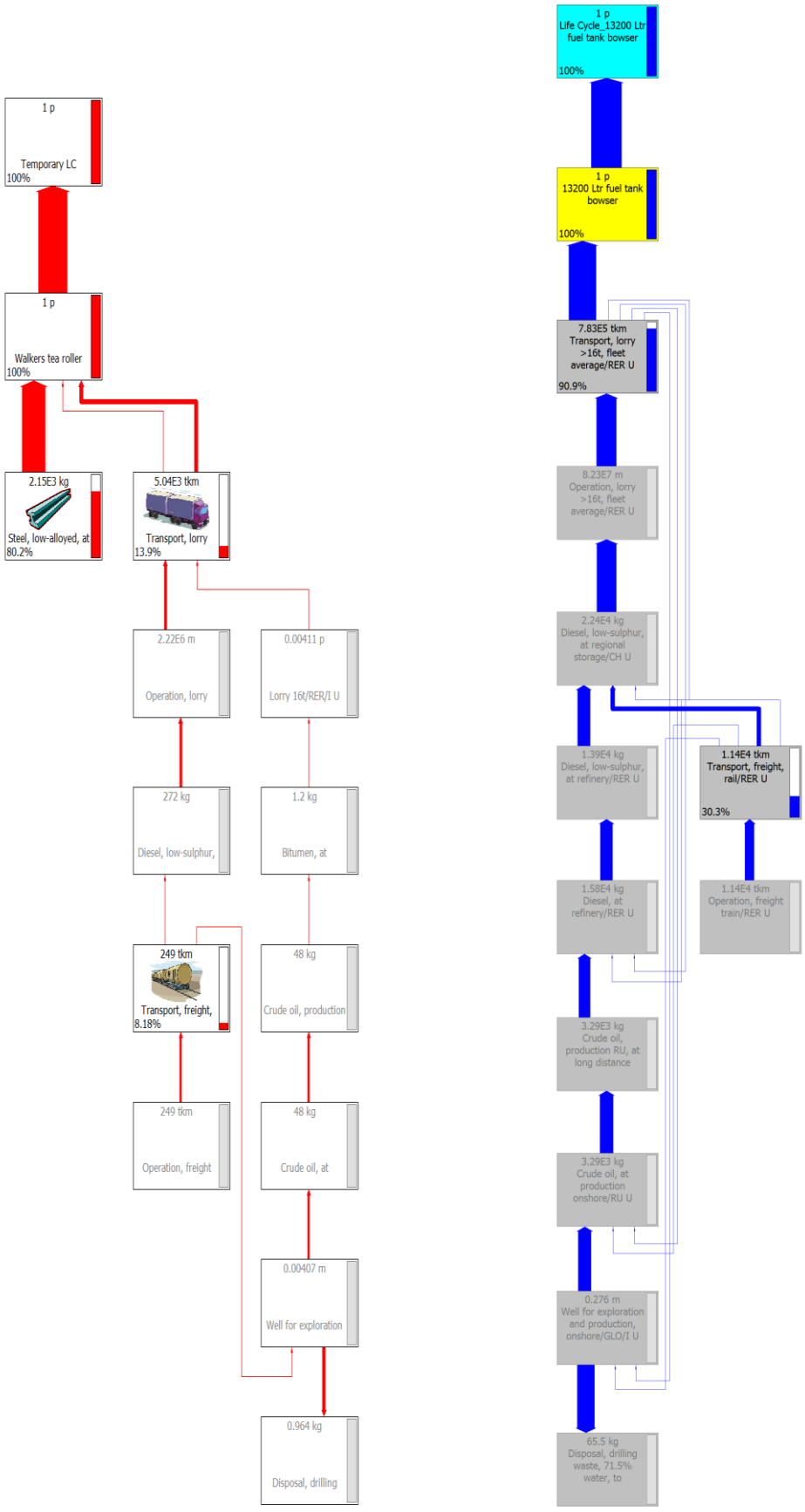

Figure 5: Network diagram of the tea roller and bowser respectively

It is obvious that the existing product design and development process is majorly based on the profits. However, if it is compared with the sustainable product design and development process, there are number of ways which can be used to increase the profit while considering the impacts on people as well as on the planet to a great extent.

When identifying customers' needs five features which should be considered has been mentioned. Before concept generation, two steps should be followed and for the establishing product architecture three steps has been proposed. Further, three steps for the "Industrial designing stage", three stages for the "Designing for manufacturing stage" have been proposed. It is important to follow the correct sequence of these steps. Also there are significant impacts to increase the sustainability of two industrial products by proposed improvements for those industries.

CONCLUSION

The major output through this research can be described as the sustainable product design and development process. How sustainable concepts can be adopted with stages of the product design and development process has been highlighted. Because of that, the product designer is guided in all stages in order to avoid the selection of any harmful, not suitable or unethical concepts. Furthermore, each factor of the product related to design and manufacturing is adjusted to an acceptable level. For different stages, number of steps has been proposed, in order to achieve required goals. Following the correct sequence of the sustainable PD&D process for specially mentioned stages is another important factor to achieve to the ultimate goal. However sustainable factors can be used to identify weaknesses of existing product design and development process of any product also.

For the process design, there are number of stages and factors have been mentioned in order to achieve to the best design. When analysing the reliability of the process four steps, when analysing the suitability another four conditions, seven factors for identifying environmental impacts because of the process, two steps for total cost analysing should have been considered and followed.

Not only in process design but also in technology selection, there are sub steps which should be considered in correct sequence as well as important factors. For workers risk analysis six factors, for Checking the possibility to maximize/ minimize number of workers two options, for Analysing disturbances to provincial people five factors, for reducing emitted toxics because of the technology three steps and additional suggestions have been proposed. In future, the sustainability aspects will be investigated in diversified local manufacturing industries in order to identify what issues hinders practicing the proposed concepts and to co relates scale of economies of those industries.

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