ENVIORNMRNTAL IMPACT ASSESSMENT OF CUTLERY MANUFACTURING IN PAKISTAN

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DEDICATION

Dedicated to my parents, teachers, and beloved family members without those this accomplishment can never be achieved.

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ABSTRACT

The world's manufacturing industries are under tremendous pressure to meet the demands of a growing number of people due to the rapid increase in population. Manufacturing sectors are essential to the development of any country, but they also have a significant negative impact on the environment. Because of its heat-resistant and thermosetting properties, melamine material is making a lasting impression in many manufacturing industries, even though there are health concerns related to it. It is necessary to conduct systematic measurements in order to evaluate and lessen these environmental repercussions. Therefore, a thorough environmental evaluation was conducted for a cutlery manufacturing facility located in Pakistan in order to close this study gap. SimaPro 9.5 was employed as the modeling software tool, and different midpoint and endpoint impacts were assessed using ReCipe 2016 techniques. The findings showed that compared to other manufacturing processes, injection molding had the greatest environmental impact. With values of 11.8 kg CO2 eq. and 12.0 kg 1,4-DCB, respectively, global warming and terrestrial ecotoxicity were the impact categories most impacted. The human health category suffered more damage at the endpoint level than others. Four distinct alternative scenarios were generated based on energy transition and technical process intervention. These scenarios were examined for their effects on the environment as well as for economic performance. In the first alternative scenario, the injection procedure was carried out using a double-cavity mold rather than a single-cavity mold. For a number of effect categories, this intervention reduced the impact by more than 30% when compared to the baseline scenario. The effects of global warming were decreased to 8.1 kg CO2 equivalent. Three more options were based on using an injection mold with a double or single cavity and either 50% or 100% solar energy. All things considered, the combination of 50% solar energy and double-cavity mold proved to be the most advantageous of the four possible situations. This alternative demonstrated a payback period of less than three years, a net present value of 21.8 million PKRs, and a reduction of more than 50% in most of the effect areas.

Keywords: Life Cycle Assessment, Environmental Impact Assessment, Cutlery Manufacturing, Melamine.

CHAPTER 1: INTRODUCTION

1.1 Historical Background

The world population is growing at an exponential rate, and this is causing a sharp rise in the use of natural resources, making them less abundant. This is also creating immense pressure on various manufacturing industries to fulfill the demands of each and every person. Climate change is the biggest issue that world is facing due to this un-monitored usage of resources [1]. Improved production capacities that yield higher-quality products are correlated with increased revenue streams from increased exports. This phenomenon is especially noticeable in light of the world's growing population, which has led to a significant increase in both production and consuming activities. The ensuing increase in supply and demand dynamics has highlighted how important it is to develop industrial processes to meet growing global demands, which in turn affects trade balances and economic results [2]. Utensils such as spoons, forks, and plates are essential items for every person. Cutlery products hold significant significance in various domains, including households, offices, restaurants, hospitals, educational institutions, and transportation (such as airplanes and ships). They are widely utilized in these sectors. After the discovery of true stainless steel in 1913, it took 30 years of extensive research to use it in the cutlery industry [3]. Over time, various materials such as plastics, bioplastics, bamboo, and polylactic acid (PLA) have been incorporated into the production of cutlery. Another material making an impact in the cutlery industry is melamine formaldehyde resin, also known as melamine. Melamine is well-known for being tough, durable, and heat resistant. Moreover, it is affordable too, making it a popular choice due to these qualities [4]. It is common knowledge that the melamine cutlery manufacturing industry is a highly resource and energy intensive sector. As a result, it has negative effects on the environment. As recommended by the makers, melamine products are generally safe to use within specified temperature ranges, which are between 30 and 120 degrees Celsius and occasionally up to 140 degrees Celsius [5].

The initial step in the production of melamine spoons was just the straightforward weighing of melamine formaldehyde resin using a weighing machine for required production. After that, the weighted melamine resin is preheated at temperatures between 40 and 50 degrees Celsius for between 45 and 60 seconds in order to get it ready for the molding process. With the assistance of a molding process, the warmed resin is then shaped into the form of the required object (cutlery product). At last, the product is moved through the finishing process to get the desired finished product. The process flow is shown below in **Figure 1.1**.

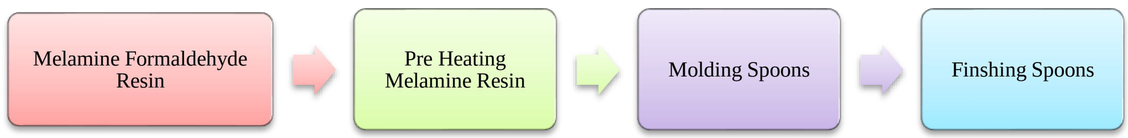

Figure 1.1: Melamine cutlery manufacturing process.

Companies are being pushed by the media and scientists to address air pollution, resource overuse, and climate change [6]. A growing number of individuals who are involved in various aspects of production such as industries, services, and goods are also considering the impact their activities have on the environment [7].

1.2 Environmental Impact Assessment

Environmental impacts refer to the adverse effects of human activities on the natural environment resulting from the utilization of environmental resources. Environmental Impact Assessment (EIA) refers to the evaluation and reduction of the adverse environmental effects associated with a project, method, product, or facility before making a decision. The initial implementations of this technology mostly concentrated on analyzing the influence of our physical surroundings. However, subsequent advancements led to the development of more comprehensive methodologies that consider both environmental and social impacts, as well as the cumulative effects resulting from their interactions. The Environmental Impact Assessment (EIA) facilitates decision-making on various environmental elements across a broad spectrum of operations. This includes decisions related to waste management plans, process installations, and location selections. In order to preserve the environmental conditions, it is necessary to evaluate the environmental impact associated with each sector. In this regard, different studies addressing different processes and products are also reported. For example, the introduction of sustainable electronic vehicles in case of transportation sector [8]. In case of manufacturing industry most of the environmental impacts are associated with the energy consumption during the process [1].

In order to determine whether an environmental impact assessment (EIA) is necessary, a screening method is first used to detect and assess potential adverse effects on the environment. The main effects are outlined in this stage for more study. The scoping phase, which comes after screening, finds and ranks important environmental issues so that the EIA concentrates on these important topics. The impact analysis phase then entails forecasting effects, investigating substitutes, and creating mitigation and monitoring strategies. Some of the strategies used in Environmental Impact Assessments such as LCA, material and substance flow analysis, carbon and water footprint are discussed below.

1.2.1 Life Cycle Assessment

Life cycle assessment (LCA) is a common method for determining how a process, product, location, or service impacts the environment at each step of its life [9].

1.2.2 A three-dimensional Environmental Approach

By emphasizing pollution prevention, a three-dimensional environmental approach attempts to address the significant sustainability issues in manufacturing. It examines three primary aspects of manufacturing: the materials utilized, the energy used, and the technologies employed [10].

1.2.3 Attributional LCA method

Using the Attributional LCA technique, the results are presented for facilitating decision-making process. These choices should result in certain, quantifiable advantages, which were calculated using the Attributional LCA technique [11].

1.2.4 Substance Flow Analysis

Measuring the amount of a substance or set of substances that enters and exits a system is done through substance flow analysis. It facilitates comprehension of their environmental impact [12].

1.2.5 Material Flow Analysis

The purpose of material flow analysis is to monitor the movement of raw materials within a certain region's industry or economy [13].

1.2.6 Carbon Footprint

The amount of greenhouse gases that are emitted into the atmosphere, either directly or indirectly, as a result of a product, service, or activity is measured by its carbon footprint [14].

1.2.7 Water Footprint

Water footprint is a term used to quantify the specific environmental impact of water use [15].

1.2.8 Risk Assessment

Risk assessment determines the likelihood that specific actions could have an adverse effect on the environment right away [16].

1.3 Cutlery Sector of Pakistan and EIA

In Pakistan, the production of cutlery has long been an important industry that is strongly ingrained in both the nation's history and its culture. The cutlery produced in Pakistan, particularly in areas such as Wazirabad, has earned appreciation on an international level due to the quality of its craftsmanship and precision. The production of high-quality cutlery, knives, forks, and other tableware is the primary focus of the sector. Stainless steel and plastics (melamine) are the primary materials used. Pakistan's position as a leading participant in the international cutlery market can be attributed, in large part, to the country's combination of time-honored manufacturing practices with more contemporary approaches.

However, the production of cutlery does have certain negative effects on the surrounding environment. The manufacturing of cutlery frequently entails operations that are resource-intensive, such as the mining of metal, the consumption of energy, and the development of waste. The Environmental Impact Assessment (also known as EIA) comes into play at this point. An environmental impact assessment (EIA) is an important process that examines the possible adverse effects that industrial activities could have on the surrounding environment and on society. In the context of the cutlery industry, an EIA can assist identify and mitigate the sector's ecological impact by promoting sustainable practices, lowering pollution levels, and conserving resources. This can be accomplished through the use of an EIA.

Pakistan can effectively reconcile the growth of its cutlery sector with its commitment to environmental stewardship by implementing eco-friendly practices and conducting thorough environmental impact studies. This will guarantee the survival of this age-old craft with the least amount of negative environmental impact. In order to achieve sustainable growth and protect the environment for the benefit of future generations, this action is crucial.

The cutlery industry contributes 0.11% of GDP. Total production value is almost 6 billion rupees per year. Industry engages almost 60,000 employees. In 2021, the export of cutlery industry of Pakistan almost reaches to around 2M US dollars. Main industrial sector of cutlery industry of Pakistan is situated in Wazirabad. The concerned location on map is also show below in **Figure 1.2**. Over 96% of the country's production is centered at Wazirabad. One big factor of more demand of cutlery products in Pakistan is the dowry culture on the occasion of weddings [17]. Melamine cutlery products are generally in more demand due to their refreshing and more fashionable looks. During last decade, a decline is seen in the performance of cutlery industry of Pakistan. A survey was conducted to address the possible problems and solutions for overcoming this decline. The major issues and barriers discussed in this survey were mostly managerial and technological [3].

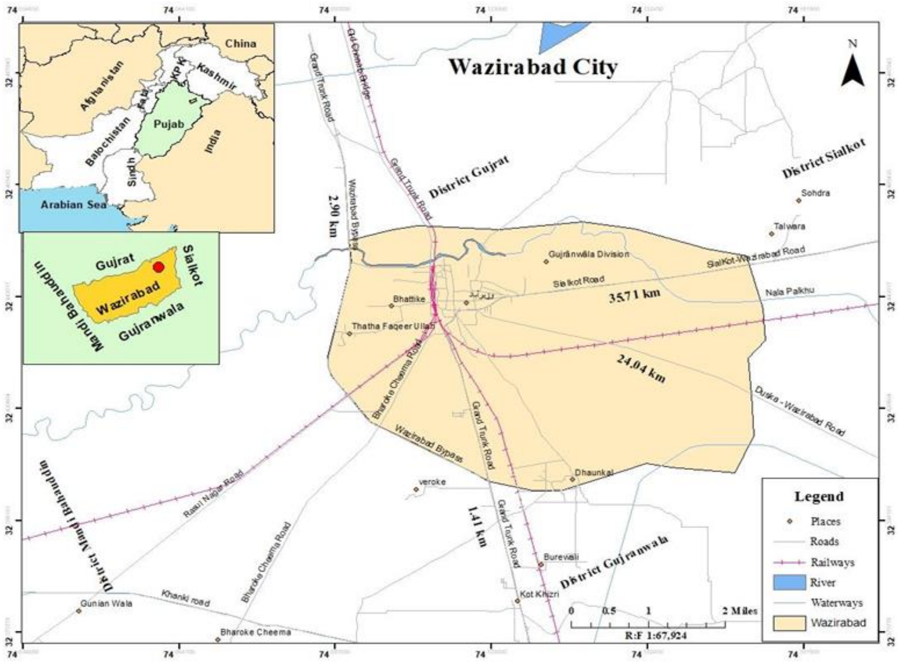

Figure 1.2: Manufacturing facility under study

1.4 Problem Statement

Climate change has a significant impact in Pakistan. Fossil fuels are largely used by industries as a source of energy, which is very bad for the environment. Country energy mix also comprises of 70% non-renewable resources inducing severe enviornmental impacts [18]. Furthermore, there aren't many studies examining how manufacturing affects the environment, particularly in sectors like the cutlery business that consume a lot of resources and energy. To our knowledge, no research study has been conducted on this topic in Pakistan. Research of this nature is essential. They assist in determining the environmental impact of Pakistani cutlery production and can direct the nation toward more environmentally friendly practices.

1.5 Research Objectives

The three main objectives of this research study are:

- Collect and develop inventory data for the cutlery manufacturing in Pakistan.
- Identification of major hotspots associated with the enviornmental impacts of cutlery manufacturing industry.

- Identify suitable ways to improve the enviornmental performance of Pakistan's cutlery production but ensure that any suggested fixes won't come at extra expenses.

1.6 Thesis Outline

This chapter contains a quick overview of the problem statement, the background, the cutlery manufacturing process, several methodologies for assessing the environmental impact, the cutlery manufacturing industry in Pakistan, and the primary goal of the study. The thorough literature review is covered in the following chapter, and in chapter 3, the specific technique employed to accomplish the study's goals is outlined. Chapter 4 presents the findings and debates, and Chapter 5 concludes with the analysis's ramifications and ultimate judgment.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

As was covered in the chapter that came before this one, various strategies for evaluating the effects of human activity on the environment have recently been established. These strategies differ in their application and scope of protection. Life Cycle Assessment (LCA) has seen widespread adoption in academic and policymaking communities all over the world as a result of the versatility of its applications. As a result, the purpose of this chapter is to present a comprehensive overview of life cycle assessment (LCA), including its significance and applicability in a variety of disciplines, the stages of LCA, and the methodologies that are used to carry out LCA. In addition, a number of research publications on life cycle assessment of cutlery manufacturing have been presented in order to get a grasp of its application in the cutlery manufacturing sector and identify prospective research needs.

2.2 Life Cycle Assessment (LCA)

The majority of goods possess a long-life cycle and almost everything has an impact on the ecosystem in which it is utilized. In essence, a life cycle assessment, or LCA, is a procedure or study that can be employed to ascertain the environmental effects associated with almost all stages of a good's life cycle. It includes every step of the process, starting with the extraction of the basic components and going all the way through their transformation, manufacturing, shipping of products to markets, and, finally, use of the goods by customers. LCA is a tool that may be used to examine and compare the adverse effects on the environment that are caused by various types of materials and processes. Human health, the condition of the ecosystem, and the consumption of resources are the three categories of ecological hazards that are taken into consideration by the life cycle assessment technique. The LCA is also helpful in identifying possibilities to upgrade and improve the environmental performance of items across their whole life cycle (that is, from the cradle to the grave). It is also helpful in the process of making decisions in the industrial sector, which involves planning, the selection of materials, the type of process used, and the design of the product. In addition to this, it also boosts the overall image of the product by utilizing environmentally friendly strategies. [19].

As time marches on and the ecosphere continues to deteriorate at an alarming rate, protecting the environment has become one of mankind's most pressing concerns. The life cycle assessment (LCA) provides manufacturers and businesses with assistance in the production of eco-friendly products through the use of methods that are themselves environmentally beneficial. The protection of people and their surroundings is the overarching goal of putting into practice LCA. In addition to this benefit, the LCA approach assists in the production of high-quality goods at lower cost. It brings about a reduction in the cost of production by ensuring that all raw materials and finished goods are utilized to their full potential before being discarded.

An important component of the integration of waste management and pollution-related concerns is the life cycle assessment (LCA). The main goals of life cycle assessment are essentially to measure inventory data and evaluate the environmental effects of any industrial process or product. This is achieved by identifying and measuring the intake and outflow of materials from any process, as well as the effects that result from the material flow. The information gathered aids in selecting environmentally friendly products and procedures, which eventually results in more thoughtful and sensible decision-making [20].

2.3 Phases of Life Cycle Assessment

Life cycle assessment can help any organization in assessing enviornmental impacts associated with their products, services or even any manufacturing facility. The overall 4 main phases of life cycle assessment methodology which are goal and scope, inventory

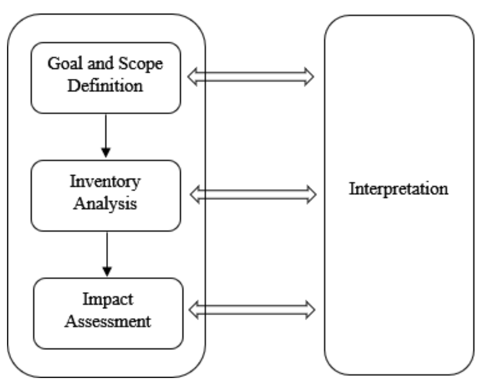

Figure 2.1: Phases of LCA

analysis, impact assessment and results are shown in **Figure 2.1**[9].

2.3.1 Goal and Scope Definition

The first step in doing an LCA is called Goal and Scope definition, and it involves describing the primary goals, the functional unit, the many sources of data and the collection of data, as well as the limits of the system [21]. The results of the LCA are frequently and substantially dependent on the decisions that are made at this important stage of the study. When defining the purpose of an LCA, the following parameters ought to be specified in the appropriate manner.

1. The use of the analysis that is anticipated.
2. Needs to conduct the analysis.
3. The target audience of the analysis.

The creation of a brand-new, eco-friendly product, the creation of environmentally conscious political strategies, and oftentimes for the regulation of current products are some of the different purposes that may be accomplished by the performance of a life cycle assessment (LCA). On the other hand, before describing the scope of the LCA study, the following components ought to be taken into consideration. Because life cycle assessment is performed using an iterative methodology, the scope can be modified in response to the findings that are gleaned from the study.

For all inflows and outflows that are going to be used in the LCA analysis, but it also details the function of the system that is being investigated. Additionally, the functional unit can be applied to study the similarities and differences across the systems that are being considered. As a consequence of this, prior to continuing with the analysis and data collection, etc., it is strongly suggested that the functional unit be specified with extreme caution and attention to detail [9].

2.3.1.1 System Boundary

This is basically employed to identify and choose the stages of life cycle of any product or process to be studies. Prior to determining the system border, it is necessary to look into a number of factors, such as the technological system's relationship with the environment, the duration, location, and the boundaries between its present phase of life and the life cycles of other connected technical systems.

2.3.1.2 LCA Methodology

The choice of the technique to be used for the performing the LCA is the next stage in the process. This step comes immediately after the definition of the system boundary. There are many various ways of impact assessment that are currently available, and each has its own unique significance; hence, the method of impact assessment must be carefully reviewed in accordance with the area that is being protected.

2.3.1.3 Impact Categories

The impact categories outline the environmental repercussions that can be expected to result from the various stages of a product's or process's life cycle or from the operation of a particular facility. During the life cycle assessment (LCA), a sizeable amount of information regarding emissions is gathered. These include emissions resulting from the production of energy, waste, raw materials, and so on. These emissions come in a wide variety of shapes and configurations due to the fact that the emissions produced during the extraction of raw materials are very different from the emissions produced during the generation of energy. As a consequence of this, the impact category combines a number of different environmental impacts into a single overall impact. In most cases, the effect categories are chosen in accordance with the method of life cycle impact assessment that is utilized throughout the evaluation. In general, emissions are divided into several midpoint categories (such as ozone depletion, global warming, and human toxicity), which are subsequently further mapped into three endpoint categories (resource depletion, ecosystem health, and human health [9, 22]. In terms of possible environmental remedies, midpoint results are more thorough than endpoint results, although the endpoint approach might miss some elements in identifying harm indications [23].

2.3.1.4 Data Acquisition

Before starting analysis and data acquisition, several visits and surveys should be conducted to identify the required data and to get a better understanding of the process on which LCA will be implemented.

2.3.1.5 Assumptions

The aim and scope definition should encompass all the assumptions pertaining to the product/process being analyzed. The assumptions may pertain to several aspects such as the input data, evaluation methodologies, limits of the system, or the addition or subtraction of life cycle phases.

2.3.2 Inventory Analysis

Using mass and energy balance, LCIA's main goal is to quantify and assess the primary inputs and outputs that have an influence on the environment. This relates to the amount of resources (such as minerals, energy sources, soil surface area, etc.) that are taken from the environment during the course of the product or service's whole life cycle that is being examined, as well as the discharge of pollutants into the environment. The inventory approach combines the previously calculated reference flows for the system's operations with the emissions and extractions associated with each process to identify and connect the many processes within the system. [24]. The fundamentals of inventory computation are simple, but the process of collecting the necessary data may require a significant amount of effort. Modern databases have the capability to consolidate data from several sources, hence necessitating the creation of comprehensive models only for the specific processes relevant to the intended applications and sectors. It is imperative to tackle the complex issue of allocating coproduct emissions, extractions, and byproducts due to the prevalence of operations that generate multiple products. The majority of primary data is obtained directly, such as through in-person interviews, factory data verification, and site visits [25]. Secondary data originates from a variety of sources, including databases, surveys, and prior research [20, 26].

2.3.3 Impact Assessment

The objective is to assess the magnitude and significance of the environmental effects measured during the inventory phase [27]. This phase comprises several distinct steps, beginning with the classification of emissions into several midpoint impact categories. Then these are further linked with endpoint to get a comprehensive overview of impacts associated with any process or product as discussed above.

The Life Cycle Impact Assessment process involves grouping similar LCI outcomes with similar effects into an intermediate level called the midpoint impact category. Subsequently, a characterization factor is applied to every individual LCI flow to determine its specific input to a certain midpoint impact category. Each midway impact category is assigned to 3 endpoint indicators which are human health, resources, and ecosystems. The damage categories are represented by a damage indicator, sometimes referred to as an end- point indicator. From the first inventory stage to the halfway stage and from the halfway stage to the final damage results, there is an increasing amount of uncertainty.

2.3.4 Interpretation

Following the fourth step in the Life Cycle Assessment, interpretation is the last stage. Its goal is to identify the precise life cycle stages at which actions might reduce the negative effects on the environment.

2.4 Optional Steps in LCA

In addition to the four primary processes of LCA, there are three additional optional procedures that might enhance the comprehension of environmental impacts. A normalization process is conducted to enhance the understanding of the extent of the harm, which provides the impacts per functional unit in relation to the overall effects in a certain impact category. It is generally advisable to standardize the damage indicators rather than focusing on middle affects [28]. Grouping is a method that involves sorting and prioritizing findings based on the area of protection or the various types of emissions. It is a semi-quantitative technique. During the weighing stage, On the basis of their corresponding values, weights are allocated to the scores of each impact category. These weighted scores are then combined into a single score, allowing for a more comprehensive understanding and comparison of the outcomes for each scenario. Weighting is commonly used to assign importance or significance to the different damage categories.

2.5 Impact Assessment Methods

The critical volumes method, an early technique used in life cycle assessment (LCA), classifies emissions based on their respective compartments. The CML (Centrum voor Milieukunde Leiden) 92 approach pioneered the examination of emissions' impacts and laid the groundwork for various future developments. The CML 92 technique was highly favored in Europe throughout a certain period. The guidebook on Life Cycle Assessment (LCA), a comprehensive manual providing precise instructions for doing LCA in a systematic manner, was developed subsequent to its adaptation to the CML 2002 methodology.

2.6 Software packages

LCA, or Life Cycle Assessment, is commonly employed to evaluate the environmental consequences of a process, product, or facility. Over time, it has been recognized as a versatile technique with several uses, such as enhancing products/processes, implementing environmental labeling, and evaluating policies. Due to its extensive range of applications and wide adoption, several Life Cycle Assessment software packages have been created to assist in the process. Experienced LCA users and practitioners have widely embraced and utilized these tools or software. Below, I will provide a quick description of two commonly used LCA software programs.

2.6.1 SimaPro

SimaPro is a software application developed and released in the Netherlands by PRe-Consultants in 1990. It is used for modeling and assessing product systems. SimaPro is a software application that gathers, evaluates, and assesses data regarding the effectiveness of different products, procedures, and services. Numerous uses for this software package exist, including assessing environmental and carbon footprints, designing products and processes, and compiling data on long-term viability. However, it is not limited to these specific uses. An additional advantage of SimaPro is its comprehensive access to numerous internet databases and unit operations. This feature is particularly valuable for doing environmental analysis and identifying key areas of negative environmental effect [29].

2.6.2 GaBi

GaBi is a software application for modeling and assessing product and process systems. It was created and released in 1992 by a German organization named PE International . Like SimaPro, The GaBi software package serves multiple purposes, including life cycle assessment, life cycle costing, analysis of working conditions throughout a product's life cycle, and generation of comprehensive life cycle reports. Additionally, it features regularly updated content databases containing detailed information about the objects under study, encompassing aspects such as cost, energy consumption, and environmental impact. Through its capabilities, GaBi contributes to enhancing the sustainability performance of products by optimizing decision-making processes.

2.7 Review of related LCA studies

There haven't been many studies in Pakistan recently that concentrate on the life cycle assessment of different sectors. Notably, these studies examined a small range of topics, such as the life cycle assessment of the matchstick industry [30], the environmental impact of manufacturing glass packaging [31], the evaluation of a supercritical coal-fired power plant [32], and alternative approaches to treating solid waste in hospitals [33]. These studies provide insightful information about the environmental factors related to various industrial processes in Pakistan.

Studies have been carried out within the context of the cutlery sector, specifically evaluating the effectiveness and environmental impact of cutlery products across various industries. These studies offer a comprehensive examination of the environmental impacts related to the production, use, and disposal of silverware in a number of businesses. They investigate factors like the materials used, the manufacturing process, the distribution process, and the proper disposal methods for cutlery. These evaluations aim to provide a thorough grasp of the numerous ways that cutlery products impact the environment, along with recommendations for future developments and eco-friendly procedures in the cutlery industry.

However, the production of melamine products has received less attention in the environmental impact assessment studies for the cutlery business than steel and other materials. For instance, a study examines the effects of bamboo and stainless-steel flatware during the stages of production and transportation [34]. According to a different study, bamboo studio cutlery is more environmentally friendly than spork [35]. Furthermore, a study concludes that single-use plastic products, regardless of their source, are harmful for the environment if there isn't a system in place for recycling them [36]. Another study that contrasts melamine and bioplastic cups finds that, both during the manufacture and use phases, the environmental effects of the polylactic acid (PLA) cup are fewer than those of the melamine cup [37]. According to a University of British Columbia study, aspen ware silverware has less of an overall environmental impact than another plastic cutlery. These effects can be further decreased by emphasizing the manufacturing and transportation processes [38]. The majority of CO2 emissions in the aviation industry are produced during transport and flight by reusable things, whereas the majority of emissions from single-use items occur during manufacture [39]. The description, results, and limitations of reviewed studies regarding life cycle assessment of cutlery manufacturing industries are shown in **Table 2.1** on the next page.

Table 2.1: Reviewed LCA Studies

	Description	Results and limitations	REF
1	The main objective of this study was to assess the environmental impacts of banning of single use plastic items. The scope of the study was cradle to grave. Data was collected mainly from life cycle inventory databases. The functional unit was chosen as one utensil(i.e., spoon). The impacts were analyzed on the basis of six impact categories i.e., global warming potential, acidification potential, eutrophication potential, marine aquatic toxicity, abiotic depletion, and plastic marine pollution.	This study concludes that in the absence of an effective recycling system, single use plastic items are harmful to the environment regardless of their material. Therefore, banning single use plastic items is a more effective method of reducing environmental impacts. This paper also suggests various other methods to reduce impacts of plastic in utensils. This study was basically performed to only assess the policy of banning single use plastic items or not and did not tell any information specifically about the processes in a cutlery industry	[36]
2	The main objective of this study was to measure the GHG emissions of the existing catering service in the aviation sector. The study was conducted at Barjas Airport (Madrid, Spain). The functional unit of 1000 passengers were selected. The scope of the study was the entry gate to the grave. The data was collected from the catering company. Gabi software was used for the analysis.	The results showed that in the aviation sector reusable items cause most of the CO_2 emissions during transport and flight, while in case of single-use items, most of the emissions takes place in the production stage. This study was basically focused on catering services of aviation sector. It only discusses the environmental performance of cutlery production in aviation sector.	[39]

3	The goal of this study was to investigate environmental impacts of three different materials used in reusable cutlery items. Three materials discussed in this study were bamboo, polypropylene plastic, and stainless steel. Social and economic assessment of these materials were also discussed in this study. This study was conducted in Columbia.	The results showed that stainless steel is the most dangerous material in case of environmental problems. Bamboo has some environmental problems associated with its transportation but has the minimum impacts in the production stage. The focus of the study was to compare three different materials used in reusable cutlery, but it does not discuss any environmental impacts associated directly with the manufacturing of cutlery items.	[34]
4	The goal of this study was to assess the environmental performance of Aspenware plastic cutlery at University of British Columbia. The functional unit was selected as one utensil. The scope of this study was cradle to grave. The impacts were analyzed on the basis of six impact categories which are Climate Change, Human Health ,Ecosystem Quality Resources, Water Withdrawal, and Water Turbined.	The results showed that Aspenware cutlery has less environmental impact as compared to another plastic cutlery. But Aspenware should also focus on transportation and manufacturing phases to further reduce the environmental impacts. This study only focuses on impacts of cutlery items used in an educational institute and did not discuss environmental impacts in general.	[38]

5	The goal of this study was to compare the enviornmental performance of reusable cutlery products of bamboo and spork to sell in the green vending machine. Triple bottom line assessment which includes enviornmental, social and economic factors are used to evaluate the performance of these two materials.	The results revealed that bamboo studio cutlery is environmentally more superior as compared to spork material. However, this study may lack the overall perspective of users due to the limitation of survey. Moreover, this study does not include comprehensive results especially regarding enviornmental performance.	[35]
6	This study was carried out to compare the environmental impacts and energy consumption of bioplastic (PLA) and melamine cup production. Impact categories of global warming, abiotic depletion, freshwater aquatic ecotoxicity, terrestrial ecotoxicity along with energy consumption are compared for raw material acquisition, production, usage, and disposal phase.	This study reveals that polylactic acid (PLA) cup has less environmental impact than the melamine cup during manufacturing and use phase. However, the way garbage is disposed of has a substantial impact on the complete life cycle effects. This study compares both alternatives on the basis of only 6 categories while other remains unexplored.	[37]
7	The main objective of this study was to assess the environmental impacts of supercritical coal-fired powerplants under the CPEC project. The functional unit was selected as 1 MWh of electricity generated. Midpoint characterization was used to assess six different impact categories which include climate change, global warming etc.	This study concludes that coal-fired power plants had the most adverse impacts in climate change category. This study lack the information of critical stages of powerplant and does not provide any information for the betterment.	[32]

8	The goal of this study was to assess the enviornmental impacts associated with the various manufacturing of various glass packaging alternatives. The scope of the study was cradle to gate and the functional unit of 1 ton of glass produced. Additionally, different situations were developed by changing the facility's power mix to observe the effects on the production of greenhouse gases. .	The extraction and processing of raw materials as well as the plant-based method of making glass were shown to have the worst effects on the environment. Comparatively speaking, green glass has the greatest impact at the midway level across a number of impact categories, including global warming, freshwater and marine ecotoxicity, etc. Human health is mostly impacted at the endpoint level by different areas of protection.	[31]
9	The main objective of this study was to assess the environmental performance of matchsticks manufacturing. The scope of this study was cradle to gate. The data was collected from matchsticks industries by questionaries and interviews. Environmental performance was measured on carbon footprint, water footprint and cumulative energy use measures. This study was conducted in Pakistan.	The study concludes that transportation of raw materials is the major cause of environmental burden. Transportation has a negative influence on neighborhoods and influences a number of effect categories, including eutrophication, environmental degradation, and global warming. As the scope of the study was cradle to gate, this study does not include the actual manufacturing process which may have more severe impacts than transportation.	[30]

10	The main objective of this study was to compare different scenarios of waste management system at hospitals. The study was conducted at Swat, Pakistan. Scenarios A & B refer to incineration or direct landfilling of solid waste. While the scenario C involves the chemical disinfection of the waste before disposal.	The results showed that Scenarios A & B has more severe environmental impacts as compared to the scenario C. This study was performed only for 1 geographical location in Pakistan. Therefore, it lacks the ability of its application around the country.	[33]

Apart from studies mentioned above in **Table 2.1**, studies regarding the migration nature and health risks associated with melamine were also reviewed. Formaldehyde was listed in category 2A of the IARC list of carcinogenic chemicals till 2004 [40]. Studies also address health issues in animals (cats and dogs) [41] and infants [42] associated with the melamine migration. Severe health issues like renal dysfunction can also be caused by toxicity resulting from melamine [43]. Keeping in mind these health issues, it is necessary to evaluate the migration rate in melamine tableware. Several studies conducted for this cause revealed that although the migration rates are significant at higher temperatures and in specific acidic conditions, but the values are still under the European standards [4, 5, 44]. However, kinetic models of liquid chromatography reveals that it is necessary to take precautionary measures when long term exposure towards melamine is expected [44].

2.8 Research Gaps

After 2005, there has been a notable decline in Pakistan's cutlery sector, which has been mostly ascribed to environmental and administrative concerns. A few studies have considered managerial issues [3], but there is a startling lack of studies that particularly examine the environmental effects of Pakistan's cutlery sector. Interestingly, there aren't many international comparative studies on the environmental impact assessment of the cutlery sector, and most of them don't include the environmental effects of the manufacturing stage of cutlery manufacture. Previous research has mostly examined the use of cutlery products in certain industries, ignoring a comprehensive assessment of the industry's environmental impact over its whole lifecycle. Therefore, a thorough ecological examination of the production phase of Pakistan's cutlery sector is required.

2.9 Summary

The life cycle assessment (LCA) concept was presented in this chapter along with an analysis of previous studies on LCA related to the production of cutlery. The chapter's conclusions highlighted areas for future research, how LCA tools are used in the manufacturing of cutlery and related industries, and most importantly the critical stages involved in carrying out LCA investigations. An important pattern that emerged from an analysis of previous research on LCA in the context of cutlery production is that developed European countries are the main users of LCA for environmental impact assessments in the cutlery industry. This analysis leads us to do a comprehensive enviornmental impact assessment of cutlery industry of Pakistan.

CHAPTER 3: METHODOLOGY

The LCA methodology described in chapter 2 is used to carry out a comprehensive life cycle assessment of cutlery manufacturing industry of Pakistan. For this purpose, one cutlery manufacturing industry situated in Wazirabad, Pakistan was selected. The complete methodology used or the analysis is described in this chapter.

3.1 Cutlery manufacturing industry

A cutlery manufacturing industry situated in Wazirabad Pakistan was selected for this study by their consent. However, the name and the information regarding industry are not discussed here due to confidential agreements. The goal and scope are then determined to determine the enviornmental impacts associated with the current manufacturing process of the industry. After these 4 more potential alternatives after discussing the feasibility of them with the plant manager were also evaluated on the basis of enviornmental and economical basis.

3.2 Goal and Scope Definition

This study's primary objective was to evaluate the environmental effects of the melamine spoon industry's manufacture. Following an assessment of the effects, the primary hotspots that have the greatest influence on the environment were found. Solutions to improve the identified hotspots and improve environmental performance were proposed and examined with the aid of the identification of main contributors to environmental consequences. Melamine spoons are sold by the designated manufacturing facility based on product amount. 50 dozen melamine spoons were produced on average per month, using 25 kg of melamine resin. Therefore, a functional unit of twelve melamine spoons was chosen for better understanding. The scope (in terms of system boundary) of this study was cradle-to-gate (starting from the acquisition of melamine formaldehyde resin to the production of spoon). For the production of melamine formaldehyde resin, the formaldehyde is mixed with melamine [37]. The study used secondary data to include the manufacturing of melamine formaldehyde resin. Transportation phase is excluded due to the absence of reliable data. The graphical representation of scope of the study is shown below in **Figure 3.1**.

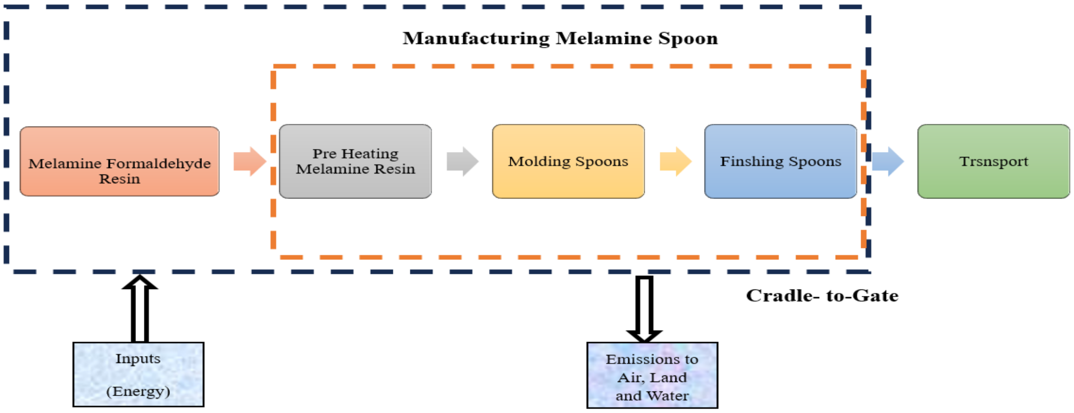

Figure 3.1: Scope of the study

3.3 Life Cycle Inventory Analysis

Several visits during March, April and June 2023 were done to understand each and every process separately and to get the required data for the analysis. During the visits, personal interviews with production manager were carried out to collect the primary data for our analysis. The average of 3 months was used as the inventory data. The process of manufacturing melamine spoons started with simple weighing of melamine formaldehyde resin required for the production of desired quantity. For our functional unit (1 dozen) it comes out to be 0.5 kg as shown in table below. After that, weighed melamine resin is pre heated (40-50°C) for 45-60 seconds to get it ready for molding process. After that, preheated resin is molded into the desired shape (spoon) with the help of molding process. At last spoons finally go through the finishing process. The data collected and organized according to functional unit is shown below in **Table 3.1**. The electricity consumption of machines used during the process is also shown in **Table 3.1**.

Table 3.1: Material and electricity data for 1 functional unit

Input Types	Units	Process	Machine Model	Power Consumption	Per functional unit
Melamine Formaldehyde Resin	kg	-	-	25 (monthly)	0.5
Electricity from grid	kwh	Pre-heating Melamine resin	High Frequency 13KvA machine	7.5 Kw	0.125

Electricity from grid	kwh	Injection Molding	MA400AJ	22.4 Kw	13.44
Electricity from grid	kwh	Finishing	Manual 3 HP Rajlaxmi bench polisher	2.2 Kw	0.88
Total electricity consumption	kwh	-	-	-	14.44

3.4 Life Cycle Impact Assessment

The next step in LCA methodology is impact assessment. In this phase, the magnitude and significance of the environmental consequences assessed during the life cycle inventory phase are studied. by using midpoint and endpoint indicators. ReCiPe Midpoint (H) 2016 and ReCiPe Endpoint (H) 2016 methods are used for the analysis. It includes 18 midpoint indicators which are global warming, stratospheric ozone depletion, ionizing radiation, ozone formation (human health), fine particulate matter formation, ozone formation (terrestrial ecosystems), terrestrial acidification, eutrophication (freshwater and marine), ecotoxicity (terrestrial, freshwater, and marine), Human carcinogenic toxicity, Human non-carcinogenic toxicity, land use, resource scarcity (mineral and fossil) and water consumption. 3 endpoint indicators are human health, ecosystem, and resources. After analyzing the impacts of baseline scenario (current manufacturing process), 4 alternative scenarios are created and evaluated on the basis of environmental as well as economical basis. The obtained results along with insightful discussions are presented in the next chapter.

3.5 Summary

In this chapter, the complete methodology implied for the research is discussed in this chapter. The procedure of data collection from the industry and data obtained through databases are also discussed in this chapter. **Table 3.1** quantifies the data according to 1 functional unit. The complete methodology used for the study is also depicted in **Figure 3.2**. The results obtained from the analysis are discussed in the next chapter.

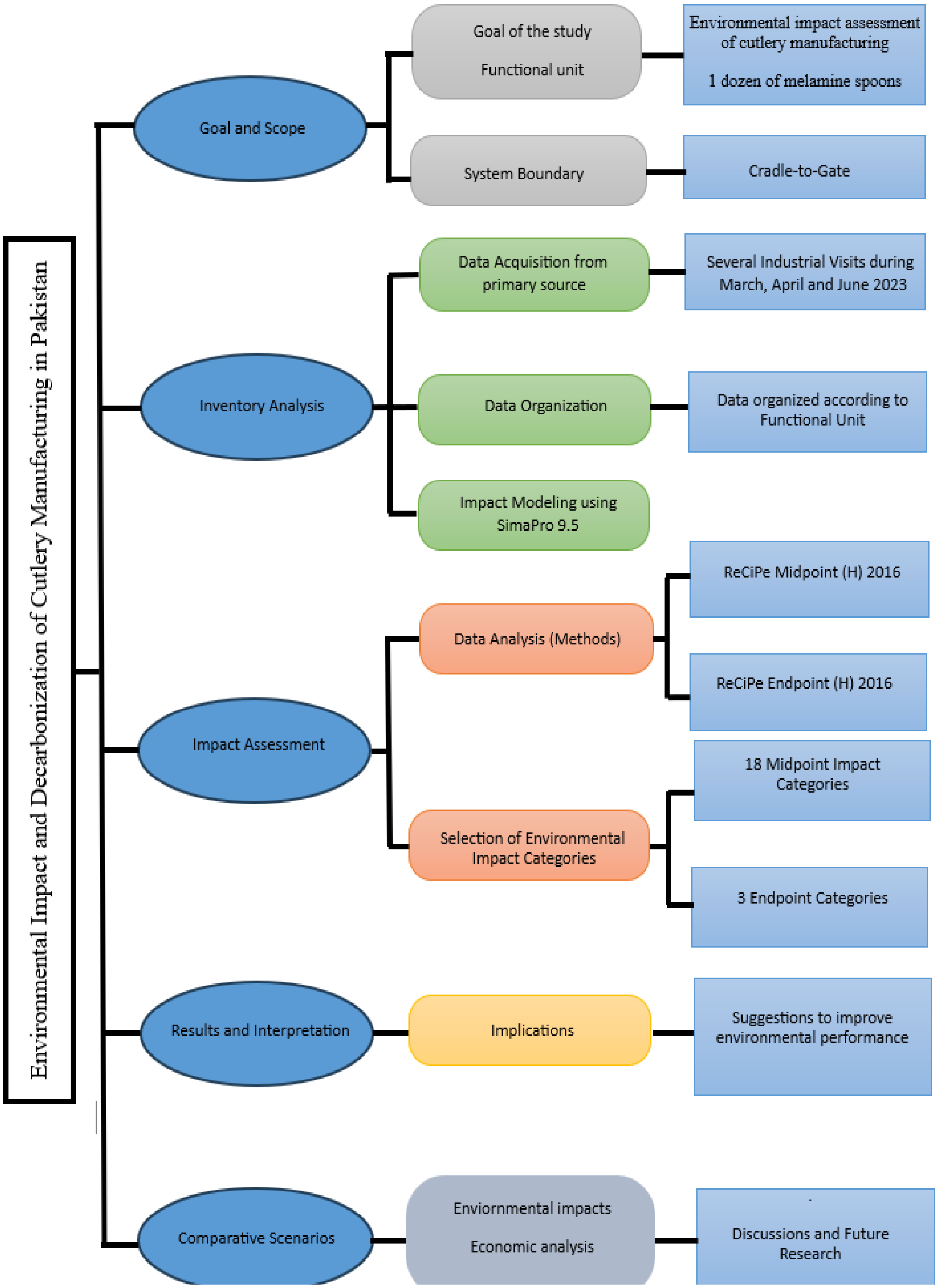

Figure 3.2: Overall methodology flowchart

CHAPTER 4: RESULTS AND DISCUSSIONS

This chapter presents a detailed analysis of enviornmental impacts associated with the manufacturing process of the selected cutlery manufacturing industry. Initially the impacts associated with the baseline scenario currently implemented in the industry are evaluated. Later four alternative scenarios are also created to suggest a better alternative which has better enviornmental performance and at the same time has economic benefits for the concerned industry.

4.1 Baseline Scenario

Table 4.1 depicts the impact scores of each impact category associated with each process of melamine spoon production in the selected manufacturing industry. Results showed that the global warming and ecotoxicity were the most affected impact categories. For validation purposes, the results were also compared to a related study that evaluated the environmental impacts linked with melamine-based cup production in Thailand [37]. The production step of melamine-based cup manufacturing is identified in this study as the primary environmental hotspot, with greater environmental implications than most other phases. For one cup of 0.06 kg melamine, the global warming value was calculated to be 950 g CO2 equivalent. It was 11.4 kg CO2 equivalent for 0.72 kg of melamine formaldehyde resin for a dozen cups. The effects of global warming were, however, far greater in our investigation, with 11.8 kg CO2 equivalent for 0.5 kg melamine formaldehyde resin (one dozen spoons). The difference in values (slightly higher in our case) is mainly due to the energy mix and maybe due to the lack of knowledge and technologies [2, 37].

Table 4.1: Quantified scores of midpoint categories

Impact category	Unit	Impact Scores				
		Total	**Melamine Formaldehyde Resin**	**Pre-heated Melamine Resin**	**Molding Spoon**	**Finished Spoon**
Global warming	kg CO2 eq	11.80048	2.7160893	0.6161302	7.9863173	0.48195073
Stratospheric ozone depletion	kg CFC11 eq	3.6142506E-6	3.8889178E-7	2.2102357E-7	2.8314457E-6	1.7288955E-7
Ionizing radiation	kBq Co-60 eq	0.078710467	0.0031370919	0.0050398687	0.066591209	0.0039422973
Ozone formation, Human health	kg NOx eq	0.023683926	0.0055164781	0.0012284503	0.015978076	0.00096092109
Fine particulate matter formation	kg PM2.5 eq	0.013784732	0.0034866696	0.00067776463	0.0090901356	0.00053016256
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.025105855	0.0059474815	0.0012952206	0.016850003	0.0010131504
Terrestrial acidification	kg SO2 eq	0.039554693	0.0098514683	0.0020355335	0.026075451	0.0015922396
Freshwater eutrophication	kg P eq	0.00022098986	7.1041545E-5	8.6202305E-6	0.00013458515	6.7429358E-6
Marine eutrophication	kg N eq	9.3236036E-5	5.3152776E-5	2.6391346E-6	3.5379736E-5	2.0643897E-6
Terrestrial ecotoxicity	kg 1,4-DCB	12.010786	4.4248252	0.52721322	6.64635	0.4123979
Freshwater ecotoxicity	kg 1,4-DCB	0.0027597356	0.00077930104	0.00012440121	0.0017587239	9.7309392E-5

Marine ecotoxicity	kg 1,4-DCB	0.011216132	0.0031874454	0.00054106952	0.0070643809	0.0004232366
Human carcinogenic toxicity	kg 1,4-DCB	0.047444626	0.032902986	0.00091180043	0.01291661	0.00071323056
Human non-carcinogenic toxicity	kg 1,4-DCB	0.7985057	0.20447296	0.037331523	0.52749967	0.029201547
Land use	m2a crop eq	0.14247064	0.02114026	0.0064899632	0.10976383	0.005076593
Mineral resource scarcity	kg Cu eq	0.0034554747	0.001413758	7.1600154E-5	0.0019141093	5.6007232E-5
Fossil resource scarcity	kg oil eq	3.8160201	0.960485	0.19387728	2.5100027	0.15165511
Water consumption	m^3	0.12645951	0.098560678	0.0015634879	0.025112349	0.001222995

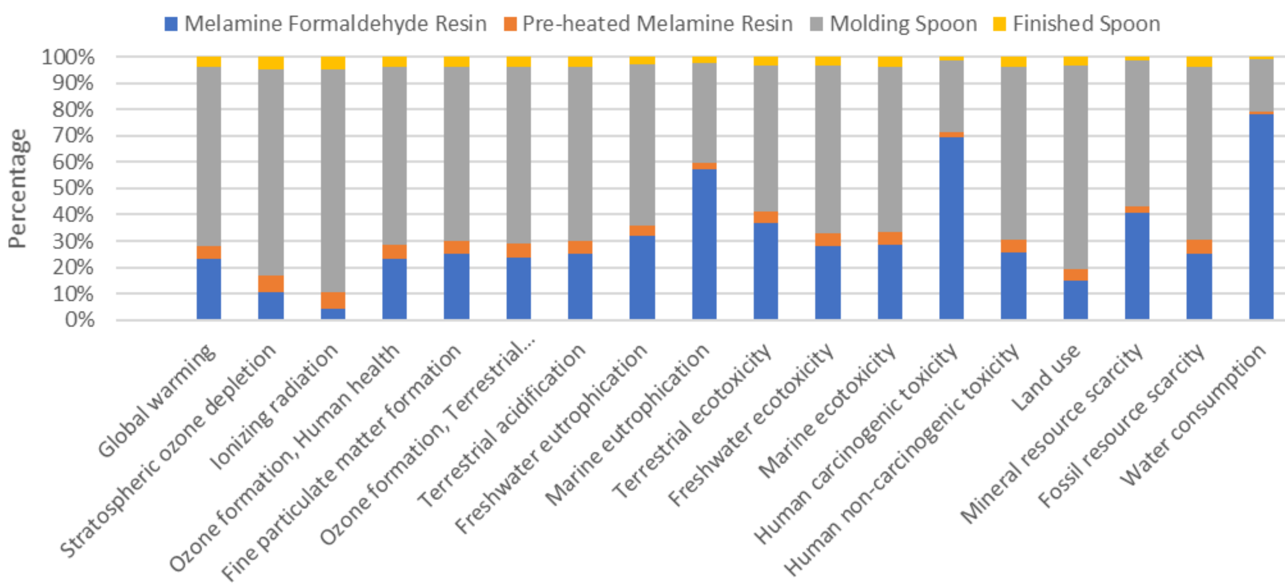

Figure 4.1: Graphical representation of midpoint results

The graphical representation of data presented in **Table 4.1** is shown in **Figure 4.1**. Studies showed that energy and electricity consumption along with waste management plays a major role in the environmental impacts associated with molding process. The graph clearly shows that the molding spoon process comes out to be the process affecting most of the impact categories (15/18) except of 3 categories which are marine eutrophication, human carcinogenic toxicity and water consumption in which weighed melamine resin process is the major source of impacts. Studies showed that in manufacturing sector, energy consumption is the major source of environmental impacts as discussed earlier [1]. Molding processes are generally characterized as more energy extensive as compared to other manufacturing processes [45]. **Table 3.1** clearly shows that molding spoons comes out to be the most energy extensive process among all the processes present in manufacturing phase. By all this discussion, graphs and table, it can easily be said that molding spoons as the most energy extensive process contribute most to environmental impacts due to this high energy consumption and the nature of molding process [46, 47]. Along with this as discussed in previous section, energy mix of Pakistan made it more harmful for the environment due to 70% of non-renewable resources [18]. If we consider other processes, pre-heating and finishing processes have negligible impacts on all of the categories. As discussed above, in manufacturing most of the environmental impacts are associated with electricity or energy consumption which are minimal in these processes resulting in least environmental impacts. As long as pre-heating is concerned, the impacts associated with heating are negligible. Because if we consider this process in melamine cutlery manufacturing, as per quanzhou shunhao moulds which is a renowned company in the field of melamine products and machines, melamine is heated up to 40-50 °C for 45-60 seconds. As discussed earlier, it is generally considered safe to use melamine in the temperature range of 30 to 120 C, and up to 140 C, therefore this heating does not cause any significant impacts on the environment. Now if we consider the process of weighing melamine resin, this process comes out to be dominant in only 3 categories which are marine eutrophication, human carcinogenic toxicity, and water consumption. The one of the major reasons behind this is the migration nature of melamine formaldehyde resin. In the meantime, formaldehyde listed in the category 1 of the carcinogenic chemicals by IARC experts contribute mainly towards human carcinogenic toxicity [40, 44].

After discussing the processes individually, in order to get the better understanding of impacts, it is necessary to have an insightful discussion on overall impacts of the whole process. As depicted in **Table 4.1** global warming and terrestrial ecotoxicity dominate adverse environmental impacts with the values of 11.8 kg Co_2 eq and 12.0 kg 1,4-DCB respectively. If global warming is concerned it is evident from **Table 4.1** that molding spoon process is the main contributor to this impact category. The main reason behind this is the high energy consumption and mainly the energy mix of Pakistan. Because, renewable and non-renewable energy resources play a vital role in global warming and climate change [48]. Meanwhile if we consider the impact category of terrestrial ecotoxicity, molding spoon along with weighing melamine processes are the main contributor to this impact category. The usage of electricity and the energy sources mentioned above are substantial contributors to the negative effects on the environment. However, a research done to evaluate the effects of different energy sources found that wind energy is very important for affecting the category of terrestrial ecotoxicity [49]. As far as energy mix of Pakistan is concerned, wind resources are not a major contributor. Therefore, the molding spoon process has less value in the impact category of terrestrial ecotoxicity as compared to global warming. The migration nature of melamine formaldehyde also plays a major role in inducing terrestrial ecotoxicity. These findings can be validated by a study carried out to compare the impacts of polylactic (PLA) and melamine cup. The results revealed that PLA cups production contribution towards terrestrial ecotoxicity is negligible as compared to melamine cup production due to difference in nature of material [37].

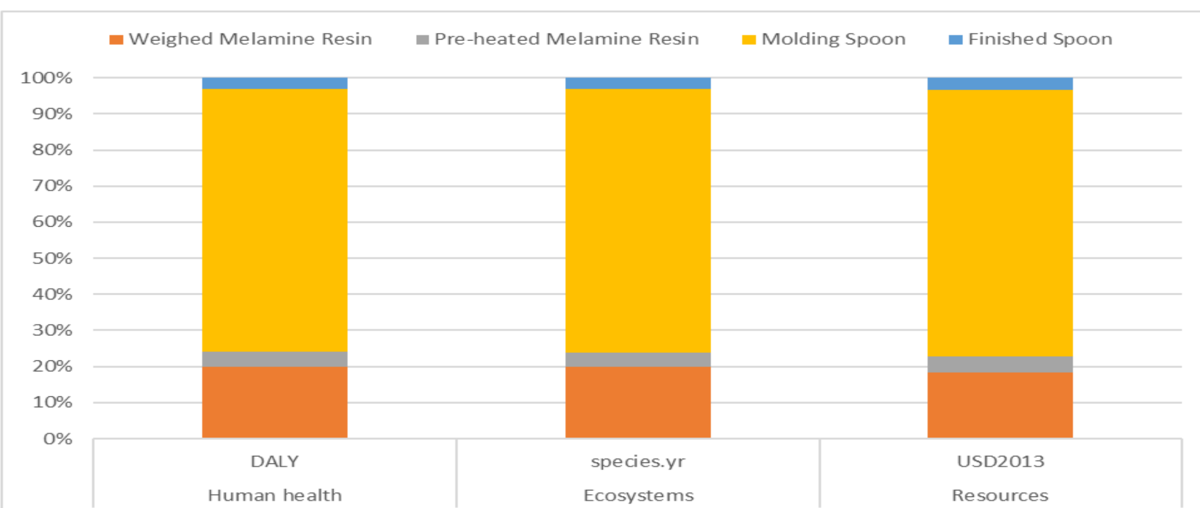

Figure 4.2: Graphical representation of endpoint results.

The contributions of processes to endpoint indicators are shown in **Figure 4.2**. The results are almost consistent as in the case of midpoint categories. The molding spoons process comes out to be the most dominant process causing most of the impacts that are maybe due to factors like electricity consumption, nature of process and energy mix as discussed above.

The normalization step is considered as an extra step in LCA which helps to evaluate the relative importance of various impact categories [28]. At endpoint level, the normalization step reveals that human health is the most affected category during our processes. Apart from energy consumption, energy mix and molding process as the major contributor, melamine material also plays a vital role in affecting human health category. Although studies in past revealed that the melamine migration is not a major issue as far as precautionary measures are taken in case of long-term exposure [44]. But in the meantime, a study has revealed the severe health issues like urine stone formation and acute renal dysfunction can be caused in humans due to high and unmonitored dosage of melamine [41]. Apart from that in the past another case of melamine migration in different food products like eggs, milk and livestock feed etc. has also been revealed. This eventually leads to several health and few death cases of infants [42]. Therefore, it is necessary to strictly monitor the amount of melamine along with the working conditions of melamine product.

4.2 Alternative scenarios and their impacts

We created four alternative scenarios to improve the cutlery manufacturing process's environmental performance for the production of melamine spoons based on earlier findings and analysis. These options were predicated on two different approaches to mitigate the effects on the environment. The first intervention was based on a technically sound yet doable suggestion for a minor change at the injection molding process stage. The next three alternatives were created to evaluate the enviornmental performance on the basis of solar energy usage for the production facility. Furthermore, to provide decision makers with a complete picture, in-depth economic studies were presented in addition to environmental analyses and comparisons for other scenarios.

4.3 Enviornmental impact assessment

If we look into the previous section, it is quite obvious that most of the environmental impacts are associated with the molding spoon process and eventually with electricity consumption. Therefore, we can say that reducing electricity consumption has a great potential of reducing environmental impacts.

If we consider the concerned industry and their manufacturing process, it was observed that one of the major issues associated with the manufacturing process of this particular facility is maybe the lack of resources or the proper guidance. For instance, single cavity mold is used in the molding process like many other facilities as they are cheaper than the multi-cavity molds and help in production due to shortened lead times. At the same time, it means that complete molding cycle yields only 1 product (spoon). If multi cavity mold is used, we can produce multiple spoons in one molding cycle with no extra energy consumption. However, there may be impacts related to mold production, but we are concerned with the processes inside gate-to-gate boundary due to our scope definition. Now, we will try to analyze if we use two spoon molds instead of single spoon, how much this action helps to increase the environmental performance of our concerned production facility.

From the above discussion, if we change single spoon mold with double spoon, the manufacturing process along with system boundary are still same as shown in **Figure 3.1**. Inventory data shown in **Table 3.1** is also the same except for the molding spoon process. The main reason behind this is that in our base scenario, 12 molding cycles were required for the production of 12 spoons (functional unit). But now that cycle will be reduced to 6 resulting in a reduction in electricity consumption. While the electricity consumption of all other processes remains the same as previous. The difference in electricity consumption is shown in **Table 4.2**. The alternative scenario is named Alt. scenario 1.

Table 4.2: Electricity reduction with alt. scenario 1

Description	Units	Base scenario	Alt. Scenario 1

		(single-cavity mold)	(double-cavity mold)
Electricity consumption by molding process	kwh	13.44	6.72
Total electricity consumption	kwh	14.44	7.72

Table 3.1 and **Table 4.2** clearly depicts that molding process came out to be most energy extensive as molding machine has highest energy consumption value. By using double mold cavity, the molding cycles have been halved resulting in significant reduction in electricity consumption as shown in table 4. Now we will see how much this reduction in electricity consumption will help in reducing in environmental impacts of the process. In order to evaluate environmental impacts, ReCiPe Midpoint (H) 2016 is used again to see the effect of electricity reduction on various midpoint indicators. The quantified results are shown in **Table 4.3**.

Table 4.3: Comparison of midpoint categories of alt. scenario 1 and baseline scenario

Impact category	Baseline Scenario (single-cavity mold)	Alt. Scenario 1 (double-cavity mold)	Reduction (%)
Global warming	11.800488	8.1201365	31.2
Stratospheric ozone depletion	3.6142506E-6	2.2940031E-6	36.5
Ionizing radiation	0.078710467	0.048605651	38.2
Ozone formation, Human health	0.023683926	0.016345983	31.0
Fine particulate matter formation	0.013784732	0.0097362183	29.4
Ozone formation, Terrestrial	0.025105855	0.01736907	30.8

ecosystems			
Terrestrial acidification	0.039554693	0.027395772	30.7
Freshwater eutrophication	0.00022098986	0.00016949835	23.3
Marine eutrophication	9.3236036E-5	7.7471606E-5	16.9
Terrestrial ecotoxicity	12.010786	8.8615661	26.2
Freshwater ecotoxicity	0.0027597356	0.0020166456	26.9
Marine ecotoxicity	0.011216133	0.0079841439	28.8
Human carcinogenic toxicity	0.047444626	0.041998138	11.5
Human non-carcinogenic toxicity	0.7985057	0.57551207	27.9
Land use	0.14247064	0.10370393	27.2
Mineral resource scarcity	0.0034554746	0.003027783	12.4
Fossil resource scarcity	3.8160201	2.6579265	30.4

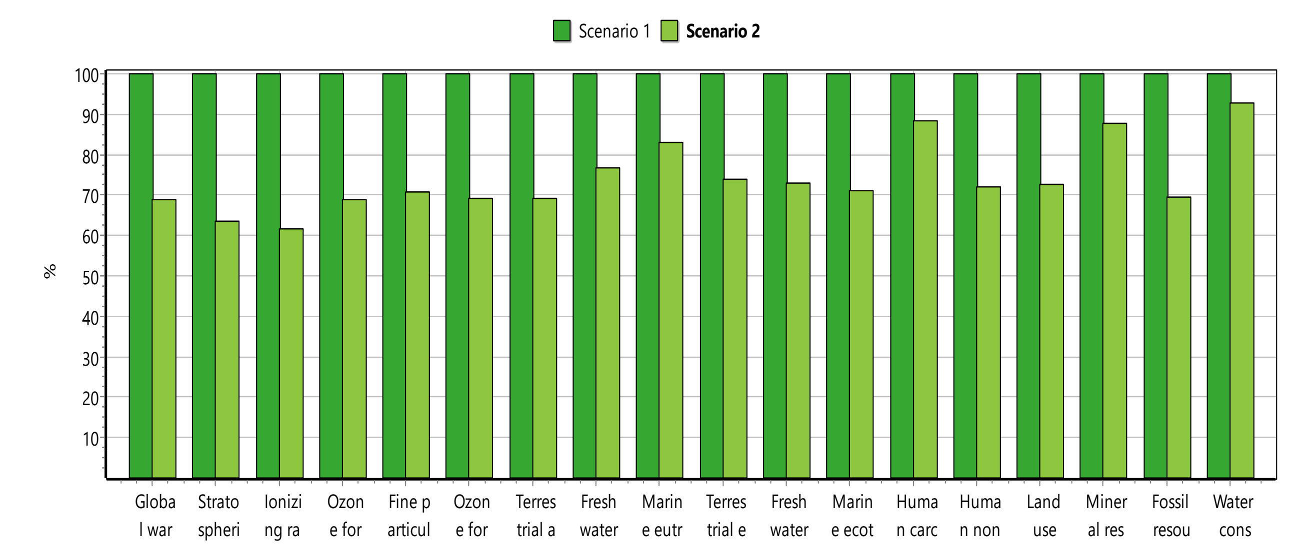

Figure 4.3: Graphical comparison of midpoint categories of baseline and alt. scenario 1

Table 4.3 shows the impact scores of alternative scenarios on all 18 midpoint indicators. Reduction in scores as compared to base scenario is clearly visible due to reduction in electricity. Impact scores of global warming, terrestrial ecotoxicity and human non-carcinogenic toxicity are reduced from 11.8 to 8.12 kg Co_2 eq, 12.01 to 8.86 kg 1,4-DCB and 0.798 to 0.575 kg 1,4-DCB respectively.

After the comparison of impact scores, it is also necessary to evaluate the change in the trend of impact categories. For this purpose, a graph is plotted between the trends of impact categories of baseline scenario and alt. scenario 1. That difference is shown below in **Figure 4.3**.

Figure 4.3 clearly shows that alt. scenario 1 contributes less to each of the impact category as compared to our baseline scenario which can be justified by less energy consumption in alt. scenario 1. However, in the marine eutrophication, human carcinogenic toxicity and water consumption categories the reduction is less as compared to other 15 categories. The main reason behind is the fact that these categories are not only affected by the energy consumption (molding process) but also by the issues like formaldehyde carcinogenic and melamine migration nature.

As discussed previously, Pakistan energy-mix is a major source behind the enviornmental impacts. In this context, three additional scenarios were developed, and their environmental effects were examined: scenario 2, which is based on a single cavity mold and 100% solar energy; scenario 3, which is based on a single cavity mold and 50% solar energy and scenario 4, which is based on a double cavity mold and 50% solar energy. **Table 4.4** shows the difference in values of all 18 impact categories for all three new created scenarios.

Table 4.4: Comparison of alt. scenario 2, 3 and 4 with baseline scenario

Impact category	Baseline Scenario (single-cavity mold)	Alt. Scenario 2 (single-cavity with 100% Solar)	Reduction (%)	Alt. Scenario 3 (single-cavity with 50% Solar)	Reduction (%)	Alt. Scenario 4 (double-cavity with 50% Solar)	Reduction (%)
Global warming	11.80049	3.405224	71.1	7.359365	37.6	5.382241	54.38967
Stratospheric ozone depletion	3.61E-06	5.90E-07	83.7	2.01E-06	44.4	1.30E-06	64.05813
Ionizing radiation	0.07871	0.007385	90.6	0.03973	49.5	0.023557	70.07133
Ozone formation, Human health	0.023684	0.006877	71.0	0.014761	37.7	0.010819	54.32124
Fine particulate matter formation	0.013785	0.004708	65.8	0.009058	34.3	0.006883	50.06853
Ozone formation, Terrestrial ecosystems	0.025106	0.007378	70.6	0.015691	37.5	0.011535	54.05653
Terrestrial acidification	0.039555	0.011785	70.2	0.024849	37.2	0.018317	53.69226
Freshwater eutrophication	0.000221	0.000104	53.2	0.000159	28.3	0.000131	40.85711
Marine eutrophication	9.32E-05	5.64E-05	39.5	7.32E-05	21.5	6.46E-05	30.68666
Terrestrial ecotoxicity	12.01079	4.299602	64.2	7.683056	36.0	5.991231	50.11791
Freshwater ecotoxicity	0.00276	0.000898	67.5	0.001695	38.6	0.001295	53.07168
Marine ecotoxicity	0.011216	0.003404	69.7	0.006875	38.7	0.005138	54.19087
Human carcinogenic toxicity	0.047445	0.035311	25.6	0.041162	13.2	0.038236	19.41006
Human non-carcinogenic toxicity	0.798506	0.29263	63.4	0.5321	33.4	0.412231	48.37467
Land use	0.142471	0.056279	60.5	0.09793	31.3	0.077104	45.88073
Mineral resource scarcity	0.003455	0.002472	28.5	0.002932	15.2	0.002702	21.81241
Fossil resource scarcity	3.81602	1.163711	69.5	2.407962	36.9	1.785824	53.20192
Water consumption	0.12646	0.104231	17.6	0.114305	9.6	0.109315	13.55736

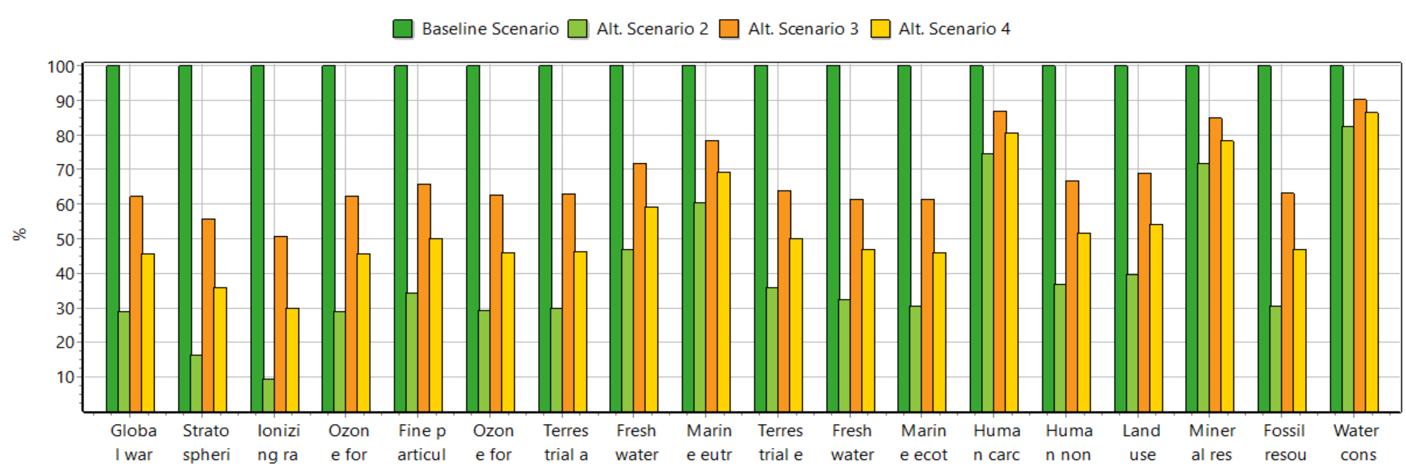

Figure 4.4: Graphical representation of alt. scenarios 2,3 and 4

The results (**Table 4.4** and **Figure 4.4**) revealed that in comparison with baseline scenario, 13 out of 18 impact categories showed more than 60% less impacts when the plant was totally run with solar energy (100% solar based scenario). More importantly, there was more than 70% reduction in the case of global warming that was quite significant from the decarbonization perspective.

The average reduction of 30-40 % is observed when energy resources are switched to 50 % solar energy the impacts are still reduced by 30-40 %. However, when 50% solar energy is combined with double-cavity mold intervention, the impacts are reduced averagely by 50-60 %. This comparison clearly highlights the great potential of reducing adverse enviornmental impacts by moving towards more clean energy resources. The graphical comparison of baseline, alt. scenario 2, alt. scenario 3 and alt. scenario 4 are also shown in figure.

4.4 Economic analysis

In recent times, studies addressing the capabilities of renewable resources for the production of electricity in Pakistan are reported. A study was conducted to address the energy crisis issue of Pakistan by discussing the deployment of various renewable energy resources such as wind, solar, hydro and biomass. This study highlights various important numbers and issues to help stakeholders in moving towards sustainable development. Solar energy is considered as one of the renewable and most environmentally friendly resources for energy consumption [50]. Another study was carried out to address the barriers in the solar energy development of Pakistan. Along with finding major barriers, this study also suggests various recommendations for policy makers to make move Pakistan towards sustainable energy development [51]. The cost associated with solar systems comes out to be one of the major barriers in moving towards solar resources. The socio-economic analysis on solar technology utilization (STU) in Pakistan was carried out. The results revealed that despite the high initial cost, in the long run, STU has more economic benefits as compared to other sources [52].

Apart from getting better results in case of enviornmental impacts, it is also necessary to have a brief cost analysis on alternatives to get a better understanding about the implementation of alternative scenarios. The payback period is an important term in finance and economical terms. It is basically time (in years) to recover the initial investment that has to be made for any project. However, payback periods are recently used in energy sectors too. For instance, payback period was used to evaluate the budgeting decisions for energy, oil and gas sectors of Oman [53]. Another study also carries out payback period analysis on stand-alone solar energy systems [54].

Now, in order to find the payback period, we have to divide the initial cash invested by the annual net cash flow of the project. Initial cash invested is basically the amount required for the implementation of some modification or change in the current project. While the net cash inflow is actually sales minus fixed and variable costs. Monthly production of the facility was assumed to be around 50 dozen spoons which results in around 772 units of electricity. The average price for a commercial electricity unit is around 45 Pkr per unit. As per these values the electricity bill of the facility due to spoon production is about 33000 Pkr per month. In order to perform cost analysis on our all four alternative scenarios, a market survey was done to get the estimated costs required for their implementation. In alt. scenario 1 we are only concerned with the price of a double-cavity mold which comes out to be around 200000 Pkr. After using double mold cavity electricity consumption and eventually the electricity bill will be halved as discussed in previous section. By this, net cash flow of 16500 Pkr per month is assumed which is multiplied by 12 to get annual values as shown below in **Table 4.5.** As per market survey, a 1 kw solar system usually costs 250000 and produces about 110 kwh of electricity per month. As our facility usually requires 772 kwh of electricity per month therefore, a 7.5 kw solar system is assumed for calculation of our alt. scenario 2 which cost is around 1800000 Pkr. By using this solar system, the electricity bill of the facility (33000 Pkr) is omitted from the cash flow and eventually the annual net cash flow becomes 396000. Similarly, for alt. scenario 3 the estimated cost of 4 kw solar system for shifting towards 50% solar is about 1005000 Pkr and annual net cash flow of 200000 Pkr is calculated. Last, for alt. scenario 4 the price of double cavity mold and the cost of around 2.5 kw solar system were added (800000 Pkr) to get the initial cash outlay for this scenario. Annual net cash flow is also calculated by assuming a reduction in electricity bills. All of the initial cash outlays and annual net cash flows are shown below in **Table 4.5**. Although, the payback period of alt. scenario 1 is much lesser as compared to other scenarios. But if we keep in mind the environmental permeance too, alt. scenario 4 comes out to be the most preferable scenario.

Table 4.5: Payback period analysis of alternative scenarios

	Alt. Scenario 1 (double-cavity mold)	**Alt. Scenario 2** (single-cavity mold with 100% Solar)	**Alt. Scenario 3** (single-cavity mold with 50 % Solar)	**Alt. Scenario 4** (double-cavity with 50% Solar)
Initial cash outlay	200000	1800000	1005000	800000
Net cash flow (Annually)	198000	396000	200000	300000
Payback period (Years)	1.01	4.54	5	2.7

Furthermore, net present values (NPV) of all three solar based alternative scenarios (alt. scenario 2, alt. scenario 3 and alt. scenario 4) were also calculated to get a more insightful cost analysis. NPV calculations usually require three main values which are cost associated with implementation of project (scenario) along the set period of time, benefits and assigned interest rate (discount rate). For our analysis a discount rate of 8% is selected for the time span of 20 years, which is usually the life of a solar panel. For NPV values, the initial cost and benefits are same as used in payback period analysis as shown in **Table 4.5**. However, maintenance costs of 30000, 15000 and 10000 were added from years 2 to 20 for alt. scenario 2, alt. scenario 3 and alt. scenario 4 respectively (solar system maintenance cost). The NPV values with the interval of 5 years are depicted below in **Table 4.6**.

Table 4.6: Net present value analysis of alternative scenarios

	Interest rate: 8%		Years: 20	
Years	**Alt. Scenario 1 (double-cavity mold)**	**Alt. Scenario 2 (single-cavity mold with 100% Solar)**	**Alt. Scenario 3 (single-cavity mold with 50 % Solar)**	**Alt. Scenario 4 (double-cavity with 50% Solar)**
5	605371.4	-177557	-178015	426404.4
10	1143411	817000.9	324698.4	1214442
15	1509592	1493880	666836.9	1750767
20	**1758808**	**1954553**	**899690.6**	**2115781**

Now mainly the higher NPV value over the set time makes that option preferable. If we compare all 4 alternatives on the basis of enviornmental performance, **Table 4.5** and **Table 4.6**, it is quite obvious that alt. scenario 4 is the most preferable as it will reduce almost 50-60% enviornmental impacts, has better payback period value and higher NPV values too.

Moreover, stakeholder and government should also look to include more renewable energy resources and especially solar energy to improve the energy mix of Pakistan and eventually resulting in reducing environmental impacts.

CHAPTER 5: CONCLUSIONS AND IMPLICATIONS

The manufacturing industries of developing nations are very crucial for their growth. However, there are many factors associated with these industries which cause adverse impacts on the environment. In developing countries specifically Pakistan, due to lack of knowledge and proper guidelines, very few importance is shown towards environmental performance of its industrial sector. This not only affects the environment but also results in a reduction in exports. For this purpose, it is necessary that proper measures should be taken to enhance the environmental performance of different manufacturing industries. This study is carried out to analyze the performance of cutlery manufacturing industry of Pakistan. This study carries various implications for stakeholders and decision-makers. The major issues associated with the overall and environmental performance of this industry come out to be lack of knowledge, proper utilization of resources and the energy mix of the country. The major reason of environmental impacts comes out to be molding process due to its highly energy extensive nature. Along with molding process, the energy mix of Pakistan makes electricity more vulnerable for these impacts. It is the responsibility of stakeholders and government personnel to look into ways to make more electricity by more efficient and renewable energy sources apart from non-renewable resources and coal based (thermal) power plants which has more adverse environmental impacts as compared to other sources. Apart from this the stakeholder should also look to make a proper system of monitoring melamine amount and product usage conditions.

This study mainly used LCA methodology to see the major hotspots which contributes most to the environmental impacts associated with the cutlery manufacturing industry of Pakistan. An industry situated at wazirabad, Pakistan which mainly deals in melamine cutlery products was considered for the analysis. Gate to gate scope was considered for this study. The functional unit was selected as 1 dozen melamine spoons. ReCiPe 2016 methods were used to analyze the impacts of manufacturing process on midpoint and endpoint levels using SimaPro 9.5.

The analysis clearly shows that molding process due to its nature and the most energy intensive among other manufacturing processes is the most vulnerable process as far as environmental impacts are concerned. The process has the greatest impact value for 15 out of 18 different midpoint indicators. Global warming and terrestrial ecotoxicity come out to be the most affected impact categories with the values of 11.8 kg co_2 eq and 12.0 kg 1,4-DCB respectively. The one of the main reasons which make molding process more vulnerable is the energy mix of Pakistan. At endpoint levels, human health is the most affected category. Along with the energy consumption and energy mix, the main reason behind this comes out to be the health issues associated with the un-monitored and long term exposure of melamine formaldehyde. Four different potential ideas were put forth to handle the situation, and their viability from an economic and environmental standpoint was evaluated. The modifications comprised straightforward engineering adjustments and a move toward renewable energy derived from solar power. As an alternative, a double-cavity mold was used in place of a single-cavity mold to cut electricity consumption in half. This reduced the environmental effect of producing cutlery by 30–40%. This demonstrated how effectively lowering electricity use can mitigate the effects on the environment. Three more options were then taken into consideration: one that used a single-cavity mold and 100% solar energy, one that used a double-cavity mold and 50% solar energy, and one that used 50% solar energy overall. The economic evaluation of each alternative included a calculation of net present values and payback durations. A comparative investigation showed that the fourth option performed better economically and environmentally, integrating engineering improvement (double-cavity mold) with energy transition (50 percent solar energy).

This study, which is based on economic and environmental assessments, has significant implications for a wide range of stakeholders, including policymakers, researchers, and practitioners. The study demonstrated to practitioners how straightforward engineering modifications could boost economic gains and lessen environmental impacts by raising productivity and lowering related utility costs. Furthermore, because the electricity provided by the national grid is polluting, switching to solar energy could be crucial to make industrial manufacturing more ecologically friendly in Pakistan. Practitioners may find it intriguing to learn that, due to Pakistan's escalating electricity costs, they may be able to recoup their solar energy investment far more quickly. There are other policy implications from the study as well. The outcomes demonstrated the significance of clean and renewable energy. Therefore, in the long run, national and local officials may look into ways to progressively decrease the amount of non-renewable energy, particularly coal-based energy, and gradually increase the share of cleaner, renewable energy in the national grid. Furthermore, giving small businesses solar panels to help them switch to cleaner energy sources could help them in the near term. In this context, offering subsidized solar energy systems could be one recommendation. Lastly, since additional studies of this kind are required from the developing world, other relevant researchers may utilize this kind of environmental and economic evaluations and analyses to study a variety of other industrial businesses, particularly in developing nations. All things considered, this could assist developing countries in certain ways in accomplishing their varied decarbonization and sustainable development goals. This study is extremely significant overall since it has a variety of applications and consequences. But it additionally carries several limitations. Initially, it is limited to a cradle-to-gate viewpoint and relies on a single cutlery manufacturing facility. Thus, the inventory information was gathered from a single case study. Therefore, it is advised that comparable studies be carried out in the future for additional melamine-based facilities as well as steel- and other cutlery-making companies. This would support the generalization of the environmental impacts and the standardization of the inventory data. The environmental effects of other life cycle stages, such as the use and disposal of cutlery goods in Pakistan and other developing nations, may potentially be the subject of future research. Additionally, by taking into consideration other viable renewable energy sources, like wind energy, etc., and implementing additional technical interventions at production plants, more environmental and economic evaluations should be conducted.

FUTURE RECOMMENDATIONS

1. The scope of this was study was cradle to gate. In future in order to get a more comprehensive overview of enviornmental impacts, a complete life cycle analysis of cutlery manufacturing industry can be done in future.

2. For this study, the data was gathered from only 1 production facility. In future studies should be carried out for data gathered from multiple production plants and more diverse geographical locations for better analysis.

3. Further study is also recommended for analyzing the enviornmental impacts of other renewable sources like wind energy.

4. Government personnels and stakeholders should also look to change energy-mix of Pakistan more towards renewable and green resources for better enviornmental performance.

5. In developing countries like Pakistan, LCA methodology should also be adopted to analyze other sectors too for helping Pakistan move towards sustainable development.

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