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Forward and Reverse Sustainable Supply Chain: A Case Study in Plastic Industry

KEYWORDS: Plastic recycling; LCA; SSCM; Case study

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ABSTRACT *Over last decade sustainability has become the most important criteria for any firm in any field to approach the government and public in best way. Now a day's sustainability is also practiced in supply chain management in big sectors. But in case of the small scale industries they have not participated in the following issue properly. We consider the small scale plastic industry, which has employed both forward and reverse supply chain for our study. Here, we are going to find out the environmental exchange and cost involvement during the forward and reverse process through life cycle analysis (LCA). A model for recycling plastic and virgin plastic were proposed. In the virtue of findings, we made a preliminary comparison on both forward and reverse supply chain of the plastic industry to make a clear view on their difference in environmental concern and cost concern.*

1. Introduction

1.1 Back Ground of the Study:-

Plastic plays a vital role in modern life with a concern of environmental, social and economical dimensions of sustainability. Plastic is very light and flexible with the ease of handling to make an application on packaging, building, industrial, electronic and electrical products. The main reason for this remarkable increase is replacing of plastics with other materials which make more cost and environmental impacts than plastics. If we use paper instead of plastic, it makes large environmental impacts due to cutting of trees for paper manufacturing results in loss of carbon dioxide absorption (Science world, 2008). Due to the recognizing importance of plastics there has been lot of efforts in research and development in the field of plastics. In this paper we are going to investigate the forward and reverse sustainable supply chain of the plastic industry by Life Cycle Analysis (LCA). "Life cycle assessment is a methodological framework for quantifying and analyzing environmental impacts attributable to the life cycle of products, services and, more rarely, processes" which is defined by (Leslie Jacquemin et al, 2011) .If we go further echelon with SSCM from the existing review "The interaction between sustainability and supply chains is the critical next step from recent examination of operations and the environment (Corbett and Kleindorfer, 2003) and operations and sustainability (Kleindorfer et al., 2005)" which is clearly discussed by Jonathan D. Linton et al (2007). "A sustainable supply chain is defined as one that is profitable and resource effective and that "meets the needs of the present without comprising the ability of future generations to meet their own needs" (WCED 1987)" which is referred by Cristiano Facanha (2005) .Also Stefan Seuring et al (2008) defined sustainable supply chain management as "the management of material and information flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e. economic, environmental and social, and stakeholder requirements into account". S.E. Daniel et al (1993) discussed the LCA in battery recycling in their paper with environmental considerations. The same was discussed in the SLI batteries by Giannis T. Tsoulfas et al (2002). In our paper we make a study on small scale plastic industry and we set out the objectives as

i) To find the environmental exchange with the plastic manufacturing on forward Sustainable supply chain (Virgin plastic)
ii) To find the environmental exchange with the plastic remanufacturing on reverse sustainable supply chain (used plastic)
iii) To compare the environmental exchanges and cost concern between the forward and reverse sustainable supply chain.

The paper is organized as follows. Section 2 is a review of the literature on Forward and Reverse sustainable supply chain and LCA method and plastic recycling processes. We discuss the base of our study by comparing with other existing journals and also provide how our journal attempts to fill that gap. Section 3 provides the methodology for our study. Section 4 gives the overview of general manufacturing techniques of virgin and reused polymer. Section 5 deals with case study of small scale plastic industry and field data. Section 6 shows the conclusion of the study.

2. Literature Review:-

S.No	Name of the journal	Author and year	Approaches
1	Applying life cycle inventory to reverse supply chains: a case study of lead recovery from batteries	Stavros E. Daniel, et al (1993)	Comparing reverse and disposal chain of Lead acid batteries using LCIA.
2	A qualitative examination of factors affecting reverse logistics systems for end of life computers	Giannis T. Tsoulfas, Costas P. Pappis, Stefan Minner (2002)	Comparing the environmental impacts of reverse and disposal chain of SLI batteries with the eco indicators.
3	The use of recycled materials in manufacturing: implications for supply chain management and operations strategy	Joy M. Field And Robert P. Sroufez (2007)	In this study they explore the implications of using recycled versus virgin materials for supply chain structure and supplier relationships in cardboard industry.
4	A qualitative examination of factors affecting reverse logistics systems for end of life computers	A.michael knemeyer, Thomas G. Ponzurick and Cyril M.Logar (2002)	In this study they utilize A qualitative methodology to examine the feasibility of designing a reverse logistics system to recycle end of life computers.
5	An integrated approach to electronic waste (WEEE) Recycling	I. Dalrymple, N. Wright, R. Kellner, N. Bains, K. Geraghty, M. Goosey, L. Lightfoot (2007)	This paper deals with the composition of WEEE, current treatment technologies, emerging technologies and research.

6	Integrating Forward and Reverse Supply Chains: Application to a metal-mechanic company	Farzad Dehghanian, Saeed Mansour (2009)	The objective of this paper is to design a sustainable recovery network, in which economical, environmental and social impacts are balanced. LCA has been applied to investigate the environmental impact of different EOL options. Analytical hierarchy process (AHP) has been utilized to calculate social impacts and GA is also used to increase the economic and social benefits
7	Integrating Forward and Reverse Supply Chains: Application to a metal-mechanic company	M. Victoria de la Fuente, Lorenzo Ros, Manuel Cardo´ s	IMSCM was proposed to integrate the forward and reverse supply chains.
8	Issues in reverse supply chains, part I: end-of-life product recovery and inventory	P. Sasikumar and G. Kannan (2008)	In this study they made a review on recycling and product inventory for EOL products.
9	A genetic algorithm approach for solving a closed loop supply chain model: A case of battery recycling	G.Kannan, P. Sasikumar and K. Devika (2009)	The objective of this paper is to develop a multi echelon, period, product closed loop supply chain network model for product returns and the decisions are made regarding material procurement, production, distribution, recycling and disposal. The proposed heuristics based genetic algorithm (GA) is applied as a solution methodology to solve mixed integer linear programming model (MILP)
10	A Study of Plastic Recycling Supply Chain	Dr. Chee Wong (2010)	They discussed about the plastic recycling about their exchange between environments.

Based on the literature review, the Daniel et al (1993) discussed the battery recycling and disposal chain and the same thing was discussed in SLI batteries instead of Lead Acid batteries by P.Pappis et al (2002). In plastic Dr. Chee Wong (2010) discussed the Environmental exchange in recycling. In all above literature they discussed only the reverse cycle with disposal but they didnot engage with the Forward cycle. In our case we have discussed the forward and reverse supply chain of plastic with environmental exchange and cost involvement in both chain. The comparison is attempted between the forward and reverse supply chain.

3. Methodology:-

In this study we have a methodology to find out the environmental exchange of forward and reverse sustainable supply chain with the reference of some basic criteria and also attempt comparison for the same. We take plastic small scale industry for our study which are undergoing both virgin and reuse plastic manufacturing, there we got the field data with some basic assumptions and these data are manipulated through Life Cycle Analysis (LCA). The results found out from this analysis are introduced in the sequence of graph with the comparison between environmental exchanges and Cost involvement of forward and reverse sustainable supply chain. The basic criteria are power demands, resource consumption (minerals, oxides, etc), airborne emissions, solid waste and liquid waste. A model is proposed for driving these set of criteria's are as collection, separation, manufacturing/remanufacturing, distribution. This LCA study also derives the mass balance and energy balance calculations.

4. Virgin and Reused polymer:-

4.1 Virgin Polymer Manufacturing (Forward):-

In primitive Days plastic was made from resin which is derived from vegetable matters, oat hulls, oil from seeds and other starch derivatives. But now, most of the plastic is obtained from petrochemicals. Fig 1 explains the forward chain of plastic. The General Forward supply chain starts from extraction of crude oil from oil source and the refining continues its operation which delivers many products such as Fuels, by products and Plastic pellets. These plastic pellets are called virgin polymer and are supplied to processing units as raw material. In the processing unit it gets molded and supplied to industries where the plastic products are manufactured such as packaging materials, window frames, plastic for electrical apparatus etc.. This is then distributed to Consumers. After the end of its life, it turns as landfills or wastes. This is the final step of forward supply chain of plastics.

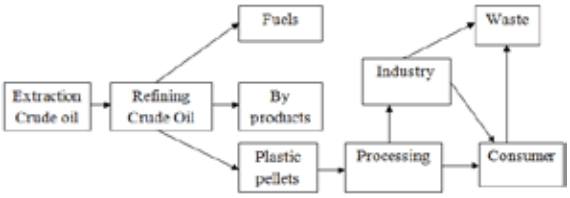

Fig 1 Forward Supply Chain of Plastics (modified from Dr.Chee wong 2010)

4.2 Reused Plastic (Reverse supply Chain):-

Plastics are used to reduce the other materials which give more hazardous effects to the planet.

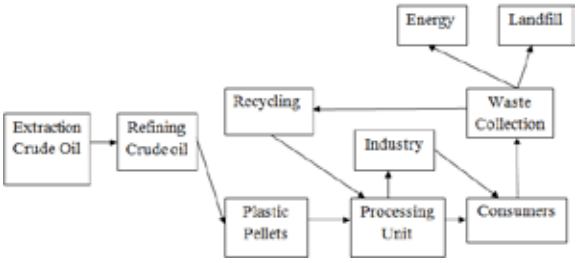

Fig 2 Reverse Supply Chain of plastics (modified from Dr. Chee wong 2010)

The use of the packaged water bottles and other materials are reused in many materials. Plastics can be recycled with maximum of six times after its EOL. As illustrated in figure 2, there are two main wastes known as municipal solid waste and commercial and industrial waste. Recycling of waste can be divided into two methods they are mechanical recycling and feed stock recycling. In this recycling process the sequence is like collection, sorting, reprocessing and distribution. Mechanical recycling involves melting, sorting and granulation of plastics. Feedstock recycling is nothing but the breakdown of polymers into their constituent monomers. The Recycling of plastics results in development of sustainability of the environment.

5. Case study of plastic industry

We made a case study on a small scale plastic industry in southern part of India which employed the both forward and reverse supply chain. In this firm they produce HDPP bags

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by virgin polymer and the recycling is also made on these bags by recycling process. Our study of plastic is based on mono polymer. But Multi layer polymer with material foil like aluminium cannot be recycled. They are used for making of plastic road or landfill.

5.1Life Cycle Analysis of Forward and Reverse Supply Chain

5.1.1 Goal and Scope:

The intention of this paper is to analyze the plastic forward and reverse supply chain and to inventory all the environmental exchanges and cost involvement associated with the logistics activities involved. Due to environmental importance of plastic we made the study on plastic forward and reverse supply chain based on inventory data. As per the study is concerned, the comparison of forward and reverse supply chain was made. In this paper, the product examined concerns the used plastic and virgin plastic. Here we define 1 ton of plastic as the functional unit.

An important task in the basic phase of LCA process is the selection of reference data and product. Forward Supply chain of batteries includes the life cycle stages of collection (virgin polymer), processing and distribution. Reverse supply chain of batteries includes the life cycle stages of collection of waste, sorting, remanufacturing and distribution.

5.1.2 Inventory Analysis

5.1.2.1 Methodology

This phase is very essential to determine the next phase of LCA. Inventories start with the data diagram and process chart, in that all relevant process is predefined and the data are outlined. In this, mass entering to the system is balanced with mass leaving the system and the energy entering to the system is balanced with energy leaving from the system. By this input and output method of analysis, we can estimate the overall performance of the system. In this phase, we must specify the data type and process type for the study. Here the environmental impacts and cost involvements are identified. After the completion of process and data specification, the next step is modeling of the system where the mass and energy balance calculations were made in each and every stage of the system. From the total specific energy and specific mass, we can assess the environmental impacts and cost involvement in the forward and reverse supply chain. All these data are listed in the inventory table.

5.1.3 Modeling of the Plastic Forward Supply chain:-

A typical presentation of the stages of the plastic forward chain is presented in fig 3. The stages are as follows

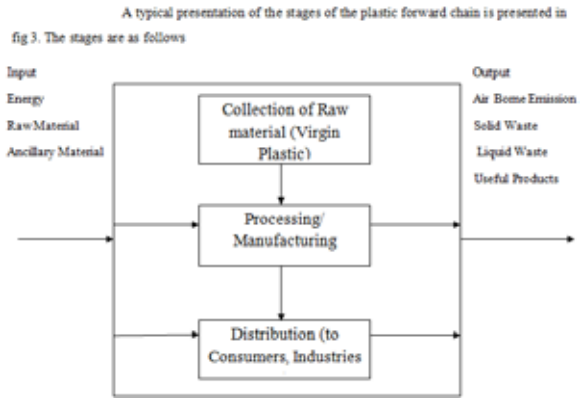

Fig 3 Model for Forward Supply chain (Modified from S.E Daniel et al 1993)

- Collection: In the plastic forward supply chain the collection is nothing but the collection of raw material from the standard distributors. After Collection it leads to the processing of raw material to finished products.
- Manufacturing: This stage includes processing of the raw material with the color ingredients.
- Distribution: After Processing or manufacturing is over then the finished products are sent to relevant areas by means of logistics.

5.1.4 Model of Plastic Reverse supply chain:

In fig 4, we have shown the inventory table for plastic recycling process by inputs and outputs. The model of reverse supply chain as follows.

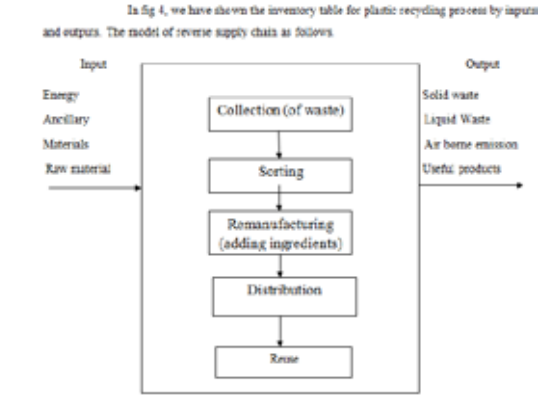

Fig 4 Modeling of Reverse Supply chain (modified from S.E Daniel et al 1993)

- **Collection:**

Here the collection is referred as collecting of waste from sectors. Waste are classified as industrial waste (waste from the industry), Commercial waste (waste from commercial households), Municipal Waste (waste from municipal).

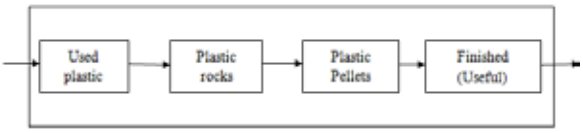

Fig 5 Model Proposed for Remanufacturing unit of plastic

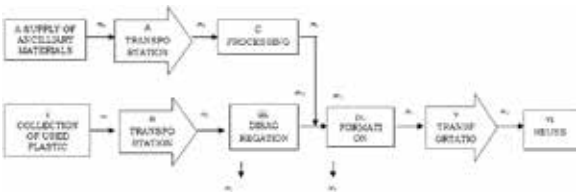

Fig.6 Mass balance in the plastic reverse chain

- **Sorting:**

In sorting process the plastic products are sorted on the basis of quality of plastics which is determined visually. Sorting includes cleaning process. For recycling process same quality of plastics are recycled due to maintain in its quality. If different quality plastics mixed up in recycling it leads to bad quality.

- **Remanufacturing:**

Remanufacturing is the process which convert the raw material (collected as waste) in to finished products. In this process, more materials are consumed and more energy is involved. Cost is also heavier than any other process. Here the ancillary material is the master batch (color ingredient).

- **Distribution:**

After remanufacturing the second quality plastics are ready for distribution.

6. Field Data:

6.1 Data for Energy Consumption

We got all relevant data for energy consumption from the industry itself. It contains the energy consumption, fuel consumption for the both forward and reverse process of

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plastic. The total values for airborne emissions as well as the total energy consumption for the supply of 1 MW h of electricity to the end user are summarized below (Georkakelos 1996) (Daniel et al 2003).

Energy consumption (MJ/MW h)	13 122
SO2 production (kg/MW h)	5.416
NOx production (kg/MW h)	1.811
Participates production (kg/MW h)	0.690
CO2 production (ton/MW h)	1.533

In our case, electricity supply for 1 ton of plastic is 4 MW h for forward supply chain and 6 MW h for reverse supply chain.

6.2 Data for Transportation – (Collection & Distribution)
Collection and distribution are the processes which come under the transportation. In this we figure out the fuel consumption for collection and distribution. We also define the emission which delivers through this process on both forward and reverse process. In our case, the vehicle type is diesel light duty vehicle which has tonnage capacity of below 3.5 tons. This vehicle type was used for both collection and distribution in both forward and reverse scenario.

6.3 Data for inventory analysis
In the inventory analysis we had shown the environmental exchanges of both forward and reverse plastic process. The set of criteria for environmental impacts are Solid waste, Liquid waste and air borne emission.

6.4 Collection (I) and Transportation (II)
In the modeling of both forward and reverse supply chain of plastics we define collection and transportation separately but they are considered as one stage. It is more difficult to collect the data for the collection process. So we obtained the data from literature survey (CEC 1991a, Daniel et al 1992). This is shown in Appendix A.

6.5 Sorting (III)
Sorting is only taking place in reverse supply chain not in forward because there is no necessity for sorting. Some unrecyclable materials are made as landfill. We are going to assess the waste in this section.

6.6 Manufacturing (III)/ Remanufacturing (IV)
In forward supply chain the processing is denoted as manufacturing and in the reverse supply chain the processing is denoted as remanufacturing. In this stage there are air borne emissions, solid waste, liquid waste and power consumptions are more ever than any other process.

Table 1:- Data Sources and Data reference
Process Type Data Source

Collection	Literature review
Separation (Reverse)	Empirical estimation
Manufacturing/Remanufacturing	Empirical estimation
Distribution	Literature review
Cost	Empirical estimation

Table 2:- Comparative analysis of forward and reverse supply chain of plastic Inventory table reverse supply chain

		Collection	Disaggregation	Remanufacturing	Distribution	Total
Power Demands	Electrical Energy (KWh)	-	-	4500	-	4500
	Fuel (Kg)	0.68	-	-	0.68	1.16
Resource Consumption	Color Ingredients (kg)	-	-	50	-	50
Air Borne Emissions	Sulphur dioxide (so2) (kg)	-	-	32.496	-	32.496
	Nitrous Oxide (Nox) (kg)	0.012	-	10.866	0.012	10.89
	Carbon dioxide (Co2) (kg)	-	-	9198	-	9198
	Carbon Monoxide (Co) (kg)	0.008	-	-	0.008	0.016
	P-Tert-butylbenzoic acid (kg)	-	-	3.35	-	3.35
	VOC Emissions (kg)	0.0025	-	-	0.0025	0.005
Liquid Waste		-	-	-	-	-
Solid Waste	Plastic Scrap (kg)	-	-	50	-	50
Cost (INR)		3000	-	12000	3000	18000

Table 3 :- Inventory table forward supply chain

		Collection	Disaggregation	Remanufacturing	Distribution	Total
Power Demands	Electrical Energy (KW h)	-	-	1000	-	1000
	Fuel (Kg)	0.68	-	-	0.68	1.16
Resource Consumption	Color Ingredients (kg)	-	-	50	-	50
	Polymer (Kg)	-	-	1000	-	1000
Air Borne Emissions	Sulphur dioxide (so2) (kg)	-	-	21.664	-	21.664
	Nitrous Oxide (Nox) (kg)	0.012	-	-	0.012	0.024
	Carbon dioxide (Co2) (kg)	-	-	6132	-	6132
	Carbon Monoxide (Co) (kg)	0.008	-	-	0.008	0.016
	P-Tert-butylbenzoic acid (kg)	-	-	-	-	-
	VOC Emissions (kg)	0.0025	-	-	0.0025	0.005
Liquid Waste		-	-	-	-	-
Solid Waste	Plastic Scrap (kg)	-	-		-	-
Cost (INR)		3000	-	8000	3000	14000

6.7 Supply of ancillary materials (α)

In plastic, there is no ancillary material except the color ingredients which is commonly named as master batch which gives color for the plastic products. Now a days, the plastic manufacturers are recommended to use the mix that makes the plastic bio degradable. By our field study they are not bio degradable they just become micro organism however the

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effect will be same.

7. Conclusion

In this study, we have made the Life Cycle Analysis comparing the Forward and reverse sustainable supply chain of plastic. The environmental and cost exchanges of forward and reverse supply chain of plastic are listed in the table below (table 3). The data source and data reference are also listed in the table below (table 1).

7.1 Resource Consumption:-

In this study when we compare the forward and reverse resource consumption we can find that there is no ancillary material in the plastic manufacturing .Virgin polymer and used polymer are used as a raw material for forward and reverse supply chain respectively. Color ingredients are common in both forward and reverse supply chain. For 1 functional unit of plastic recycling, 1.02 ton of plastic is needed. If we compare both the supply chains, forward supply chain has greater resource consumption than the reverse supply chain.

7.2 Air Borne emission:-

Both forward and reverse supply chain of plastic undergoes air borne emissions. In our study, from the data source and references and inventory analysis (table 2 & 3) it is clear that the reverse supply chain has more emission than the forward supply chain. No emission takes place in the manufacturing of plastic in forward supply chain. Logistics emission is common in both cases. In recycling of plastic there is also an emission of Volatile Organic Compound (VOC) gases. The comparison of emission in both cases is illustrated in fig 6.

7.3 Liquid Waste:-

By the inventory analysis and real life data there is no liquid waste in production of plastic in both forward and reverse supply chain.

7.4 Solid waste:-

In forward supply chain of plastic there is no solid waste because the scrap is reused immediately at the same stage and the percentage of scrap is also very less. But in reverse supply chain, the scrap is non-reusable because in reverse chain the raw material is the Used-plastic. Hence, the plastic becomes second quality in this stage.

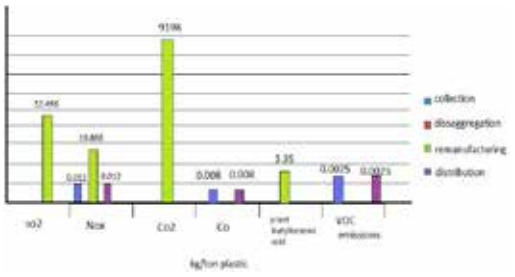

Fig 7 Airborne emission on recycling of plastic in all stages

If we use the scrap of second quality plastic it will become third quality plastic which has low strength and not popular in practice. So these scrap become landfill. In practice due to lack of availability of land it is impossible for storage of scrap. So they burn the scrap which leads to severe environmental problems.

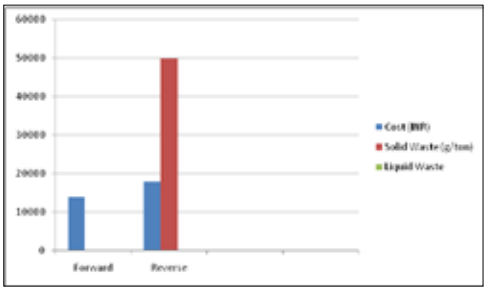

Fig 8 Comparison of solid waste and cost on both forward and reverse chain

7.5 Impacts of working environment:-

With the assistance of our inventory analysis we post the results of environmental exchanges and cost involvement in both forward and reverse sustainable supply chain of plastic manufacturing. In this Power consumption is more on recycling process than forward which is obvious. Air borne emission only exists in reverse supply chain because collection of used plastics contains different kinds of material. Due to the melting of different kinds of plastics at high temperature releases fumes which is the result of chemical reactions and which cannot be studied deeply. However, reverse is more costly because the only difference is raw material. In forward supply chain, virgin polymer is costlier but that cost nullifies with manufacturing of pellets from used plastic in reverse chain. For example, the used plastic bags are first converted into plastic pellets and then it is converted into useful products. So converting the used plastic into pellets leads to cost equal to that of virgin polymer. Resource consumption is needed more in forward supply chain because we use only the used plastic in reverse supply chain. Solid waste is greater in reverse supply chain because there is no solid waste in forward supply chain. By our virtue of findings, recycling is greater in Power, airborne emission, cost and solid waste. But the recycling is lesser in resource mainly the virgin plastic. If we stop recycling the plastic, then there is demand for virgin polymer which results in demand of crude oil. Demand of crude oil will create the environmental and economical imbalance in future. So, recycling is better than forward chain which is concluded from our study.

Future scope:-

From this study, a lot of questions may arise. There is no proper emission measurement and control in small scale industries of plastics in southern part of India. Even though the fumes are emitted at the time of remanufacturing, it is left uncared. The small scale industry has a lack of knowledge about the emission. They don't even know the reason for emission. So, further study in this emission and its control is an important issue for green environment. From this study, we conclude that the reverse supply chain has a greater impact in emission and cost. we can make a research to minimize this criteria. In this study we have considered mono polymer and in further study, people can deal the same study with multi layer polymer.

Appendix A:-

Table I:
Emission factors for diesel light duty vehicles < 3.5 tonns (CEC, 1991a).

	Co (g/km)	No_x (g/km)	VOC g/km)	Par-ticulates (g/km)	Consumption (g/km)
Urban	2.00	1.60	0.40	0.25	106.25
Rural	0.80	1.20	0.25	0.25	68.00
Highway	060	1.25	0.13	0.16	63.75

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