Faculty of Engineering

Department of Textile Engineering

"Life Cycle Analysis of a Polyester Garments- A comparative study between Virgin polyester & Recycled polyester "

Course Title: Thesis

Course Code: TH-518

Submitted By:

Md. Arafat Hossain

ID: 173-32-356

Supervised By:

Prof. Dr. Engr. Md. Mahbubul Haque

Professor & Head

Dept. of Textile Engineering

Daffodil International University,

Dhaka, Bangladesh.

This Report Presented in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Textile Engineering

13 July, 2019

DECLARATION

I hereby declare that, the research work of this thesis has been conducted by me under the supervision of & **Prof. Dr. Md. Mahbubul Haque,** Professor & Head, Department of Textile Engineering, Faculty of Engineering, Daffodil international University (DIU). All belongings of this report are authentic according to my knowledge. I also declare that, neither this thesis report nor any part of it has been submitted elsewhere for award of any degree or diploma.

Md. Arafat Hossain

ID: 173-32-356

M.Sc. Student
Department of Textile Engineering
Daffodil international University (DIU).

Letter of Approval

*We hereby declare that, this project paper title "***Life Cycle Analysis of a Polyester Garments-Design Its Recycling to Reduce Waste and Contribute for Environment with Minimum Consumption of Energy"** *is prepared by* **Md. Arafat Hossain***; bearing ID* **173-32-356***. This thesis report is submitted in partial fulfillment of the requirements for the degree of* **Master of Science in Textile Engineering***. The whole report is prepared based on proper investigation and interpretation though critical analysis of data with required belongings.*

Dr. Md. Mahbubul Haque
Professor & Head
Department of Textile
Engineering,
Daffodil International University
M.Sc. Project Co-Supervisor

Md. Arafat Hossain
Department of Textile
Engineering,
Daffodil International
University
Author (M.Sc. Student)

ACKNOWLEDGEMENT

First of all, the author wishes to express her deepest gratitude to the Almighty Allah, forgiving this opportunity and for enabling to complete the project successfully.

I owe my indebtedness to all those who helped directly or indirectly in the accomplishment of this work. I extend my unfeigned thanks to my Project supervisor Dr. Md. Mahbubul Haque**,** Professor & Head of Textile Engineering Department, Daffodil International University for his kind co-operation as and when the need arose. I would also like to thank Dr Engr Md Saifur Rahman, Professor, Dr. Rina Khanum, Associate Professor, Mr. Md. Syful Islam, Associate Professor, Mr. Sumon Mazumder, Assitant Professor, Department of Textile Engineering, Daffodil International University (DIU), for their valuable guidance & cooperation. I will always be obliged for their kind support.

Finally, the author expresses his thanks to his family and friends for their continuous encouragement and support.

The Author

July, 2019

DEDICATION

This thesis is dedicated to:

The sake of Allah (swt) most Magnificent & Gracious, my Creator and my Master,

My great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the persistence of life,

My motherland Bangladesh, the largest part of heart;

The great martyrs of our freedom fight, the symbol of sacrifice;

My phenomenal parents, who are the great establishment of my life;

My dearest wife, who leads me through the valley of darkness with light of hope and care;

My beloved brother and sister, the great source of inspiration;

My friend, who encourage and support to believe that, I can;

All the people in my life who touch my heart,

I dedicate this research.

ABSTRACT

The global warming put emphasis on green products to save our environment. Due to the continuous pressure from different stakeholders for the conservation of environment, eco-friendly product manufacturing has received much fuel from corporate stakeholders to gain competitive advantage through earning reputation at present business state. Polyester control in fashion markets accelerates as overcapacity limits margin expansion throughout the chain of global fashion market. It has been asserted that synthetic polymers in the ocean would be regarded as hazardous waste. All synthetic fiber has an environmental collision. The compulsive demand for polyester in fashion markets increases its production. The demand for polyester crosses the limit margin throughout the chain of the global fashion market. It has been developed that synthetic polymers in the ocean would be observed as destructive waste. The recycling process of polyester clothing will be established in the textile material recovery and reuse. The study produced the life cycle analysis of 100% virgin polyester trouser (work ware) of one production cycle for 400000 pieces. The primary and secondary data was collected from PET resin manufacturing industry, fabric manufacturing and trouser manufacturing industry. The study also provided recycling process of polyester fabric which reduces environmental emissions. The significance of recycling textiles is increasingly being recognized. Once in landfills, natural fibers can take hundreds of years to decompose. The virgin and waste of polyester release the hazardous micro-plastic, carbon dioxide and methane gas which is polluting accordingly our acoustic life and environment. The reusing process and recycling approach of polyester reduces our dependability on petroleum by eliminating some PET manufacturing process and minimizing the atmosphere, water, soil, and landfill pollutions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

TERMINOLOGY AND SYMBOLS

ADMI = American Dye Manufacturers Institute

APIC = The Association for Professional in Infection Control

ATO = Antimony Trioxide

ATMf = American Textiles Manufacturers Institute

DMT = Dimethyl Terephthalic

EPI = Ends Per Inch

ETP = Effiuent Treatment Plant

GSM = Gram per Square Meter

KWh = Kilowatt Hour

MEG = Mono Ethylene Glycol

PET = Polyethylene Terephthalate

PPI = Picks Per Inch

PTA = Purified Terephthalic Acid

RMG= Ready-made Garments

Chapter-1

INTRODUCTION

1.1 INTRODUCTION

Environmental sustainability is not a simple expression; rather it is an indispensable part of any business that wants to maintain its existence in today's globally competitive business arena. This is also true for our textile industry, which is bit by bit going green. We have to accentuate on green products. Formulation of strategies is now on discussion to go green by dealing with the top issues like social, environmental safety, scarcity of natural resource and energy. Therefore, we have to take into deliberation of ecological fashion called ‘Eco Fashion’. Eco Fashion is a part of the developing design thinking and trend of sustainability. We have to emphasize on green products to accumulate our environment. The synthetics are complicated because they do not biodegrade. Global 2013 fiber production estimated at 85.5 million tons where synthetic fiber production estimated at 55.8 million tons. Polyester refers to the connection of numerous monomers within the fiber. Polyester fibers are long chain polymers formed from elements derived from- “Coal, Air, Water and Petroleum.” It is about 85% by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalic units-and para-substituted hydroxyl-benzoate units, Polyethylene terephthalate, the repeating unit of the polyester polymer with a degree of polymerization of 115-140 units. It’s having crystalline around 60-65%. It’s having high glass transition temp around 70-80^{o}c. It is produced basically two routes by step growth polymerization [1].

Global synthetic fiber volume growth is 98%+ of future total fiber production increases. Polyester (filament and staple) makes up 95%+ of future global synthetic fiber production growth. Polyester filament growth nearly three times the average of all fibers during the last five years (7.9% vs. 3.1%). According to the Synthetic Fibers Raw

Materials Committee Meeting at APIC 2014 Pattaya major production increases forecast for China, India and the US. Global polyester staple production growth during last five years 6.4% due to cotton substitution where China dominates with 65% of global production. Chemical Polyester is used 60% for textile and fiber, about 30% bottle and packaging resins and about 9% film and other application [2]. Polyester is one of the mechanized plastics which are commonly used. Polyethylene terephthalate, more commonly known as PET, the great usage of PET is in yarn industry. PET, as polyesters family, is a thermoplastic polymer with long branches of those which their wastes can be useable and bring economic benefits by using appropriate recycling methods [3, 4].

1.2 STATEMENT OF THE PROBLEM

Gradually polyester the synthetic fiber ever- cumulative problematic of plastic pollution in the world's oceans and other bodies of water. Global 2013 fiber production estimated at 85.5 million tons where synthetic fiber production estimated at 55.8 million tons. It is difficult to stop the production of synthetic fiber in a day but it is achievable to develop eco-friendly polyester fiber by recycling of PET fabric. Above 80 billion apparels are manufactured yearly, worldwide. In 2010, about 5% of the U.S. municipal waste stream was textile scrap, totaling 13.1 million tons. Only 15 % recovery rate. The recovery rate for textiles is still only 15%. As such, textile recycling is a significant challenge to be addressed as we strive to move closer to a zero landfill society. Once in landfills, natural fibers can take hundreds of years to decompose. They may release methane and CO_2 gas into the atmosphere. Synthetic textiles are designed not to decompose. In the landfill, they may release toxic substances into groundwater and surrounding soil and accumulation of these wastes cause pollution and severe diseases. To control these diseases and infection, we have started using sustainable synthetic polymers. This kind of polymers consists of similar functional groups as biopolymers. Polyester requires petroleum and other chemicals to produce, as well as energy to heat and power the process. It's not biodegradable, but can be recycled.

1.3 OBJECTS OF THE STUDY

- To converting polyester garments and fabric into recycled polyester by using less energy and solid waste in the case of standard polyester reducing consumption of energy and solid waste.

- To use more recycled polyester reduces our dependence on petroleum as the raw material for our fabric needs.

- To create from recycled polyester can be recycled again and again with no degradation of quality, allowing us to minimize energy, wastage as well as environmental emissions.

1.4 SCOPE OF THE THESIS

The aim of this research project was to evaluate virgin polyester and recycle polyester life cycle analysis for their ability to recover the energy and solid waste for decreasing environmental emission. The results to develop a novel approach to prefer the appropriate recycling product of polyester which reduces energy and solid waste in terms of environmental emission and environmental impact. To achieve this goal, life cycle of virgin and recycle polyester trousers were analyzed. The secondary data of 4, 00,000 pieces work wear (trousers) manufacturing, use of consumer and disposal were analyzed to compare and minimize energy and solid waste.

1.5 ORGANIZATION OF THE THESIS

The literature review is accessible in Chapter 2 and begins with a brief introduction to the life cycle analysis of polyester trouser and recycling as well as sustainable product. This includes an overview energy consumption of different stage in manufacturing. Chapter 3 presents the methodology adopted for the study beginning with an overview of the rationale for choosing the systems that were to be included in the study. Chapter

4 section presents the detail analysis and related information of process energy consumption and transport energy requirements for virgin and recycle product. Chapter 5 presents analysis of 100% polyester trouser (work ware) energy consumption of consumption of virgin trouser. Chapter 6 presents the decision of the method and results to reducing energy by recycling. Chapter 7 presents the conclusions, thesis contributions, and further work.

Chapter-2

LITERATURE REVIEW

2.1 BACKGROUND AND SIGNIFICANCE

Polyester is nevertheless a plastic material synthesized from crude oil and natural gas. And, like other plastics, polyester is a long polymer chain, making it non-biodegradable in any practical human scale of time, especially in the ocean because of the cooler temperatures [5]. Plastic bottles, which are produced from these materials, have been expanded widely. Interestingly, due to the high resistance of these bottles against breakage, temperature, and diffusion of gases, having low weight and having cheaper price in comparison with other packaging materials, such as glass and metals, bring a remarkable state for them in recycling industry [4, 6]. Since 1999, due to increasing trend of using plastic bottle and packages as a worldwide phenomenon that naturally leads to the entry of used PET bottles into the waste stream, recycling has become an important topic. These bottles have high volume compared with their weight ratio which causes occupying lots of space during transport and burial account. On the other hand, analysis of them takes too much time in nature (about 300 years) which occurs by natural agent. Thus, this phenomenon, the problem of recycling these bottles, is going to be in a great deal of attention, especially in recent years [4, 7]. Nowadays many countries have realized the importance of this issue and started to recycle PET bottles and turn them into recycled polyesters in both mechanical and chemical methods according to their needs. Through mechanical recycling, waste PET bottles can be found in films, sheets, strapping packaging, and fiber used for sacking and their usage for insulation and for floor covering has also been studied [4, 8]. By chemical recycling in adequate methods it can be reachable to recover raw material of PET or produce new recycling material from them, which can be reused again. Chemical recycling of PET can be done by acids, methanol, and glycols, with each having its own advantages [7]. Recently, researchers have found that enzyme can be used as a new degradation biocatalyst for PET [4]. We synthesized plastic from crude oil and natural gas. It is a long polymer chain, similar to other plastics and it is not biodegradable specifically in the ocean because of the cooler temperatures [9]. Though the polyester and its micro-plastics do not biodegrade it is very dangerous for water and environment and for human body. Instead, they add to the ever intensifying problem of micro plastic pollution in the world's oceans and other bodies of water even in atmosphere. The researchers also provided strong indication linking polyester garments for energy use of laundry. Plastics are synthetic polymers which also contain other chemicals to improve performance [10], the durability of plastic makes it highly resistant to degradation and therefore, disposing of plastic waste is a big challenge [11]. Plastics are entered into the water environment due to their disorganized disposal and harm fully affects the oceanic and surface water. During the last few decades, this is an issue of major concern as marine ecosystem has maximum contribution towards global primary productivity [12].Once enters in the environment, these plastic materials are degraded by various means and lost their structural rigidity [13]. The extensive degradation of plastics finally results into powdery fragments and microscopic-sized plastics, called microplastic [14]. Nowadays, pharmaceuticals and cosmetic manufacturer are using PET in various daily used products and polluting the environment via wastewater, ultimately transferred along food chain and impacting oceanic ecosystem after reaching into the sea and human food effect human body. The main sources of polymeric microplastic and nanoplastic in marine habitat are synthetic clothes, cosmetic products, toothpastes, hand cleansers and variety of cleaning products; which enter the water channels via household and industrial drainage systems as domestic effluents [15-17].

The quantity of post-consumer plastics recycled has increased every year since at least 1990, but rates lag far behind those of other items, such as newspaper (about 80%) and corrugated fiberboard (about 70%) [18]. Overall, U.S. post-consumer plastic waste for 2008 was estimated at 33.6 million tons; 2.2 million tons (6.5%) were recycled and 2.6 million tons (7.7%) were burned for energy; 28.9 million tons, or 85.5%, were discarded in landfills [19].To solid waste management, recycling is the most extensively recognized concept where the environment al benefits of recycling plastic are touted in a different place. It reduces the amount of garbage we send to landfills: The American Chemistry Council impart with the plastic recycling which is a continues process and reduce the world wastage 85.5% of the total production by heating plastics in the absence or near absence of oxygen to break down the long polymer chains into small molecules. Under mild conditions polyolefins can yield petroleum-like oil. Special conditions can yield monomers such as ethylene and propylene. Some gasification processes yield syngas (mixtures of hydrogen and carbon monoxide are called synthesis gas, or syngas). In contrast to pyrolysis, combustion is an oxidative process that generates heat, carbon dioxide, and water. So, the newspaper and plastic bottle recycling process is a great example for the polyester fabric recycling.

2.2 ENVIRONMENTAL EFFECTS

When plastics or synthetic textiles get littered, they start to break down into smaller pieces. These broken-down plastic particles get swept by rain into lakes, rivers, sewers, etc. Eventually it can get into the ocean. Micro-plastics from synthetic have also been found in the air we breathe. The main sources of polymeric microplastic and nano-plastic in marine habitat are synthetic clothes, cosmetic products, toothpastes, hand cleansers and variety of cleaning products; which enter the water channels via household and industrial drainage systems as domestic effluents [20].

Chapter-3

METHODOLOGY

3.1 METHODOLOGY

The study was conducted in two phase. At First life cycle analysis data of virgin polyester products (4, 00,000 pieces 100% polyester trouser, work ware) was collected from polyester resin manufacturing industry, polyester fabric manufacturing and garment manufacturing industry. In second phase recycle polyester in laboratory condition data was collected from polyester recycling industry. Unstructured online survey (email, telephone) was considered for collecting tertiary data of life cycle analysis of polyester resin manufacturing industry. The name of the factories was cover up in order to publish this analysis and obligation of factories restriction of data accuracy and environmental impact in business aspects. A review of literature on polyester fabric pollution was analyzed in this study in order to develop research hypothesis. The study was developed a recycle fiber-fabric minimizing use of raw materials. Polyester outfit was tested and recycled under controlled laboratory conditions; and the environmental emissions. High automatic textile recycling machine which was used to process yarn waste in industries, textile fabric waste for re-spinning recovered polyester fiber from textile fabric waste.

3.2 DATA COLLECTION VIRGIN POLYESTER

Necessary data was collected to develop a hybrid life cycle for polyester fabric raw materials sequential visits was done of five different textiles composite and dyeing factories and polyester trouser manufacturing Ready-made Garments factory. The study was developed the polyester fabric life cycle prospective the environmental impact of the apparel sector. The hybrid life cycle analysis and case study provides estimates on unlawful flows of materials estimates and polyester footprint of consumption, and highlights the advantages and challenges of using life cycle analysis approaches to study and quantify a negative environmental impact as an input to production. Life cycle analysis significant for the mark out the polyester supply chain. Input life cycle analysis provided hybrid supply chain of the product as well as environmental footprint. The approach will produce green polyester.

3.3 EXPERIMENTAL (RECYCLE POLYESTER)

The experimental data was collected from polyester recycling industry. There was additional small number of recycling processes which was tasted for recycling and manufacturing polyester by cost minimizing to use wastage polyester fabric similar to PET bottle recycling. The polyester fabric was bleached to remove color to develop finished white. The scouring and bleaching of wastage polyester fabric was done combined by using wetting agent, detergent, peroxide stabilizer, caustic soda, soda ash and H_2O_2. The environmental emission was tested in laboratory condition for fabric recycling.

3.4 THEORETICAL BACKGROUND

Polyester refers to the linkage of several monomers (easters) within the fiber. Polyester fibers are long chain polymers produced from elements derived from- “Coal, Air, Water and Petroleum.” It is about 85% by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalic units-P(-R-CO-C_6-H_4-CO-O-$)_x$ and para-substituted hydroxyl-benzoate units, P(-R-CO-C_6H_4-O-) $_X$ Polyethylene terephthalate, the repeating unit of the polyester polymer with a degree of polymerization of 115-140 units. $_n$Hooc-R-COOH-$_n$HO-R-OH-+C-R-C-O-R-O-$_n$. It’s having crystallinity around 60-65%. It’s having high glass transition temp around 70-80^{o}c. It is produced basically two routes by step growth polymerization.

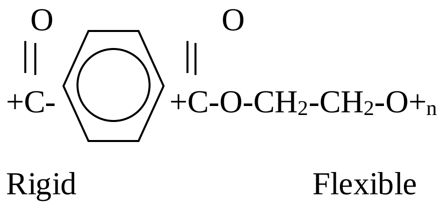


Figure3.1. Chemical structure of polyester

Table 3.1 Raw Materials of polyester

1.	2.	3.	4.
Purified Terephthalic Acid (PTA) Synonym: 1,4 Benzene-di-Carboxylic Formula: $C_6H_4\ (COOH)_2$ Molecular weight: 166,13	DimethylTerephthalic (DMT) Synonym: 1,4 Benzene-di-Carboxylic acid, Dimethyl ester Formula: $C_6H_4\ (COOCH_3)_2$ Molecular weight: 194, 19	Mono Ethylene Glycol (MEG) Synonym: 1,2 Ethane di-ol Formula: $C_2H_6O_2$ Molecular weight: 62,07	Antimony Trioxide (ATO) Formula: Sb_2O_3 Molecularweight: 291,51

Polyethylene Terephthalate $(C_{10}H_8O_4)_n$ and monoethylen glycol produces oligomers at 250^o c on the other hand polyethylene terephthalate and methanol generates dimethyl terephthalate. We also get terephthalic acid buy adding polyethylene terephthalate (PET) and water etc. There is an additional small number of recycling process which was tasted for recycling and manufacturing by cost minimizing. It is important to bleach polyester to remove color to develop finished white. The scouring and bleaching of PET will be done combined by using wetting agent, detergent, peroxide stabilizer, caustic soda, soda ash and H_2O_2. High automatic textile recycling machine which was mainly used to process yarn waste, textile fabric waste for re-spinning was recovered polyester fiber from textile fabric waste. Hydrolysis, aminolysis, alcolysis and glycolysis was used for depolymerization treatment to turn the fabric into staple or filament yarn.

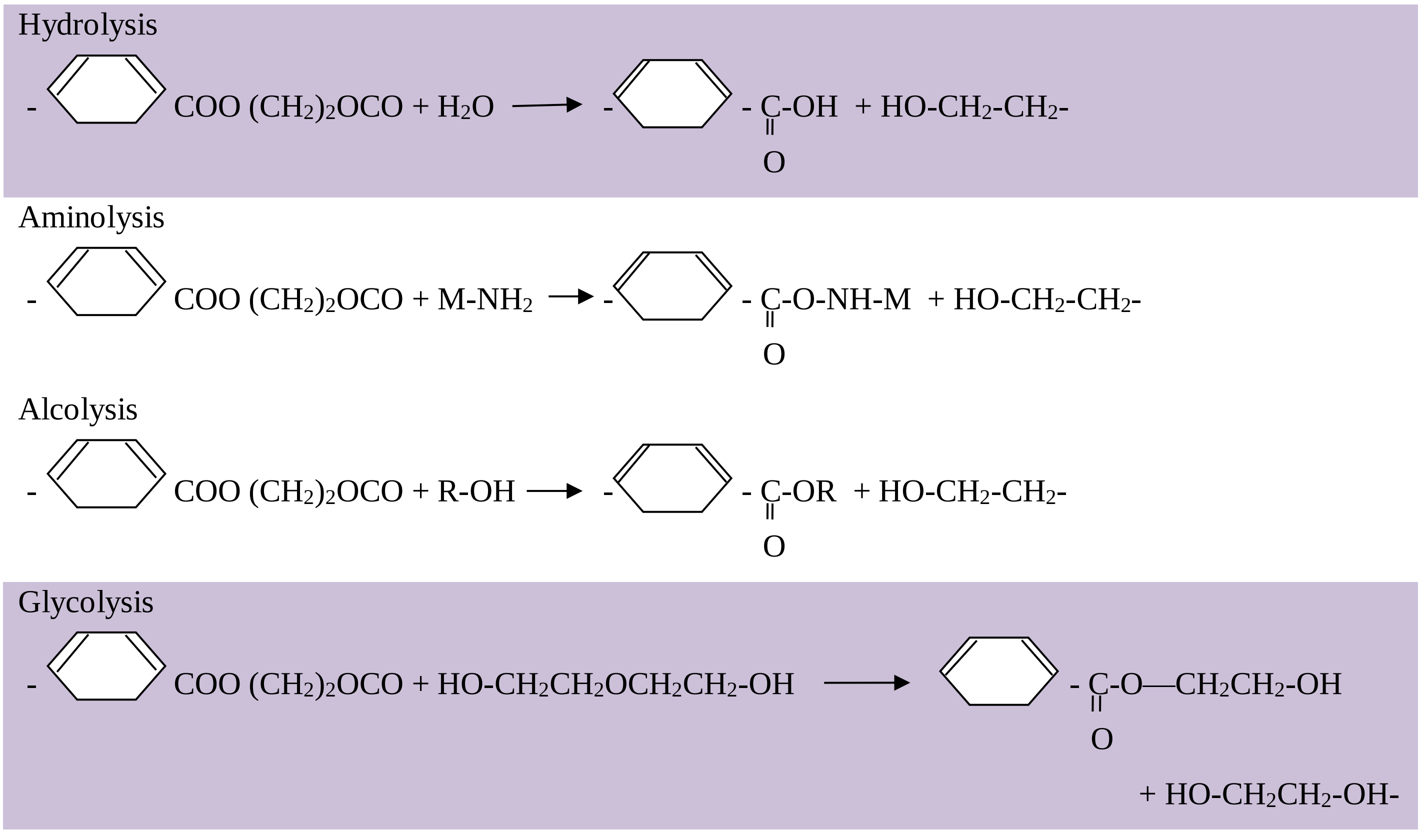


Figure 3.2 Depolymerization of PET

Hydrolysis, Aminolysis, Alcolysis and Glycolysis affords depolymerization treatment to turn the fabric into staple or filament yarn. The hydrolysis process provides the terephthalic acid which esterified with methyl alcohol to form dimethyl terephthalate. Recycled polyethylene terephthalate makes by condensing ethylene glycol with either terephthalic acid itself or with dimethyl terephthalate. The glycolysis process also provides dimethyl terephthalate. Condensation of ethylene glycol with terephthalic acid is an esterification reaction, water being eliminated as the reaction takes place [21]. The condensation carries out by heating the ethylene glycol and terephthalic acid or dimethyl terephthalate and removing the water or methyl alcohol in vacuo. High temperature provides the polymerization of colorless polyester chips. The polyester chips provide the undrawn yarn. Polyethylene Terephthalate $(C_{10}H_8O_4)_n$ and monoethylen glycol will produce oligomers at 250^o c on the other hand polyethylene terephthalate and methanol generate dimethyl terephthalate. We also get terephthalic acid by adding polyethylene terephthalate (PET) and water etc.

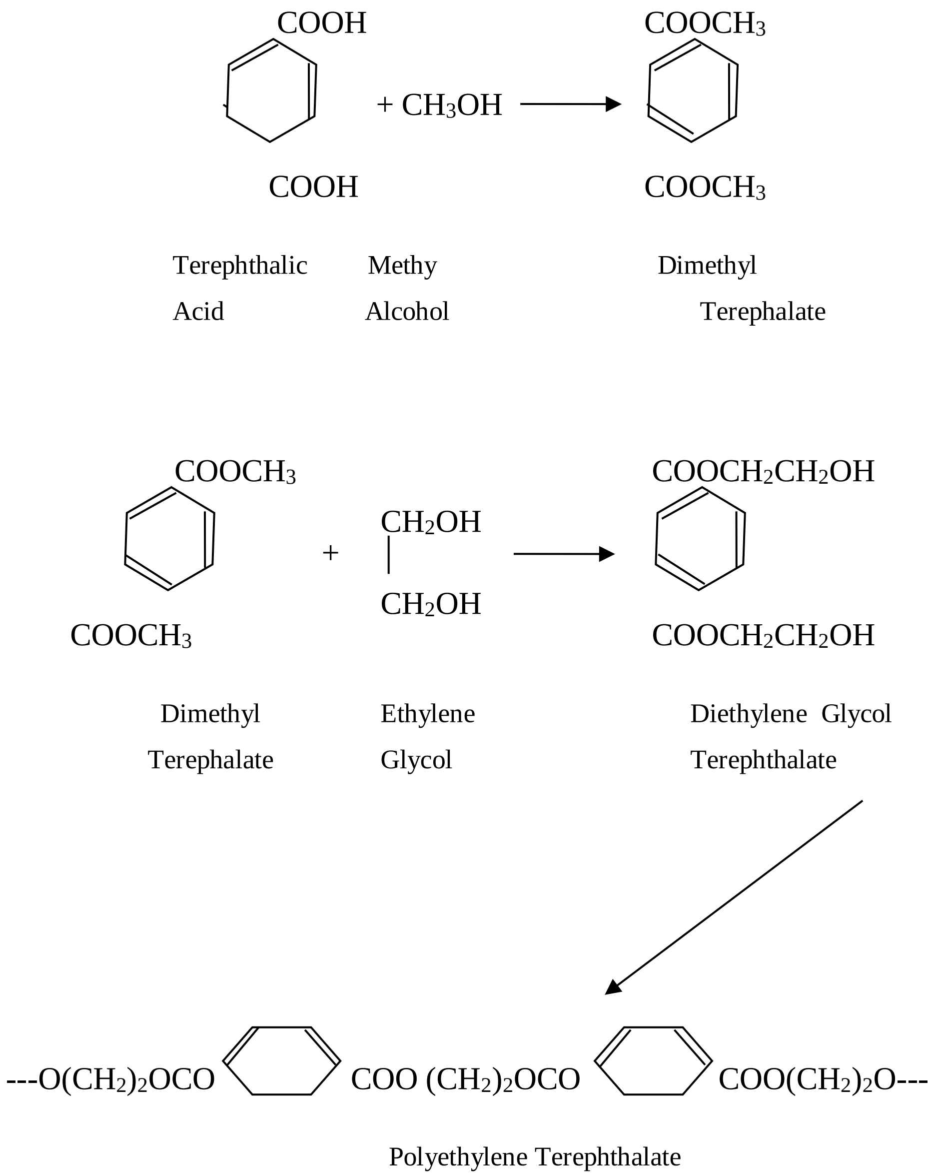


Figure 3.3 Production of recycle polyethylene terephthalate

Chapter-4

DATA ANALYSIS OF VIRGIN AND RECYCLE PET

4.1 ENERGY AND WASTE OF PET RESIN MANUFACTURING

The textile polyester fibers are formed from the most important polymers polyethylene terephthalate. Ethylene glycol and Terephthalic acid produce polyethylene terephthalate. There are the two separate plant sections usually for producing textile polyester fiber. The melting stage reaction used to fabricate copolymers among an essential viscosity which is appropriate for manufacturing textile fiber.

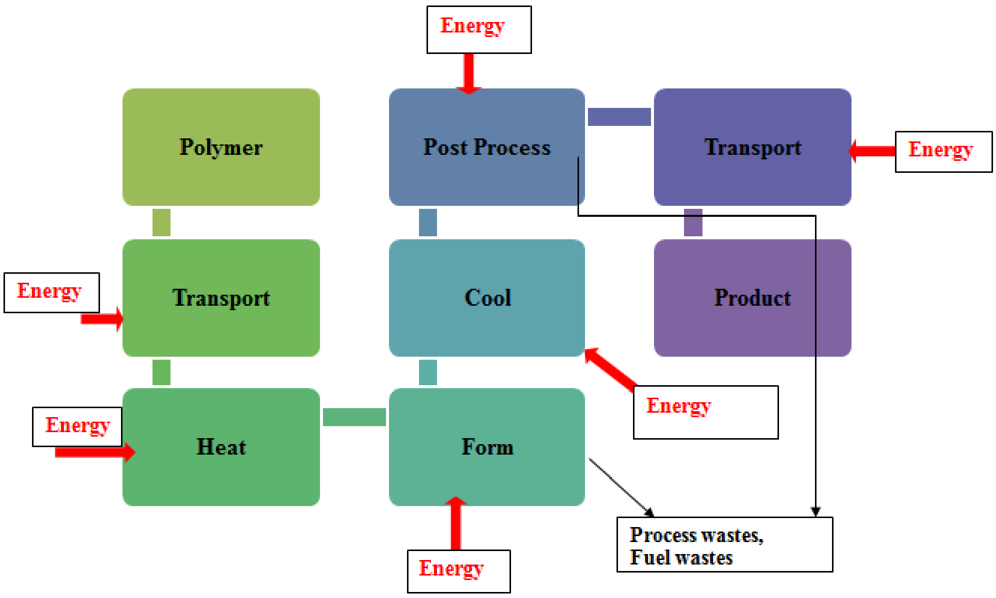


Figure 4.1: Energy uses in PET resin manufacturing (textile fiber processing)

Table 4.1: Energy requirements for resin manufacturing for 400000 wearing of polyester trouser (work ware)

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes
				Process wastes		Fuel wastes		
				Kg	M^3	Kg	M^3	
PET resin manufacture	1985000	93930.8	190000	1405.68	0.036	197730.57	0.54	0

Source: Polyester trouser manufacturing industry (Life cycle analysis of 400000 wearing of polyester trouser)

The manufacturing of resin requires of a comprehensive range of processing. The volume of the plan types prepared the manufacturing process for resin and its end use. The resin product produce may vary according to its next manufacturing product. In the resin manufacturing section consumed 19, 85,000 kWh process energy and 93930.8 kWh of transportation energy. The huge amount of material resource energy was used (1, 90,000 kWh) in this process. The processes also discharged of massive industrial process and fuel waste consequently 1405.68 kg and 197730.57kg.

4. 2 ENERGY USE AND SOLID WASTE IN MANUFACTURING PROCESS OF POLYESTER FIBER AND PACKAGING

4.2.1 Manufacturing Process of Polyester Fiber

The white powder of developed polyester PTA is fed by a twist transmits and for polymerization catalysts and TiO_2 are added. Subsequent raised the temperature high point for Esterification to form monomer. After that high temperature at 300^0C in vacuity Polymerisation which is thick sticky liquid was made. The liquid is drive to dissolve in the spinning machines. The accurate measure of polymer with fixed denier of the fiber is produce by pumping the polymer. The TOW manufacturing takes some steps. First, the polymer moves toward out of the hole of the spinneret. The cool dry air makes the polymer which comes out from the hole of the spinneret directly congeal. The polyester filament formed small ribbon. To draw the polymer, the collected ribbons are formed of a sheet to pass all the way through a channel of 70^{0}C hot water. After that the essential denier is given for all filaments.

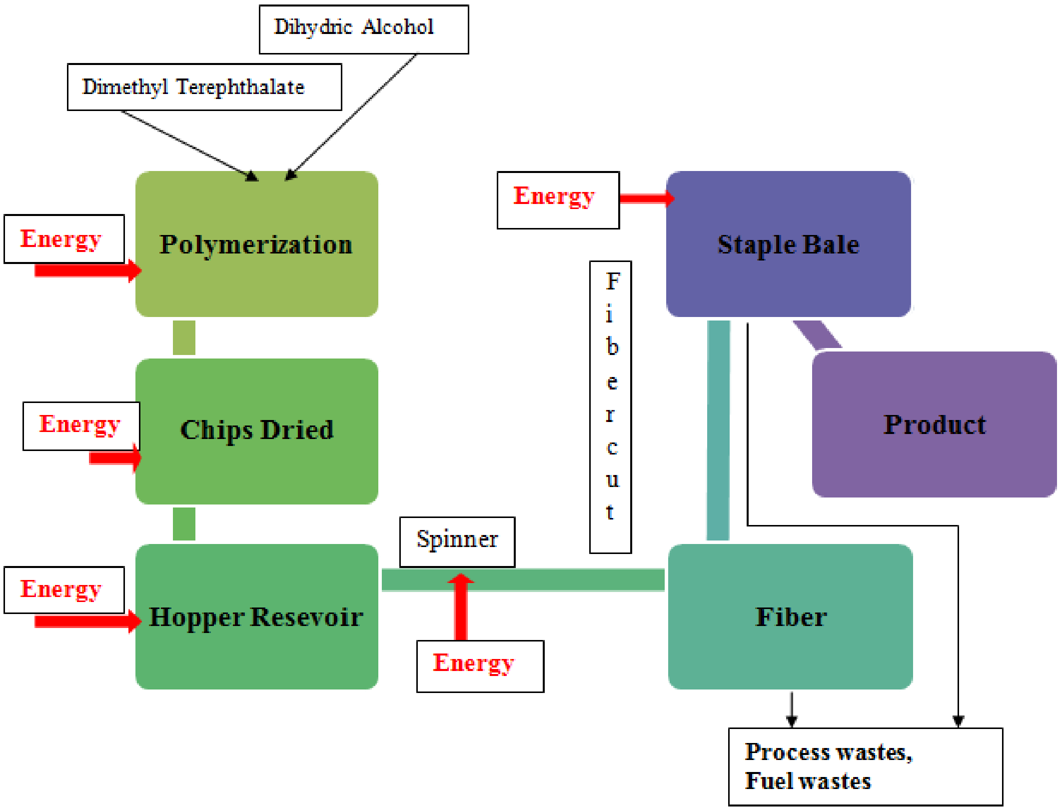


Figure 4.2: Energy uses in polyester fiber manufacturing

Table 4.2: Energy requirements for PET fiber manufacturing packaging for 400000 wearing of polyester trouser (work ware)

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
PET Fiber Manufacturing	5540.82	352.378	58.614	17.33	0.073	147.63	0.37	-	-
Packaging	450.299	82.5	78.614	1.95	.0052	8.36	0.0097	95.68	0.22

Source: Polyester trouser manufacturing industry (Life cycle analysis of 400000 wearing of polyester trouser)

The manufacturing of PET Fiber involves of all-inclusive range processing and packaging procedures. The length of the preparation types prepared the manufacturing process for preparing different quality of yarn and fabric. The shape and size of the fiber may vary according to manufacture of different quality of yarn and fabric and its end uses. In the fiber manufacturing sector consumed 5540.82 kWh process energy and 352.378 kWh of transportation energy. In additionally packaging unit of fiber also used 450.299 kWh process energy and 82.5 kWh of transportation energy. 58.614 kWh material resource energy was used in this process, moreover 78.614 kWh in packaging. The process was throwing out of considerable industrial process waste and fuel waste therefore 17.33kg and 147.63kg. The packaging unit released post-consumer wastes of 95.68kg.

4.3 DYE MANUFACTURING

Manufacturing process the companies use the latest obtainable process technology for the production. This section includes the energy consumption and solid waste made during dye manufacturing, chemical reactions, and mass balance of each product.

Table 4.3: Energy requirements for Dye manufacturing and packaging for 400000 wearing of polyester trouser (work ware)

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
Dye manufacture	1 865.355	69.307	-	7.83	0.005	35.76	0.033	-	-
Packaging	50.39	28.30	28.51	.75	.002	2.36	0.0037	25.68	0.002

The Dye manufacture engages of comprehensive range handing out and packaging dealings. The preparation of different dyes prepared the manufacturing process for preparing different types of color for different yarns and fabrics. The manufacturing of dye differs according to fabricate of different purpose and products. In the dye manufacturing subdivision consumed 1 865.355 kWh process energy and 69.307 kWh of transportation energy. Furthermore packaging unit of dye manufacturing required 50.39 kWh process energy and 28.30 kWh of transportation energy. 28.51 kWh material resource energy was used in this packaging process. The process has significant industrial process waste and fuel waste and post consumer disposal.

4.3.1 Polyester Dyeing

Polyester can be very challenging to dye properly. The dyeing of hydrophobic fibers like polyester fibers with disperse dyes may be considered as a process of dye transfer from liquid solvent (water) to a solid organic solvent (fiber) [22]. Firstly, fabric was loaded and added required water label and raise temperature to 60^{o} C. After that NOF was added and increased temperature to 90^{o}C for 10 min. In this step again required water label was added and temperature 45 ^{o} C than Neutracid was added (10 min). In fourth steps dye dosing for 45 minutes where temperature 130 ^{0}C. Subsequent to cooling at 70^{0}C checking shade was completed for bath drop step in addition Hydrose+ Caustic at 80^{0}C for 20 min. After completing hot wash acetic wash at was done in cold temperature for 10 minutes. Acetic Acid + Softener were added at 45^{0}C & run for 10 min then cold wash fabric unload [22].

4.4 FABRIC MANUFACTURING

Polyester fiber is usually drawn to about five times its original length. It is even and long fiber as well as bright fiber. Most of the fiber is circular conversely square, oval and hollow fibers can also be created. On the other hand, drawing it out additional makes it thinner and this process produce latest microfibers. The expected color of polyester fiber was given in dyeing section.

4.4.1 Weaving

Generally there are three types of polyester fabric manufacturing process; weaving, knitting and nonwoven. Among them weaving technology is widely used to polyester manufacturing fabric [33]. The process of producing a polyester fabric by interlacing warp and weft threads is known as weaving. The machine used for polyester weaving is known as weaving machine or loom. Different fabrics are produced in Weaving Industry. These fabrics are weaved by using various looms and related machines. Before going straightly to the Weaving process; some pretreatment and pre-process should be carried out. Before weaving various processes are done. After spinning process, yarns are divided into two forms, one is weft form and another is warp form. Weft yarns are produced by cop winding and warp yarn are produced by wool winding process [23].

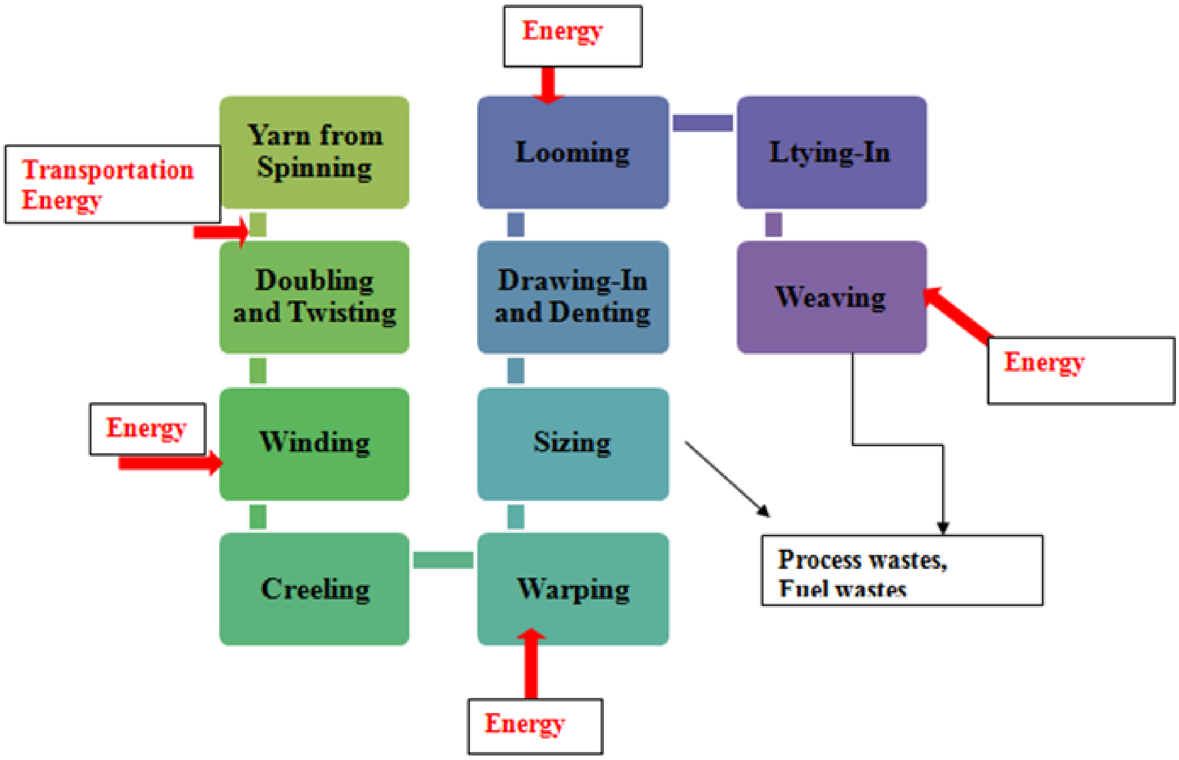


Figure 4.3: Energy uses in polyester fabric manufacturing

Table 4.4: Energy requirements for polyester fabric manufacturing and packaging for 4, 00,000 wearing of polyester trouser (work ware).

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
Fabric Manufacture	4.235505 $\times 10^4$	285.149	-	17.74	0.083	631.23	0.73	-	-
Packaging	586.835	49.307	29.307	4.85	0.0021	9.73	0.013	185.68	0.48

4.5 APPAREL PRODUCTIONS

Ready-made garments production is a planned action containing of sequential procedures. Fabrics source and storing, fabric relaxing, garments design, marker making, spreading, cutting, sewing, quality and quantity inspection, concluding finishing and packaging and shipment. In this process converting fabric into finished apparel products. Apparel industry sourcing and storing fabric according to their requirements from textile industry.

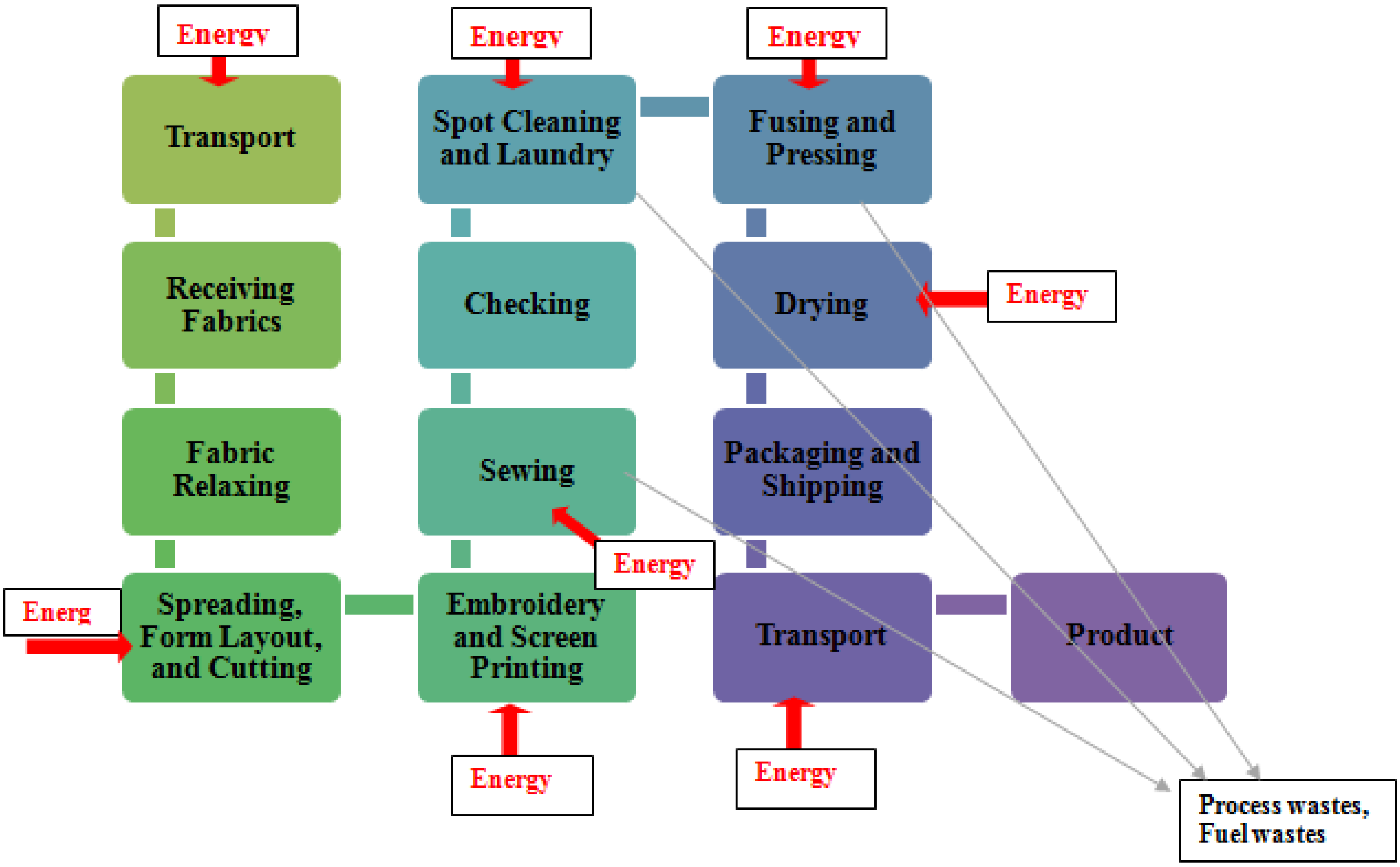


Figure 4.4: Energy uses in polyester apparel manufacturing

Relaxing is necessary because fabric needs to relax and convention previous to being manufactured. The polyester fabric material is repetitively under rigidity all through the different phases of the textile developed process, including weaving, dyeing, printing finishing, packaging etc. Afterward the fabric relaxation is done; fabrics are spread in cutting table for cutting according to marker. Finally, the fabric is cut by considering all parameters of cutting and checking quality to the according to design using one or the other manually operated cutting equipment or a computerized cutting system. After that embroidery or printing is completed using semi-automatic or computerize automated machines. Printing is also completed by using drying energy. Sewing is done after cutting, shorting, bundling and tacking according to garments parts, color and size. In the sewing section garments are sewn in a proper production line according to its preparation and assembling. Additionally, fusing machines is used for fusing collar cuff and others parts of the garments.

The semi-automatic, automatic and comprised sewing machines use maximum energy during garments parts preparations and assembling. In concluding in this phase of manufacture a product retail-ready, apparels are folded, tagged, sized, and packaged according to buyer specifications. Moreover, the apparel product may be placed in defending plastic bags, either manually or using an automated system, to ensure that the material stays clean and pressed during transport. Lastly, the product are placed in cardboard boxes and shipped to consumer distribution centers to finally be sold in selling stores. Most apparel products are packed in plastic bags, either at the end of assembly or when they enter the finished goods store.

Table 4.5: Energy requirements for polyester apparel manufacturing and packaging for 4, 00,000 wearing of polyester trouser (work ware).

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
Apparel production	334.456	2842.789	--	51.74	0.243	1831.23	2.13	-	-
Packaging	5 773.500	176.535	--	12.85	0.61	27.73	0.313	396.68	14.8

4.6 DETERGENTS MANUFACTURING

The manufacturing of detergent involves of a comprehensive range processing and packaging procedures. The size of the plan types prepared the manufacturing process for different types of detergent. Detergent product and packaging may vary according to its end uses. In the detergent manufacturing segment consumed 7183.799 kWh process energy and 844.756 kWh of transportation energy. It is also release 322.23/0.13 kg/m^3 of fuel waste.

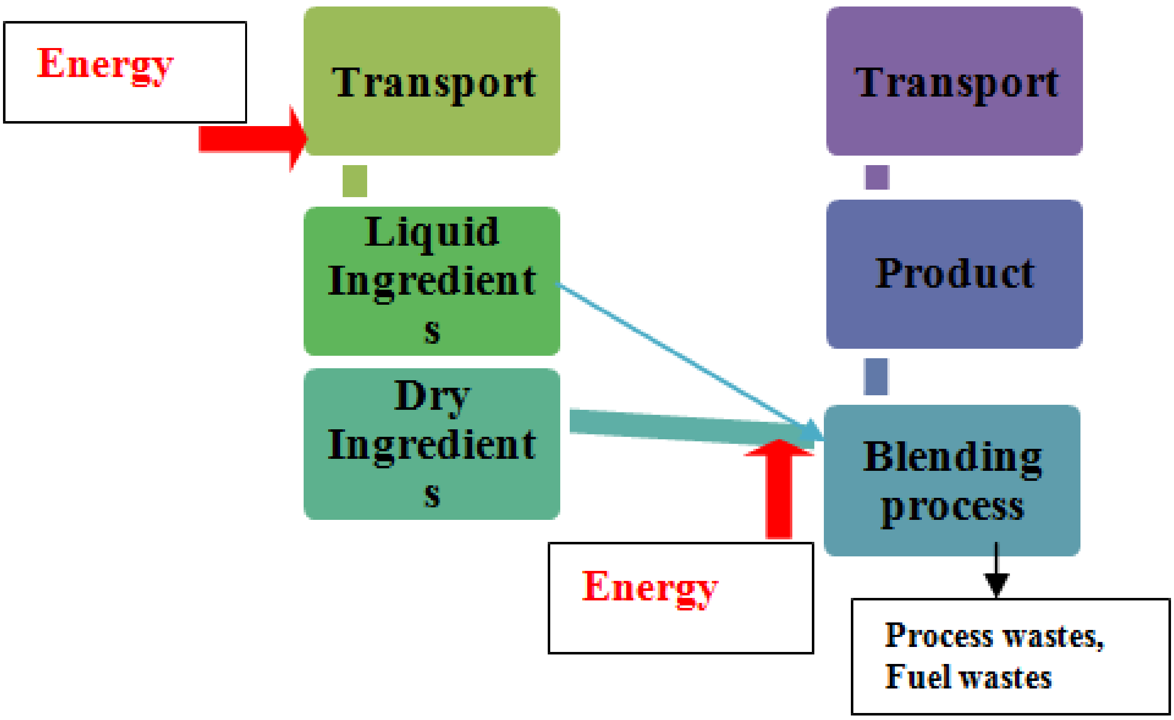


Figure 4.5: Energy uses in detergents manufacturing

Table 4.6: Energy requirements for polyester apparel manufacturing and packaging for 4, 00,000 wearing of polyester trouser (work ware).

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
Detergent Manufacture	7 183.799	844.756	2 904.961	03.24	0.023	322.23	0.13	-	-
Packaging	3 930.710	97.921	186.535	2.85	0.001	0.63	0.011	56.68	2.8

4.7 CONSUMER USE

The Industrial process wastes, fuel wastes and solid waste creation analysis are presented in Table 4.7 presents the solid waste issues of the polyester trouser (work ware) consumer use of laundry and postconsumer disposal. Consumer use and postconsumer disposal generate the principal percentage of the waste [24]. Most of the solid waste produced during after using. In the period of consumer use 4.830 795 $\times 10^5$ kWh energy was use for laundry and 1022.23/56.13 kg/$m^3$of fuel waste. Almost 297200 kg of the postconsumer waste creation after consumer use and disposal. The disposal also consumed 234.456 kWh transportation energy.

Table 4.7: Energy requirements for polyester apparel during consumer laundering and postconsumer waste for 4, 00,000 wearing of polyester trouser (work ware).

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
Laundry	4.830795 $\times 10^5$	-	-	-	-	1022.23	56.13	126.20	65.3
Post consumer disposal	-	234.456	-	-	-	0.2	00	297200	238.2

4.8 RECYCLE POLYESTER

4.8.1 Inventory Analysis

To get the positive effect of energy inputs, emissions to air, to surface water and as solid waste Life Cycle Inventory analysis was done. The analysis also computed and made out environmental saddle crossing method limitations. The investigation data were represented the direct environmental dilemma connected with polyester fabric waste recycling activities and re-ported for every stage of the recycling procession. And also the indirect environmental problem allied with the fabrication, transportation and use processes of all the needs for carrying out the different polyester fabric waste in recycling activities were calculated from secondary data of 100% polyester fabric recycling industry (the name of the industry was ignored due to restrictions and business development intention). The required transport system was an environmental burden for fabric waste collection. The transportation consumes energy and consequences in noteworthy air emissions. The scrutinize of transportation stated an energy consumption of 0.16 kWh/kg of collected 100% polyester apparel waste. There was an additional small number of recycling processes which was tasted for recycling and manufacturing polyester fabric by energy and emission minimizing to use wastage polyester fabric similar to PET bottle recycling. High automatic textile recycling machine which was mainly used to process yarn waste, textile fabric waste for re-spinning was convalesce polyester fiber from textile fabric waste. The mechanical system (forces and movement and function) of high automatic textile recycling machine was considered to produce the fiber form from the wastage polyester fabric. The energy consumptions data averaged for the high automatic textile recycling machine was identical to 1.35 kWh/kg of process yarn waste, textile fabric waste for re-spinning. Subsequent to that bleaching was completed to remove color to develop finished white. The scouring and bleaching of wastage polyester fabric was done combined by using wetting agent, detergent, peroxide stabilizer, caustic soda, soda ash and H_2O_2.The categorization stage colored and white every stage of the sorting process was observed by evaluating the energy and material consumptions [25]. In general categorization efficiency, averaged was process energy 0.90 kWh /kg and energy material resource 0.16 kWh /kg.

Manual categorization and selection of polyester fabric materials to automatic mechanization procedures that involve tear up, separate. Some fabrics are also separated by color before they are recycled. The polyester apparel recyclables are then frayed. These ragged remains then endure processes to put an end to impurities like labels, buttons, and zippers. This material was melted and often extruded into the form of bits which are then used to manufacture new products which was kept exposed of landfills because the polyester fabric takes five hundred years to breakdown. Polyester can convert petroleum-based waste streams such as plastics into fuels and carbons [26-30]. Heat compression provided all unsorted, cleaned polyester fabric in soft and hard plastic forms. For Plastic or other polymer compatibilization there was developed used another process in which many kinds of plastic can be used as a carbon source in the recycling of scrap steel [31]. There is also a possibility of mixed recycling of different plastics, which does not require their separation. It is called compatibilization and requires use of special chemical bridging agents' compatibilizers [32]. It can help to keep the quality of recycled material and to skip often expensive and inefficient preliminary scanning of waste plastics streams and their separation/purification [33].

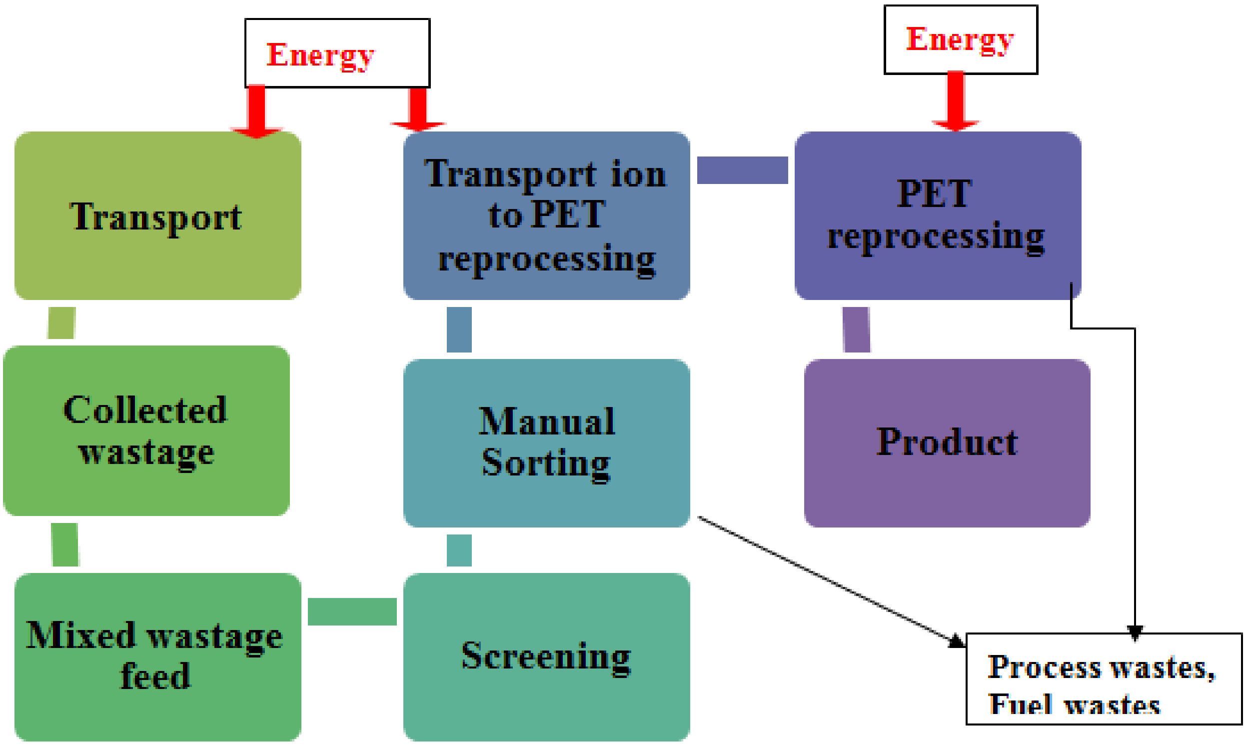


Figure 4.6: Energy uses in Recycle Polyester

Polyethylene Terephthalate $(C_{10}H_8O_4)_n$ and mono-ethylene glycol produced oligomers at 250° c on the other hand polyethylene terephthalate and methanol generated dimethyl terephthalate. It produced terephthalic acid buy adding polyethylene terephthalate (pet) and water etc. Hydrolysis, aminolysis, alcolysis and glycolysis processed was used for de-polymerization treatment to turn the fabric into staple or filament yarn. The hydrolysis process provided the terephthalic acid which esterified with methyl alcohol to form dimethyl terephthalate. Recycled polyethylene terephthalate made by condensing ethylene glycol with either terephthalic acid itself or with dimethyl terephthalate. The glycolysis process provided dimethyl terephthalate. Condensation of ethylene glycol with terephthalic acid is an esterification reaction, water being eliminated as the reaction takes place [32]. The condensation carried out by heating the ethylene glycol and terephthalic acid or dimethyl terephthalate and removing the water or methyl alcohol in vacuo. High temperature provided the polymerization of colorless polyester chips. The polyester chips provided the undrawn yarn.

Table 4.8: Energy requirements for recycle polyester fiber for 4, 00,000 wearing of polyester trouser (work ware).

<table>
<tr><td rowspan="3"></td><td rowspan="3">Process energy</td><td rowspan="3">Transportation energy</td><td rowspan="3">Energy of material resource</td><td colspan="4">Industrial</td><td rowspan="3">Post-consumer wastes</td></tr>
<tr><td colspan="2">process wastes</td><td colspan="2">fuel wastes</td></tr>
<tr><td>Kg</td><td>M^3</td><td>Kg</td><td>M^3</td></tr>
<tr><td rowspan="2">Recycled polyester fiber</td><td>1.35 kWh/kg</td><td rowspan="2">0.16 kWh/kg</td><td rowspan="2">Resource 0.16 kWh /kg.</td><td rowspan="2">0.001</td><td rowspan="2">00</td><td rowspan="2">0.51</td><td rowspan="2">.0002</td><td rowspan="2">-</td></tr>
<tr><td>energy 0.90 kWh /kg</td></tr>
</table>

The study showed in reprocessing phase that the industry of polyester fabric recycling strongly connects the PET and the PE procedures for recycling and produce polyester filament as well as polyester yarns. The industries process signifies the specific and the average energy consumptions [34]. Process energy consumptions 1.35 kWh/kg and energy 0.90 kWh /kg. The table demonstrates of transportation consumption of 0.16 kWh/kg of collected 100% polyester apparel waste.

4.9 CONSUMER USE OF RECYCLE POLYESTER

The Industrial process wastes, fuel wastes and solid waste creation analysis are presented in Table 4.9 highlights the solid waste contributions of the polyester trouser (work ware) consumer use of laundry and postconsumer disposal. Consumer use and postconsumer disposal create the largest portion of the waste. Most of the solid waste produced during after using.

Table 4.9: Energy requirements for recycling 4, 00,000 wearing of polyester trouser (work ware).

	Process energy [kWh]	Transportation energy [kWh]	Energy of material resource [kWh]	Industrial				Post-consumer wastes	
				Process wastes		Fuel wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
Laundry	4.830795 $\times 10^5$	-				1022.23	56.13	126.20	65.3
Post-consumer disposal		234.456				0.2	00	00	00

Chapter-5

ANALYSIS OF 100% POLYESTER TROUSER (WORK WARE)

5.1 MATERIALS AND MEASUREMENT OF THE TROUSER

Figure: 5.1 Name polyester suede (100% polyester)

The material of fabric was 100% polyester, commercial name polyester suede, and satin style golden and blue color which features was anti static, shrinkage resistant and one side light brushed. Fabric width was 48 inches weight 120 GSM. Small size trouser was considered for this analysis. The trouser back length was (inseam) -28" body rise-13", back crotch width -15", hem height -1½", back allover allowance -½", front pocket facing length ,width, allowance -8", 5", ½", belt loop length, width, allowance-17.5", 2", 0, waist band length, width -36" , 2", waistband allowance -½" considering wastage 5%. The pocketing fabric weight was neglected in this study due to a smaller amount of weight.

5.2 FABRIC CONSUMPTION

Table Fabric consumption of the trouser

$$\text{Fabric Consumption} = \frac{\text{Full Length} \times \text{Crotch or Thigh width (Back)} \times 4}{\text{Fabric Width} \times 36''} + \text{wastage\% yard/piece}$$

Full Length =Trouser Length (In Seam + Body Rise) +Hem Height+ Allowance

=(28"+13")+1½" + ½"

Full Length= 43"

Crotch (Back) = Back Crotch + Allowance

= 15" + ½ "+ ½"

Crotch (Back) = 16"

Fabric width = 48" Without selvage its usable width 47"

Wastage = 5%

So,

(i)Front and back consumption

$$= \frac{43'' \times 16'' \times 4}{47'' \times 36''} + \text{Wastage 5\% yard / piece}$$

= 1.626 + 5% Wastage

= 1.626 +0.0813

= 1.7073 yard/piece for fabric width 48/47…………..**(i)**

Front pocket facing length ,width, allowance8", 5", ½"

(ii)Front pocket facing consumption

$$= \frac{9'' \times 6'' \times 2}{47'' \times 36''} + \text{Wastage 5\% yard / piece}$$

= 0.0638 yard

…………………………………………......**(ii)**

belt loop length, width, allowance 17.5", 2", 0 (iii)belt loop consumption $= \frac{17.5'' \times 2'' \times 1}{47'' \times 36''}$ + Wastage 5% yard / piece

= 0.020 yard

…………………………………………….....**(iii)**

waist band length, width 36"

, 2" waistband allowance

½"

(iv)waist band facing consumption $= \frac{37'' \times 3'' \times 1}{47'' \times 36''}$ + Wastage 5% yard / piece

= 0.0656 yard ……………………………………..….....**(iv)**

(v)Trouser fabric consumption = (i)+ (ii)+ (iii)+(iv)

= 1.7073 + 0.0638 + 0.020 + 0.0656

= 1.8567 yards/ piece…….……………………………………………......(v)

5.3 Yarn Consumption

5. 3.1 Fabric construction

- EPI (Ends per inch) and PPI (Picks per inch)
- Yarn count (warp count and weft count)
- Fabric width

Fabric construction = $\frac{\text{(Warp count x Weft count)}}{\text{Ends per inch x Picks per inch}}$ x Fabric width [33].

Canvas Fabric construction = $\frac{54 \times 54}{160 \times 144} \times 48$

5.3.2 Experiment 1-warp yarn count

Warp Yarn Length = (7.3cm x 30)/100 =2.19m [30 scraps yarn, 1yarn length=7.3cm]

Warp Yarn Weight = 0.024 gm

Ne= L x w / W x l = 2.19 m x 453.6gm / 0.024gm x (840 x 0.91m) = 54

5.3.3 Experiment 2-weft yarn count

Length = (8cm x 31) m/100 =2.48m [31 scraps yarn, 1yarn length=8 cm]

Weight=0.0275 gm

Ne = L x w/ W x l = 2.48 m x 453.6gm / 0.0275 gm x (840 x 0.91m =54

5.3.4 Experiment 3-Crimp percentage (warp crimp and weft crimp)

Crimp= L-p/p x 100, Warp Crimp = 7.5-7.3/7.3 x 100 = 2.74% and Weft Crimp = 8.21-8/ 8 x 100 =2.62%. So, average crimp of warp and weft yarn is 2.68%.

5.3.5 Experiment 3-Fabric Weight

Fabric GSM = (EPI/warp count + PPI/Weft count) x (100+crimp %) X 0.2327 GSM = (160/54+ 144/54) X (100+2.68%) X 0.2327 = 135gm/ m^2

5.3.6 Weight of 4, 00,000 Pieces Trousers

Fabric construction= (54 × 54/160 × 144) × 48".

Total weight of warp yarn in one yard fabric = EPI × Fabric width × Crimp allowance /840 × Warp Count = 160 x 48 × 2.74/840 x 54 =.464 lb. So, total weight of warp yarn in one yard fabric 0.464 lb. Total weight of weft yarn in one yard fabric = PPI × Fabric width × Crimp allowance /840 × Weft Count = 144 x 48 × 2.62/ 840 × 54 =0.40 lb. So, total weight of weft yarn in one yard fabric = 0.40 lb. The weight of yarn in one yard fabric is (0.464 lb + 0.40 lb) 0.864 lb or 0.40 kg (0.864 × 453.6/ 1000). The weight of one trouser was 0.743 kg (1.8567 yards/ piece ×0.40 kg). So, 4, 00,000 pieces of polyester trouser (work ware) weight was **2, 97,200 kg** (0.743 kg ×4, 00,000).

Chapter- 6

RESULTS & DISCUSSIONS

6.1 RESULTS & DISCUSSION

Results are explained on the base of process energy, transportation energy, energy of material resource and releases of industrial process wastes, fuel wastes and solid waste of 4, 00,000 wearing (100% polyester trouser work ware) and also calculated the very small numbers associated with the single virgin and recycle polyester. The results of the energy consumption analysis are presented in Table 6.1 indicates the comparative segment of energy. Most of this energy is spending during resign and fiber manufacturing. The analysis accessible fabric manufacturing and packaging unit used more energy than apparel production. All the process stage eroded huge transportation energy. The results of the solid waste formation analysis are also presented in Table 6.1 highlights the solid waste contributions of the polyester trouser manufacturing operations. Simultaneously, apparel production packaging and fabric manufacturing packaging unit produced more solid waste in trouser production. Fabric production and apparel manufacturing engender the principal segment of the solid waste from the trouser manufacturing process. The largest part of the solid waste formed during apparel manufacturing is created from covering used in transporting the ended trouser to the merchant and customer. Almost 92% of the post-consumer waste creation occurs after completion of the manufacturing process and is directly related to consumer use and disposal.

Table:6.1 Energy consumption and solid waste configuration during **virgin polyester** trouser manufacturing operations (4, 00,000 pieces).

Manufacturing Stage of Product	Process Energy	Transportation Energy	Energy of Material Resource	Industrial				Post-Consumer Wastes	
	[kWh]	[kWh]	[kWh]	Process Wastes		Fuel Wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
PET resin manufacture	1985000	93930.8	190000	1405.68	0.036	197730.57	0.54	0	0
PET fiber Manufacturing	5 540.82	352.378	58.614	17.33	0.073	147.63	0.37	0	0
Packaging	450.299	82.5	78.614	1.95	0.0052	8.36	0.0097	95.68	0.22
Dye manufacture	1 865.355	69.307	0	7.83	0.005	35.76	0.033	0	0
Packaging	50.39	28.3	28.51	0.75	0.002	2.36	0.0037	25.68	0.002
Fabric manufacture	4.235 505 $\times 10^4$	285.149	0	17.74	0.083	631.23	0.73	0	0
Packaging	586.835	49.307	29.307	4.85	0.0021	9.73	0.013	185.68	0.48
Apparel production	334.456	2842.789	0	51.74	0.243	1831.23	2.13	0	0
Packaging	5 773.500	176.535	0	12.85	0.61	27.73	0.313	396.68	14.8
Detergent manufacture	7 183.799	844.756	2904.961	3.24	0.023	322.23	0.13	0	0
Packaging	3 930.710	97.921	186.535	2.85	0.001	0.63	0.011	56.68	2.8
Laundry	4.830 795 $\times 10^5$	0	0	0	0	1022.23	56.13	126.2	65.3
Postconsumer disposal	0	234.456	0	0	0	0.2	0	2556.68	238.2
Total (4, 00,000 pieces trouser,(Table1,Appendix A)	**1986422**	**98994.2**	**190382**	**1526.81**	**1.0833**	**201769.9**	**60.4134**	**3443.28**	**321.802**
One kg (for virgin product)	**6.683788627**	**0.333089**	**0.64058**	**0.005137**	**4E-06**	**0.6789027**	**0.000203**	**0.011586**	**0.001083**

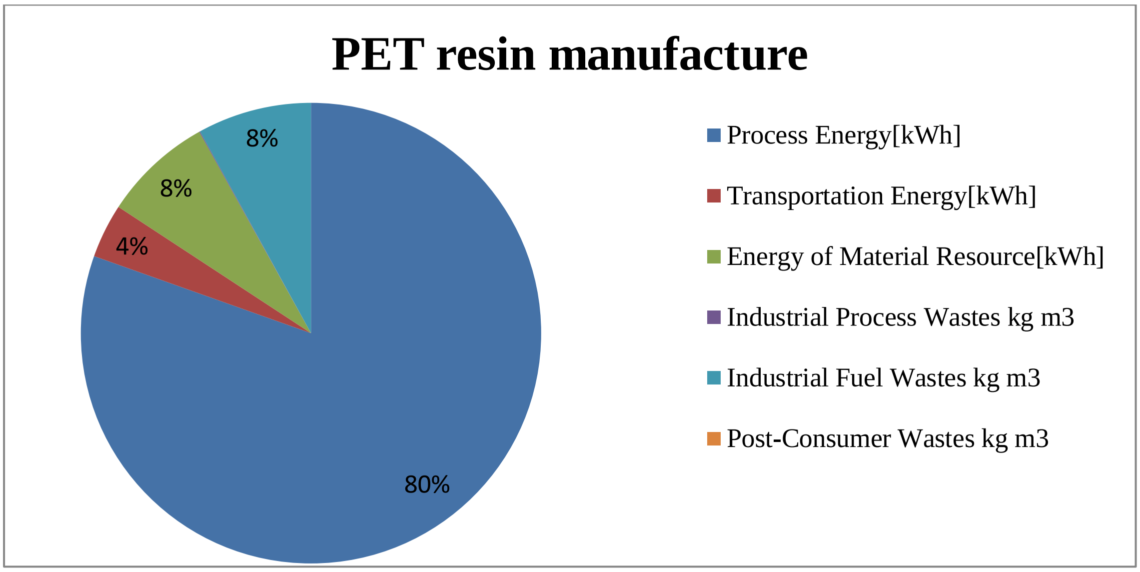


Figure: 6.1 Energy use and solid waste of PET resin manufacturing

There are inclusive ranges of processing for resin manufacturing. In the first stage of the virgin product requirements 80% process energy and 4% of transportation energy. It is also spending 8% energy of material resource and turn out 8% industrial process and fuel waste totally.

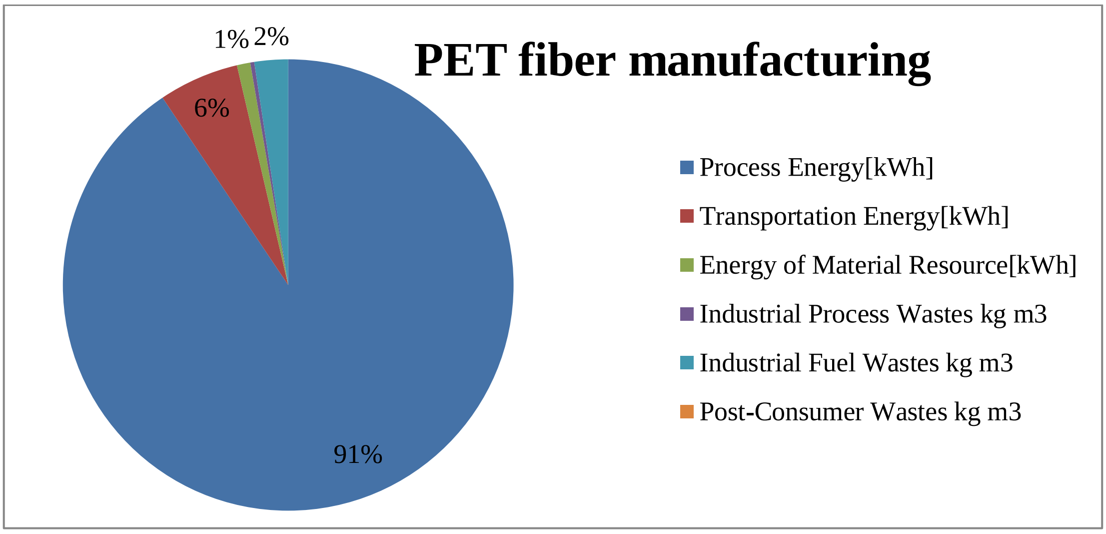


Figure: 6.2 Energy use and solid waste of PET fiber manufacturing.

In the second stage of the virgin product consumed 91% process energy and 6% of transportation energy. It is also consumed 1% material resource energy and produces 2% of industrial process and fuel wastage.

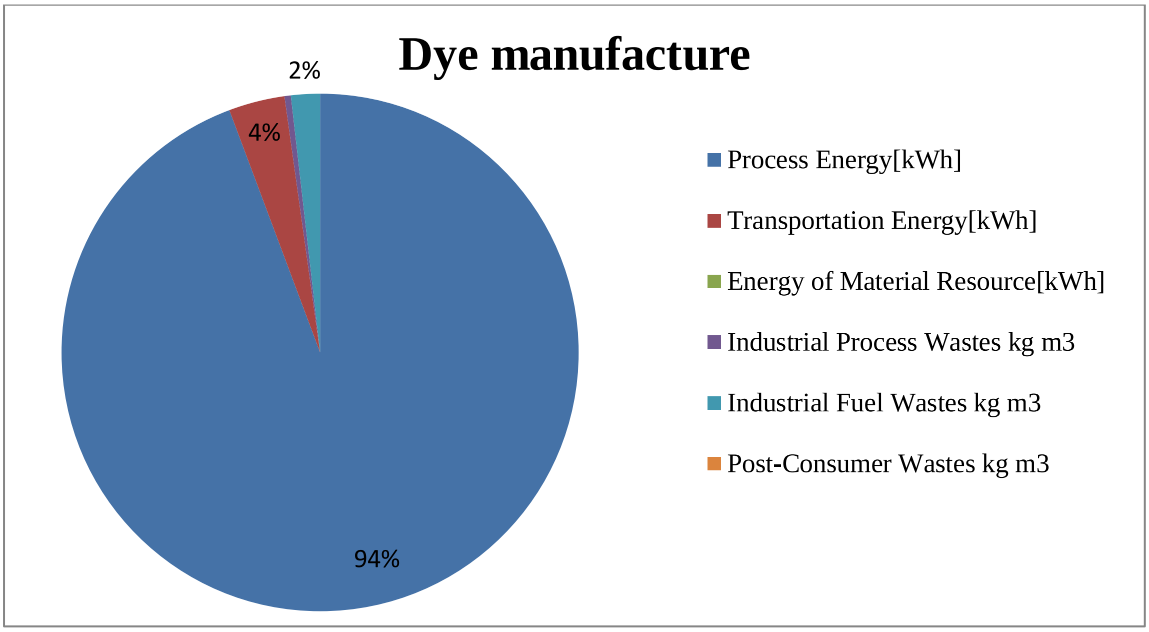


Figure: 6.3 Energy use and solid waste of dye manufacturing

In the dye manufacturing consumed 94% process energy and 4% of transportation energy. It is also create 2% of industrial process and fuel wastage.

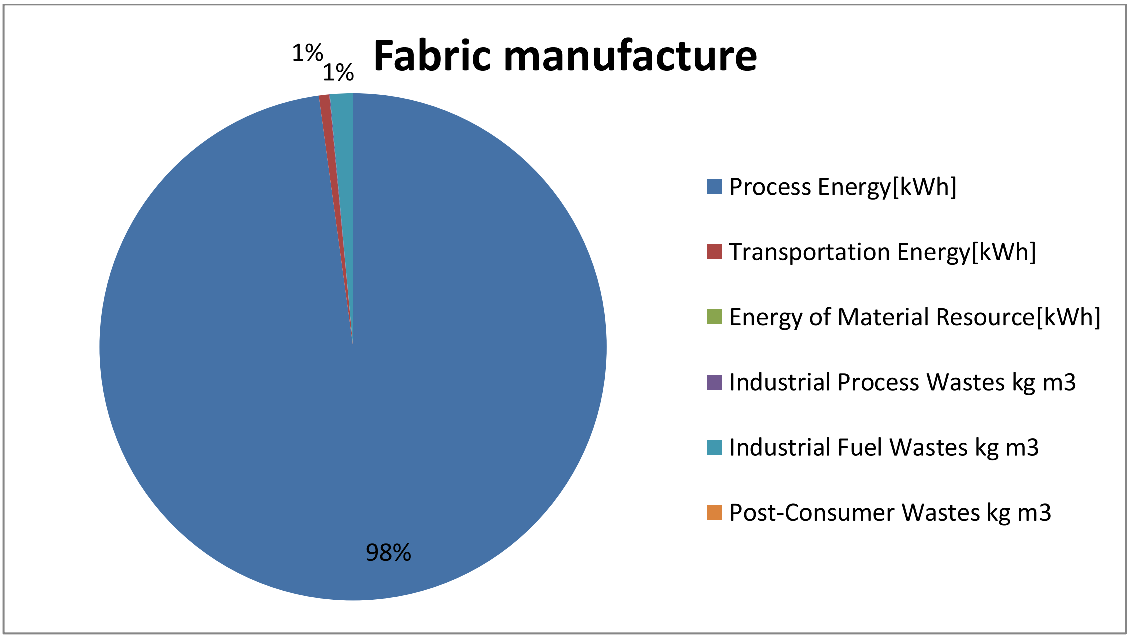


Figure: 6.4 Energy use and solid waste of fabric manufacturing

In the fabric manufacturing stage of the virgin product consumed 98% process energy and 1% of transportation energy. It is also makes1% of industrial fuel wastage.

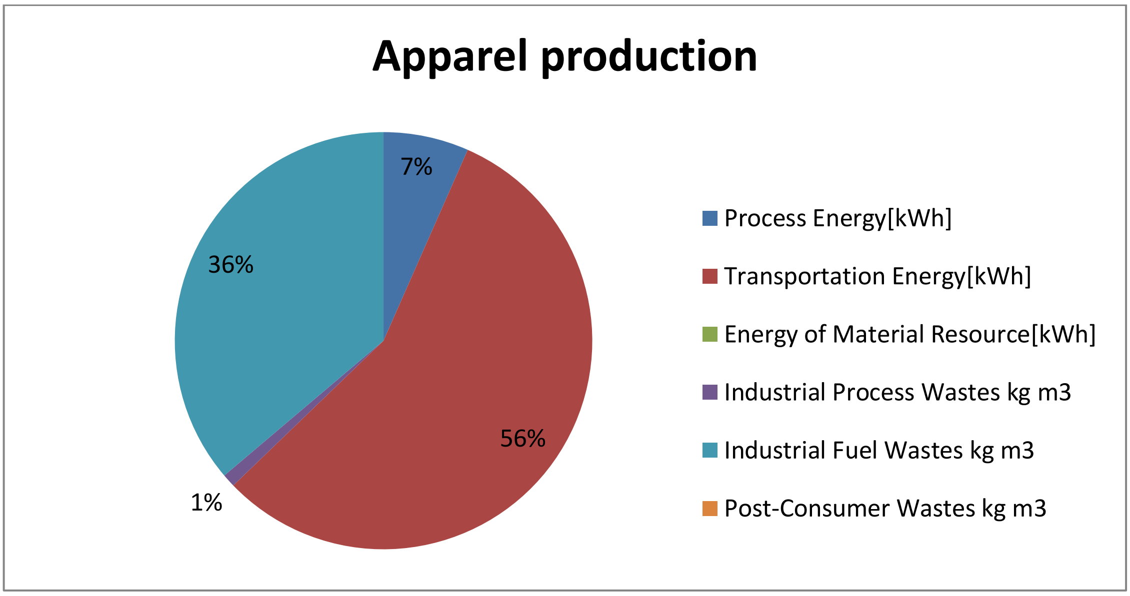


Figure: 6.5 Energy use and solid waste of apparel production

In the apparel production phase of the virgin product consumed only 7% process energy and 56% of transportation energy. It is also release 1% of industrial process waste and 36% of fuel waste.

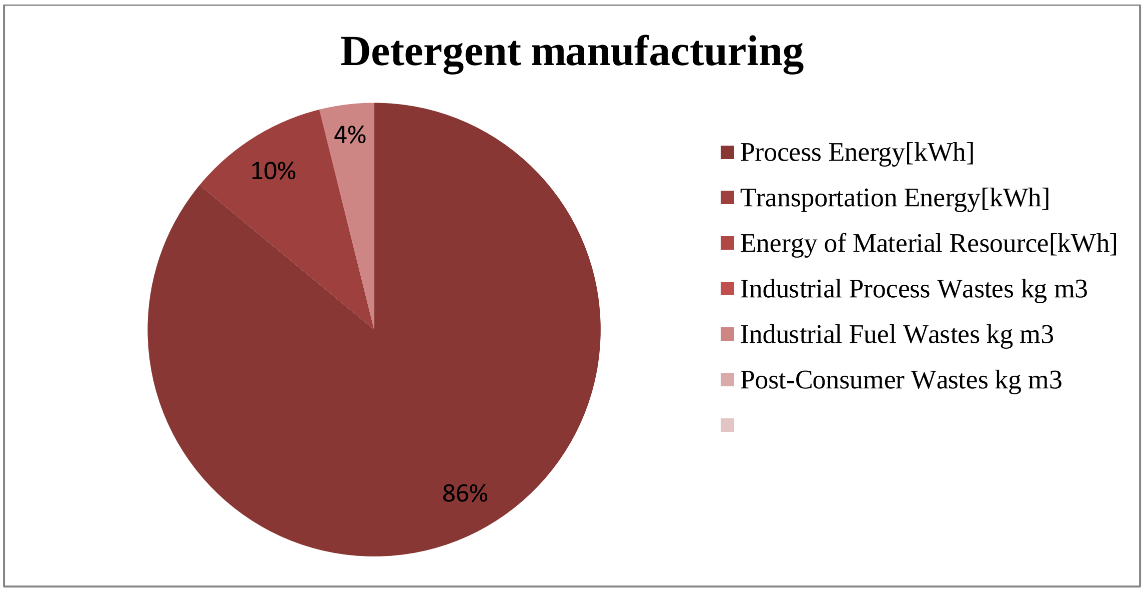


Figure: 6.6 Energy use and solid waste of detergent manufacturing

In the detergent manufacturing segment consumed 86% process energy and 10% of transportation energy. It is also release 4% of fuel waste.

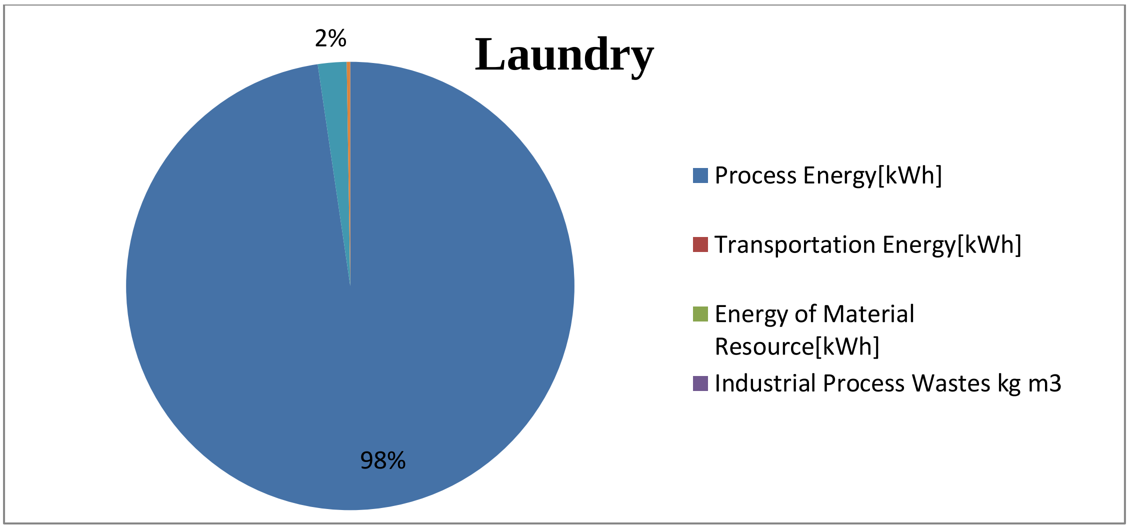


Figure: 6.7 Energy use and solid waste of laundry.

In the period of consumer use 98% energy was use for laundry and 2% of fuel waste.

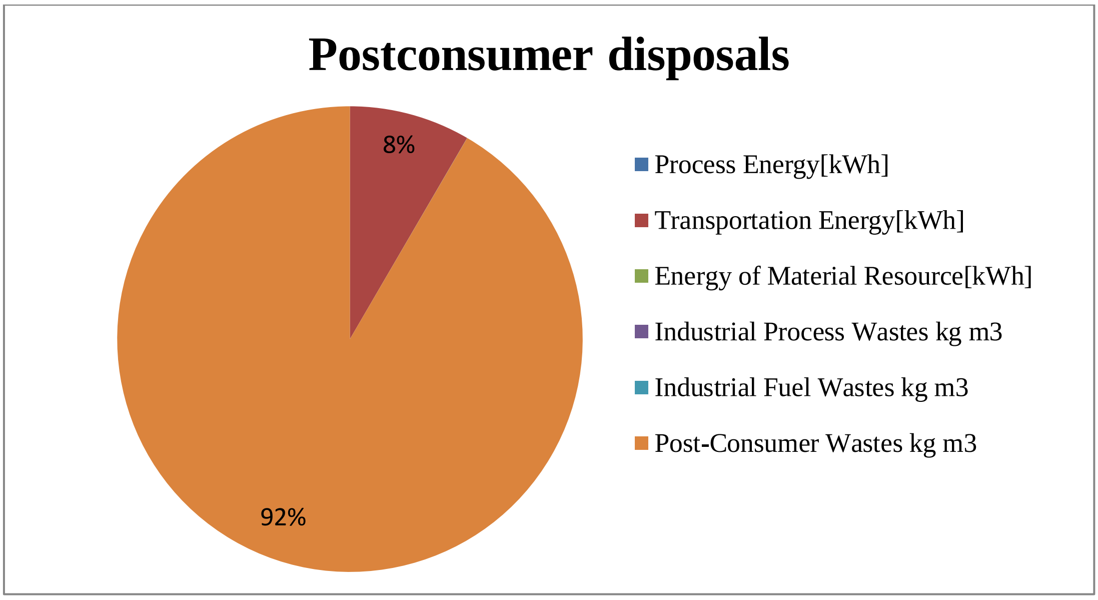


Figure: 6.8 Postconsumer disposals

Almost 92% of the postconsumer waste formation occurs after conclusion of the manufacturing procedure and is directly related to consumer use and disposal. The disposal also consumed 8% transportation energy.

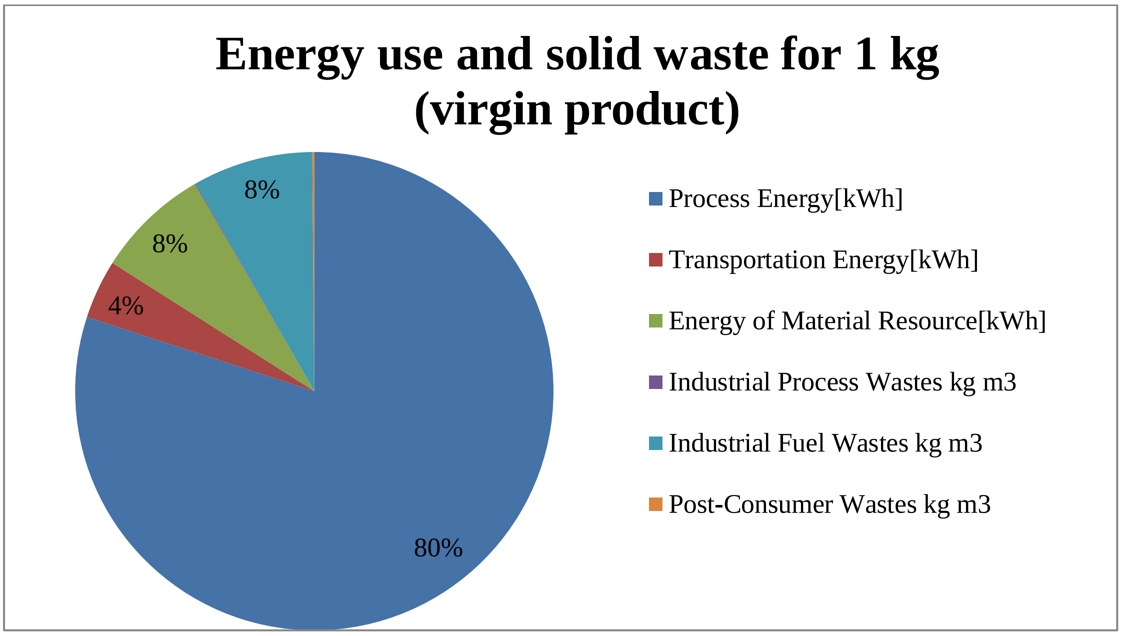


Figure: 6.9 Energy use and solid waste for 1 kg (virgin product)

1 kg virgin product consume 80% process energy of its total, 4% transportation energy, 8% energy consumed from material resources and create 8% of industrial waste.

Table: 6.2 Energy consumption and solid waste configuration for 4, 00,000 pieces trouser (weight 2, 97,200 kg) during recycling.

	Process energy	Transportation energy	Energy of material resource	Industrial				Post-consumer wastes
				process wastes		fuel wastes		
				Kg	M^3	Kg	M^3	
Recycled polyester fiber (raw materials) kWh/kg	1.35	0.16	0.16	0.001	0	0.51	0.0002	-
4, 00,000 pieces trouser weight (2,97,200 kg)	401220	47552	47552	297.2	0	151572	59.44	

Table: 6.3 Energy consumption and solid waste configuration during recycled polyester trouser manufacturing operations (4, 00,000 pieces).

Manufacturing Stage of Product	**Process Energy[kWh]**	**Transportation Energy[kWh]**	**Energy of Material Resource [kWh]**	**Industrial Process Wastes**		**Industrial Fuel Wastes**		**Post-Consumer Wastes**	
				Kg	M^3	Kg	M^3	Kg	M^3
Recycled polyester kWh/kg	**1.35**	**0.16**	**0.16**	**0.001**	**0**	**0.51**	**0.0002**	**-**	
4, 00,000 pieces (weight 297200 kg) (resin/raw materials)	401220	47552	47552	297.2	0	151572	59.44	0	0
PET Fiber manufacturing	5 540.82	352.378	58.614	17.33	0.073	147.63	0.37	0	0
Packaging	450.299	82.5	78.614	1.95	0.0052	8.36	0.0097	95.68	0.22
Dye manufacture	1 865.355	69.307	0	7.83	0.005	35.76	0.033	0	0
Packaging	50.39	28.3	28.51	0.75	0.002	2.36	0.0037	25.68	0.002
Fabric manufacture	4.235 505×10^4	285.149	0	17.74	0.083	631.23	0.73	0	0
Packaging	586.835	49.307	29.307	4.85	0.0021	9.73	0.013	185.68	0.48
Apparel production	334.456	2842.789	0	51.74	0.243	1831.23	2.13	0	0
Packaging	5 773.500	176.535	0	12.85	0.61	27.73	0.313	396.68	14.8
Detergent manufacture	7 183.799	844.756	2 904.961	3.24	0.023	322.23	0.13	0	0
Packaging	3 930.710	97.921	186.535	2.85	0.001	0.63	0.011	56.68	2.8
Laundry	4.830 795 ×10^5	0	0	0	0	1022.23	56.13	126.2	65.3
Postconsumer disposal	0	0	0	0	0	0	0	0	0
Total 4, 00,000 pieces trouser, (Table 2, appendix A)	402641.98	52380.942	47933.58	418.33	1.0473	155611.12	119.3134	886.6	83.602
One kg (for recycle product)	1.35478459	0.17624812	0.161283917	0.001407571	3.5E-06	0.5235906	0.0004015	0.0029832	0.000281

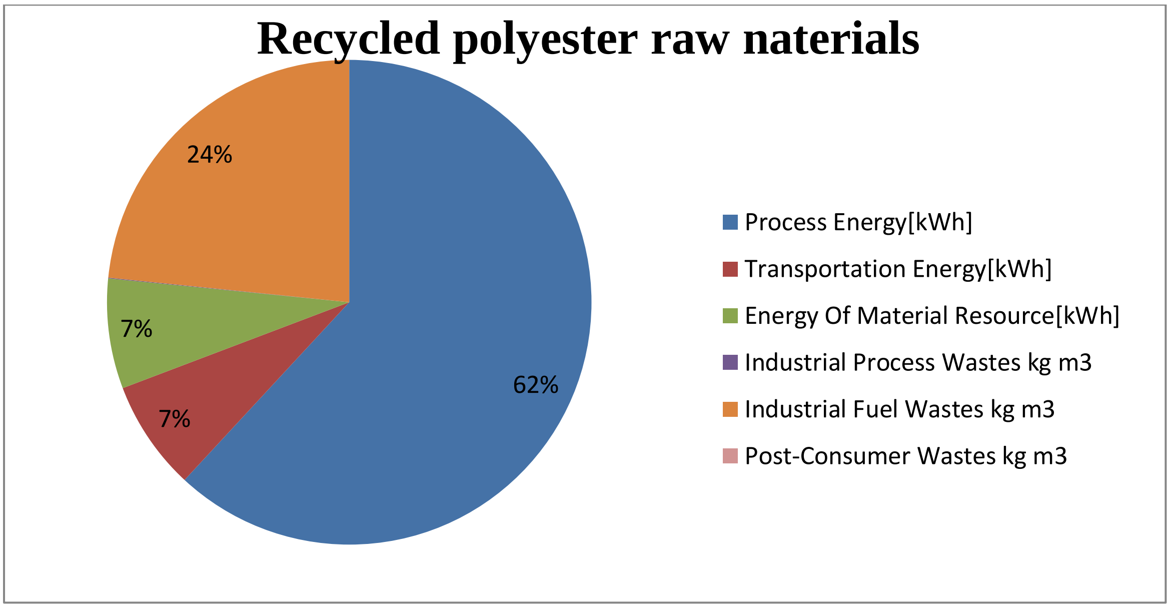


Figure: 6.10 Energy use and solid waste of PET recycling

In the first stage of the recycled product necessities only 62% process energy of its total energy and 7% of transportation energy. It is also consumed only 7% energy of material resource and turn out 24% of industrial fuel wastage.

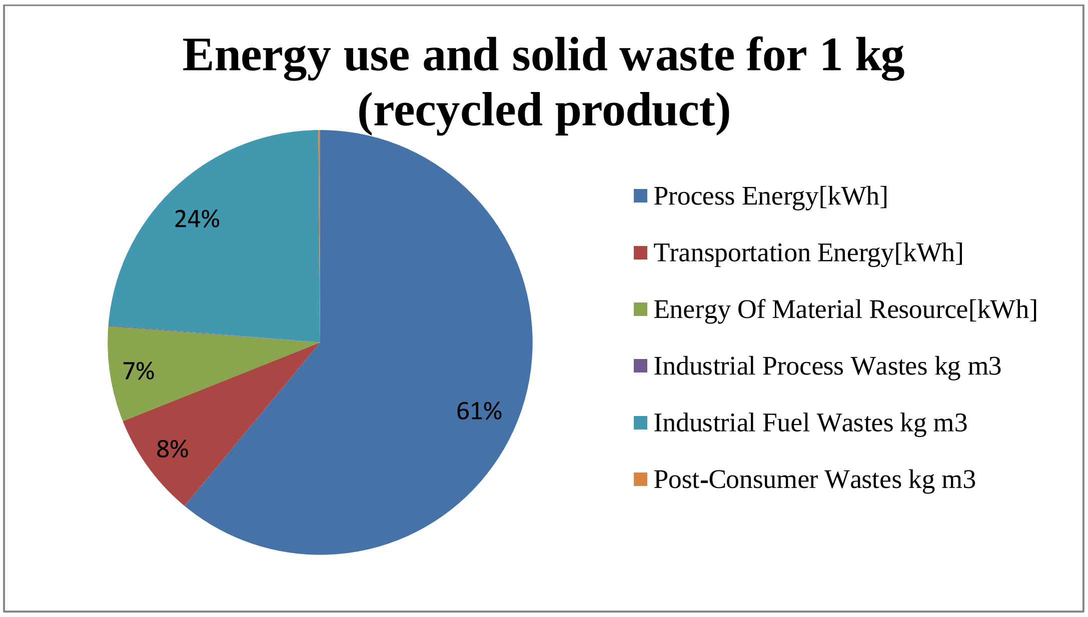


Figure: 6.11 Energy use and solid waste for 1 kg (recycled product)1 kg recycled product requirements only 61% process energy of its total energy and 8% of transportation energy. It is also consumed only 7% energy of material resource and turn out 24% of industrial fuel wastage.

Table: 6.4 Evaluation of energy consumption and solid waste formation in 1 kg virgin and recycled polyester materials manufacturing.

Manufacturing Stage of Product	Process Energy [kWh]	Transportation Energy [kWh]	Energy of Material Resource [kWh]	Industrial				Post-Consumer Wastes	
				Process Wastes		Fuel Wastes			
				Kg	M^3	Kg	M^3	Kg	M^3
One kg (for virgin product)	6.683789	0.333089	0.640584	0.005137	3.65E-06	0.678903	0.000203	0.011586	0.001083
One kg (for recycle product)	1.354785	0.176248	0.161284	0.001408	3.52E-06	0.523591	0.000401	0.002983	0.000281

In the primary phase of the virgin product consumed 80% process energy where the recycled product requirements only 62% process energy of its total energy. On the other hand the virgin product needs 4% of transportation energy but 7% of transportation energy however recycle product raw material is solid wastage and it's consumed more energy than virgin product. Virgin product also consumed 8% energy of material resource and turn out 8% industrial process where recycling consumed only 7% energy of material resource and produce 24% of industrial fuel wastage. Approximately 92% of the postconsumer waste formation occurs after end of the manufacturing procedure and is directly related to consumer use and disposal. The disposal also consumed 8% transportation energy where recycling consumed 0.01% postconsumer waste. On the other hand 1 kg virgin product consume 80% process energy of its total, 4% transportation energy, 8% energy consumed from material resources and create 8% of industrial waste. But 1 kg recycled product requirements only 61% process energy of its total energy and 8% of transportation energy. It is also consumed only 7% energy of material resource and turn out 24% of industrial fuel wastage

Table: 6.5 Assessments of energy consumption and solid waste creation for single virgin and recycled polyester trouser manufacturing and consumer using and post-consumer disposal (Table 3, Appendix A)

Manufacturing Stage of Product	Process Energy[kWh]	Transportation Energy[kWh]	Energy of Material Resource[kWh]	Industrial Process Wastes		Industrial Fuel Wastes		Post-Consumer Wastes	
				Kg	M^3	Kg	M^3	Kg	M^3
Energy an solid waste for single virgin trouser	4.966055227	0.247485127	0.47595391	0.00381679	2.71E-06	0.504425	0.000151	0.008608	
Energy an solid waste for single recycle trouser	1.006605255	0.130952264	0.11983401	0.00104614	2.62E-06	0.389028	0.000298	0.002216	0.000209

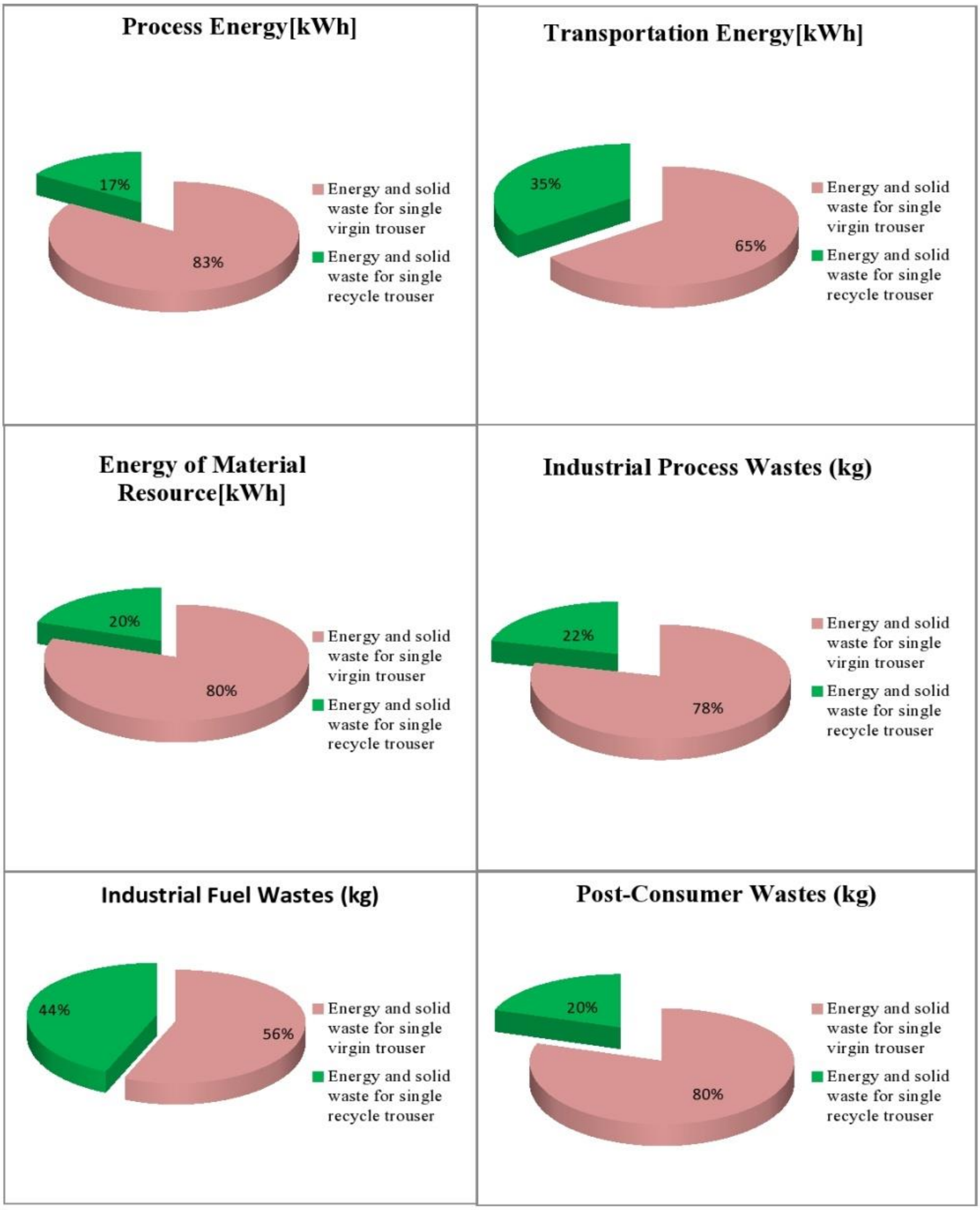
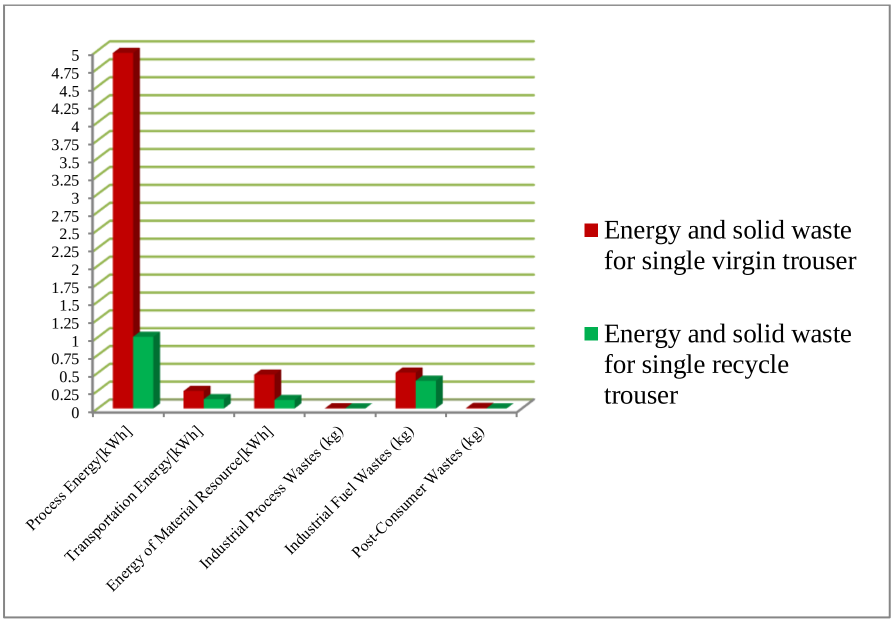


Figure: 6.12 Estimation of energy consumption and solid waste creation for single virgin and recycled polyester trouser manufacturing and consumer using and post-consumer disposal

Figure: 6.13 Assessments of energy consumption and solid waste creation for single virgin and recycled polyester trouser manufacturing and solid waste.



The main segment of the evaluation result of virgin trouser (work ware) and recycle trouser presented that the virgin trouser consumed 83% of process energy on the other hand the recycled trouser needs only 17% process energy of its life cycle. In additional the virgin trouser consumed 65% of transportation energy but recycling used 35% of transportation energy in its one life cycle. In the third phase 80% energy of materials resources was used for virgin polyester trouser where recycle polyester trouser needs only 20% of materials resources energy. Virgin trouser produce huge industrial waste which was process waste 78% and 56% of fuel waste but the recycling trouser generate only 22% industrial process waste and fuel waste only 44%.end of the life cycle the virgin trouser has 80% post-consumer waste excluding the recycling trouser has only 20% post-consumer wastes. The results interpret that enormous energy savings for trouser recycling in its one life cycle.

Chapter- 7

CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

On this basis, we conclude that the resin manufacture of virgin polyester trouser expends maximum energy in process phase and limited energy for transportation and releases few industrial process and fuel wastage. Broadly translated our findings indicate that virgin fiber consume full of its total energy for manufacturing along with few industrial waste. This is an important finding in the understanding of the dye manufacturing also eroded more process energy with limited of transportation energy. Dye manufacture period also discharged hazard waste in environment. More generally, these basic findings are consistent with research showing that fabric manufacturing needs additional process energy on the other hand apparel production phase and packaging unit consumed less energy than transportation. In addition, these findings provide additional information about detergent manufacturing segment which consumed material resources energy and process energy more in its processing unit by discharging hazardous waste in environment. It is also consumed average transportation energy. Importantly, our results provide evidence for consumers are consuming big proportion of energy for laundry of the trouser and release fuel waste. We have shown that the ending of the manufacturing procedure and packaging is directly related to consumer use and disposal. The trouser disposal also consumed transportation energy. This conclusion follows from the fact that one kilogram virgin polyester expend 80% process energy of its total manufacturing, packaging and consumer energy and also created 8% waste in one life cycle. Nevertheless, we found that the recycled polyester consumed with a reduction of process and transportation energy during recycling. The recycling reduces the dependency on raw materials as well as decrease post-consumer waste. This conclusion follows from the fact that one kilogram virgin polyester spends 80% process energy of its total manufacturing, packaging and consumer energy and also created 8% waste in one life cycle. Collectively, our results appear consistent with one kilogram recycled polyester requirements only 61% process energy where virgin polyester takes 80% process energy in addition to an immense reduction of post-consumer waste. This experiment adds to a growing corpus of research showing that the principal part of the virgin polyester resin manufacturing consumed more process energy than recycle polyester. In conclusion, it would appear that the virgin product needs fewer of transportation energy than recycle product. The present findings confirm that recycling releases more industrial fuel waste than virgin polyester along with using identical material recourse energy. The findings of this study can be understood as the virgin polyester produced postconsumer waste which is directly related to consumer use and disposal. The disposal also consumed transportation energy conversely recycling has no postconsumer waste.

The analysis leads to the following conclusions the recycling of polyester reduce 66% of process energy from virgin polyester trouser in its one life cycle. However, we found recycle trouser are diminishing 30% transportation energy. Recycle has an immeasurable reduction of materials resources energy. Recycle trouser condense 56% of industrial process waste over and above 12% of fuel waste. These findings provide a potential mechanism for zero expulsion of postconsumer waste. This aspect of the research recommended that polyester fabric recycling which melodramatically reduce process energy and also decrease the dependency of raw materials during resin manufacturing and fiber construction. The limited emission and use of energy and industrial process and fuel waste will formulate the recycle polyester trouser as an emerald product for our environment. And those steps place encumber of reducing energy use and environmental pollution on their consumers rather than changing the way their clothing is made. The development of the factories on effective fabric recycling, reprocess, re-design method produce sustainable product which will save the earth environment. So, both eco-friendly product and recycling need to be established everlastingly. Without any agricultural land, exclusive of consuming gallons of water like cotton we will get recycled polyester which has unlimited life span.

REFERENCES

[1] Kumar A., Recycling Process of Polyester, Textile Learner, https://textilelearner.blogspot.com/2014/11/major-formula-on-garments-for-beginners.html.

[2] Shen, L., Nieuwlaar, E., Worrell, E., & Patel, M. K. (2012). Life cycle energy and GHG emissions of PET recycling: change-oriented effects. The International Journal of Life Cycle Assessment, 16(6), 522-536.

[3] F. Welle, "Twenty years of PET bottle to bottle recycling—an overview," Resources, Conservation and Recycling, vol. 55, no. 11, pp. 865–875, 2011.

[4] Khoonkari, M., Haghighi, A.H., Sefidbakht, Y., Shekoohi, K. and Ghaderian, A., 2015. Chemical recycling of PET wastes with different catalysts. *International Journal of Polymer Science*, *2015*.

[5] Barnes, D. K., Galgani, F., Thompson, R. C., &Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B, 364, 1985–1998.

[6] L. Bartolome, M. Imran, B. G. Cho, W. A. Al-Masry, and D. H. Kim, "Recent developments in the chemical recycling of PET," in Material Recycling—Trends and Perspectives, D. Achilias, Ed., InTech, 2012.

[7] V. Sinha, M. R. Patel, and J. V. Patel, "PET waste management by chemical recycling: a review," Journal of Polymers and the Environment, vol. 18, no. 1, pp. 8–25, 2010.

[8] A. Ghaderian, A. H. Haghighi, F. A. Taromi, Z. Abdeen, A. Boroomand, and S. M.-R.Taheri, "Characterization of rigid polyurethane foam prepared from recycling of PET

waste," PeriodicaPolytechnica Chemical Engineering, vol. 59, no. 4, pp. 296–305, 2015. View at Publisher

[9] Barnes, D. K., Galgani, F., Thompson, R. C., &Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B, 364, 1985–1998.

[10] Da Costa, J. P., Santos, P. S., Duarte, A. C., & Rocha-Santos, T. (2016).(Nano) plastics in the environment–sources, fates and effects. *Science of the Total Environment*, *566*, 15-26.

[11] Sivan A (2011) New perspectives in plastic biodegradation. CurrOpinBiotechnol 22:422–426

[12] Gregory MR (2009) Environmental implications of plastic debris in marine settings: entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Philos Trans R SocLondSer B BiolSci 364:2013–2025.

[13] Browne MA, Galloway T, Thompson R (2007) Microplastic—an emerging contaminant of potential concern? Integr Environ AssessManag 3:559–561.

[14] Barnes DKA, Galgani F, Thompson RC, BarlazM (2009) Accumulation and fragmentation of plastic debris in global environments. Philos Trans R SocLondSer B BiolSci 364:1985–1998

[15] Zitko V, Hanlon M (1991) Another source of pollution by plastics: skin cleansers with plastic scrubbers. Mar Pollut Bull 22:41–42Environ SciPollut Res (2017) 24:21530–21547 21547

[16] Gregory MR (1996) Plastic 'scrubbers' in hand cleansers: a further (and minor) source for marine pollution identified. Mar Pollut Bull 32: 867–871

[17] Fendall LS, SewellMA(2009) Contributing tomarine pollution bywashing your face: microplastics in facial cleansers. Mar Pollut Bull 58: 1225–1228

[18] The Self-Sufficiency Handbook: A Complete Guide to Greener Living by Alan Bridgewater pg. 62--Skyhorse Publishing Inc., 2007 ISBN 1-60239-163-7, ISBN 978-1-60239-163-5

[19] Themelis, N. J., Castaldi, M. J., Bhatti, J., & Arsova, L. (2011). Energy and economic value of non-recycled plastics (NRP) and municipal solid wastes (MSW) that are currently landfilled in the fifty states. New York, NY: Columbia University.

[20] Sharma, S. and Chatterjee, S., 2017. Microplastic pollution, a threat to marine ecosystem and human health: a short review. *Environmental Science and Pollution Research*, *24*(27), pp.21530-21547.

[21] Cook, J.G., 1984. *Handbook of textile fibres: man-made fibres*. Elsevier.

[22] Sohel R., Process Flow Chart For 100% Polyester Dyeing , Process Flow Chart For 100% Polyester Dyeing, Textile Flowchart https://www.textileflowchart.com/2015/03/process-flow-chart-for-100-polyester.html

[23] Biplob S., Major Formula on Garments for Beginners, Textile Learner,https://textilelearner.blogspot.com/2014/11/major-formula-on-garments-for-beginners.html.

[24] Furuholt, E., 1995. Life cycle assessment of gasoline and diesel. *Resources, conservation and recycling*, *14*(3-4), pp.251-263.

[25] Arena, U., Mastellone, M.L. and Perugini, F., 2003. Life cycle assessment of a plastic packaging recycling system. *The international journal of life cycle assessment*, *8*(2), p.92.

[26] Plastics Europe: Association of Plastics Manufacturers. *Waste Pre-Treatment and Sorting*. Retrieved 8 July 2015.

[27] *"ScienceDirect". www.sciencedirect.com. Retrieved 2019-03-20.*

[28] Plastic Pyrolysis Plant". RESEM Group China. Retrieved 23 October 2016.

[29] Engineer's plastic-to-fuel device passes patent office tests". The Times of India. Retrieved 23 October 2016.

[30] "Plastic 2 Oil". Retrieved 23 October 2016.

[31] M. Kreiger, G. C. Anzalone, M. L. Mulder, A. Glover and J. M Pearce (2013). Distributed Recycling of Post-Consumer Plastic Waste in Rural Areas. MRS Online Proceedings Library, 1492, mrsf12-1492-g04-06 doi:10.1557/opl.2013.258

[32] Ignatyev, I.A.; Thielemans, W.; Beke, B. Vander (2014). "Recycling of Polymers: A Review". ChemSusChem. 7 (6): 1579–1593. doi:10.1002/cssc.201300898. PMID 24811748.

[33] Kreiger, M.A.; Mulder, M.L.; Glover, A.G.; Pearce, J. M. (2014). "Life Cycle Analysis of Distributed Recycling of Post-consumer High Density Polyethylene for 3-D Printing Filament". Journal of Cleaner Production. 70: 90–96. doi:10.1016/j.jclepro.2014.02.009.

[34] Arena, U., Mastellone, M.L. and Perugini, F., 2003. Life cycle assessment of a plastic packaging recycling system. The international journal of life cycle assessment, 8(2), p.92.

APPENDICES

APPENDIX-A

Table1: Energy consumption calculations for 4, 00,000 pieces trousers.

Manufacturing Stage of Product	**Process Energy**	**Transportation Energy**	**Energy of Material Resource**	**Industrial**				**Post-Consumer Wastes**	
	[kWh]	**[kWh]**	**[kWh]**	**Process Wastes**		**Fuel Wastes**			
				Kg	**M^3**	**Kg**	**M^3**	**Kg**	**M^3**
PET resin manufacture	1985000	93930.8	190000	1405.68	0.036	197730.57	0.54	0	0
PET fiber Manufacturing	5 540.82	352.378	58.614	17.33	0.073	147.63	0.37	0	0
Packaging	450.299	82.5	78.614	1.95	0.0052	8.36	0.0097	95.68	0.22
Dye manufacture	1 865.355	69.307	0	7.83	0.005	35.76	0.033	0	0
Packaging	50.39	28.3	28.51	0.75	0.002	2.36	0.0037	25.68	0.002
Fabric manufacture	4.235 505×10^4	285.149	0	17.74	0.083	631.23	0.73	0	0
Packaging	586.835	49.307	29.307	4.85	0.0021	9.73	0.013	185.68	0.48
Apparel production	334.456	2842.789	0	51.74	0.243	1831.23	2.13	0	0
Packaging	5 773.500	176.535	0	12.85	0.61	27.73	0.313	396.68	14.8

Detergent manufacture	7 183.799	844.756	2 904.961	3.24	0.023	322.23	0.13	0	0
Packaging	3 930.710	97.921	186.535	2.85	0.001	0.63	0.011	56.68	2.8
Laundry	4.830 795 $\times 10^5$	0	0	0	0	1022.23	56.13	126.2	65.3
Postconsumer disposal	0	234.456	0	0	0	0.2	0	2556.68	238.2
Total (4, 00,000 pieces trouser, weight 2,97,200kg)	**1986422**	**98994.2**	**190382**	**1526.81**	**1.0833**	**201769.9**	**60.4134**	**3443.28**	**321.802**
4, 00,000 pieces weight (kg)	297200	297200	297200	297200	297200	297200	297200	297200	297200
One kg (for virgin product)	6.683788627	0.333089	0.64058	0.005137	4E-06	0.678902 7	0.000203	0.011586	0.001083

Table: 2 Energy consumption calculations and solid waste configuration during recycled polyester trouser manufacturing operations (4, 00,000 pieces).

Manufacturing Stage of Product	**Process Energy[kWh]**	**Transportation Energy[kWh]**	**Energy of Material Resource[kWh]**	**Industrial Process Wastes**		**Industrial Fuel Wastes**		**Post-Consumer Wastes**	
				Kg	M^3	Kg	M^3	Kg	M^3
Recycled polyester kWh/kg	**1.35**	**0.16**	**0.16**	**0.001**	**0**	**0.51**	**0.0002**	**-**	
4, 00,000 pieces (weight 297200 kg) (resin/raw materials)	401220	47552	47552	297.2	0	151572	59.44	0	0
PET Fiber manufacturing	5 540.82	352.378	58.614	17.33	0.073	147.63	0.37	0	0
Packaging	450.299	82.5	78.614	1.95	0.0052	8.36	0.0097	95.68	0.22
Dye manufacture	1 865.355	69.307	0	7.83	0.005	35.76	0.033	0	0
Packaging	50.39	28.3	28.51	0.75	0.002	2.36	0.0037	25.68	0.002
Fabric manufacture	4.235 505×10^4	285.149	0	17.74	0.083	631.23	0.73	0	0
Packaging	586.835	49.307	29.307	4.85	0.0021	9.73	0.013	185.68	0.48
Apparel production	334.456	2842.789	0	51.74	0.243	1831.23	2.13	0	0
Packaging	5 773.500	176.535	0	12.85	0.61	27.73	0.313	396.68	14.8

Detergent manufacture	7 183.799	844.756	2 904.961	3.24	0.023	322.23	0.13	0	0
Packaging	3 930.710	97.921	186.535	2.85	0.001	0.63	0.011	56.68	2.8
Laundry	4.830795 $\times 10^5$	0	0	0	0	1022.23	56.13	126.2	65.3
Postconsumer disposal	0	0	0	0	0	0	0	0	0
Total (4, 00,000 pieces trouser, weight 297200 kg)	402641.98	52380.942	47933.58	418.33	1.0473	155611.12	119.3134	886.6	83.602
4, 00,000 pieces weight (kg)	297200	297200	297200	297200	297200	297200	297200	297200	297200
One kg (for recycle product)	1.35478459	0.17624812	0.161283917	0.001407571	3.5E-06	0.5235906	0.0004015	0.00298832	0.000281

Table: 3 Assessments of energy consumption calculation and solid waste creation for single virgin and recycled polyester trouser manufacturing and consumer using and post-consumer disposal

Manufacturing Stage of Product	**Process Energy[kWh]**	**Transportation Energy[kWh]**	**Energy of Material Resource [kWh]**	**Industrial Process Wastes**		**Industrial Fuel Wastes**		**Post-Consumer Wastes**	
				Kg	M^3	Kg	M^3	Kg	M^3
One kg (for virgin product)	6.683789	0.333089	0.640584	0.005137	3.65E-06	0.678903	0.000203	0.011586	0.001083
The weight of one trouser was 0.743 kg	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743
Energy an solid waste for single virgin trouser	4.966055227	0.247485127	0.47595391	0.00381679	2.71E-06	0.504425	0.000151	0.008608	
One kg (for recycle product)	1.354785	0.176248	0.161284	0.001408	3.52E-06	0.523591	0.000401	0.002983	0.000281
The weight of one trouser was 0.743 kg	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743	0.743
Energy an solid waste for single recycle trouser	1.006605255	0.130952264	0.11983401	0.00104614	2.62E-06	0.389028	0.000298	0.002216	0.000209